TECHNICAL SESSION PROCEEDINGS

Irrigation Show 2006
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Table of Contents

Agricultural

Modernizing Canal Check Structures With Bi-fold Overshot Gates
Ram Dhan Khalsa | Ram Dhan Khalsa

Deficit Irrigation of Alfalfa as a Strategy for 'Saving' Water
Blaine Hanson | Daniel Putnam

Soil Water Evaporation & Residue Management in Sprinkler Irrigation
Norman Klocke | Randall Currie | Troy Dumler

The Effect of Dropping Water Tables on Center Pivot Performance
Dale Heermann

Using Technology to Develop Integrated Water Resources Management Schemes
Owrang Kashef

Determination of the Optimal Date for Sowing of Wheat in Canal
T.B.S. Rajput | Neelam Patel

Innovative Subsurface Drip Irrigation (SDI) Alternatives for On-site Wastewater Disposal in the Alabama Black Belt
Mark Dougherty | Jiajie He | Earl Ducote | Willie Harper | Joey Shaw | Wes Wood | John Fulton

Applying Swine Wastewater With SDI & LEPA Sprinkler Irrigation
Freddie Lamm | Todd Trooien

Safe Reuse of Treated Wastewater for Inedible Seed Production
Ahmed El-Araby | Essam Wasif | Hazem Mehawed

Injecting Phosphoric Acid With SDI Systems
Juan Enciso | Charles Stichler | Warren Multer | Paul D. Colaizzi, PhD

The Use of Multi-sensor Capacitance Probes as a Tool for Drip Irrigation Management in Humid Regions
Ian McCann | Jim Starr

Near-surface Soil Water & Temperature for SDI, LEPA & Spray Irrigation
Paul Colaizzi, PhD | Steven Evett | Terry Howell

Shock Chlorination of Irrigation Wells to Reduce Iron-related Bacteria & Emitter Clogging Michael Clubb | Joseph Henggeler

Evaluation of a Low-cost, Low-tech Microirrigation System Designed for Small Plots
Daniel Smeal | Michael K. O'Neill | Richard N. Arnold

Drip Irrigation for the Third World Kitchen Garden
Richard Chapin | William Chapin

Turf

Water Quest: Saving Water by the Yard
Courtney Brown

Urban Rainwater Harvesting for Landscape Irrigation
Dick Peterson

Update on U.S. EPA Market Enhancement Program
Stephanie Tanner

Water Industry/Irrigation Cooperation During Drought
Karen Guz | Donna Fossum

Watersaver Contractor Program – A Win-win for Industry & Public-owned Utilities
Mark Peterson, MPA, BS | Donna Fossum

Irrigation of Native Plants vs. Popular Landscape Plants: A Head-to-Head Comparison
Bob Galbreath

Utilizing Multiple Water Sources for Landscape Irrigation
Eddie Wilcut | Bruce Rathburn

Evaluation of Sensor-based Residential Irrigation Water Application
Melissa Baum Haley | Michael Dukes | Grady Miller

Secondary Water Supply & First Phase Design of a Regional System
Stephen Smith

Rain Water Irrigation in Toronto
Lorne Haveruk

Water Utilities: Influencing the Smart Controller Market
Scott Sommerfeld

Weather & Soil-moisture-based Technologies for Landscape Irrigation
Mark Spears | Paula Sunde

A New Method of Calculating the Wetted Radius of Sprinklers
Edward Norum

Sprinkler Irrigation & Soil Moisture Uniformity
Michael Dukes | Melissa Baum Haley | Stephen Hanks

Spacing & Pattern Effects on DULQ of Spray Heads
Brent Mecham

Using Evapotranspiration Calculations & Aerial Photography to Reduce Water Use
Amanda Dewees | Jessica Woods

Irrigation Analysis for Water Savings – A New San Antonio City Ordinance
Donna Fossum | Dwayne De La Zerda

'Water Checks' – Free Water Audits for Homeowners & Large Public & Private Properties
Earl Jackson | Rachel Lopez

Irrigation Runoff From Landscape Turf
Eudell Vis | Ramesh Kumar | Shoumo Mitra

Green Industries of Colorado (GreenCO) Partners With the Colorado Water-Wise Council (CWWC) to Provide Educational Training on the 'Green Industries Best Management Practices (BMPs) for the Conservation & Protection of Water Resources in Colorado'
Brenda O'Brien | Anne Haueter

Socialization of Weather-based Irrigation Technology
Bruce Cardinal

Irrigation Industry Response to Drought Conditions in Several Southwest States
Laurence Budd

Don't Be a Drip, Be a WWIP!
Karen Stewart

Water Conservation Education Using Children's Water Festival: Experiential Learning & Quality of Retention
Mahbub Alam

How Water Budgets Can Increase Flexibility for Irrigation Professionals
Leslie Martien | William B. DeOreo

A Formula for Success: Save Water, Increase Business, Advance Industry Professionalism, Achieve Community Goals
Dana Nichols | Patricia T. Garza

The effects of subsurface drip and furrow irrigation on the movement of salts and nitrate in the root zone

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ABSTRACT

Water quality issues coupled with diminishing water supplies have led to increased acreage in drip irrigation in the Arkansas River Valley (Ark Valley) of southeastern Colorado. A field experiment was conducted at the Arkansas Valley Research Center (AVRC) in 2005 to determine the effects of irrigation type and scheduling and fertilizer rate on corn yield and salt and nitrate-nitrogen (NO_3-N) concentration in the root zone. Four N fertilizer rates (0, 60, 120, and 180 lb N/acre) and four manure rates (0, 10, 20, and 30 t/acre) were tested under subsurface drip irrigation (SDI) and furrow irrigation (FrI) with full (FI) and deficit (DI) irrigation regimes. The results show no significant difference in corn yield between SDI and FrI, even though nearly twice as much water was applied with FrI than with SDI. Deficit irrigation decreased corn yield by 20 bu/acre on average. Corn yield generally increased with increasing N fertilizer rate, reaching a high of 233 bu/acre with FI and 180 lb N/acre. Corn produced the lowest yield with 30 tons of manure/acre under DI or SDI, similar to the no N fertilizer treatment. The high manure application rates increased soil salinity early in the season, which may have contributed to the lower corn population, compared to the non-manure treatments. After corn harvest, the difference in soil salinity between the manure (20 t/acre) and non-manure (120 lb N/acre) treatments was negligible. Subsurface drip irrigation had higher ECe in the furrow compared to FrI, which had higher ECe in the middle of the bed. There appeared to be salt build-up at the 4- to 6-ft depth under SDI compared to FrI, possibly due to leaching of salts with FrI. Soil NO_3-N concentration was higher under SDI than under FrI, but the difference was only significant in the top foot. There was much more NO_3-N in the top 4 ft. of soil in the spring of 2006, prior to fertilizer application, than in the fall of 2005; with no significant difference between FrI and SDI. The high manure-rate treatments had significantly more residual NO_3-N than the other treatments. More results will be available in 2006.

INTRODUCTION

Gates et al. (2006) reported moderate to high salt concentrations in the waters and soils of the Ark Valley. Average soil ECe values ranged from 3.3 to 6.5 dS/m in 1999 to 2005. Irrigation contributes approximately 14% of the total salt load in the Ark Valley (Miles, 1977). As water moves across the field or through the soil, it dissolves salts and other pollutants. Excess water flows back to the river or augments the water table, thus increasing soil salinity through re-use and evapotranspiration. Substantial reductions in salt dissolution and transport can be achieved by improving irrigation efficiency and reducing canal seepage (Gates et al., 2006).

High NO_3-N concentrations have also been reported in the Ark Valley (Yergert et al., 1997). Research indicates that corn N fertilizer rate can be reduced substantially, particularly after vegetable crops, while maintaining optimum yield (Halvorson et al., 2002 and 2005). Leaching of NO_3-N below the root zone is exacerbated by inefficient irrigation since most cropland in the Ark Valley is furrow-irrigated. Over-application of manure can also lead to NO_3-N leaching and possibly salt build-up.

Water quality issues, coupled with recent droughts and diminishing water supplies have led to renewed interest in drip irrigation, which is used mostly for high-value crops such as onions, cantaloupes, and watermelons. Research elsewhere has shown the feasibility of subsurface drip irrigation (SDI) for corn and other field crops (Lamm et al., 1995). A well designed and managed SDI system can save water by eliminating runoff and minimizing evaporation and deep percolation. It also has the potential to reduce the leaching of salts and NO_3-N, but little is known about their movement under drip irrigation in the Ark Valley.

The objective of this research was to determine the effects of irrigation type and scheduling, and N fertilizer and manure rates on corn yield, N uptake, and on salt and NO_3-N concentration in the root zone.

MATERIALS AND METHODS

A field experiment was conducted in 2005 and 2006 at AVRC near Rocky Ford, CO to accomplish the objective stated above. Only the 2005 results are included in this paper. The soil at the study site is Rocky Ford silty clay (fine-silty, mixed, calcareous, mesic Ustic Torriorthents). Prior to fertilizer (manure) application, the soil had a pH of 8.1, 1.5% O.M. and 153 lb NO_3-N/acre in the 0- to 6-ft. depth. The plot area was in soybeans in 2004 and on 27 April 2005 it was planted to corn hybrid Asgrow RX752RR/YG at 33,723 seeds/acre in 30-in. rows. The recommended N fertilizer rate was 120 lb N/acre or 10 tons of manure/acre based on a 250 bu/acre yield goal.

Irrigation treatments consisted of Furrow (FrI) and subsurface drip irrigation (SDI) applied to achieve a full (FI) or deficit (DI) irrigation regimes. Corn was irrigated 11 times in FI and eight times in DI (Fig. 1). Water was withheld from DI at approximately the 10-leaf, silk, and milk growth stages. All the plots were furrow-irrigated on 5 May and on 16 May 2005 to ensure adequate corn germination and emergence. Drip tapes of 0.875-in. diameter and 0.45 gpm/100 ft. flow rate were used in SDI. They were buried 8 in. below ground and spaced 60 in. apart. Water was pumped from the Rocky Ford Canal and filtered before it reached the drip tapes. In FrI, water from the irrigation ditch was delivered to every other furrow with siphons.

The fertilizer treatments consisted of two checks (<u>0NP</u>: no N or P added and <u>0N</u>: 46 lb P_2O_5/acre and no N added), 60 lb N/acre (<u>60N</u>), 120 lb N/acre (<u>120N</u>), 180 lb/acre (<u>180N</u>), 10 t manure/acre (<u>10T</u>), 20 t manure/acre (<u>20T</u>), and 30 t manure/acre (<u>30T</u>). Treatments 60N, 120N, and 180N received the same amount of P_2O_5/acre as 0N. A polycoated urea with a release time of 30 days was used as the N source. Phosphorus source was 0-46-0. Nitrogen and P fertilizers were broadcast on 10 March 2005 with a hand spreader. Feedlot beef manure was applied on 18 March 2005 with a Hesston S260 manure spreader. It had 41% moisture, 1.78% total N, 1.43% Organic C, 0.35% NH_4-N, 0.001% NO_3-N, 0.4% P, a C/N ratio of 13, and a pH of 7.6. The whole plot area was disked shortly after manure application.

The experiment was designed as a randomized complete block, split-split plot with four replications. Irrigation type was assigned to the main plots, irrigation scheduling to the split plots, and fertilizer treatments to the split-split plots. Split-split plot size was 20 ft. (8 corn rows) by 60 ft. Rows 3 and 6 were used for biomass sampling (data not shown) and rows 4 and 5 for grain harvest. Corn was harvested on 18 Oct. 2005. Hot and dry conditions in July led to a somewhat severe spider mite infestation which was partially controlled with Dimethoate at 14.5 oz/acre.

Soil water status was monitored weekly with WaterMark® sensors in 120N under furrow and drip irrigation (Full and Deficit Irrigation). They were placed within 6 in. of the corn row at 1- and 3-ft soil depths. Soil samples were taken in selected treatments in March and November 2005 in FI and analyzed for NO_3-N. Other soil samples were taken in June and October 2005 in 120N and 20T of FI to assess soil salinity with the electrical conductivity (EC) method (Rhoades, 1996). An excellent correlation was found between 1:1 (soil-to-water ratio, by weight) EC and saturated-paste extract EC or ECe (data not shown). Data was analyzed using the PROC MIXED procedure (SAS 9.1 Software, 2002-2003). Grain yield was adjusted to 15.5% moisture and 56 lb/bu.

RESULTS AND DISCUSSION

Water Management:

A total of 47 in. of water was applied with FrI-FI and 33 in. with FrI-DI (Fig. 1). By comparison, only 26 in. and 19 in. were applied with SDI-FI and SDI-DI, respectively. The SDI totals include the first two furrow irrigation application amounts. Achieving adequate seed germination and plant emergence with SDI is a concern in this dry environment, unless drip tapes are placed close enough to the soil surface and to each other, which is usually the case in vegetable production systems. Another concern is salinity, thus most growers in the Ark Valley who use drip irrigation also have the option to flood or furrow-irrigate their fields to flush out the excess salts.

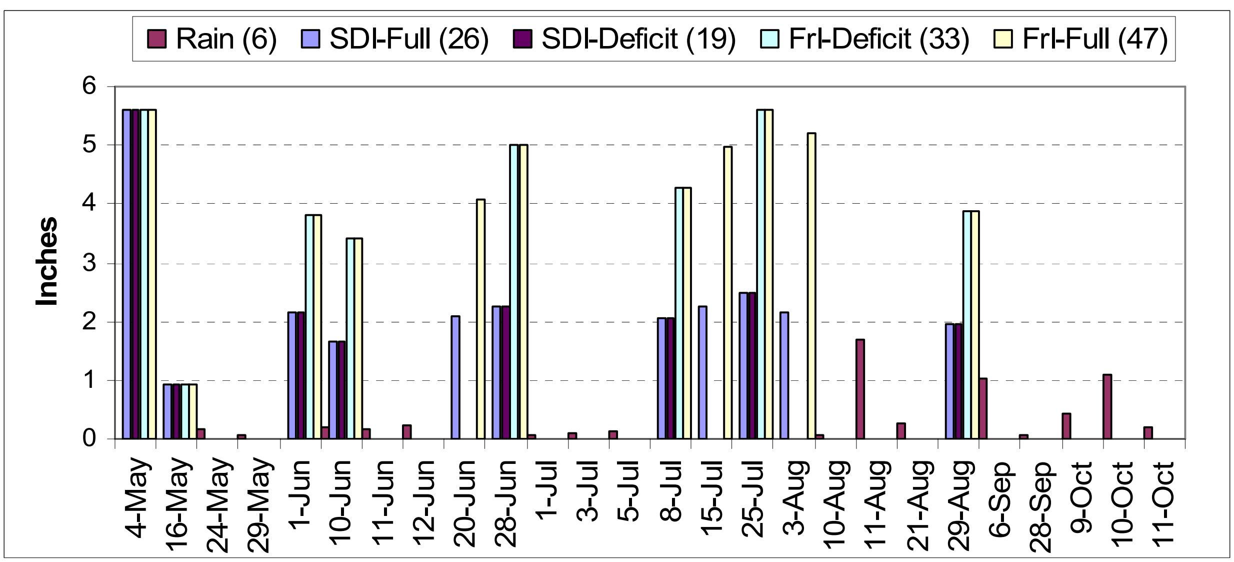

Figure 1. Rain and irrigation amounts during the 2005 corn season. Numbers in parenthesis are total gross amounts in inches.

Irrigation efficiency was estimated at less than 50% with FrI and at least 90% with SDI. There was very little rainfall except on 11 Aug. and 6 Sept. when 1.7 and 1.0 in. of rain, respectively were recorded (Fig. 1). WaterMark sensor readings indicate adequate irrigation scheduling, particularly with SDI (Fig. 2 to 5). Deficit irrigation was imposed once during the vegetative growth stage and twice during the reproductive growth stage. A more targeted deficit irrigation approach was adopted in 2006.

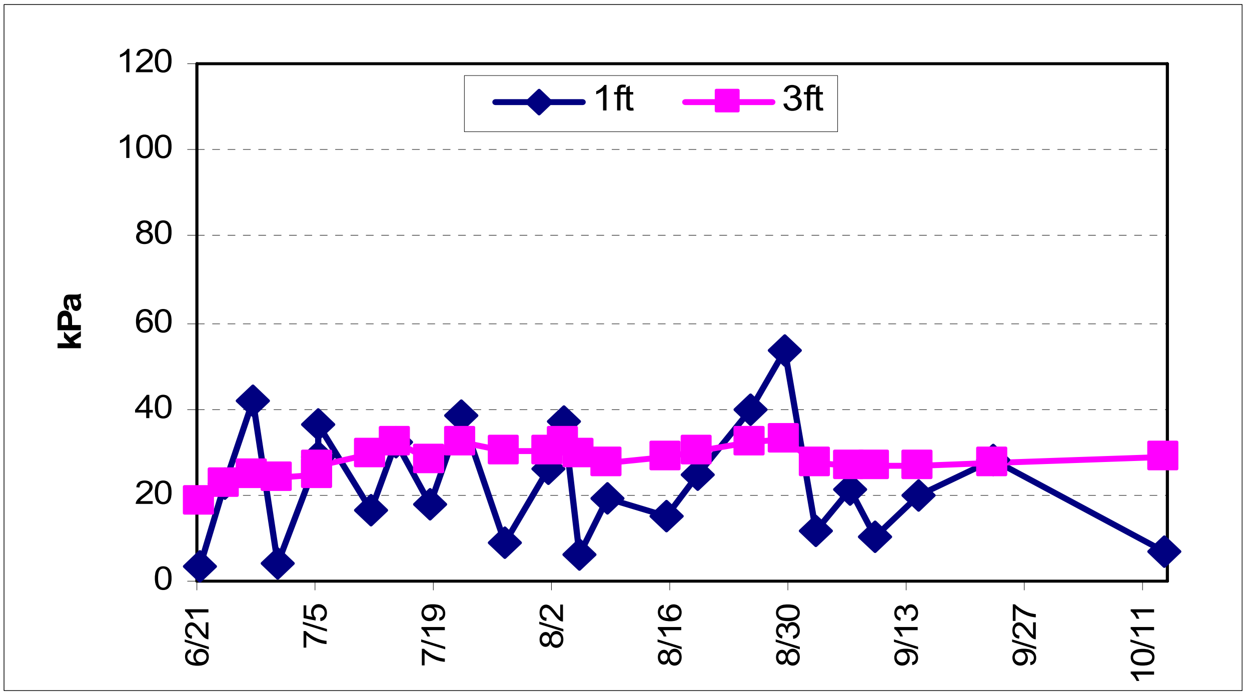

Figure 2. 2005 WaterMark sensor readings (kPa) at 1- and 3-ft depths in SDI_FI.

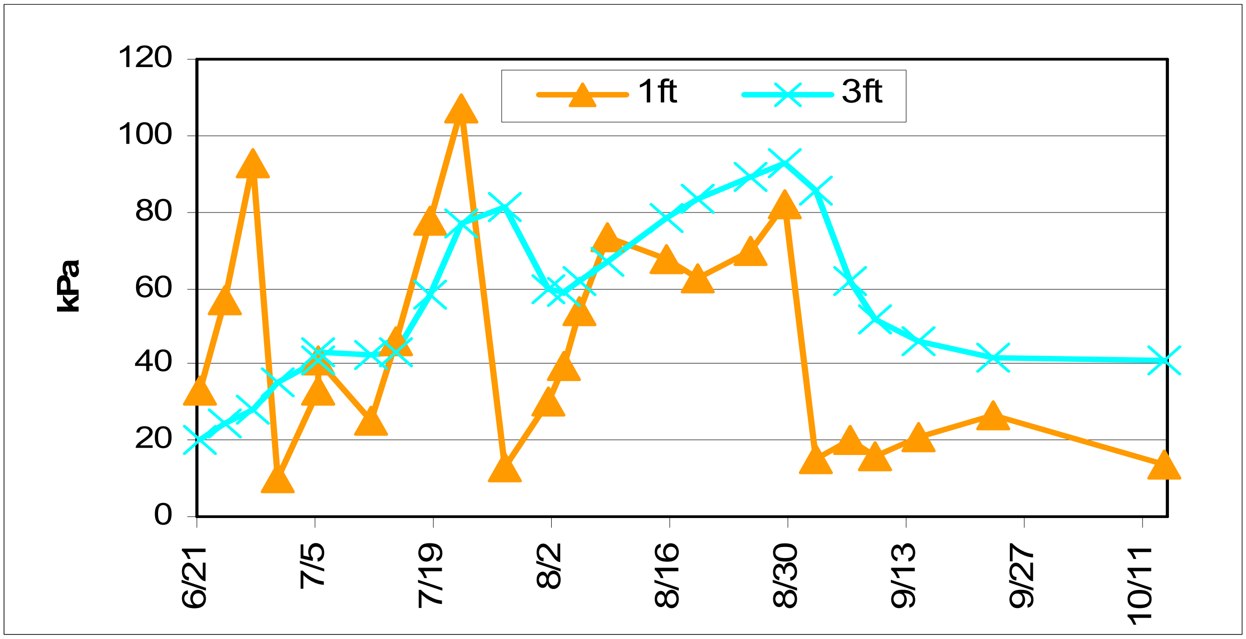

Figure 3. 2005 WaterMark sensor readings (kPa) at 1- and 3-ft depths in SDI_DI.

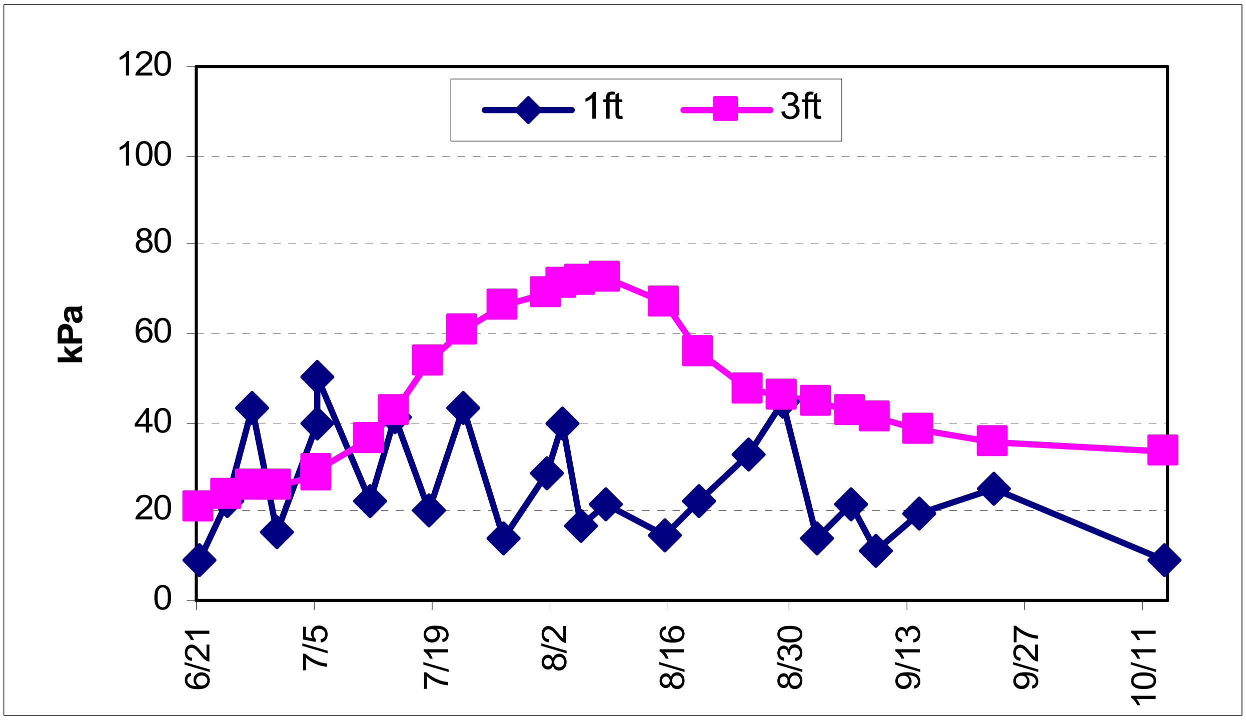

Figure 4. 2005 WaterMark sensor readings (kPa) at 1- and 3-ft depths in FrI_FI.

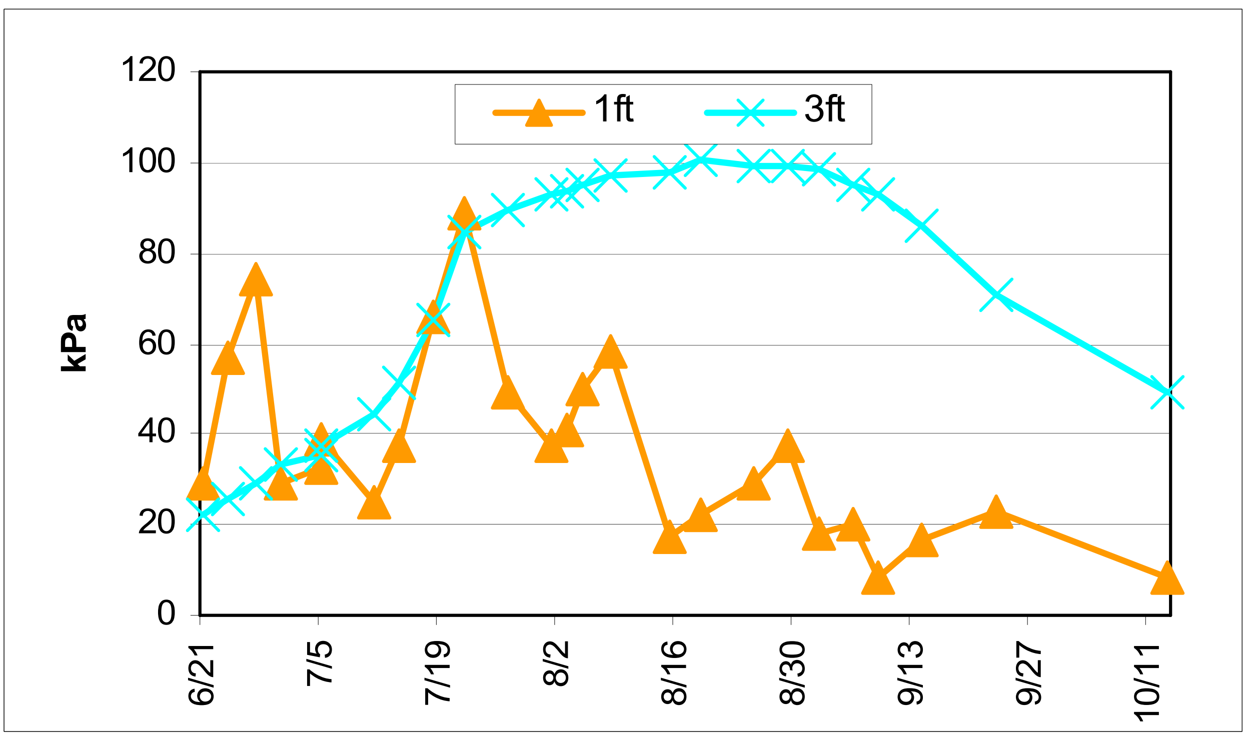

Figure 5. 2005 WaterMark sensor readings (kPa) at 1- and 3-ft depths in FrI_DI

Corn Yield:

Corn yields averaged 197 bu/acre across all treatments. Irrigation scheduling (P=0.001), fertilizer rate (P <0.0001), irrigation type by fertilizer rate (P=0.018), and irrigation scheduling by fertilizer rate (P=0.109) all had a significant effect on corn yield. There was no significant difference in corn yield between SDI and FrI, even though much more water was applied with FrI than with SDI.

Corn yield increased significantly with 60 lb N/acre with SDI and up to 120 lb N/acre with FrI (Fig. 6). Corn also responded positively to 10 tons of manure/acre (10T=20T=30T>0NP) with FrI, whereas corn yield of SDI dropped sharply at 30T (Fig. 7). It was unclear at this writing why 0N and 0NP had such relatively high yields with SDI, as opposed to FrI (Fig. 6 & 7). Halvorson et al. (2006) also found higher onion yields with SDI than with FrI with no N applied.

The highest corn yield of 233 bu/acre was obtained with FI and 180 lb N/acre. The response was linear, indicating that a higher N rate may have been required to achieve maximum yield with FI (Fig. 8). Corn yield leveled off at or below 120 lb N/acre with DI. There was no significant response to manure application with FI, whereas corn maxed out at 196 bu/acre with DI and 20T, then dropped to 175 bu/acre with 30T (Fig. 9).

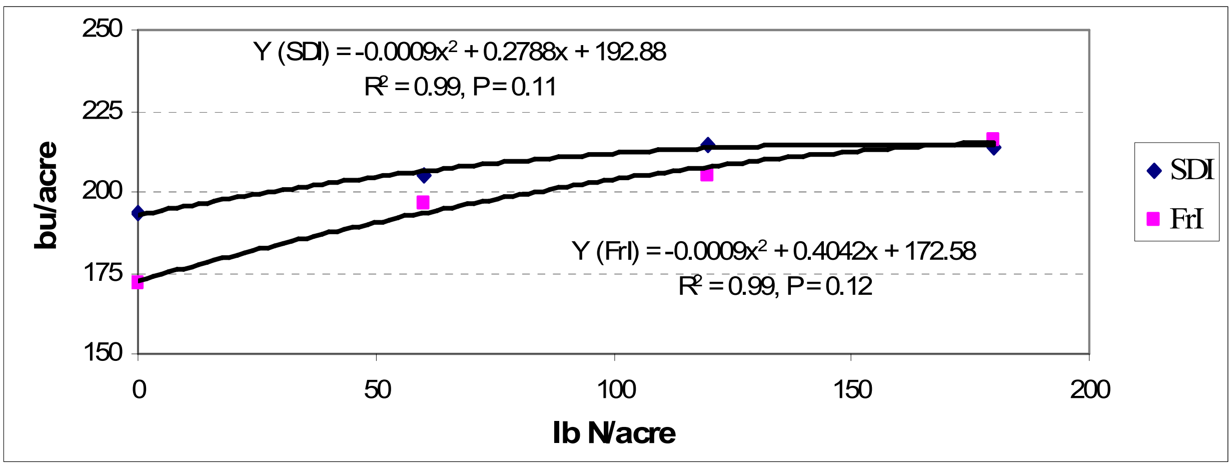

Figure 6. 2005 corn yield of SDI and FrI as a function of N fertilizer rate.

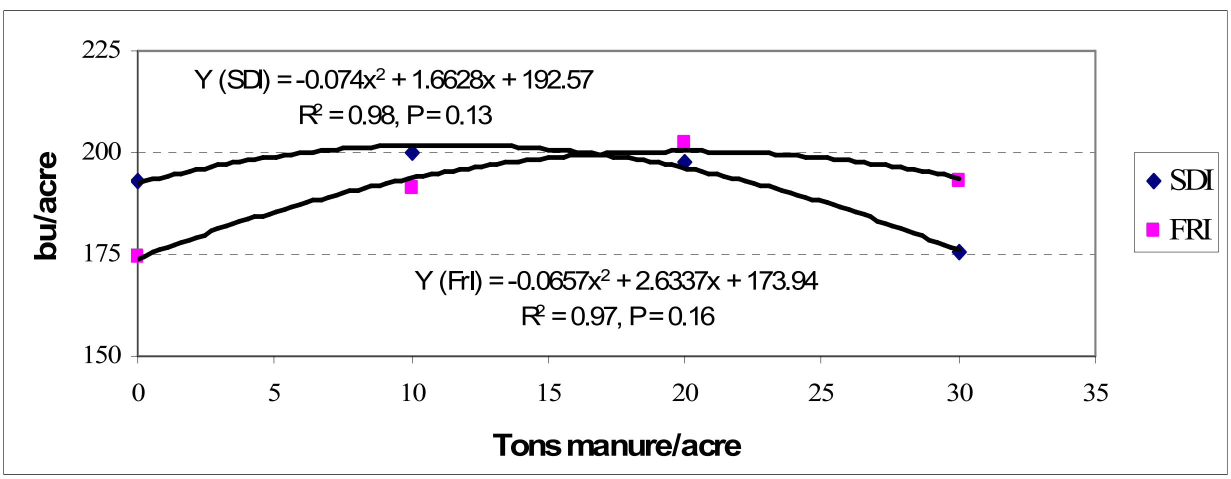

Figure 7. 2005 corn yield of SDI and FrI as a function of manure rate.

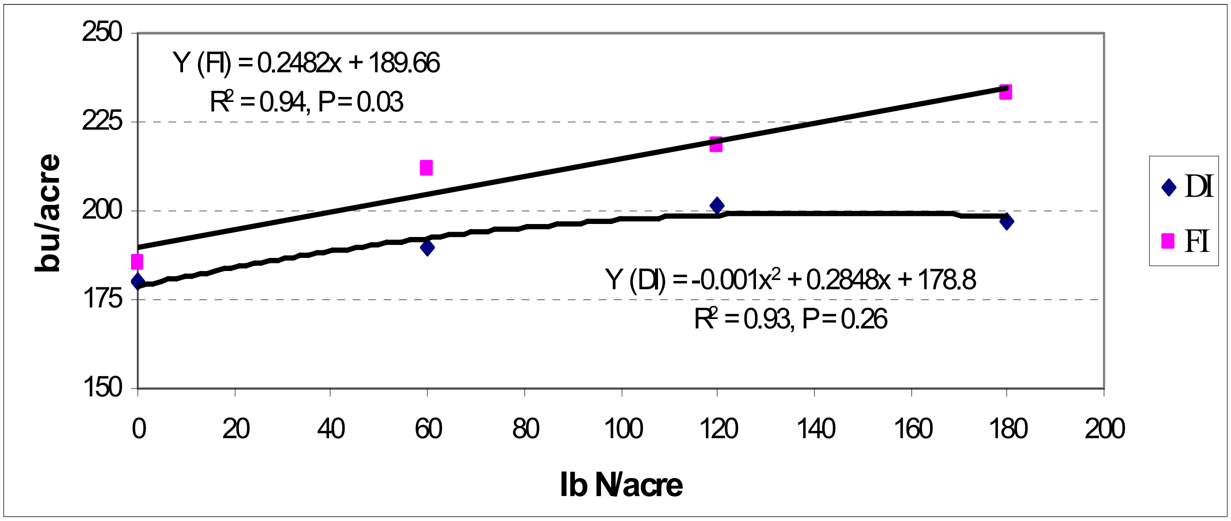

Figure 8. 2005 corn yield of FI and DI as a function of N fertilizer rate.

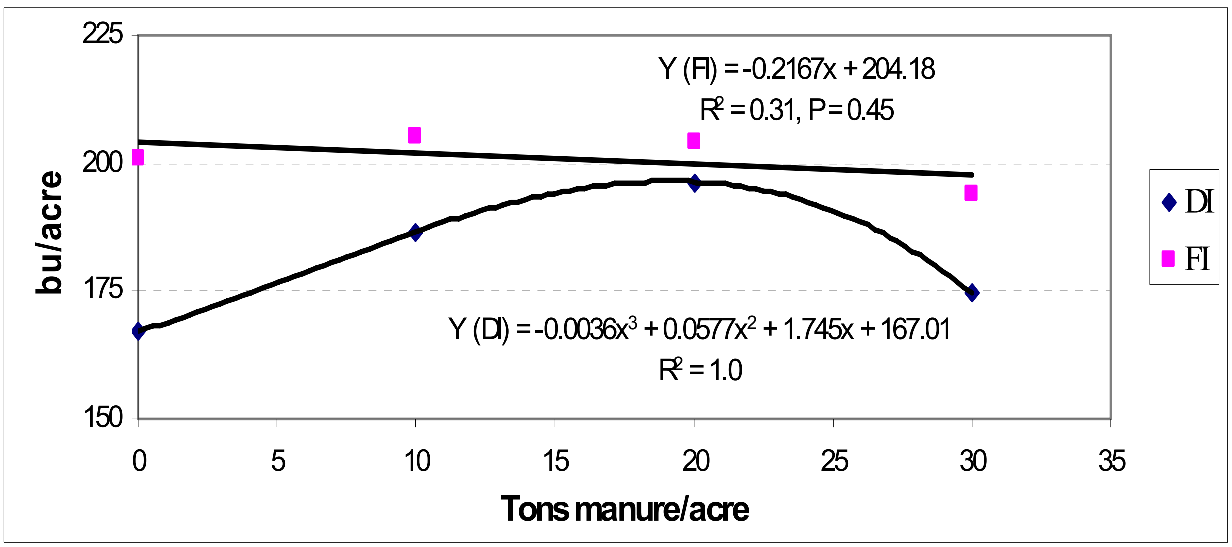

Figure 9. 2005 corn yield of FI and DI as a function of manure rate.

Corn N uptake was significantly higher in 20T and 30T manure treatments than in the other treatments, probably due to more available N at the high manure rates (Table 1).

Table 1. Corn grain N uptake in 2005 at AVRC as affected by N or manure rate.

Treatment	Checks	N treatments	10T	20T & 30T
lb N/bu	0.74c*	0.77b	0.78b	0.82a

*Values followed by a different letter are significantly different at P=0.05

Plant population at harvest:

The generally lower corn yields with manure, particularly at the highest rate of 30 t/a, could be attributed in part to low plant population (Fig. 10). Harvest plant population was significantly lower at 20T and 30T than at the other treatments, with either FrI or SDI; even though the whole experiment was furrow-irrigated at the start of the season to ensure adequate corn seed germination. There were skips in the corn rows of the manure treatments and some of the seedlings were clearly stressed and eventually died. Figure 11 shows that water in 30T did not move as much laterally as it did in the non-manure treatments, particularly with SDI. Most of the manure was located near the soil surface since the field was not moldboard plowed after manure application, hence, more water may have been required to imbibe the seedbed due to high organic matter content, compared to the non-manure treatments.

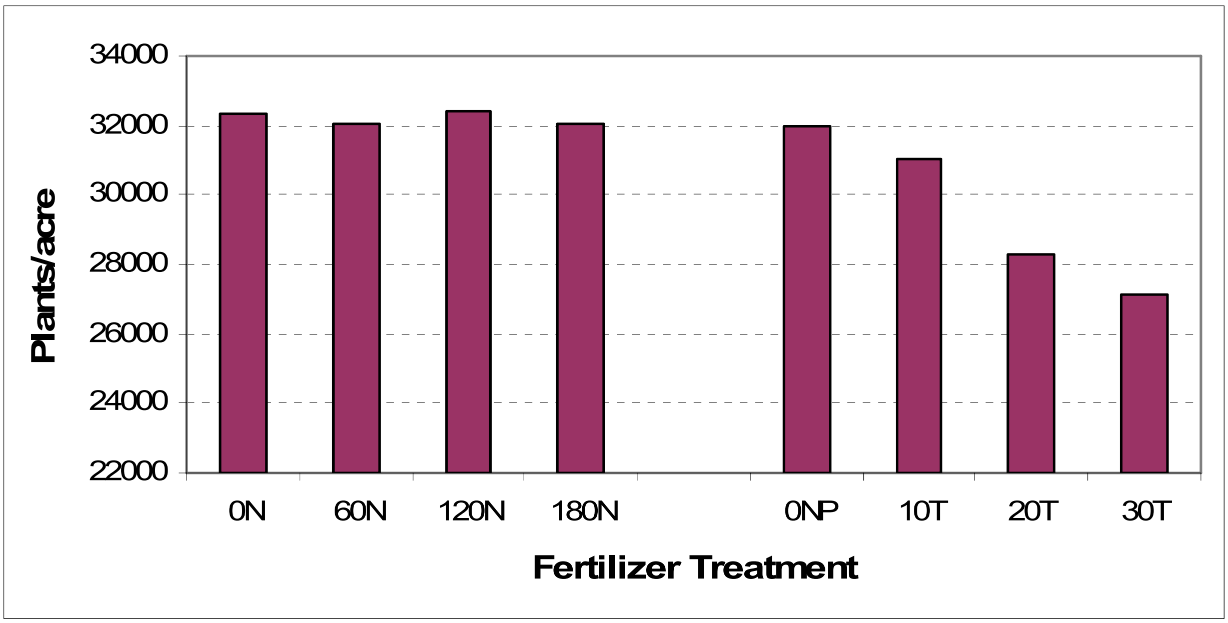

Figure 10. Harvest corn plant population in 2005 at AVRC as affected by N or manure rate.

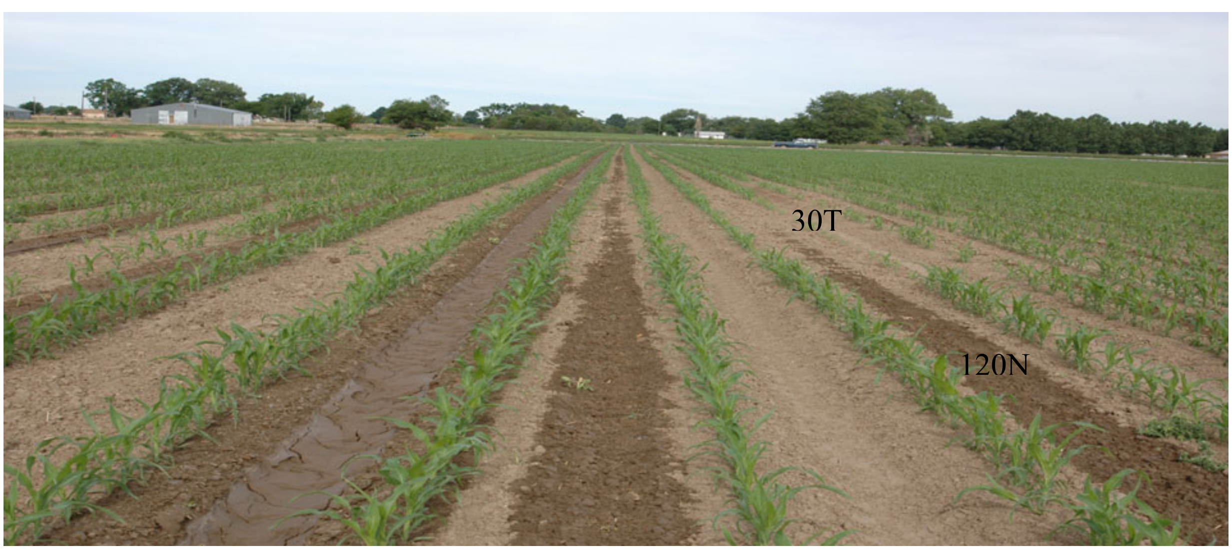

Figure 11. Early-season corn stand shortly after an irrigation event.

Soil salinity:

Soil ECe was substantially higher in 20T (and by inference 30T) than in 120N early in the season, particularly with SDI (Fig. 12), which may have adversely affected corn population and yield. ECe values were much lower after corn harvest, which would indicate a downward movement of salts in the soil profile, due to rain and irrigation (Table 2). Furthermore there was no significant difference between 20T and 120N (data not shown), whereas ECe varied with irrigation type and sampling depth and position on the bed. ECe generally increased with depth, with the exception of FrI in the middle of the bed (Table 2). Subsurface drip irrigation had higher ECe than FrI in the furrow and to lesser extend the corn row, while FrI had higher ECe in the middle of the bed, although the relative ranking varied with depth. On average, SDI had significantly higher ECe than FrI at the 4- to 6-ft. depth, which could be due to leaching of salts with FrI.

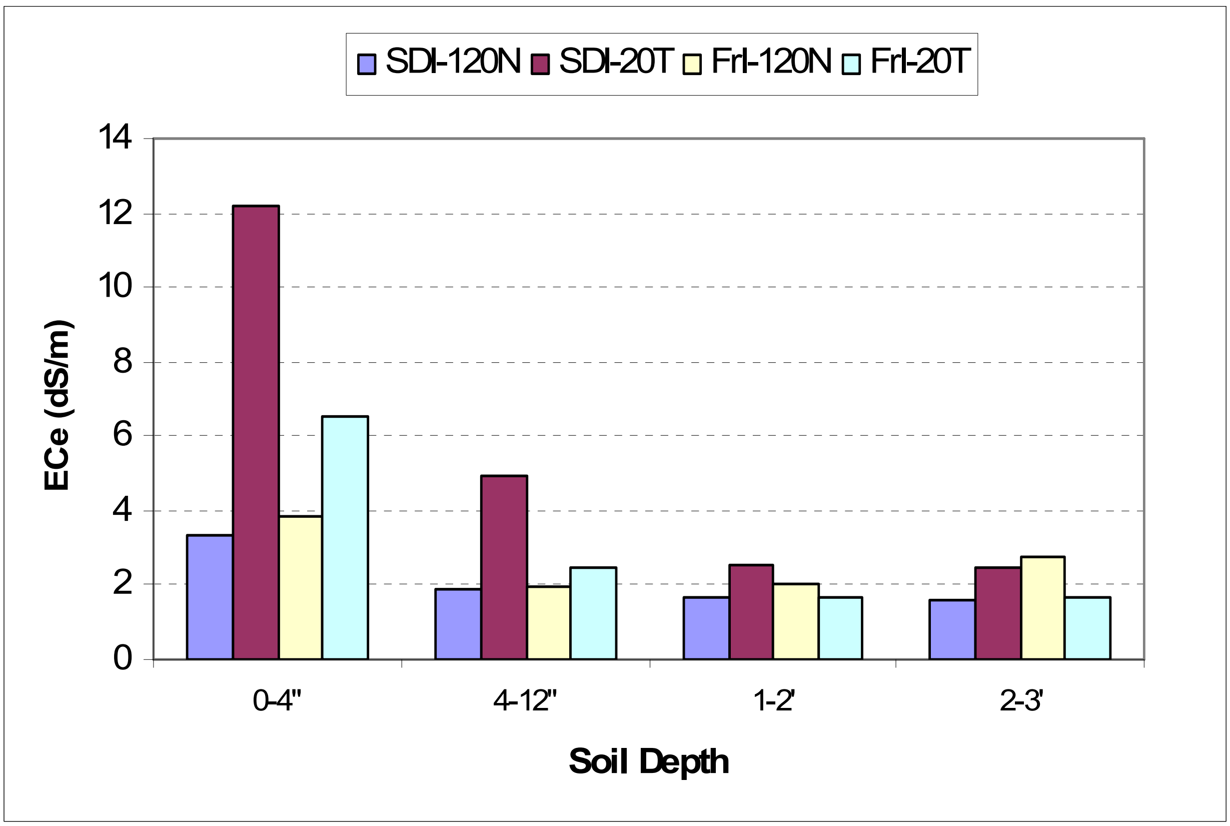

Figure 12. June 2005 ECe under SDI and FrI in 120N and 20T.

Table 2. Post-harvest soil ECe (dS/m) under SDI and FrI as affected by sampling depth and position.

Soil Depth	SDI			FrI		
	Furrow	Row	Bed Center	Furrow	Row	Bed Center
	ECe (dS/m)					
0-6”	2.59	1.53	1.95	1.38	2.01	4.25
6-12”	2.01	1.49	1.28	1.61	1.28	2.62
1-2’	2.06	2.38	1.12	2.02	1.49	1.83
2-3’	2.46	2.94	1.28	2.03	1.91	1.52
3-4’	2.65	2.85	1.95	2.30	2.23	1.65
4-5’	3.32	3.63	3.26	2.76	2.85	2.09
5-6’	3.35	3.72	3.49	2.58	2.94	2.01

Soil NO_3-N concentration:

Post-harvest soil NO_3-N concentration was significantly higher in 20T, 30T, and 180N than in 0N at the 0- to 1-ft and 0- to 3-ft depths (Table 3). There was also substantially more NO_3-N under SDI than under FrI, similar to that reported by Halvorson et al. (2006); however the difference was only significant in the top foot (P=0.1). There was no significant difference in soil NO_3-N concentration between FrI and SDI in the spring of 2006, prior to fertilizer (manure) application (Fig. 13). Nitrate-N soil concentration in 0- to 4-ft depth was much higher in the spring of 2006 than in the fall of 2005, in all the treatments (Fig. 14), possibly due to corn residue decomposition and mineralization of N. Treatments 30T and 20T had significantly more NO_3-N than 10T, 180N, 120N, and 60N, which in turn had more NO_3-N than 0N.

Table 3. Soil NO_3-N concentration after corn harvest in 2005.

Fertilizer	Soil depth/lb NO_3-N		
Treatment	0-1'	0-3'	0-6'
0N	13.5	24.4	113.1
60N	16.4	92.6	190.6
120N	37.0	61.3	248.9
180N	96.6	147.0	192.2
10T	56.7	85.5	225.2
20T	109.9	155.3	231.6
30T	124.0	168.7	228.4
Average	**64.9**	**105.0**	**204.3**
Pr>F	0.01	0.08	0.81
FrI	37.3	70.7	149.0
SDI	81.3	120.3	238.7
Pr>F	0.1	0.19	0.39

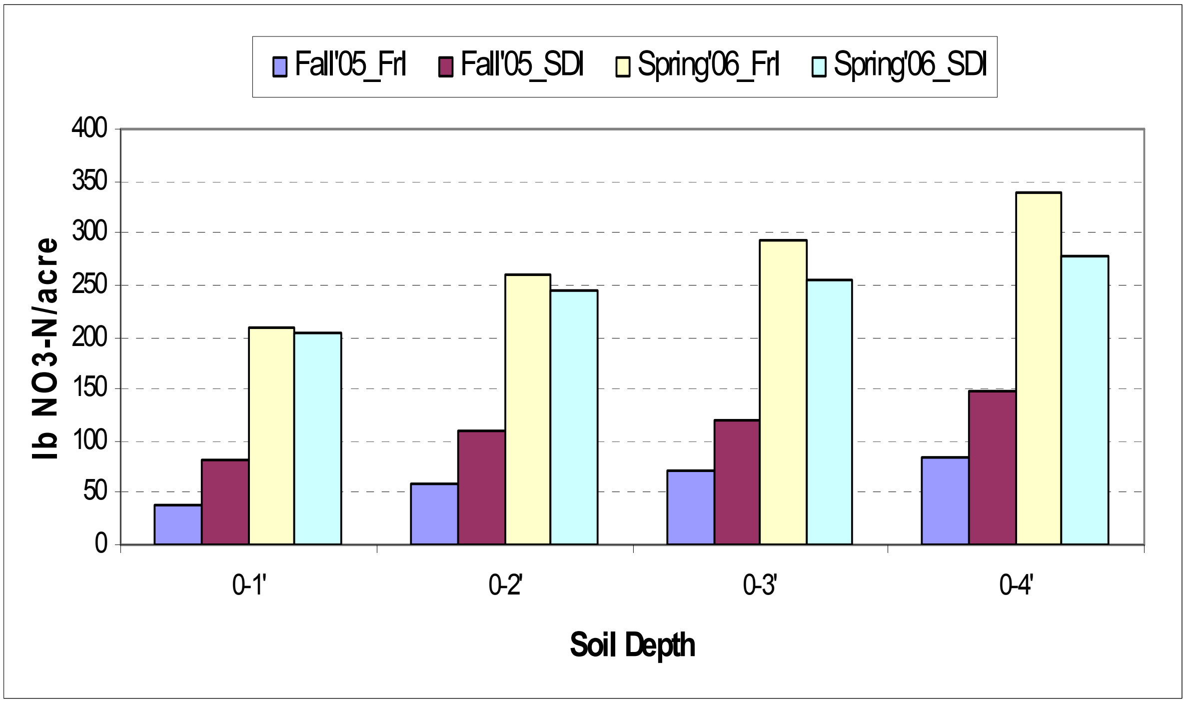

Figure 13. Soil NO_3-N concentration under SDI and FrI after corn harvest in the fall of 2005 and prior to fertilizer application in the spring of 2006.

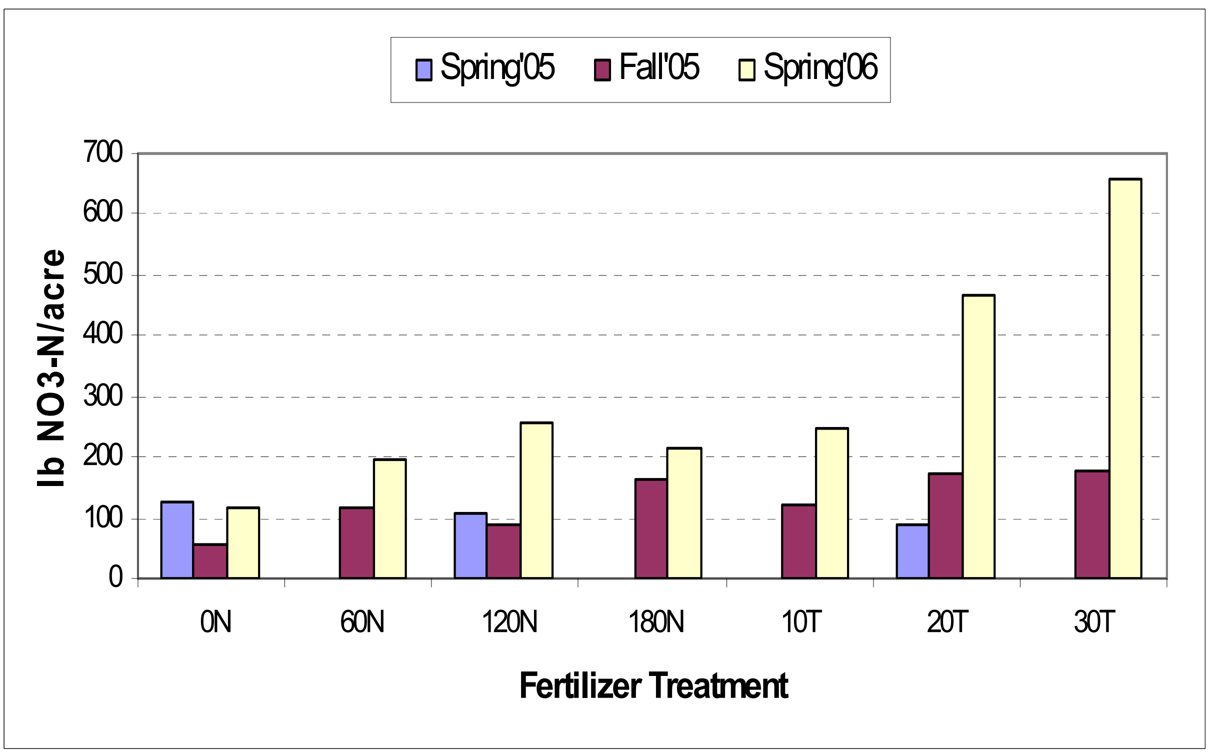

Figure 14. Soil NO_3-N concentration as influenced by N or manure application rate, in 0- to 4-ft depth after corn harvest in the fall of 2005 and prior to fertilizer application in the spring of 2005 and 2006.

PRELIMINARY CONCLUSIONS

There was no significant difference in corn yield between FrI and SDI even though nearly twice as much water was applied with FrI. Deficit irrigation decreased corn yield by an average of 20 bu/acre. Corn yield generally increased with increasing N fertilizer rates, but leveled off quicker with SDI or DI than with FI or FrI. The highest yield of 233 bu/acre was achieved with full irrigation and 180 lb N/acre. Manure at 30 t/acre depressed corn yield with either SDI or DI. Manure at 10 or 20 t/acre increased corn yield significantly with both irrigation types and scheduling regimes when compared to 0N, but only with FrI or DI when compared to 0NP. The relatively high corn yield of 0NP with FI or SDI could not be explained at this writing.

Corn population in 20T and 30T was significantly lower to that of the other treatments and may have been due in part to high salt concentration early in the season. The fact that manure was not plowed in after application in 2005 may explain the high ECe values at or near the seedbed in 20T, and by extension 30T. Manure was applied earlier (Nov.'05) in 2005-06 and plowed in; consequently corn population was more uniform in 2006 than in 2005, but it was still significantly lower in 30T than in the other treatments (data not shown). Similarly, ECe values were higher in 20T and 30T than in the other treatments (data not shown). After corn harvest in 2005, ECe values were not significantly different between 20T and 120N. There appeared to be salt build-up at the 4- to 6-ft depth with SDI, which was not the case with FrI, possibly due to leaching. Soil NO_3-N concentration was also higher under SDI than under FrI, but the difference was only significant in the top foot. There was much more NO_3-N in the top 4 ft. of soil in the spring of 2006, prior to fertilizer application, compared to the fall of 2005; probably due to corn residue decomposition and mineralization of N. Subsurface drip irrigation and FrI had similar soil NO_3-N concentrations in the spring of 2006, while the high manure-rate treatments had significantly more residual NO_3-N than the non-manure treatments. More results will be available after corn harvest in 2006.

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IRRIGATION GUIDELINES FOR OILSEED CROPS IN THE U.S. CENTRAL GREAT PLAINS

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ABSTRACT

Development, water use and yield formation of oilseed crops are inter-related. Greatest yields are expected with a well-established canopy, a plant population sufficient to support a large number of seeds set per acre and favorable weather conditions for an extended seed fill period. Oilseed water requirements closely follow canopy formation and evaporative conditions. Irrigation scheduled by the water balance method results in higher yields than with irrigation scheduled by growth stage. A straight-line relationship between yield and water use indicates the yield threshold (maximum water use with no expected yield) and yield response to increased water use. When precipitation, available soil water and limited irrigation fail to meet crop water requirements, yield reductions depend on the degree of plant water stress at critical stages of growth. Full-season soybean with full irrigation offers greatest productivity potential. A smaller yield threshold and extensive rooting system for sunflower provides advantages for limited irrigation or double-crop conditions. Winter canola can provide good productivity during fall and spring growing seasons when heat stress can be minimized.

INTRODUCTION

Oilseed crops (i.e. soybean, sunflower, canola) provide management options for irrigators seeking to reduce irrigation requirements, diversification and/or to reduce input costs. In 2003, soybeans were planted on 25% of irrigated cropland in Nebraska and on 12% of irrigated acres in Kansas (NASS). Sunflower is emerging as an irrigated crop in W. Kansas with a substantial increase in double-cropped sunflowers reported in 2005. Canola, irrigated in the San Luis Valley of Colorado, is an emerging feedstock for biodiesel production.

Irrigated soybean yields range from 55 to over 70 bu/A in variety trials conducted throughout the central Great Plains (2003 – 2005); greatest yields occurred in north-central Kansas and the east-central Platte valley of Nebraska. Varieties with top yields exceeded trial averages by 10%. Irrigated sunflower yields ranged from 2200 to 2900 lb/A in similar trials located in the central High Plains with greatest yields in NW Kansas. Top-yielding hybrids exceeded trial averages by

20% or more. Irrigated winter canola yields of 2600 lb/A have been recently reported for w. Nebraska.

Several irrigation guidelines are available for oilseed crops (Baltensperger et al., 2004; Bauder, 2006; Kranz et al., 2005; Rife and Salgado, 1999; Rogers, 1997; Rogers et al., 2005). This report is intended to integrate these guidelines with recent and regional field studies. Emphasis is given to crop development, water use and yield responses for irrigated oilseed crops.

DEVELOPMENT, WATER USE, YIELD FORMATION

Oilseed development, water use and yield formation are inter-related. Water, nutrients, sunshine and soil conditions must be sufficient, with minimal stress from pests and heat for crop growth to meet potential productivity. Water requirements and yield formation factors frequently correspond with development stages. Crop-specific considerations will follow a general discussion of oilseed development, water use and components of yield.

Development

Uniform seedling emergence is favored by soil-seed contact in a firm moist seedbed at a sufficient soil temperature. Expansive growth of seedling leaves require assimilates, derived from photosynthesis and nutrient uptake, as well as sufficient plant-available water for turgor-driven growth. Development of new leaves corresponds with plant temperature as well as time. Thus, leaf appearance is related to degree-days (^oF-d). For example, new leaves of a standard sunflower hybrid appear in 67 ^oF-d intervals. Leaf appearance and growth comprise the major processes of canopy formation.

Rapid canopy closure is desirable, because the crop canopy shades the soil and reduces evaporative water losses. Leaf expansion is typically exponential during early to mid-vegetative growth when supported by sufficient water, nutrients and non-stress conditions. Crop water requirements increase with canopy formation (Figure 1) because transpiration increases in proportion to leaf area. Light penetration into lower layers of the crop canopy is desirable. Photosynthesis can be limited by the amount of light reaching shaded leaves. Canopy formation nears completion with flowering for some determinant crop types such as sunflower. However, canopy formation continues with flowering for indeterminant crops such as canola and most soybean varieties of maturity group IV and earlier.

Reproductive development marks the end of the juvenile phase and begins with differentiation of floral buds. Potential seed number (a yield formation factor) can be set at this point, for determinant crops. Development and growth of floral organs proceeds systematically through stages including pollen shed, seed set and seed fill. Again, sufficiency of water, nutrients and light will support these yield formation processes. The onset of reproductive development frequently varies with thermal time, but may be affected by day-length as well. Reproductive stages of soybean, sunflower and canola are presented in Tables 1, 2 and 3.

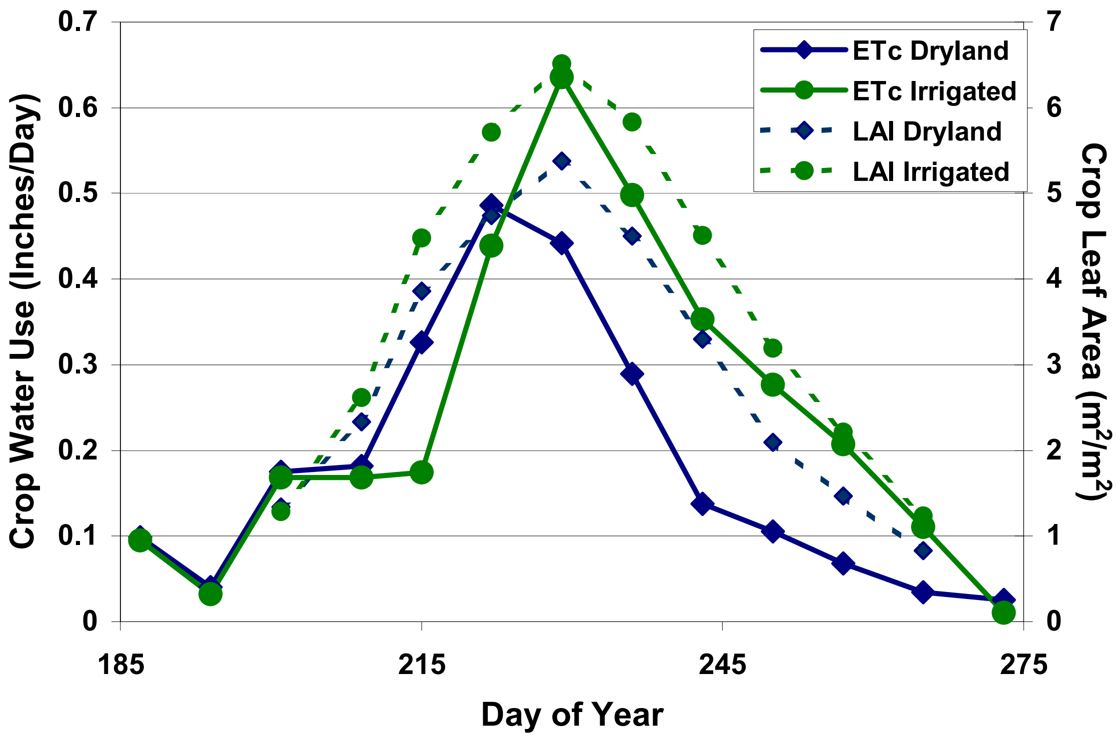

Figure 1. Sunflower water use and canopy formation (leaf area) for dryland and irrigated crop (adapted from Aiken and Stockton, 2003).

Table 1. Description of soybean reproductive stages (from Ritchie et al., 1994).

Stage	Title	Description
R1	Beginning flowering	Open flower at any node on main stem. Indeterminate plants start at bottom and flower upward. Determinate plants start at top four nodes and flower downward.
R2	Full bloom	Open flowers on one of the two uppermost nodes on main stem.
R3	Beginning pod	Pod 3/16 inch long at one of the four uppermost nodes on main stem.
R4	Full pod	Pod 3/4 inch long at one of the four uppermost nodes on main stem.
R5	Beginning seed	Seed 1/8 inch long in one of the four uppermost nodes on main stem.
R6	Full seed	Pod containing a green seed that fills pod cavity on one of the four uppermost nodes.
R7	Begin maturity	One normal pod on main stem has reached mature pod color.
R8	Full maturity	95% of pods have reached mature pod color. Approximate 5 to 10 days ahead of harvest.

Table 2. Description of sunflower reproductive stages (from Schneiter and Miller, 1981.)

Stage	Description
R-1	The terminal bud forms a miniature floral head rather than a cluster of leaves. When viewed from directly above, the immature bracts form a many-pointed starlike appearance.
R-2	The immature bud elongates 1/4 to 3/4 inch above the nearest leaf attached to the stem. Disregard leaves attached directly to the back of the bud.
R-3	The immature bud elongates more than 3/4 inch above the nearest leaf.
R-4	The inflorescence begins to open. When viewed from directly above immature ray flowers are visible.
R-5	This stage is the beginning of flowering. The stage can be divided into substages dependent upon the percent of the head area (disk flowers) that has completed or is in flowering. [i.e., R-5.3 (30%), R-5.8 (80%), etc.]
R-6	Flowering is complete and the ray flowers are wilting.
R-7	The back of the head has started to turn a pale yellow color.
R-8	The back of the head is yellow but the bracts remain green.
R-9	The bracts become yellow and brown. This stage is regarded as physiological maturity.

Table 3. BBCH decimal description of canola growth stages (from Canola Council of Canada www.canola-council.org).

Stage	Description
0	Germination: sprouting development
1	Leaf development
3	Stem elongation
5	Inflorescence (flower cluster) emergence
6	Flowering
7	Development of seed
8	Ripening

Stand establishment, canopy formation and reproductive development are significant components of the yield formation process. The crops' capacity to fill seed and achieve yield potential can depend on the active leaf area and number of seeds set per acre. Greatest yields are expected with well-established canopy, a plant population sufficient to support a large number of seeds set per acre and favorable weather conditions for an extended seed fill period.

Water use

Oilseed water requirements closely follow canopy formation and evaporative conditions. When scheduling irrigation relative to evaporative conditions, crop coefficients can be used to calculate daily crop water use (e.g., KanSched, Rogers et al., 2002). Typical crop coefficients, daily water use and development stages for soybean and sunflower are presented in Figure 2. Lower seasonal water requirements for canola can be expected for the spring growing season, which is shorter and with less evaporative demand than the summer growing season of soybean and sunflower. When soil water reserves are insufficient, actual crop water use is less than evaporative demand (Figure 3) and yield reductions are likely.

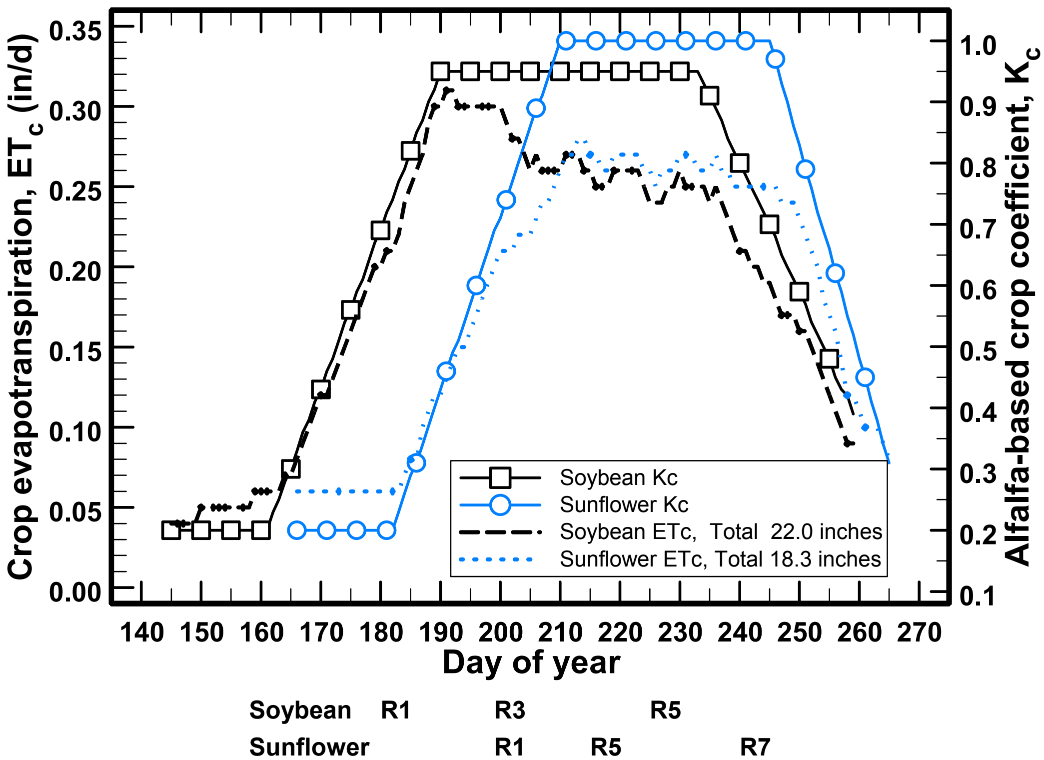

Figure 2. Crop coefficient (Kc) and daily crop evapotranspiration (ETc) for soybean and sunflower, calculated from 34 years (1972-2005) of weather recorded at Colby, KS. Reproductive development stages for soybean and sunflower are noted below the graph for reference.

Irrigation is generally required to meet crop water requirements in the central Great Plains. Two methods of scheduling irrigation are by water budget or by growth stage. Water budgets seek to maintain available soil water above a minimum value (e.g., 65% of available water holding capacity). Growth stage irrigation seeks to provide sufficient water to meet crop water requirements during specific critical stages. Studies in west-central Nebraska (Klocke et al., 1989; Elmore et al., 1988) and north-central Kansas (Gordon, 1996) indicate greater soybean yields with water budgets than with growth stage irrigation scheduling. Similar studies are in progress for sunflower.

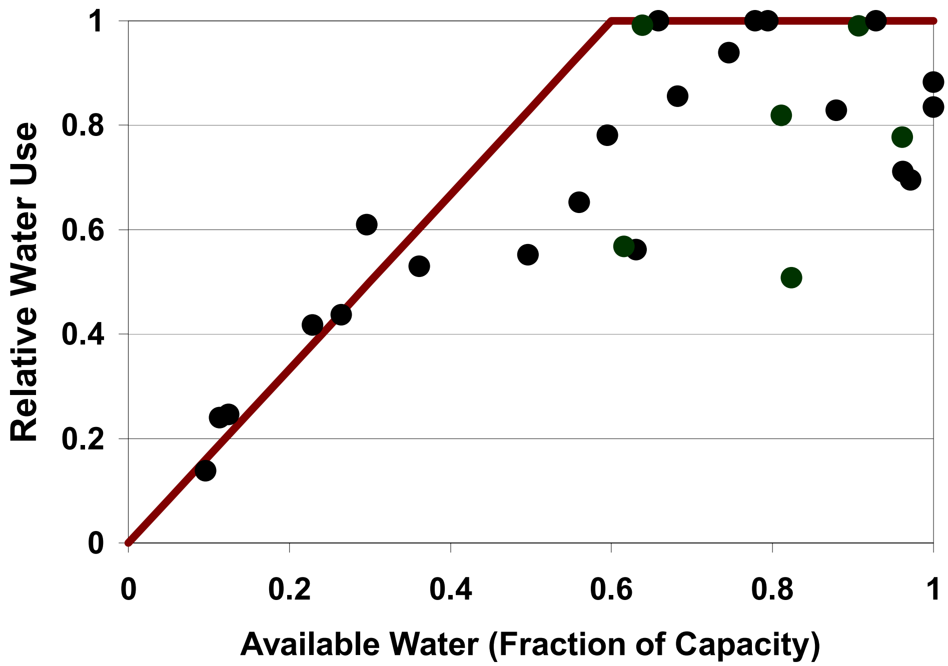

Figure 3. Water uptake by sunflower roots (relative to maximum observed uptake) is reduced when the available soil water in the wettest soil layer is less than 60% of available water capacity. The line approximates an envelope containing observations of water uptake in relation to available soil water. Water uptake from all soil layers is equivalent to crop evapotranspiration (Aiken and Stockton, 2003).

For limited irrigation systems, water available to the oilseed crop is likely to be insufficient during canopy formation and/or reproductive development stages. For example, Figure 4 shows that sunflower canopy formation at flowering (R5) can be limited by available soil water during earlier reproductive growth (R3). Limited irrigation, while not providing full water requirement of the crop, can improve seed yield. For example, a one-inch irrigation applied to soybean in SE Kansas at R4 (full pod), R5 (beginning seed) or R6 (full seed) increased seed yield by 241 lb/A. The R4 application increased the number of seeds per plant while the R5 and R6 applications increased seed weight (Sweeney et al., 2003).

Yield responses

When supply of water limits crop water use, seed yields are frequently limited as well. A straight line can represent the relationship between seed yield and seasonal crop water use (Figure 5). For example, soybean yield at Colby, KS increased 3.7 bu/A with each additional inch of water use (precipitation, irrigation plus change in stored soil water). The yield threshold (the amount of water use at which the first increment of yield is expected) occurred with 7.3 inches of crop water use. Similar results were reported for west-central Nebraska (Klocke et al., 1989; Payero et al., 2005). For sunflower, the yield threshold was 4.2 inches and the yield response was 166 pounds per inch of crop water use (Figure 6).

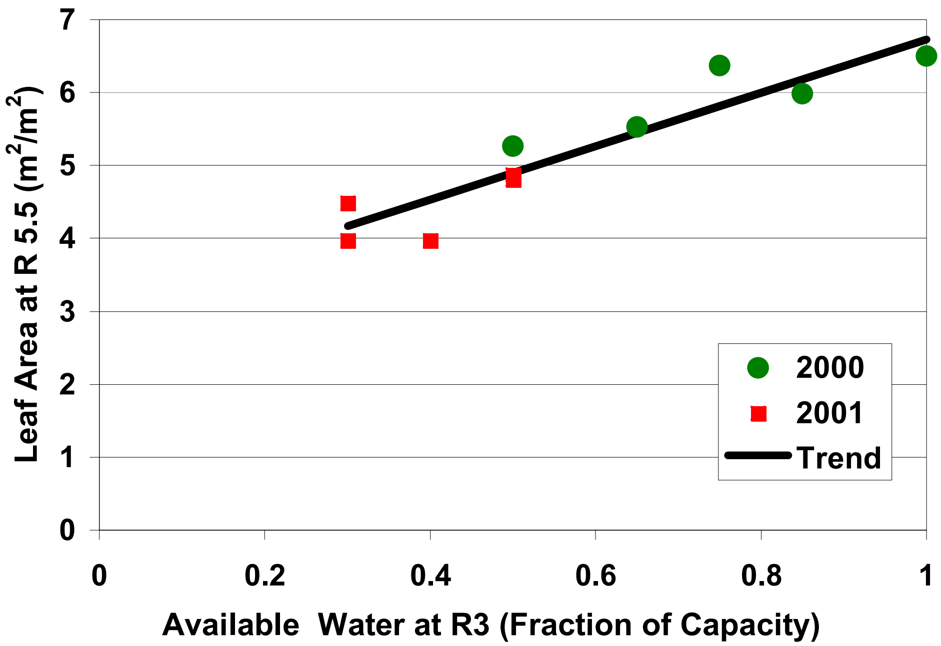

Figure 4. Sunflower leaf area at flowering (R5) in relation to available soil water at mid-bud (R3) growth stage (Aiken and Stockton, 2003).

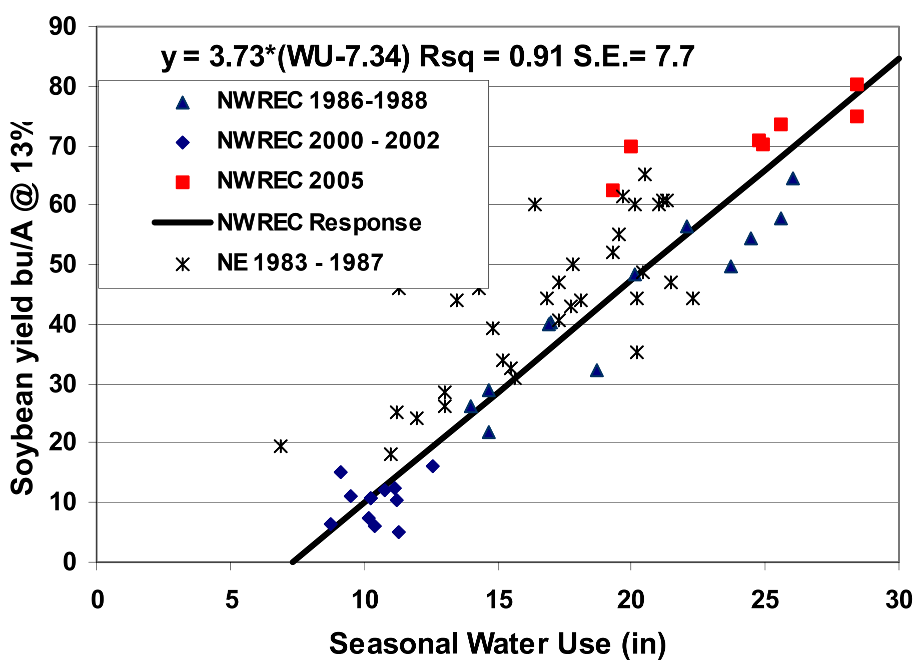

Figure 5. Soybean yield response to seasonal water use at Colby, KS and central Nebraska sites (adapted from Aiken and Gordon, 2003; Lamm, 1989).

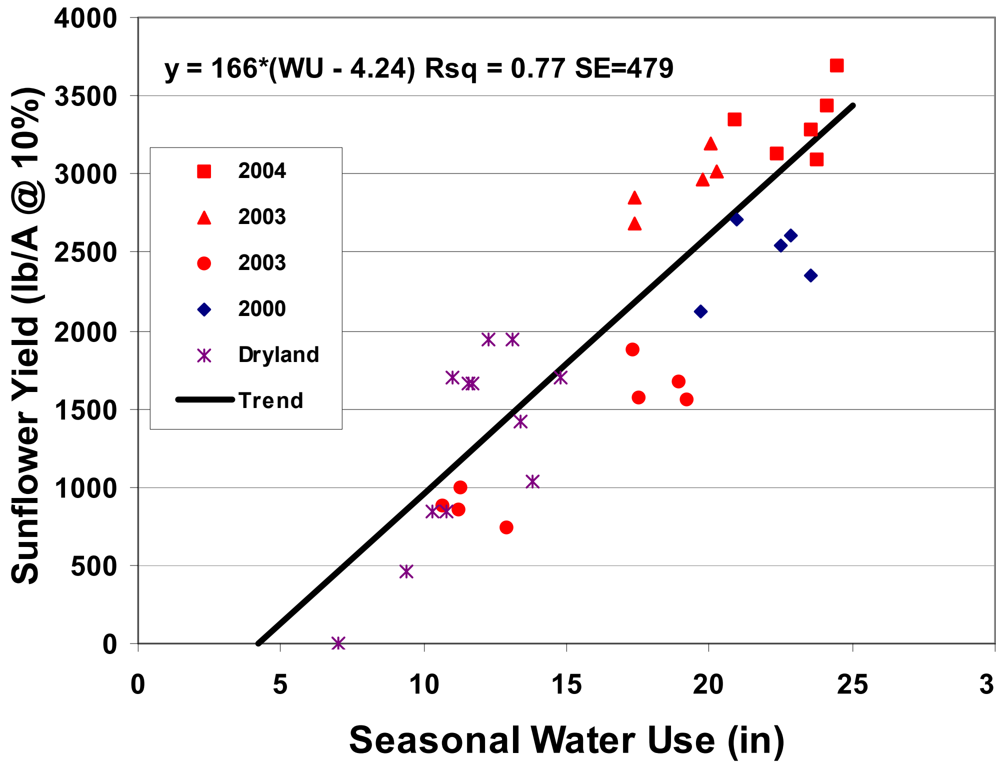

Figure 6. Sunflower yield response to seasonal water use at Colby, KS (adapted from Aiken and Stockton, 2003; Lamm, pers. comm).

Under limited irrigation, water can be allocated to minimize the impact of water deficits on yield formation. For example, soybean yield can be most sensitive to water deficits during flowering and full pod reproductive stages (Table 4). The yield response to limited irrigation can be greatest if water is applied to alleviate deficits during stages which are most critical for yield formation. Critical stages, with maximum crop water use rates, are R3 to R6 for soybean and R1 to R7 for sunflower. Water stress during these critical stages is expected to reduce yield potential. However, Table 4 and Figure 4 indicate that sunflower is also susceptible to soil water deficits during vegetative growth. Additionally, a recent study at Akron, CO showed that delaying limited irrigation until the R4 stage increased oil content of sunflower, though yields were less than that of full irrigation. Irrigators with limited capacity will benefit from good judgement and additional water use and growth stage information.

Double cropping

Soybean or sunflower can be double-cropped after wheat harvest where growing season temperatures and the length of growing season are sufficient. Yield potential will be reduced due to the reduced growing period and effects of the yield threshold. The smaller yield threshold of sunflower may indicate a comparative advantage for double-cropping. Cooler weather can extend the duration of grain fill period but may alter the composition of fatty acids in oil (cooler temperatures can slow the conversion of linoleic fatty acids to oleic forms in oilseeds).

Table 4. Susceptibility of soybean and sunflower to soil water deficits (Adapted from Lamm and Stone, 2005).

	Soybean		Sunflower	
Growth Stage	Time period (days)	Susceptibilty Factor	Time period (days)	Susceptibilty Factor
Vegetative	38	6.9	53	43.0
Flowering	33	45.9	17	33.0
Seed Formation	44	47.2	23	23.0
Ripening	-	-	7	1.0

CROP-SPECIFIC CONSIDERATIONS

Soybean

A full-season, well-watered soybean crop offers relatively greatest productivity potential for non-calcareous soils with acid to neutral pH. The nitrogen-fixing crop can require minimal N fertilizer, provided soil is properly inoculated. Iron chlorosis can limit productivity on calcareous soils with pH exceeding 7.5 (Penas and Wiese, 1990); foliar diseases can also limit productivity. “Early determinate varieties are recommended for production systems involving narrow rows, high seeding rates, early plantings, good fertility, and a yield potential in excess of 50 bushels per acre” (Schapaugh, 1997). Photoperiod effects on flower initiation highlight the importance of selecting varieties from maturity groups appropriate for planting period and desired days to maturity.

Sunflower

Sunflower is commonly planted in early June, in the central Great Plains, to avoid stem weevil and sunflower moth pests. The deep-rooted crop can extract more soil water than other crops. Combined with the smaller yield threshold, sunflower can give relatively greater yields when water supplies are limited. The heat-tolerant crop also tolerates calcareous soil and high pH conditions. Decreasing daylength (when less than 15 h) near the R1 stage can reduce the duration of reproductive stages, due to photoperiod effects, when grown at latitudes less than 40^{o}.

Canola

Winter canola is established in early fall and harvested mid-summer, similar to winter wheat. The yield advantage of winter varieties over spring varieties is similar to that of winter wheat, approximately 30%. The small-seeded cool-season crop may be difficult to establish, as well as sensitive to heat stress during yield formation stages.

Physiological perspectives

Oilseed crops tend to produce less yield than feed grain crops (i.e., corn and grain sorghum). Less productivity results from differences in photosynthesis and in seed composition. The C3 physiology of oilseed crops is inherently less effective than the C4 physiology of feed grain crops. The C3 carbon-fixing enzyme Rubisco, is approximately 2/3 effective when exposed to atmospheric oxygen concentrations. Plants with C4 physiology also use Rubisco, but it functions in bundle sheath cells where oxygen concentrations are very small, and the enzyme functions at near complete effectiveness, resulting in increased crop productivity.

The second difference between oilseed and feed grain crops involves oil and protein content. The amount of starch which can be produced from a unit of carbohydrate (sugars produced from photosynthesis) is 0.88. The remaining fraction, 0.12, is consumed in the conversion process. More carbohydrate is used up in the formation of oil (0.67) and protein (0.65). As a consequence, the fraction of carbohydrate converted to oil is 0.33; to protein is 0.35. Smaller seed yields of oilseed crops is a consequence of greater oil and protein (in the case of soybean) content, for which a greater fraction of the photosynthetically-fixed carbohydrates are consumed.

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DEVELOPING WATER MANAGEMENT PERFORMANCE MEASURES

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ABSTRACT

The United States Bureau of Reclamation (Reclamation), in cooperation with the California- Bay Delta Water Use Efficiency Program (WUE), has developed performance measures to quantify the project level benefits of water management actions. Quantification of project benefits is an important means of determining the relative effectiveness of various water management efforts and for improving program level implementation. Additionally, with shrinking federal budgets, it is imperative to demonstrate the effectiveness of water management expenditures. Currently, quantifiable information is limited, and varying measurement methodologies make it difficult to compare benefits from program to program, or location to location. This paper presents and defines performance measures developed for a number of water management project types including water measurement, canal lining and piping, system automation, spillage reduction, drainwater reuse, water marketing and water banking. Use of these performance measures will help standardize quantification methods and facilitate comparability throughout the water management industry.

INTRODUCTION

Reclamation was created by an act of Congress in 1902 to develop and provide water resources for the arid western United States. Since 1902, Reclamation has constructed over 475 major structures including Hoover Dam on the Colorado River and Shasta Dam on the Sacramento River. Beginning in the 1980's environmental concerns and population growth in such areas as Los Angeles, San Francisco, Las Vegas and Phoenix required Reclamation to expand its mission to include managing and protecting Reclamation's water resources in an environmentally friendly and economically sound manner in the interest of the American public.

Added to Reclamation's expanded mission is the increased accountability at state and federal levels to prioritize expenditures and determine the most cost-effective means of using limited funding resources. In the water management industry, this requires analyzing the cost versus the benefits of projects that focus on water demand management to determine which practices, in which situations, result in the best use of funding. In addition, decision makers need to determine whether the problems associated with limited water resources can be best addressed by concentrating funding on reducing water demands or increasing water storage.

This is a major dilemma now facing the CALFED Bay-Delta Program. CALFED is a combined State of California and federal program focused on the restoration of the Delta's fragile ecosystem while improving water supply reliability for urban and agricultural water users. Historically, competing stakeholder groups have debated the issue of storage versus demand management with limited data available to determine which combination of new water supply projects and demand management projects is most cost effective. By establishing performance measures and measuring the success of various WUE projects, decisions can be made based on objective criteria.

In addition to its involvement in CALFED, Reclamation has historically funded several WUE projects geared towards decreasing water demands in order to meet environmental, agricultural and growing urban needs. In 1997, Reclamation created the Water Conservation Field Services Program (WCFSP), designed to encourage water conservation through financial and technical assistance. The WCFSP provides cost share funding to Reclamation contractors for the implementation of best management practices identified in their water conservation plans. Over the last several years Reclamation has given hundreds of small grants to contractors for projects such as canal lining and piping, irrigation scheduling, system delivery, system modernization and measurement.

Another Reclamation program addressing water conservation is Water 2025. Initiated in 2004, Water 2025 focuses attention on the complex water issues of the West. The demand for urban water needs, the emerging needs for environmental and recreational water and the national importance of the domestic food and fiber production from western farms and ranches are driving major conflicts between competing water users. Water 2025 provides a forum for public discussion of the issues so that decisions can be made in advance of water supply crises.

An important aspect of Water 2025 is the Challenge Grant Program. Challenge Grant funding is provided on a 50/50 cost-share basis to irrigation and water districts, Western States and other entities with water delivery authority for projects that stretch existing water resources. Challenge Grant projects focus on modernizing aging water delivery infrastructure, water marketing and improving water use efficiency and conservation. Between years 2004 and 2006, the Water 2025 Challenge Grant program has funded 78 projects that represent approximately $60 million in water system and water management improvement across the West. These projects will create new water banks, promote the use of advanced technology to improve water management and increase collaboration among Federal, State, tribal, and local organizations.

PERFORMANCE MEASURE DEVELOPMENT

Prior to 2006, Reclamation had no standardized methods to quantify the results of WUE projects even though initial estimates of water savings were required. In order to quantify benefits of a project, determine effectiveness of water management efforts and summarize the overall effectiveness of the WUE grant programs, Reclamation, in cooperation with CALFED, developed performance measures to compare pre- and post-project water use data. By implementing these performance measures, one can calculate the anticipated project benefits and verify results, i.e. water conserved, after a WUE project is implemented.

This effort to quantify benefits is consistent with laws such as the Government Performance and Results Act of 1993 (GPRA) and with the Program Assessment Rating Tool (PART) which require federal agencies to strategically plan according to program objectives and to track and report their performance. GPRA and PART promote measurable results and assess performance using program results. Developing water management performance measures for Reclamation's WUE projects adheres to GPRA and PART requirements and will allow Reclamation to measure program effectiveness and to calculate the costs and benefits of conservation efforts. Performance monitoring will give output measurements that are expressed in a quantifiable manner, which will give water managers real data to use when evaluating the financial feasibility of future projects.

Currently, quantifiable information for water use efficiency projects is limited, and varying measurement methodologies make it difficult to compare benefits from program to program, or location to location. Standardizing quantification methods for measuring WUE benefits with performance measures will allow comparison of the results from varying grant programs such as Water 2025, WCFSP and CALFED WUE Programs. These programs have collectively spent over $80 million in WUE projects in the last 5 years.

Performance measures for WUE projects are based on specific indicators to assess program performance and progress towards program goals. Indicators are used to measure quantitatively an attribute of interest. Indicators can be classified into three types, described below:

- **Administrative Indicators-** indicators that summarize administrative actions and describe resources (i.e. funds, personnel, projects) focused on a particular subject. Example: amount of funds spent on projects to improve water use efficiency.
- **Driver Indicators-** indicators that are representative of controlling factors (example: hydrologic year type) or implementation actions for example acres of district with improved delivery flexibility.

- **Outcome Indicators-** Indicators that are representative of a response to controlling factors. For example the improvement in WUE for a given project such as improved delivery flexibility.

Performance measures are used to determine if targets, the level of indicator performance sought within a given timeframe, have been attained. Targets may be quantitative (specific numbers or rates of change) or stated in qualitative terms. Quantitative targets can be useful when interpreting data and assessing progress towards goals. For example a canal-lining program may “target” a 10% annual reduction in deep percolation on an annual basis.

Specific performance measures were developed for various WUE projects including canal lining or piping, installation of measurement devices, SCADA, system controls to decrease spillage, drainage reuse projects, landscape evapotranspiration controllers, irrigation system improvements, water marketing and ground water banking. Types of data collected will include quantification of seepage, spills, water deliveries consumptive use, crop ET, improvements in delivery flexibility, pumping volumes and end of season water stores. Table 1 is an abbreviated version of Reclamation’s and CALFED’ s drafted performance measures for canal lining, measuring devices and data acquisition projects. The complete performance measures document can be viewed at http://www.usbr.gov/mp/watershare/documents/PerformanceMeasures final 3-2.pdf.

Reclamation understands that there are limitations to the drafted performance measures. In some cases, baseline data may not be available for post-project comparisons. One may face challenges quantifying the direct benefits for certain projects such as measurement and automation since no previous data on water consumption exists for that area. It is also impossible to come up with a “one size fits all” performance measure for each project type. In addition, verifying water conserved from certain projects may take several years due to temporal and spatial scales.

Table 1: Examples of drafted performance measures for WUE projects.

Action	***Pre-project estimations of baseline data***	***Post-project verification methods***
<u>Canal Lining or Piping</u>	▪ Ponding Tests: Conduct ponding tests along canal reaches proposed for lining or piping. ▪ Inflow/Outflow testing: Measure water flowing in and out of the canal reach, taking evaporation into consideration.	▪ Using ponding tests, compare pre- and post-project test results to calculate water savings. ▪ If ponding or inflow/outflow tests cannot be performed, compare estimated historic seepage and evaporation rates for the lateral length of the canal to the post-project seepage and evaporation. ▪ Compare ratio of historic diversion-delivery rates. Also include a comparison of historical and current canal efficiencies. ▪ Record reduction in water purchases by shareholders and compare to historical water purchases.
<u>Measuring Devices</u>	▪ Pre-project estimated savings are difficult to measure; however, one can collect historical data on water use to estimate the amount of delivered water.	▪ Compare post-project water measurement (deliveries or consumption) data to historical water uses. ▪ Compare pre- and post-project consumptive use by crop via remote sensing information. ▪ Survey users to determine utility of the devices for decision making. ▪ Document rate structure changes such as volumetric or tiered water pricing due to the use of measurement devices (assumes non-metered to metered district) so that water users are billed for actual water used instead of at a flat rate.
<u>Data Acquisition</u>	▪ Collect data on diversions and deliveries to districts and ditch companies, making estimates if necessary. ▪ Document employee time spent on pre-project ditch/canal monitoring and water control.	▪ Calculate amount of increased carryover storage in associated reservoirs. This measure will be more meaningful over a period of years. ▪ Track and record the diversions to individual districts and ditch companies or district laterals and compare to pre-project diversions. This would show results of improved management if yearly fluctuations in weather are accounted for. ▪ Report delivery improvements- i.e. changes in supply, duration or frequency that are available to end users because of SCADA. ▪ Document other benefits such as less mileage by operators on dusty roads (which saves time and influences air quality) and less damage to canal banks due to fluctuating water levels in canals.

CONCLUSION

Until recently, Reclamation and CALFED's WUE efforts have been focused on administrative indicators. As with most funding efforts the initial step is to insure that funds are being expended for specific actions identified by legislation or agency priorities. This includes quantifying funds spent for specific WUE measures and the cost share provided by funding recipients.

As program implementation has matured, funding entities such as Reclamation and CALFED are now focusing on outcome indicators that can be used to identify the benefits received from WUE funding, determine which projects provide the greatest benefit and compare benefits derived from storage projects. The performance indicators addressed in this paper focus on quantifying the outcomes from the implementation of specific projects. Outcome indicators can also be used to evaluate the effectiveness of management actions and help refine our understanding of how the system works.

Reclamation has initiated this process with the understanding that performance measures are a work in progress that will be further refined as monitoring programs are implemented and project results are analyzed. It is Reclamation's desire that other local, state and federal efforts related to WUE will work with Reclamation in this effort in order to better assess the benefits and costs derived from implementing water use efficiency practices.

LIMITED IRRIGATION OF FOUR SUMMER CROPS IN WESTERN KANSAS

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SUMMARY

Research was initiated under sprinkler irrigation to evaluate limited irrigation in a no-till cropping system. Corn, grain sorghum, soybean, and sunflower were grown with 5, 10, or 15 inches of annual irrigation. The objectives were to determine the impact of limited irrigation on crop yield, soil water, water use, and profitability. Irrigations were schedule to correspond with the most critical growth stage (reproductive) of each crop which generally was from mid-July to mid-August. With higher irrigation amounts, irrigations were begun sooner and continued later in the growing season. Soil water at planting and harvest was increased with increased irrigation amounts while crop had little impact on soil water. Average grain yields of all crops increased when irrigation amounts were increased from 5 inches annually to 10 inches. Corn was the most responsive crop with a 60 bu/acre increase (53%), while all other crops responded with 21 to 27% higher yields. When irrigation amounts were increased to 15 inches, corn, sorghum, and soybean yields increased an additional 10% while sunflower yields showed a slight yield decrease (3%). Average net returns to land, irrigation equipment, and management were similar for soybean and corn and only slightly less for grain sorghum with 5 inches of irrigation. Profitability increased for all crops when irrigation was increased from 5 inches to 10 inches. At 10 inches of irrigation or more, corn was the most profitable crop. Ten inches of irrigation was sufficient to optimize net returns for grain sorghum, soybean, and sunflower while corn was the only crop where profitability was greatest with 15 inches of irrigation.

INTRODUCTION

Irrigated crop production is a mainstay of agriculture in western Kansas. However, with declining water levels in the Ogallala aquifer and increasing energy costs, optimal utilization of limited irrigation water is required. While crop rotations have been used extensively in many dryland systems, the most common crop grown under irrigation in western Kansas is corn (about 50% of the irrigated acres), often in a continuous corn system. While corn responds well to irrigation, it also requires substantial amounts of water to maximize production. Almost all of the groundwater pumped from the High Plains (Ogallala) Aquifer is used for irrigation (97% of the groundwater pumped in western Kansas in 1995 [Kansas Department of Agriculture, 1997]). In 1995, of 2.46 million acre-ft of water pumped for irrigation in western Kansas, 1.41 million acre-ft (57%) was applied to corn (Kansas Water Office, 1997). This amount of water withdrawal from the aquifer has reduced saturated thickness (in some areas up to 150 ft) and well capacities. Although crops other than corn are grown under irrigation, they have not been grown as extensively because of relatively inexpensive water and a ready market for corn to the livestock feeding industry in the area. The trend in western Kansas during the last decade has been towards increasing acreage of irrigated corn (665,000 acres in 1990 compared to 1.2 million acres in 2000) with corresponding reductions in grain sorghum (326,000 acres in 1990 compared to 71,000 acres in 2000) and winter wheat (692,000 acres in 1990 compared to 455,000 acres in 2000) [Kansas Farm Facts, 1991 and 2001]. Although corn is expected to remain the dominant irrigated grain crop (especially in areas with abundant groundwater), the need exists to develop strategies to more effectively utilize limited irrigation water for corn. While there have been increases in irrigated soybean acreage (71,000 acres in 1990 compared to 134,000 acres in 2000), there has been limited research on water use characteristics in western Kansas.

Alternative crop management practices are needed to reduce the amount of irrigation water required while striving to maintain economic returns sufficient for producer sustainability. To prepare for less water available for irrigation in the future, whether from physical constraints (lower well capacities and declining water tables) or from regulatory limitations, information on crop productivity and profitability with less irrigation water will be beneficial for agricultural sustainability.

PROCEDURES

A field study was initiated under sprinkler irrigation at the Tribune Unit, Southwest Research-Extension Center near Tribune in the spring of 2001. The objectives were to determine the impact of limited irrigation on crop yield, soil water, water use, and profitability. All crops were grown no-till while other cultural practices (hybrid selection, fertility practices, weed control, etc.) were selected to optimize production. The experimental design was a split plot with crop being the main plot and irrigation amount as subplots. The crops evaluated were corn, grain sorghum, soybean, and sunflower grown in a 4-yr rotation (a total of 12 treatments). The crop rotation was corn-sunflower-grain sorghum-soybean (alternating grass and broadleaf crops). Irrigation amounts were 5, 10, and 15 inches annually. The irrigation amounts for a particular plot remained constant throughout the study, e.g. a plot that received 5 inches of water one year when corn was grown also received 5 inches in the other years when grain sorghum, sunflower, or soybean were grown. All treatments were replicated four times. Irrigations were scheduled to supply water at the most critical stress periods for the specific crops (generally flowering through grain fill) and limited to 1.5 inches/week. Soil water was measured at planting, during the growing season, and at harvest in one-ft increments to a depth of 8 ft. Crop water use was calculated by summing irrigation amount plus growing season precipitation plus soil water depletion (soil water at planting less soil water at harvest). Grain yields were determined by machine harvest. An economic analysis determined net returns to land, irrigation equipment, and management. Cost assumptions were based on local input costs and grain prices at harvest. Custom rates were used for all equipment operations.

RESULTS AND DISCUSSION

Precipitation during the growing season (May through September) varied greatly from year-to-year (Table 1). One year (2002) was especially dry with only 55% of normal precipitation, one year (2001) was near normal (92% of normal precipitation) and three years were wetter than normal (2003 to 2005 with 115 to 124% of normal precipitation). Hail caused severe crop damage in 2002 and moderate crop damage in 2005.

Table 1. Monthly precipitation from May through September during study period at Tribune, KS.

Year	May	June	July	August	September	Total
	-----------------	-----------------	-----------------	inches	-----------------	-----------------
2001	3.10	1.18	4.50	1.34	0.81	10.93
2002	1.20	1.30	0.44	1.91	1.64	6.49
2003	3.07	5.39	3.99	1.74	0.58	14.77
2004	0.05	4.86	3.62	3.01	2.15	13.69
2005	2.13	4.75	0.76	4.57	1.55	13.76
Normal	2.76	2.62	3.10	2.09	1.31	11.88

Irrigations were scheduled to supply water during the reproductive growth stage for all crops. So with the lowest irrigation treatments, the initial irrigation was delayed until later in the season than with higher irrigation treatments and also the termination of irrigation was soonest with the lowest irrigation treatment. As irrigation amounts increased, the irrigations were initiated earlier in the growing season and continued later in the growing season. The average beginning and ending irrigation dates are shown in Table 2. In general, irrigations were initiated earlier for corn than the other crops because of the earlier planting date. When precipitation was sufficient within a given week, irrigations were not done thereby saving the water for later in the season.

Table 2. Average date of irrigation initiation and termination of four crops from 2001 through 2005 at Tribune, KS.

Irrigation amount	Corn	Sorghum	Soybean	Sunflower
inches	- - - - - - - - - - - - - - period of irrigation - - - - - - - - - - - - - -			
5	7/15 - 8/8	7/21 - 8/12	7/19 - 8/11	7/17 - 8/9
10	6/30 - 8/11	7/10 - 8/26	7/7 - 8/25	7/7 - 8/25
15	6/19 - 8/29	6/27 - 8/31	6/24 - 8/31	6/24 - 8/30

Soil water at planting increased with increased irrigation amounts, particularly when irrigation increased from 5 to 10 inches (Table 3). There was little difference in soil water at planting between the 10 and 15 inch irrigation treatments. Crop selection had little impact on soil water at planting.

Table 3. Soil water at planting of four crops as affected by irrigation amount from 2002 through 2005, Tribune, KS (2001 excluded because of previous irrigation history was not consistent with study treatments).

Irrigation amount	Corn	Sorghum	Soybean	Sunflower
inches	- - - - - - - inches of water in 8 ft profile - - - - - -			
5	5.65	6.26	4.83	6.93
10	9.35	9.36	8.84	10.51
15	9.46	10.34	9.59	10.34

Profile soil water at harvest responded similarly to that at planting in that there was considerably more soil water with 10 rather than 5 inches of irrigation but little further increase with 15 inches of irrigation (Table 4). In general, soil water at harvest was 1 to 2 inches less than at planting. Crop selection had little impact on soil water at harvest.

Table 4. Soil water at harvest of four crops as affected by irrigation amount from 2001 through 2005, Tribune, KS.

Irrigation amount	Corn	Sorghum	Soybean	Sunflower
inches	- - - - - - - inches of water in 8 ft profile - - - - - -			
5	4.76	3.71	3.74	4.63
10	8.18	7.81	8.36	8.45
15	8.50	8.64	8.79	9.79

Crop water use increased with increased irrigation amounts (Table 5). Crop water use was greater with grain sorghum at the lowest irrigation amount but with corn at the highest irrigation amount. Sunflower used the least amount of water.

Table 5. Crop water use by four crops as affected by irrigation amount from 2001 through 2005, Tribune, KS.

Irrigation amount	Corn	Sorghum	Soybean	Sunflower
inches	- - - - - - - inches of water - - - - - -			
5	17.95	19.26	17.43	16.92
10	22.48	22.34	21.44	20.71
15	26.38	25.81	25.15	22.89

Average grain yields of all crops increased when irrigation amounts were increased from 5 inches annually to 10 inches (Table 6). Corn was the most responsive crop with a 60 bu/acre increase (53%), while all other crops responded with 21 to 27% higher yields. When irrigation amounts were increased to 15 inches, corn, sorghum, and soybean yields increased an additional 10% while sunflower yields showed a slight yield decrease (3%). Grain yields varied greatly during the study period (values in parenthesis in the table). The low yields were caused by hail damage in 2002 and 2005. The highest yields for most crops were in 2004 except grain sorghum which had the highest yields in 2001.

Table 6. Average grain yield of four crops from 2001 through 2005 as affected by irrigation amount, Tribune, KS. Values in parenthesis are range in grain yields.

Irrigation amount	Corn	Sorghum	Soybean	Sunflower
inches	- - - - - - - - - - - -	bu/acre	- - - - - - - - - -	lb/acre
5	114 (14-204)	93 (13-134)	30 (12-49)	1550 (70-2530)
10	174 (73-245)	114 (57-149)	38 (23-52)	1880 (230-2700)
15	191 (93-260)	125 (80-172)	42 (28-51)	1820 (270-2780)

With 5 inches of irrigation, average net returns were similar for soybean and corn (Table 7) and only slightly less for grain sorghum. Profitability increased for all crops when irrigation was increased to 10 inches. At 10 inches of irrigation or more, corn was the most profitable crop. Corn was also the only crop where profitability was greatest with the highest irrigation level. All other crops were more profitable with 10 inches of water. In this study, sunflower was the least profitable crop at all irrigation levels.

Table 7. Average net return to land, irrigation equipment, and management for four crops as affected by irrigation amount from 2001 through 2005, Tribune, KS.

Irrigation amount	Corn	Sorghum	Soybean	Sunflower
inches	- - - - - - - - - - annual net return, $/acre -- - - - - - -			
5	27	12	31	-12
10	130	28	56	-3
15	146	27	52	-26

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Remote Monitoring and Control of Irrigation Pumps for Energy, Water, Labor and Cost Savings

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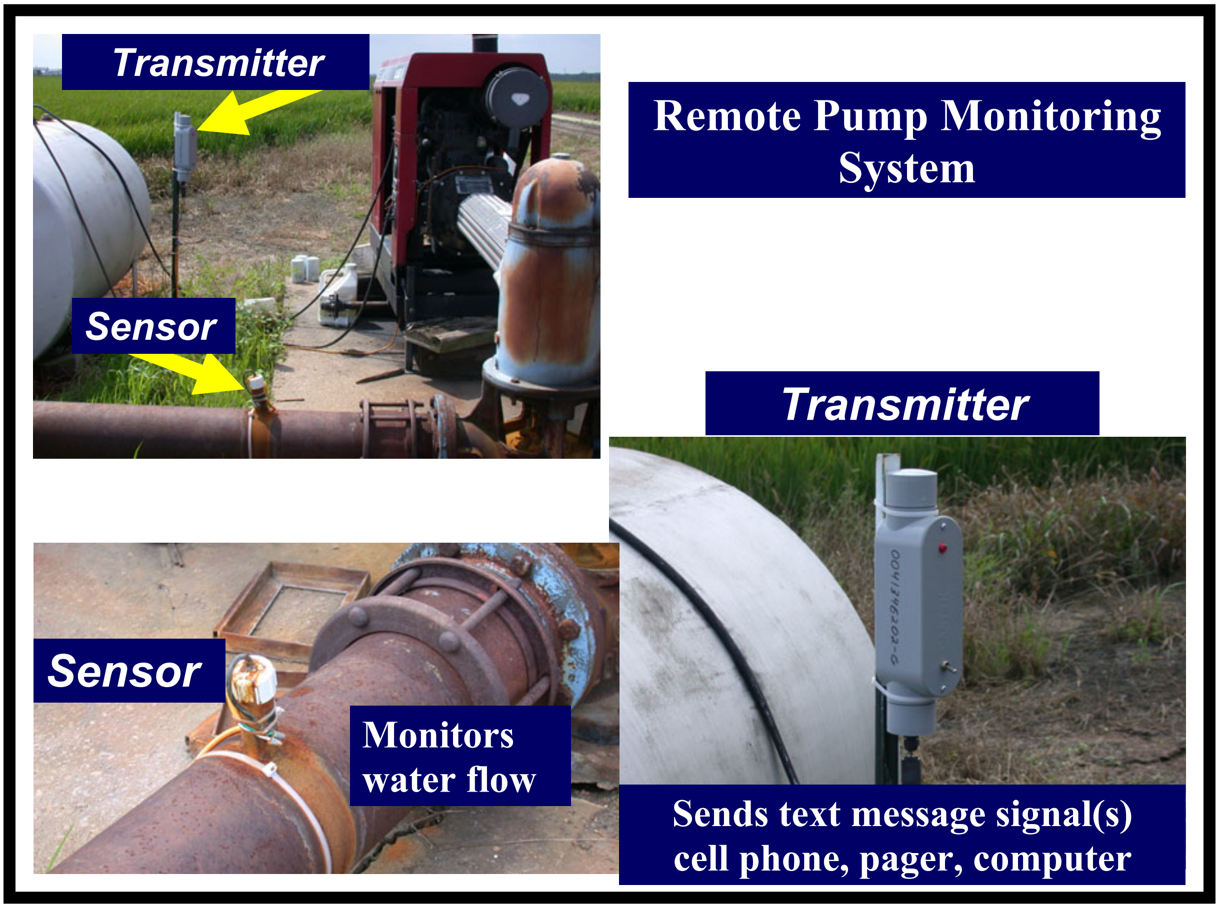
Situation

Agricultural producers continue to look for ways to more effectively manage time and labor. There always seems to be more to do than can be done within the time needed and with the labor that is available. Some farming operations expend a significant amount of time and labor to monitor the operation of the irrigation pumps on the farm. There are over 45,000 irrigation pumping systems in operation in the Arkansas Delta. In many cases the irrigation pumps are located in remote areas that are several miles apart and also at a significant distance from the farm shop or headquarters. During the irrigation season, one or more farm employees will spend several early morning hours and late evening hours traveling to the irrigation pumps in order to start them, service them, turn them off or to just make sure they are still running. There can be a lot of times when this schedule gets interrupted because the employee(s) have to take care of other things like fixing equipment that is broken down, getting parts or picking up seed or chemicals that are needed. If one or more irrigation pumps have shut down for a significant time before anyone realizes it then the crop(s) irrigated by these pumps can suffer. In the same respect, if no one is available to shut off a pump and it runs longer than necessary, then precious irrigation water and energy in the form of diesel, electric etc. can be wasted, resulting in additional cost to the producer.

Remote Monitoring System

A pump monitor system recently became available to agricultural producers to help address the situations described above. The system is composed of a sensor and a transmitter (Fig 1). The sensor is positioned in the water flow of the discharge from the irrigation pump and set so that it senses whether or not water is present. When it senses that water is not flowing, it can be wired into the power unit's shut down system so that the power unit automatically shuts off if needed. At the same time, a signal is transmitted to indicate that the pumping system is not pumping water. The transmitted signal can be received as a text message by a cell phone, an e-mail message or a page to a designated person or persons. It can be set up to either alert two different people or to alert the same person using two different contact methods. Each pump being monitored is given a descriptive name or number that is indicated in the message so the producer knows exactly which pump is not operating. Once the pump is operating again the system sends a signal indicating that the water flow has been reestablished. It is also possible to use the monitor system to turn off power units remotely from a computer through an internet web site.

Figure 1: Field Picture of Remote Pump Monitoring System



The system can be used to monitor electric wells but some additional electrical components are needed to accomplish automatic or remote shut down. However, once the components are in place it is also possible to turn the electric pump on remotely through an internet web site. There is a setup in Mississippi that allows monitoring and automatic on and off control of electric pumps that are located 87 miles from the agency headquarters.

The transmitter component can be moved to a grain bin fan equipped with a different sensor that monitors air flow. In this application the monitor will notify someone when a fan has stopped operating in the same manner as is done with the irrigation pump. Another application of the system is to monitor the fuel level in the diesel tank that supplies the irrigation system's diesel power unit. A sensor is placed in the tank at a desired depth and when the fuel level drops below this depth someone is notified so plans can be made to refill the diesel tank. Both of these applications also have the element that a signal is received indicating that the fan is now running or the diesel tank has been filled.

Field Experience

The pump monitoring system was installed on two of the irrigation wells at the North East Research and Extension Center in Keiser, Arkansas. The installations were done by a company technician and went smoothly and quickly. The station employees who work with the monitoring systems are very pleased with their performance. On more than one occasion they were able to remotely turn off the wells from an internet website during a thunderstorm. This not only made it safer for the employees to not be out in the storm but it also avoided the rutting of field roads.

There have been numerous times when someone had just left an irrigation pump while it was running and in just a few minutes been notified that it had stopped. The first time this occurs the person is skeptical of the monitoring system but their confidence is established when they return to the pump and find that it had stopped. They also realize the benefit this gives them and the potential it offers for time and labor savings from not having to make trips to check on the status of the pump. Table 1 is one producer's estimate of the direct savings and also the indirect savings of using time spent checking pumps to spray fields himself rather than having to hire it done. He also noted the benefit of being able to better spray on his schedule and under more desirable conditions than might be available if he had to wait on it to be done by a custom applicator.

Table 1: Example of Producer's Estimate of Savings

Direct Savings:
40 miles round trip to check pumps
Average 10 mpg @ $2.20/gal fuel cost
4 gals x $2.20/gal = $8.80 per trip
3.5 labor hours and truck hours to make trip and service engines @$10/hr
3.5 x $10/hr = $35 per trip
$8.80 + $35 = $43.80 per trip
60 days of pumping saving 1 trip per day
60 trips x $43.80/trip = *$2628/season*

Indirect Savings (value of 3.5 hrs spraying)
80 ac/hr x 3.5 hrs = 280 ac @ $5/ac application savings
280 ac x $5/ac = *$1400/day*

Significant that spraying will more likely be done on your schedule and with desirable conditions!!

Many electric wells have peak load management switches that allow the power provider to turn off electric wells when needed to manage the electrical demand on their system. The switches are supposed to allow the electric wells to automatically come back on after a 2 to 4 hour period. Producers who have the monitoring system on these wells will get a notification that the water is running again. If they don't get notification when they should, they know to check the well and they also have information they can use with the power provider as proof that the pump did not come back on as it was supposed to.

When irrigation pumps are located in remote areas it becomes difficult for someone to always be available to go to the area in order to turn the unit off. Even though the producer knows the pump can be turned off, he and all of his labor may be busy. This can result in the pump running for a few hours or maybe even overnight before someone can go and turn it off. Unfortunately, this wastes water and energy and results in unnecessary pumping costs for the producer. The ability to remotely turn off the pumping unit can help avoid this situation.

A producer can reduce the down time for an irrigation pump when he knows within minutes of when it has shut down. This can avoid getting behind on crop irrigation and reduce the potential for lost yield due to drought stress. If a producer doesn't know he has a pump down until 6 pm when someone checks it, then it can lead to the loss of valuable pumping time. If he needs repair part(s) from a store that is closed until 7 am the next morning it can easily result in the pump being down for 12 to 24 hours. This situation can become even more serious if it occurs on a Friday or Saturday evening and parts aren't available until Monday. It is difficult to put a value on avoiding lost pumping time but producers know how important this can be especially at critical crop growth stages. One Arkansas producer was attending a baseball game in St. Louis, MO, which is over 350 miles from his farm, when he got a cell phone text message that one of his primary irrigation pumps had shut down. He was able to contact someone on the farm and 2 innings later he got a call letting him know that the pump was now operating.

Summary:

Application of remote monitoring and/or control technology to irrigation pumping and other agricultural operations makes sense. The fact that the system uses cell phones (telemetry technology) is very positive since most producers now use cell phones instead of radios. Experience indicates that the system transmitter has adequate power (approximately 2 watts) to send out a signal from very remote areas. Most producers purchase only a couple of the monitoring systems initially but soon put in an order for more units once they realize the benefits that they provide. This is an indication that they trust the technology and that they feel they can justify the cost for the monitoring system. One producer commented, "It is like having someone standing at the pump and it is hard to put a value on the peace of mind that gives you".

Low Pressure Systems Reduce Agricultural Inputs

Paper #1484

By

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Introduction:

Since its introduction in the 1960's, the availability, quality, management and performance of drip irrigation (DI) and subsurface drip irrigation (SSDI) have greatly improved. The uses of DI and SSDI have increased significantly as understanding and benefits of real-time irrigation methods increased and plastic materials availability, manufacturing processes, emitter designs and fertilizers improved. However, the perceived high initial cost of DI and SSDI systems and the energy cost to pressurize the system have slowed down the conversion of gravity irrigation to DI and SSDI.

The low pressure system (LPS) is a systematic development of a low cost DI system. The system is designed to operate at low pressures (2-3psi; 0.14-0.21 kg/cm2) by taking advantage of the slopes graded into furrow irrigated fields. Thus, LPS provides an effective low energy and economical upgrade for furrow irrigation. Furthermore, LPS mitigates environmental issues arising from difficult-to-control surface irrigation, non-point source pollution, deep percolation of soluble salts and pesticides, erosion and sedimentation of watersheds. The introduction of LPS provides an alternative initial low cost, low energy systems with a multiyear life expectancy, displaying a number of advantages associated with permanent DI and SDI systems.

The major objective of LPS is to provide a one-to-five year life span irrigation system with water and fertilizer application advantages of DI and SDI systems but at a lower initial cost. The initial LPS cost is dependent on the sophistication level of the system Conceptually, LPS is designed to: (1) help growers use existing infrastructures such as leveled fields, water sources and pumps, (2) minimize front end investment (3) provide fast return on investment, (4) reduce energy cost for pumping and pressurizing, (5) move and reuse equipment easily and (6) provide low system maintenance and management.

Two additional advantages of LPS could be: (1) low pressure/low flow design suggests that LPS could operate similarly to furrow irrigation by applying water uniformly over 1/4 mile- (400 m)-long rows and thus could potentially replace large Western furrow irrigated acreage and (2) water discharge rates being lower than most soil infiltration rates would not require the use of rigorous high frequency irrigation scheduling (LPS can stay on for longer periods of time without creating runoff and/or deep percolation). It is the purpose of this paper to present and discuss evidence for the applicability of LPS for use in 400 meter long rows and the Agronomic benefits of low pressure/ low flow irrigation. In addition, the economic benefits of low pressure drip irrigation will be discussed.

Components of a Typical LPS System

A typical LPS consists of several specific components. Depending on the size of the system, the topography of the site, the soil characteristics, the crop, the water/fertility requirements, the water source, availability and/or quality or the application considered, LPS may vary considerably in physical layout but generally will basically consist of some of the components shown in Figure 1, although LPS will often be as simple as the system shown in Figure 2. The various components of the system can be added as desired and are divided into: (1) connection to water source, (2) control headworks including a fertigation system, (3) field distribution system, (4) dripper line laterals, (5) accessories and installation tools and (6) optional automation and instrumentation.

Reservoir and Pump--Many farms are storing water in elevated reservoirs to supply water on demand to their irrigation systems and will not required a pump if the reservoir static pressure is at least 7-8 ft. (2.1-2.5 m). In cases where the static pressure from the reservoirs do not meet this minimum pressure requirement, a pump can be used to supply pressurized water for the LPS. Direct Connection to a Pressurized System--Many Irrigation Districts are supplying pressurized water to on-farm turnouts to supply water on-demand for their irrigation clients. In these cases, a pump may not be required if the static pressure from the turnout is at least 7-8 ft. (2.1-2.5 m). In cases where the static pressure from the irrigation district does not meet this minimum pressure requirement, a pump could be used to increase the water pressure for the LPS. Figure 3 shows a basic example of an on-farm low pressure water turnout supplying water for a LPS via a screen filter and a pressure regulating standpipe.

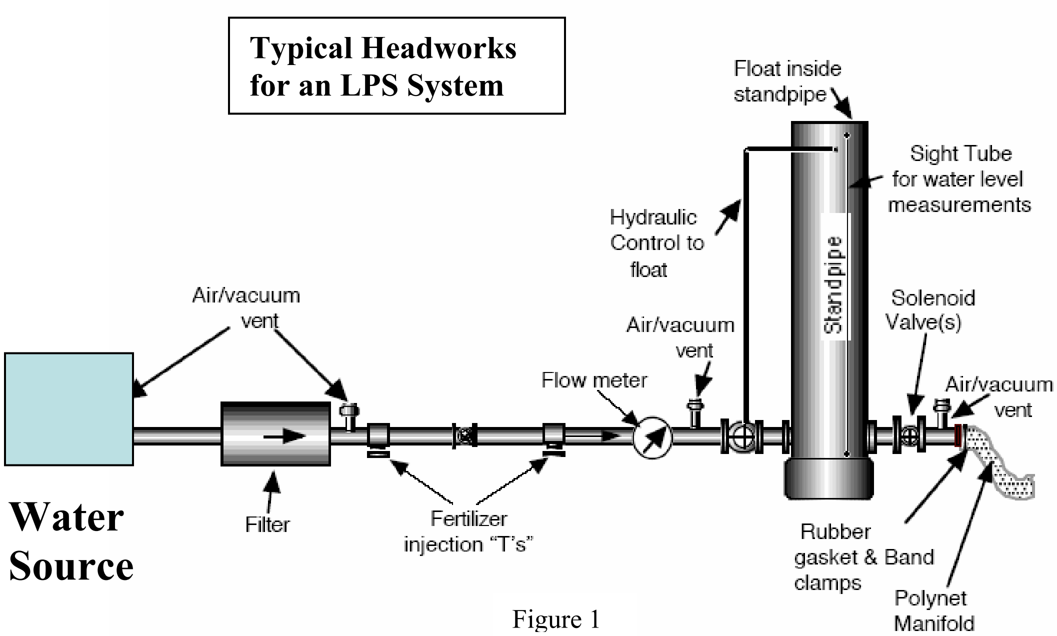

Figure 1

Figure 2

Figure 3

. Control Headworks The headworks of a basic LPS consists of specific components, as shown in Figure 1. Field systems may vary considerably in physical layout but generally will consist of the following or some variations of the following components:

a. Air vents-- Air vents are a critical component of any hydraulic network. If air is not released, air pockets are formed in the distribution lines, reducing the effective diameter of the pipe. The use of air relief valves at all high points of the LPS is the most efficient way to control air. There are three major types of air vents: (1) Air/Vacuum Relief Vents, also known as kinetic air valves. These air vents discharge large volumes of air before a pipeline is pressurized, especially at pipe filling. They admit large quantities of air when the pipe drains and at the appearance of water column separation; (2) Air Release Vents are also known as automatic air valves. These vents continue to discharge air, usually in smaller quantities, after the air vacuum valves close, as the line is pressurized and (3) Combination Air Vents, also known as double orifice air valves, fill the functions of the two types of air vents described above.

b. Filtration--The main purpose of filtration is to keep mainlines, submains, laterals and emitters clean and working properly. Many factors affect the selection of a filtration system. Designers should use the correct equipment for a specific farm water source. With LPS, the choice of a filtration system is further limited by the availability of electrical power and hydraulic pressure. Screen filters, such as shown in Figure 3 and gravity filters (low pressure) have been used successfully with LPS.

c. Flowmeter--Knowing how much water and when it is supplied are critical measurements for correctly operating LPS irrigation. Inline flow meters should record total flow and flow rate.

d. Float Control Valve--The main control valve is regulated by a float, located in the pipe at the preset maximum water level. The valve is hydraulically controlled by the float and opens or closes to maintain a constant water level and head pressure on the downstream LPS system.

e. Standpipe--The main purpose for the standpipe is to accurately control the pressure applied to the LPS dripperlines. Typical standpipes are 10.7 ft. high and 1 to 2.25 ft. diameter with inlet and outlet flanges. Water level and downstream pressure control are achieved by using a float which activates the float control valve shown upstream of the standpipe as in Figure 1. A clear, external water level tube allows the operator to visually determine the water level in the standpipe. Inlet and outlet pipes are connected to the standpipe by bolted flanges. In areas where wind gusts are occurring, the standpipe can be anchored to the ground by three or more steel cable ties.
f. Fertilizer Injector--Fertilizer injection methods range from dripping fertilizers at calculated rates into the standpipe (no available electrical power or necessary pressure) to using fully computerized monitoring and control systems. When electrical power is available, injecting with metering pumps is the most versatile method for injecting chemicals into LPS systems. Automatic time and programmable controllers are usually the best way to control fertilizer injection. When full automation is used, the metering of the fertilizer is programmed for injection during the middle of the irrigation cycle to avoid the line filling time of the irrigation cycle. Injection of chemicals can also be stopped during filter flushing operations. Continuous measurements of pH and EC are also recommended to ensure adequate system performance and to control the pump on or off and/or in the case of accidents and malfunctions.

3. Field Distribution System
The field distribution system consists of (1) automatic or manual valves, (2) Flexible Poly submains/manifolds with lateral connectors, (3) air vents and (4) manual clamps. Figure 4 shows a photograph of a typical manifold and lateral setup (the manual valve for system operation is not visible). Depending on the type of LPS applications, there are several types of thin-wall dripperlines with emitters integrated within the pipe wall that are available for LPS. The available types of LPS dripperlines are based on life expectancy (1-5 years) and types of tillage application. Emitters with different flow path configurations, discharge rates and operating pressure range are presently being used in LPS applications.

Figure 4

Full automation of LPS is available, although strictly an option. Because LPS applies water at a rate usually lower than the soil infiltration rate, high frequency irrigation management is not necessary to prevent runoff and/or deep percolation. Hence irrigation scheduling is typically less complicated and intense than for DI and SDI. However, although optional, instrumentation to measure weather and soil water conditions or access to a system that does (State Weather Network) can help meet the rapidly changing evapotranspiration demand of the crop and improve water use efficiency.

LPS Design Considerations.

The first step in designing LPS systems is to measure the flow rates of drippers at low pressures to ensure that they correspond to the theoretical rates. Table 5 gives comparative results for theoretical flow rates based on K and X values and those measured using a manometer (only the theoretical values are plotted). The values closely match. Such a measurement is not trivial as the flow rates at low pressures are very low and the pressure must be absolutely constant. A manometer is the best way to produce constant low pressures but maintaining the reservoir height requires careful experimental technique. In these experiments a large reservoir was used so that the manometer height would change little over the course of the experiment.

875ID - Typhoon 0.4 gph	K	X		Pressure (psi)										
				0	1	2	3	4	5	6	7	8	9	10
	0.128	0.45	Flow (gph)	0.000	0.128	0.175	0.210	0.239	0.264	0.287	0.307	0.326	0.344	0.361
measured flow rates			Flow (gph)	0.000	0.130	0.179	0.217	0.248	0.276					

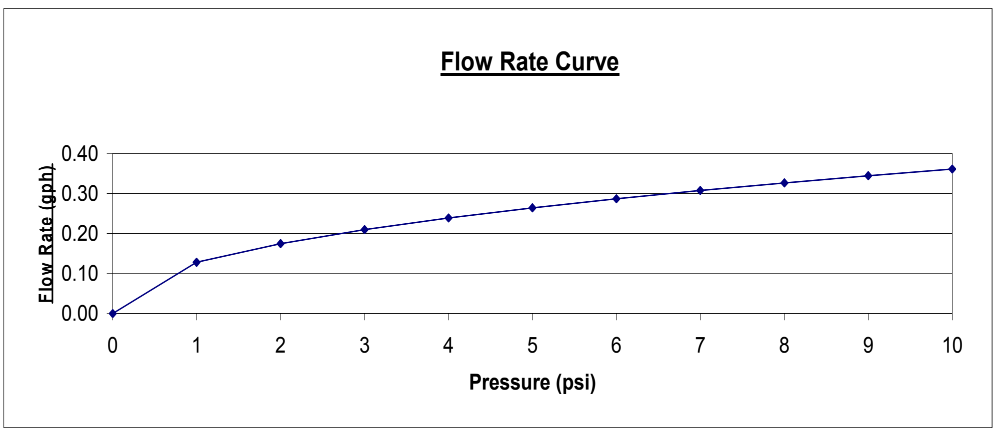

Figure 5

A second test was applied which looked at dripper turbulence. The turbulence factor denoted by K is a measure of the amount of turbulence produced in a dripper. The K factor is a function of the cross sectional area of the flow path, the number of teeth in the dripper and the pressure flow relationship. The application of the pressure flow data from the above experiments to the flow coefficient (K) indicates that the dripper maintains its turbulence down to 3.9 feet of head (1.7psi) (Figure 6).

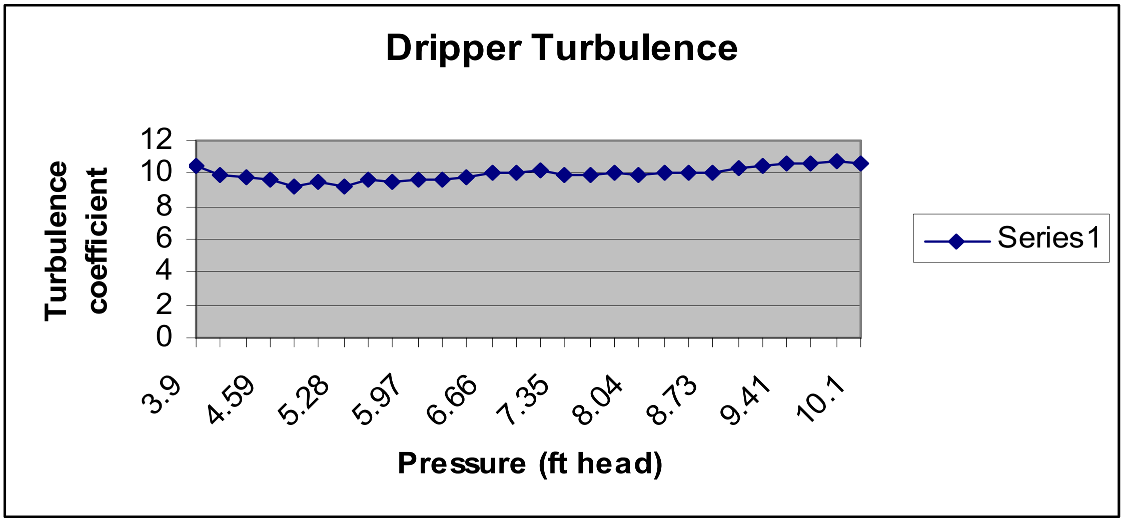

Figure 6

LPS is designed to work with level fields or those graded for flood irrigation. One of the system objectives is to work with 400 meter (1300 ft, or ¼ mile) rows. This was investigated by applying a standard dripper lateral design program using the appropriate dripper parameters determined above and varied slopes (Figure 7). The tubing internal diameter was 7/8 inches and the dripper spacing of 24 inches employed. The lateral input pressure was maintained constant at 3 psi and pressure along the lateral computed. Even over a distance of 1300 feet at an inlet pressure of only 3 psi the maximum variation in pressure was 1 psi or less. In all cases the emission uniformity was greater than 90%. The effect of slope on the pressure in the lateral is to increase pressure on the end of the line. The greater the slope the more pressure is increased as you move to the end of the lateral. There is obviously a "sweet spot" where the slope overcomes the pressure drop in the lateral line and the beginning and ending pressures are the same.

This computation shows that LPS systems can deliver excellent uniformity at row lengths up to 1300 ft. This computation only considered one flow rate emitter, 7/8 inch pipe and a single spacing. By varying these parameters it is possible to address a wide range of design challenges. Although the design uniformity for these computations was over 90% for all slopes uniformity is not the only reason for converting flood irrigated land to drip irrigation. The ability to provide water at any time needed in the crop cycle and the ability to send equipment into a field you are irrigating are just two cultural advantages of drip irrigation compared to flood or furrow irrigation.

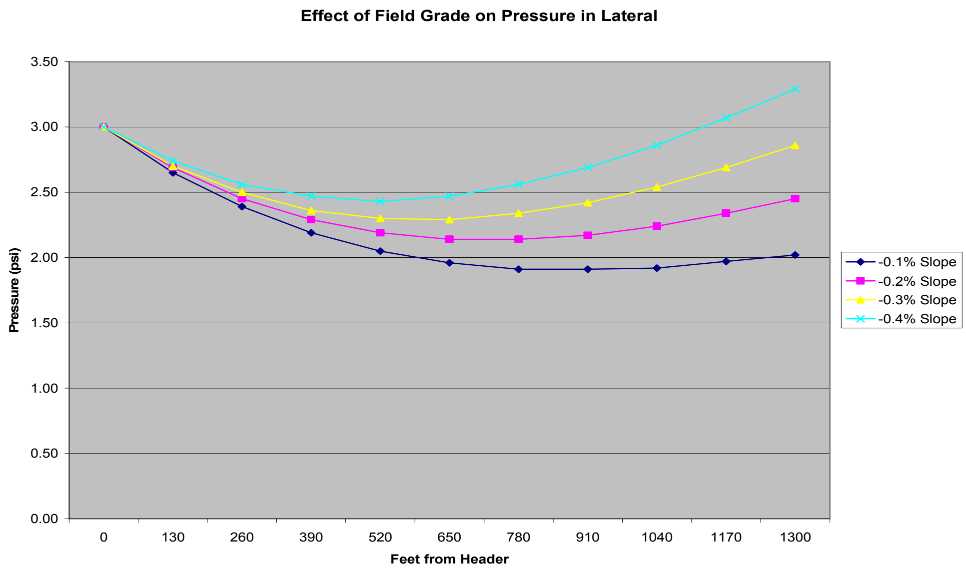

Figure 7

Agronomic Considerations of LPS

Operating drippers at low pressures results in lower dripper flows generally about one half the nominal flow rate (see Figure 5). At low flow rates water behaves in the soil differently than at higher application rates. At higher application rates the soil becomes saturated. In saturated soils the dominant force for water movement is gravity and thus water moves down the soil column and there is less lateral movement. At lower application rates the soil does not become saturated and the matric forces in the soil dominate. The matric potential is the result of small pores in the soil structure attracting water much like a straw. These forces pull the water in all directions and tend to result in a larger wetted area. An additional advantage of low flows is that the large pores remain filled with air resulting in a better root environment. Figure 8 demonstrates graphically the water movement in soils under higher flow and lower flow (LPS) drip regimes.

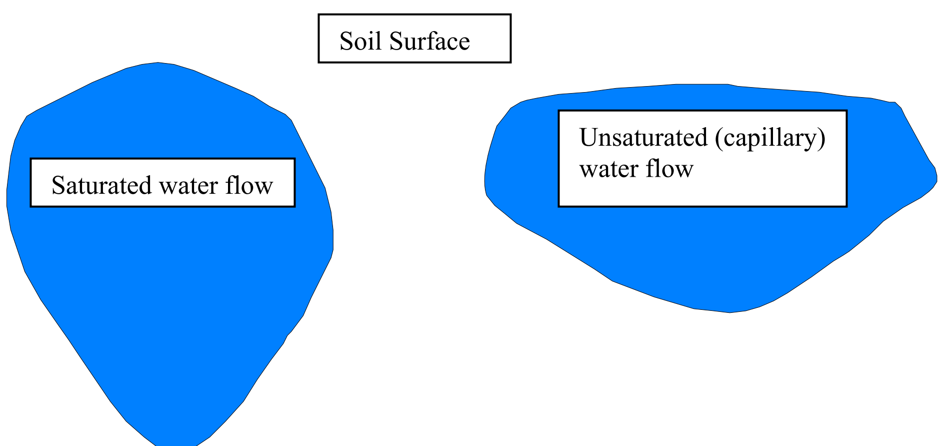

Figure 8

Experimental results on potatoes and corn show that the theoretical advantages of LPS can be translated into real savings in water when compared to flood irrigation. Figure 9 summarizes the results on water use efficiency for a crop of potatoes grown in Chihuahua, Mexico. The LPS plot yield required 40% less water than typical flood plot to produce equal yields. Figure 10 gives shows even more impressive savings with corn.

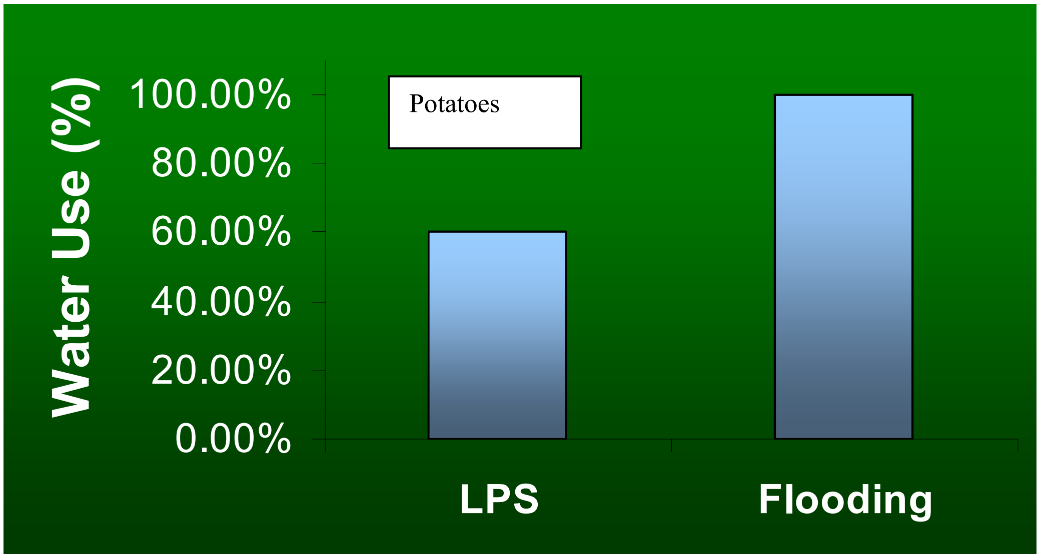

Figure 9

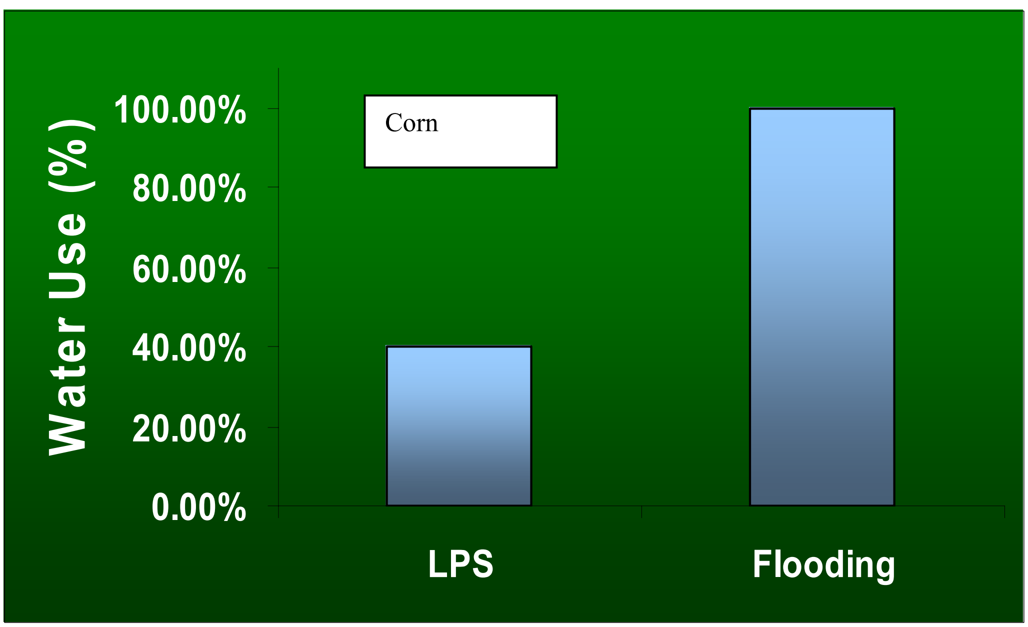

Figure 10

The most obvious advantage of LPS may be energy savings. Of course a flood irrigated crop using gravity or low head pumps on the surface is one of the most energy efficient irrigation systems. However when you consider the potential increased water use efficiencies as illustrated in Figures 9 and 10 about twice the energy is required to produce a flood irrigated crop than an LPS crop. As many farmers are turning to sprinkler systems to conserve water it is important to consider the relative energy savings LPS has over these systems

There are several major variables which directly affect energy uses and cost of irrigating crops:
1. Lift of water when pumping groundwater.
2. Pressure required to distribute water uniformly.
3. Amount of water required to sustain crop growth.
4. Pumping efficiency.
5. Energy price.

To illustrate potential energy savings three hypothetical irrigation scenarios were considered
1. A Fanjet/microsprinkler/drip system irrigating a 40-ac block, operating at 65% pumping efficiency, with a lift of 100 ft. at a pressure of 35 psi, a kWh cost ranging from $0.1 to $0.3/kWh, with a cotton crop requiring 3.5 ac-ft water application to meet water requirement.
2. A LPS or Furrow system irrigating a 40-ac block, operating at 65% pumping efficiency, with a lift of 100 ft. at a pressure of 4 psi, a kWh cost ranging from $0.1 to $0.3/kWh, with a cotton crop requiring 3.5 ac-ft water application to meet water requirement.
3. A LPS irrigating a 40-ac block, operating at 65% pumping efficiency, with a lift of 100 ft.at a pressure of 4 psi, a kWh cost ranging from $0.1 to $0.3/kWh, with the same cotton crop as above but requiring 2.5 ac-ft water application to meet water requirements.

The costs for system 1 above in $/kWh/ac-ft. range from $99.83 for a kWh rate of $0.1/kWh to $299.48 for a kWh rate of $0.30/kWh.
The costs for system 2 above in $/kWh/ac-ft. range from $60.40 for a kWh rate of $0.1/kWh to $181.19 for a kWh rate of $0.30/kWh.
The costs for system 3 above in $/kWh/ac-ft. range from $43.14 for a kWh rate of $0.1/kWh to $129.42 for a kWh rate of $0.30/kWh.
The $/ac. cost difference attributed to pressure reduction (down from 35 psi to 4 psi operating pressure) ranges from $39. 43 to $118.29 in $/kWh/ac-ft.
The $/ac. cost difference attributed to water application reduction (down from 3.5 ac-ft. to 2.5 ac-ft. water applied) ranges from $17.26 to $51.77 in $/kWh/ac-ft.
These are achievable and significant operating cost reductions that help justify the case for switching to the LPS concept.

Conclusion

LPS is a well researched system for drip irrigation at low pressures, typically those available for flood irrigated crops. There are significant agronomic advantages to using a low pressure, low flow drip system specifically related to greater lateral water movement in the soil and a better air water ratio. These advantages translate into measured improved water use efficiency when compared to flood irrigated crops and energy savings compared to flood and sprinkler irrigated crops.

Development of a mechanical Archimedean screw

By
Wasif, E., Lotfy, A * and S.E. Bader

Abstract

The aim of this research is increasing discharge rate, For irrigation all crop such as sugar beet, sugarcane, grain and forage crops, decreasing power consumption and consequently decreasing irrigation cost for mechanical Archimedean screw model or Egyptian traditional pump (Tambour Elwady). Some design factors affecting on the performance of mechanical Archimedean screw were studied as follow:-

A. The relation between top and bottom diameters, three rates, (1:1, 1.5:1 and 2:1).
B. Impeller fixed positions (1- At the bottom end, 2-at distance equal bottom diameter inside the screw 3-at distance equal bottom radius inside the screw).
C. Clearance between impeller and casing (three different clearances: 2, 4, and 6mm).
D. Different impeller speeds (450 – 650 r.p.m).

The highest discharge rate, lowest power consumption and best economical condition noticed at:-

- Screw top diameter equal 1.5-bottom diameter.
- Impeller fixed on distance equal bottom radius inside the screw.
- 2.0 mm impeller clearance.
- Impeller speed about 500 to 600 r.p.m.

Key word: Mechanical Archimedean Serew, Egyptian Tambour, Model, Impeller and Discharge

Introduction

Egypt is mainly an agricultural country in which agricultural and irrigation technologies play an important role in supporting national economy. Surface irrigation is the prevailing system in Egyptian fields (**Fouad and Abd Ellatif 1991**), the Egyptian traditional Tambour pump (Mechanical Archimedean screw) was the common pump used in Egyptian fields for lifting water from the irrigation canals by the reaction of lift forces that produced by rotating its impeller. This action pushes the water towards the upper end of screw and to the land surface.

The centrifugal pumps have been using instead of Egyptian Tambour. The centrifugal pumps or some parts are exported from foreign countries with higher price. Main while, farmer and end-user are retuning back to use Egyptian mechanical Tambour (mechanical Archimedean screw) to avoid exported spares parts and higher price for centrifugal pump. The PULLEY of the tractor is used to rotating impeller of the Tambour. Therefore the main goal of this research is to increase the discharge rate and consequently decrease lifting water costs for irrigation all crop such as sugar beet, sugar cane, grain and forage crops **Ibrahim et al (2001)** found that the best and economical operating conditions (for the Egyptian traditional axial flow pump) were achieved using conical casing shape, double stages with 25 cm spacing between the two impellers, blade angle 25º and impeller speed of 540 r.p.m. fouad and **Fouad** and **Abd Ellatif. (1991)** reported that the commonly used low lift irrigation pumps in Egypt are the centrifugal pumps.

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The used types of them are: A) Axial – flow pumps (fixed). B) Radial – flow pumps (fixed or movable). C) Mixed – flow pumps (fixed or movable). **Schwab et al (1991)** classified the flow through impeller (dynamic) pumps as radial, axial, or mixed. In radial-flow pumps, the fluid moves through the pump impeller perpendicular to the axis of rotation of the impeller. In axial flow pumps, the fluid moves through the pump parallel to the axis of rotation of the impeller. Pumps that discharge flows from their impeller on vectors that lie between radial and axial are mixed – flow pumps, **FAO (1986).** Reported that the Archimedean screw can only operate through low heads, since it is mounted with its axis inclined so its lower end picks up water from the water soured and the upper end discharges the water in to a channel. Each design has an optimum angle of inclination. Inclination of 30º to 40º could be used, depending on the pitch and the diameter of the internal helix. **Morcos (1996*)*** recorded that the discharge of the screw depends mainly on the inner volume between each two adjacent blades, which is occupied with water. This volume is affected by the operating angle of the screw B, the number of blades n, and the screw pitch P. it is clear from the maximum discharge occurs at B= zero, **El-Awady (1998)** reported that in Egypt, the number of diesel operated pumps was about 33000 (according to 1995 enumeration) most of them are imported in spite of the achievement of old local industry. This variation is related to the difference between the local and the imported kinds in operating power (the local production is between 5-15 hp) and the imported ones are distinguished by the better efficiency and the cheap price especially the Indian types. **Abdel-Maksoud et al (1994).** Found that the highest installation and pumping energy was recorded with permanent sprinkler. Moreover, they indicated that the energy requirements for irrigation could be minimized through the pumping energy.
Objective of this research to obtain higher discharge rates at minimum costs of mechanical Archimedean screw through evaluate some design parameters.

Materials and Methods

The mechanical Archimedean screw was a constructing model similar to the traditional design in the Egyptian market Fig (1). It is consists of Casing shape, drive shaft (1), Impeller , two bearings , power source (An electrical motor 0.4 hp), and cone pulley was fixed on the top of drive shaft to obtain different speeds. The screw was fixed on a well. The well is a barrel (0.6 m diameter and 1.0 m height), the water flow from screw top in a water tank (1.0 m width and 0.5 m height). Measuring scale was fixed inside the water tank for measuring the height of the water and subsequently calculating the discharge rate of the screw. After calculating the discharge rate the water flow in a barrel similar to the previous in the dimensions. Through a cylindrical tube 0.3 m diameter) in bottom the water reached to the screw well.
Some design factors of mechanical Archimedean screw were considered such as:-

1- Top and bottom diameters (three ratio 1:1, 1.5:1 and 2:1), Fig 1
2- Clearance between impeller and casing (three clearances 2, 4, 6 mm).
3- Impeller positions at the bottom, at distance equal radius of the bottom and at distance equal to the diameter of the bottom inside the screw, fig (2) These design factors studied on discharge rate, power requirement and water lifting cost under different impeller speeds (450, 500, 550, 600 and 650 r.p.m). The experiments were conducted in the laboratory of El-Serw Agric. Res. Station, Demitted Governorate.

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Measurements

- **Consumed energy was measured by watt –hour meter.**

$$SpecificEnergy = \frac{consumedenergy(kw/h)}{Discharerate(m^3/h)} = kw/m^3$$

- Discharge rate was measured by using water –meter.
- Speedometer for measuring screw speed r.p.m.
- Stop watch for measuring the time.

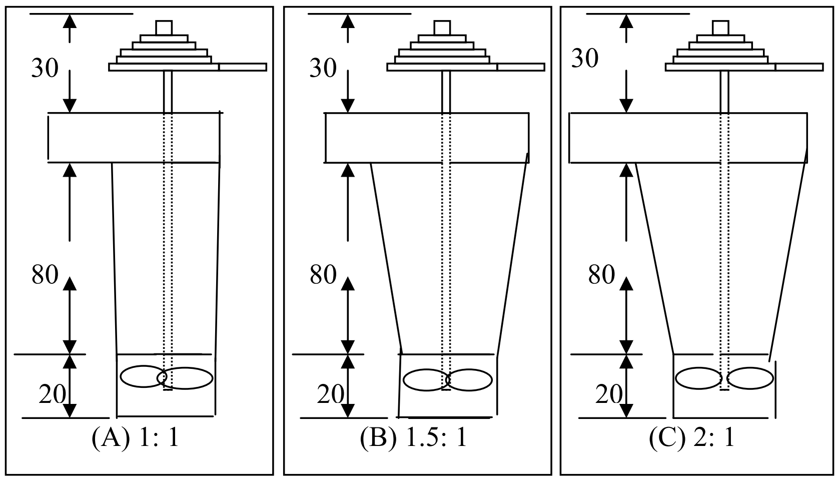

Fig (1) Relation between top and bottom diameters

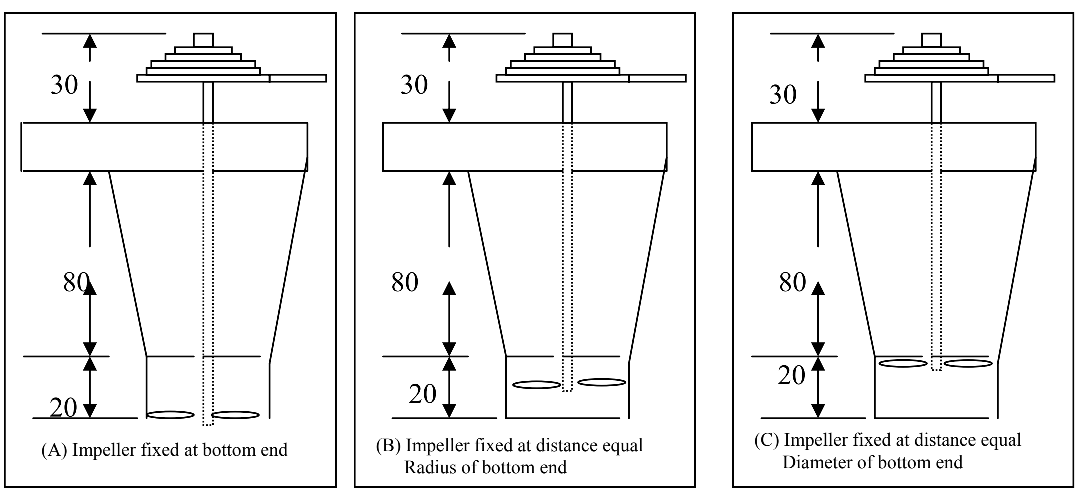

Fig (2) Impeller positions

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1- Mechanical Archimedean screw
2- Cone Pulley
3- Tank (1/2m3)
4- Water valve
5- Measurement scale
6- Electric Motor
7- V-Belt
8- Archimedean well
9- Irrigation canal

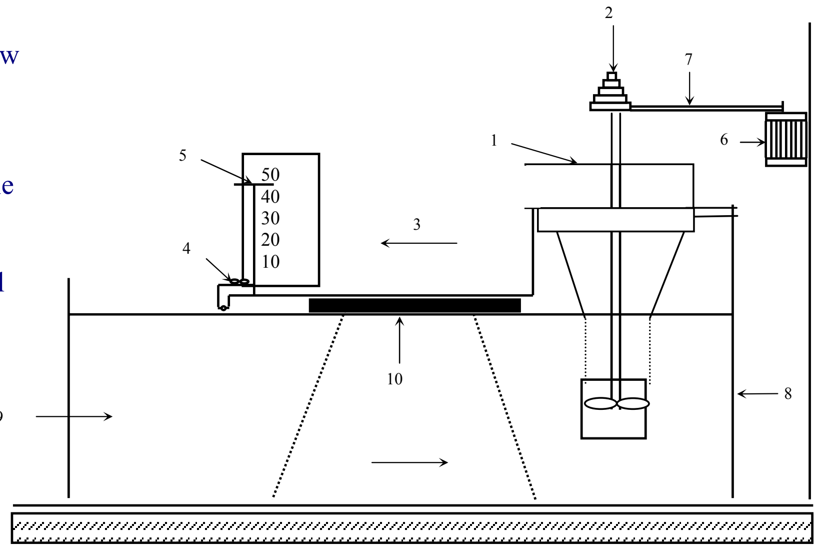

Fig (3) the experimental laboratory on mechanical Archimedean screw

Results and discussion

1) Effect of the relation between top and bottom diameters on discharge rate.

fig. (1) show that the effect of three ratio between top and bottom diameters screw (1:1), (1.5:1) and (2:1) on the discharge and power consumed under different impeller speed (rpm) with 6 mm impeller clearance and impeller fixed on distance equal bottom diameter inside the screw.

Table (1) Effect of top and bottom diameters on discharge rate and consumed energy. (At impeller, 2 mm impeller clearance)

Impeller Speed (r.p.m)	Top diameter : bottom diameter								
	1:1			1.5:1			2:1		
	Discharge Rate (m^3 /h)	Consumed Energy kW. h	Specific Energy kW /m^3	Discharge Rate m^3 /h	Consumed Energy kW /h	Specific Energy kW /m^3	Discharge Rate m^3/h	Consumed Energy kW /h	Specific Energy kw / m^3
450	15.17	0.51	0.0336	19.46	0.52	0.0267	16.10	0.48	0.0298
500	18.74	0.56	0.0299	22.57	0.56	0.0248	20.30	0.52	0.0256
550	21.56	0.62	0.0288	26.14	0.63	0.0241	23.44	0.58	0.0247
600	24.21	0.74	0.0306	28.11	0.69	0.0240	25.88	0.69	0.0267
650	25.78	0.81	0.0314	30.59	0.78	0.0255	27.55	0.77	0.0279

Data in (table 1) indicated that the highest values of discharge rates were 19.46, 22.57, 26.14, 28.11 and 30.59 m^3 / h noticed at rate of (1.5:1) between top and bottom diameter. While the lowest value of discharge rates were 15.17, 18.74, 21.51, 24.21 and 25.78 m^3/h when the rate of (1:1) between top and bottom diameter of screw. Also were remarked that the discharge rates increased with increasing impeller speed. While the specific power were decrease with increasing impeller speed,. this is due to increase discharge rate. And it is noticed that the lowest values of specific power when the impeller speeds at 500 to 600 rpm. On the other hand the consumed energy were increase with increasing impeller speeds.

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2) Effect of impeller clearance on discharge rate and consumed energy.

fig. (2) shows that the effect of three impeller clearance (2.0, 4.0 and 6.0 mm) on discharge rate and consumed energy at fixed impeller on a distance equal bottom diameter inside the screw and top diameter equal 1.5 time bottom diameter.

Table (2) Effect of impeller clearance on discharge rate and consumed energy at fixed impeller on a distance equal bottom diameter and top diameter equal 1.5 time bottom diameter.

Impeller Speed (r.p.m)	Impeller clearance (mm)								
	2 mm			4 mm			6 mm		
	Discharge Rate (m^3/h)	Consumed Energy kW. h	Specific Energy kW /m^3	Discharge Rate m^3/h	Consumed Energy kW /h	Specific Energy kW /m^3	Discharge Rate m^3/h	Consumed Energy kW /h	Specific Energy kw / m^3
450	22.46	0.38	0.0169	21.12	0.43	0.0204	19.46	0.52	0.0267
500	26.97	0.42	0.0156	24.75	0.49	0.0198	22.57	0.56	0.0248
550	29.78	0.49	0.0165	27.42	0.57	0.0208	26.14	0.63	0.0241
600	32.19	0.55	0.0171	30.12	0.64	0.0212	28.34	0.69	0.0240
650	34.42	0.62	0.0180	32.15	0.71	0.0221	30.59	0.78	0.0255

Data in (table 2) indicated that the lowest discharge rate and the highest consumed energy noticed at 6mm impeller clearance under different impeller speeds; while the maximum discharge rate and minimum consumed energy noticed at 2.00 mm impeller clearance.

Table (3) Effect of impeller fixed positions on discharge rate and consumed energy. (Impeller clearance =2.0 mm)

Impeller Speed (rpm)	Impeller positions								
	Fixed at the bottom end			Fixed on distance equal bottom radius			Fixed on distance equal bottom diameter		
	Discharge Rate (m ^{3}/h)	Consumed Energy kW. h	Specific Energy kW / m	Discharge Rate m^3 /h	Consumed Energy kW /h	Specific Energy kW /m^3	Discharge Rate m^3 /h	Consumed Energy kW /h	Specific Energy kw / m^3
450	15.46	0.34	0.0220	24.71	0.41	0.0166	22.46	0.38	0.0169
500	18.65	0.39	0.0209	28.86	0.44	0.0152	26.97	0.42	0.0156
550	22.29	0.46	0.0206	31.74	0.50	0.0158	29.78	0.49	0.0165
600	24.74	0.53	0.0214	33.92	0.57	0.0168	32.19	0.55	0.0171
650	25.31	0.58	0.0229	35.79	0.63	0.0176	34.42	0.62	0.0180

Table (3) show that the effect of three different impeller positions. First at the bottom end, second at distance equal bottom radius and the third at distance equal bottom diameter. On discharge rate and consumed energy under different impeller speeds when 2.0 mm impeller clearance. Data in Fig.(3) indicated that the maximum discharge rate was noticed with the second position more than with the first and third positions. Also the specific power with second position was little than it's with first and third positions.

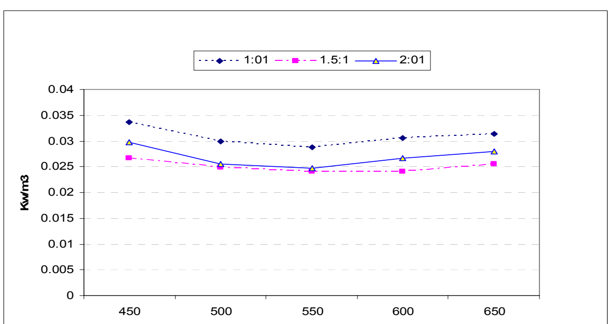

Fig (4) Relation between Specific Energy (KW/m3) and Top diameter : bottom diameter

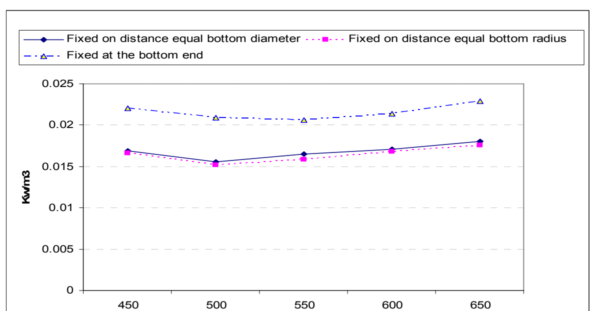

Fig (5) Relation between Specific Energy (KW/m3) and Impeller positions

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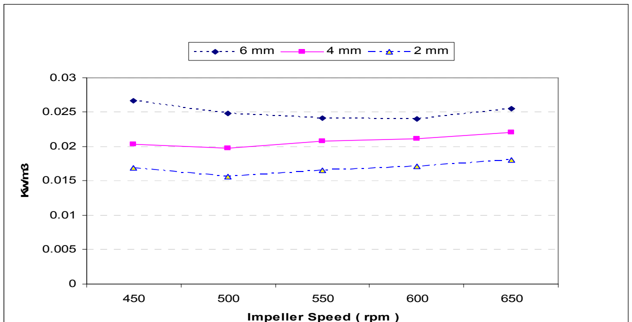

Fig (5) Relation between Specific Energy (KW/m3) and Impeller clearance (mm)

The statistical Analysis

Statistical analysis using statically package for social science (spss). Data indicated that discharge rate and economic operation energy consumption increased significantly when using 1.5:1 top to bottom diameter at 2mm impeller clearance compared with the other tested ratios (2:1& 1:1). Regarding the relationship between the discharge ratio and impeller speed the proper discharge was realized using impeller speeds of 500 to 600 rpm. On the other hand, when using the other tested ratios "2:1 & 1:1" top to bottom diameter the discharge increases were insignificant under 4mm and 6mm impeller clearances.

Table (4) the analyses of data in table (2).

Source	Type lll Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7571.193a	29	261.076	344.916	.000
Intercept	3301.763	1	3301.763	4362.068	.000
IMPSPED3	73.781	4	18.445	24.368	.000
ENERGY3	6262.538	2	3131.269	4136.823	.000
MECHANC3	6.137	1	6.137	8.108	.012
IMPSPED3*ENERGY3	140.198	8	17.525	23.153	.000
IMPSPED3* MECHANC3	.125	4	3.115E-02	.041	.996
ENERGY3* MECHANC3	18.924	2	9.462	12.500	.001
IMPSPED3*ENERGY3* MECHANC3	.252	8	3.144E-02	.042	1.000
Error	11.354	15	.757	-	-
Total	11404.560	45	-	-	-
Corrected Total	7582.547	44	-	-	-

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Table (5) the analyses of data in table (3).

Source	Type lll Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7580.732a	29	261.405	25.069	.000
Intercept	3642.066	1	3642.066	349.278	.000
IMPSPED3	71.256	4	17.814	1.708	.200
ENERGY3	6900.930	2	3450.465	330.903	.000
MECHANC3	37.484	1	37.484	3.595	.077
IMPSPED3*ENERGY3	133.938	8	16.742	1.606	.204
IMPSPED3* MECHANC3	4.631E-02	4	1.158E-02	.001	1.000
ENERGY3* MECHANC3	73.766	2	36.883	3.537	.055
IMPSPED3*ENERGY3* MECHANC3	9.129E-02	8	1.141E-02	.001	1.000
Error	156.411	15	10.427	-	-
Total	11562.040	45	-	-	-
Corrected Total	7737.143	44	-	-	-

Conclusions

The highest discharge rate, lowest consumed energy and economical operations noticed at:-

Out of the experimental design of the mechanical Archimedean screw considering top to bottom ratios, impeller clearances and impeller speeds it can be concluded that the proper design of the mechanical Archimedean screw which has 1.5: 1 top to bottom ratio impeller clearances of 2mm fixed on distance equal to bottom radius form inside, the maximum discharge obtained using impeller speed of 500 to 600 rpm.

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Introducing a flow distortion Wetting Front Detector

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ABSTRACT

The move toward precision irrigation with frequent small applications of water has shifted the irrigation scheduling question from 'when to turn the water on' to 'when to turn the water off'. A Wetting Front Detector is a funnel-shaped object that is buried in the root zone. The infiltrating water converges inside the funnel and the soil at the base becomes so wet that water seeps out of it, passes through a filter and is collected in a reservoir. This water activates a float, which in turn operates an indicator flag above the soil surface. The detector also retains a sample of water which can be extracted via a tube using a syringe. This can be analyzed for its salt or nitrate concentration. This paper gives a brief outline of how the Wetting Front Detector works and how it is being used by irrigators. The Wetting Front Detector is a novel device that was awarded the WATSAVE Award for "Conservation of Water in Agriculture" by the International Commission for Irrigation and Drainage in 2003.

INTRODUCTION

Irrigation scheduling by soil water status requires the soil water content or tension to be directly measured. Knowledge of the drained upper limit of the soil and an acceptable level of soil water depletion and rooting depth completes the information needed to calculate the timing and duration of irrigation. Scheduling in this way can be compromised by the typically large site to site variability (Schmitz and Sourell, 2000) and uncertainty over the accuracy of the tools used (Evett et al 2002). Nevertheless, soil water monitoring overwhelmingly improves irrigation management when the water content at the monitored site is adequately correlated to other locations, and the relative change in soil water accurately reflected by the monitoring tool.

Accordingly, there has been a major effort to improve the adoption of soil water monitoring tools in Australia, with considerable success. Adoption rates among commercial irrigators increased from 13 to 22% between 1996 and 2003, but it appears a ceiling may have been reached, as less than 10% of irrigators surveyed intended to invest in soil water monitoring tools in the foreseeable future (Australian Bureau of Statistics 2005). Surveys conducted by Stevens *et al.* (2005) in South Africa showed that improving the accuracy of irrigation was still viewed as a low priority in the commercial sector, and a very low priority amongst the small-scale farmer sector.

In order to extend the benefits of irrigation scheduling to more irrigators, we seek the least and simplest information requirement that has the potential to improve irrigation practice. This paper reports of the development of a flow distortion Wetting Front Detector, and its deployment amongst irrigators in Australia and South Africa.

THE WETTING FRONT DETECTOR

The Wetting Front Detector (WFD) is a funnel-shaped instrument that is buried in the soil (Figure 1). The funnel concentrates the downward movement of water so that saturation occurs at the base of the funnel. The free (liquid) water produced from the unsaturated soil activates a mechanical float, alerting the farmer that water has penetrated to or past the desired depth. The detector retains a sample of soil water that is used for nutrient and salt monitoring.

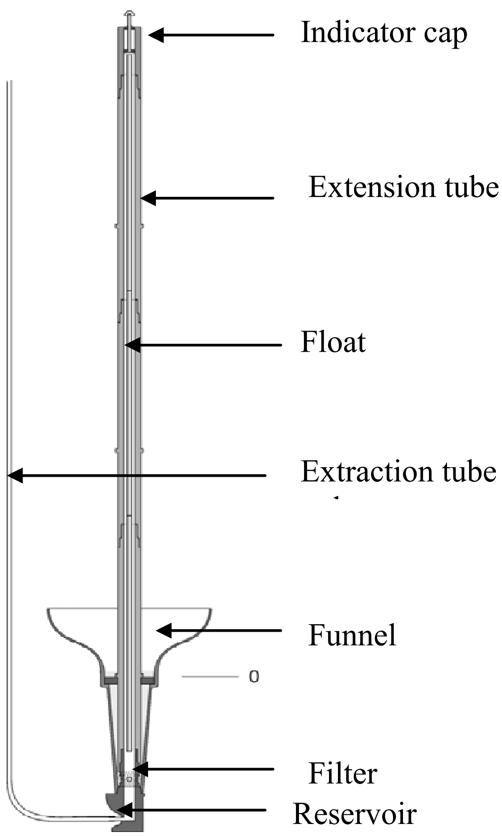


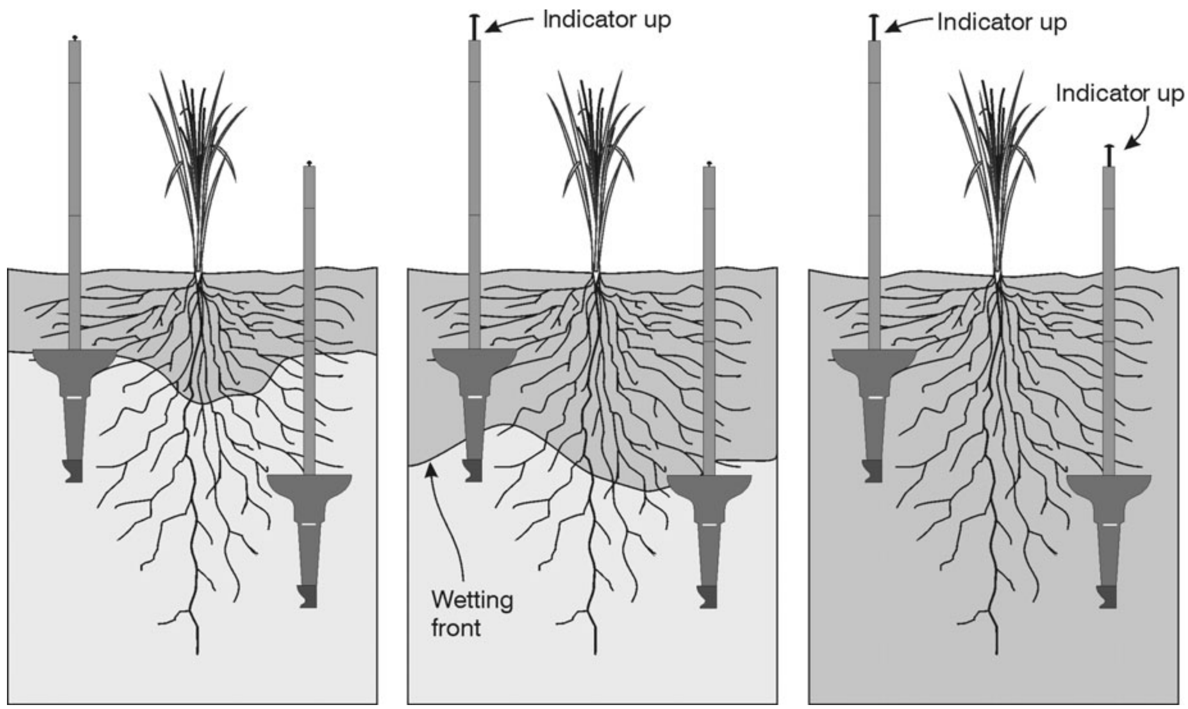
Figure 1. The funnel of the wetting front detector converges the downward flow of water, forming saturation at the base. Water moves through a filter into a reservoir and lifts a float, which in turn activates a magnetically latched indicator, visible above the soil surface. After irrigation, water is sucked out of the funnel by capillarity. A soil solution sample is retained in the device and can be removed using a syringe via the extraction tube.

Knowing how deep a wetting front moves into the soil is critical for irrigation management. If a crop is given frequent but light sprinklings of water, the wetting front will not go deep and the WFD will not be activated. Much of the water will evaporate from the soil surface. If too much water is applied at one time, the wetting front will go deep into the soil, perhaps below the rooting depth of the crop, wasting water, nutrients and energy.

Dry soil can absorb a lot of water, so the wetting front may not go all that deep if the soil starts dry, even with a heavy irrigation. However, if the soil is already wet, a light irrigation can penetrate deeply into the soil. This is because wet soil cannot absorb much extra water, so any irrigation water just keeps moving downwards.

The Wetting Front Detector captures a small water sample from each passing front. By measuring the electrical conductivity of this water and its nitrate concentration, crop nutrient and salt management can be greatly improved. This is explained more fully at the WFD website: www.fullstop.com.au.

Wetting Front Detectors are usually used in pairs. By watching how shallow and deep detectors respond through the season, the irrigator can get an idea if they are applying too much or too little water, as described in the diagram below.



Shallow Indicator: DOWN Deep Indicator: DOWN	Shallow Indicator: UP Deep Indicator: DOWN	Shallow Indicator: UP Deep Indicator: UP
If neither indicator is triggered, then watering is generally too shallow	Water has moved past the shallow detector to the lower part of the root zone.	The deep indicator should be triggered only when it is necessary to fill the whole root zone.

Figure 2. The position of wetting front after irrigation and the management response

CONTROL and FEEDBACK

The original prototypes of the Wetting Front Detector contained two electrodes inside the filter in the neck of the funnel. The water passing through the filter completed the circuit between the two electrodes, thus providing the signal that the wetting front had reached the detector. This system proved to be very robust, but a cheaper solution was to replace the conductivity cell with an electronic float switch. The WFDs were used in automatic control mode. The conductivity cell or float switch was connected in series to a commercially available irrigation controller and a solenoid valve. The solenoid valve would open according to the start time set on the controller and the detector could override the run-time. For example, if the wetting front reached the desired depth before the end of the designated run time, the float switch would rise, thus breaking the circuit between the controller and the solenoid.

Trials showed that the above method worked well and resulted in accurate irrigation scheduling (Stirzaker 2003, Stirzaker and Hutchinson 2005). However, one of the most important factors determining farmer adoption of a new technology is their ability to try it out and "see if it works for them" (Pannell 1999). Most farmers do not have irrigation controllers and electronic valves that can be automatically shut down by a detector. For those who do, it is a considerable risk to hand over control to a buried device. Conventional soil monitoring equipment provides information to the manager but a WFD in control mode takes over the management. Something as simple as a broken wire could spell disaster.

The commercial version of the WFD was therefore designed to be completely mechanical – like the tensiometer, it requires no wires, batteries or loggers. It is used in feedback, rather than control mode. The operator simply adjusts the irrigation interval or duration according to the response of the WFD to the previous irrigation. In this sense the WFD is an interactive learning tool.

LEARNING BY DOING

Kolb (1984) describes a learning cycle that starts with the individual taking an action step - in our case the installation of a WFD. The indicator is either triggered or not in response to irrigation - so there is something to observe. After several irrigation events the irrigator can then reflect on how a pair of WFDs respond to the way they irrigate. Reflection leads to generalization i.e. the shallow detector will only respond after less than one hour of irrigation if the soil is wet but after more than two hours if the soil is dry. From generalization the irrigator moves to conceptualization – improving the mental model of how water requirements change through the season. From here the irrigator can test their new understanding. Experimentation leads to more observation - reflection - etc. With each movement through the cycle, expertise is enhanced.

We ask the irrigator to record the duration of each irrigation event and record the response of the shallow and deep WFD. The table below gives a very basic interpretation.

Table 1. The response of the Wetting Front Detectors to irrigation, as shown by the position of the indicator float, what it means and the required action. The shallow WFD has a yellow indicator and the deep WFD a red indicator.

Shallow WFD	Deep WFD	What it means	What you should do
		Not enough water for established crops.	Apply more water at one time or shorten the interval between two irrigations. May be the desired result for young crops or when trying to minimize leaching of nutrients.
		Wetting front has penetrated into the lower part of the root zone.	Much of the time this is the desired result. However during hot weather or when the crop is at a sensitive growth stage irrigation should be increased. The deep detector should respond from time to time, showing that the entire root zone is wet.
		The wetting front has moved to the bottom or below the root zone.	Both detectors should respond when irrigating to satisfy high demand for water. However if this happens on a regular basis over-watering is likely. Reduce irrigation amounts or increase the time interval between irrigations.
		Soil or irrigation is not uniform or the soil surface is uneven.	Ensure the soil is level over the detectors and water is not running towards or away from the installation site. Check uniformity of irrigation or location of drippers.

Frequently the farmer expectation of the WFD response deviates from what they actually see in the field. To help them learn through this, an interactive visualization tool is provided on the website www.fullstop.com.au "The FullStop Game". The irrigator can type in their application rate and days since last irrigation and the visualization game shows them how deep the wetting front should penetrate down into the soil for drip and sprinkler irrigation.

If the results of the visualization tool match the WFD response in the field, then the irrigator can start altering either the irrigation interval or duration. If the results of the WFD are very different from the animation, the website provides a number of leads as to what might be happening. For example, water might be running off the surface of the beds and into furrows so the detector is not activated, or water might be infiltrating through preferential pathways and activating the detector much earlier than expected.

One of the most difficult aspects to get right during the roll-out phase was the optimum depth of placement for a range of soil and crop types and irrigation methods. When the indicator float is in the "up" position, a wetting front has moved ***past*** the detector. The suggested depths in the table below are drawn from our experiences with many users. The depths may at first appear to be quite shallow, but when a WFD triggers the soil above is as wet as it can be (usually 12 to 2 kPa suction), and redistribution will occur to deeper soil layers. A third detector, 10 cm below the deep detector depth shown above, can be installed if necessary.

Type of irrigation	**Notes**	**Shallow Detector**	**Deep Detector**
Drip	Amount applied per dripper usually less than 6 litres at one time (e.g. row crops, pulsing)	30 cm	45 cm
Drip	Amount applied per dripper usually more than 6 litres at one time (perennial crops)	30 cm	50 cm
Sprinkler	Irrigation is usually less than 20 mm at one time (e.g. centre pivot, micro-jets)	15 cm	30 cm
Sprinkler	Irrigation is usually more than 20 mm at one time (e.g. sprinklers and draglines)	20 cm	30 cm
Flood	Deeper placements than shown needed for infrequent irrigations or very long furrow	20 cm	40 cm

FIELD EXPERIENCE

We have documented a number of cases where the simple data derived from WFDs has stimulated irrigators to rethink their practices. In most cases soil water content or tension were measured by other more sophisticated methods, and confirmed that the WFDs were moving the farmers in the right direction. Some examples are given below:

- WFDs under drip were activated much more quickly than the grower expected. The grower responded by increasing the frequency of irrigation and decreasing the amount given at each irrigation (Stirzaker and Wilkie 2002).
- The grower over-estimated the amount of water needed at the start of the season and underestimated the amount needed at the critical flowering stage (Stirzaker and Wilkie 2002).
- Wine-grape growers using slightly saline water were initially surprised that deep detectors were rarely activated. However when they were activated, there were high levels of dissolved salts in the water captured by the WFDs. The growers realized that their practices of deficit irrigation were causing unacceptable levels of salt build up in the root zone. (Stirzaker and Thomson 2004).
- Vegetable growers found out that they were leaching most of the nitrate from the profile in the first few weeks after planting (Stirzaker 2003, Stirzaker and Wilkie 2002).
- A grape grower used a strategy of 'insurance' irrigation during critical growth periods involving a very long irrigation once per week over and above the normal

daily applications. The WFDs showed that this insurance policy was unnecessary and the practice was discontinued (Stirzaker et al 2004).

- WFDs have helped irrigators diagnose poor distribution uniformity or find out that their systems application rates were very different from what they thought. (Stirzaker et al 2004).

The ability of the WFD to provide a soil solution sample is seeing them used increasingly for salt and nitrate monitoring. One grower of avocados, who has slightly saline irrigation water, uses the electrical conductivity for the WFD sample to adjust his crop factor. If the EC in the WFD sample is increasing, the crop factor is increased to lift the leaching requirement.

LIMITATIONS AND OPPORTUNITIES

The WFD does not tell an irrigator when to start irrigating – it simply informs them how well the last irrigation filled the profile and helps them to make a decision about the timing and duration of the next irrigation. The WFD also has a sensitivity limitation. After irrigation has ceased and redistribution of water occurs down the profile, the wetting fronts become weaker and can fall below the detection limits of the WFD. In some situations we have observed significant amounts of water passing deep detectors without activating them. Work is continuing on more sensitive WFDs for specific applications.

As with all soil water monitoring equipment, there is a concern over soil disturbance during installation. The WFD has a diameter of 20 cm and is generally installed by augering a hole from the surface. It is important to note that the velocity of the wetting front is strongly dependent on the initial water content but only weakly on the soil structure, as long as water is supplied at a rate below the saturated conductivity (Rubin and Steinhardt 1963, Stirzaker and Hutchinson 2005). Therefore the potential change to rooting patterns following installation is more important than changes to unsaturated hydraulic conductivity, which could be influenced by soil disturbance. For annual crops, the upper detector of a pair is usually in the ploughed layer, so disturbance is not such an issue. For perennial crops it is important to let the roots grow back into the disturbed area, so that the water content above the detector would be similar to an undisturbed area.

Over the past couple of years many thousands of WFDs have been installed by irrigators. The major limitation is the lack of experience with this type of device. It takes time to work out the depths and detector response rate that suit individual applications. We are heavily reliant on 'product champions' for the fine-tuning of their deployment in a multitude of different situations.

ACKNOWLEDGEMENTS

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USING A WETTING FRONT DETECTOR TO MANAGE DRIP IRRIGATION IN STRAWBERRY

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Summary

During irrigation, water infiltrates into the soil forming a wetting front, defined as the boundary between wet soil above and drier soil below. The depth the wetting front reaches can be used to manage irrigation. The Wetting Front Detector (WFD) is a buried funnel that allows to detect when a wetting front has reached a given depth, and to collect the corresponding solution. The objectives of the present experiment were: 1) to verify the feasibility of managing the irrigation of a strawberry crop using only the information provided by a set of Wetting Front Detectors, 2) to verify whether this irrigation practice matched the demand of the crop by comparing it with 25% lower or 25% higher irrigations amounts.

Three irrigation treatments with 3 replicates were applied in a field experiment. The "control" treatment, in which the irrigation was managed so that the wetting front depth was stable around 45 cm, was compared with two other treatments, in which irrigation levels 25% lower ("deficit") and 25% higher ("excess") respectively were applied. Vegetative growth was evaluated by destructive sampling of 3 plants per treatment every 3 to 4 weeks. The fruits were harvested during the whole production cycle to evaluate yield and fruit quality. The plants that received the "control" and "excess" irrigation had a similar yield and fruit quality while the plants receiving "deficit" irrigation had a smaller yield and their fruits were drier (with higher °Brix). We conclude that the WFD allowed to manage the irrigation within an error margin lower than 25%.

Introduction

The applications of irrigation water and nitrogen fertilizer for strawberry crops in the state of Michoacán (México) are, in general, excessive. The Comisión Nacional del Agua estimates the water requirements of the crop at 12 500 m^3 ha^{-1} (1250 mm) during the cultivation cycle (CNA, 2005), but calculations of evaporative demand based on local reference evapo-transpiration (ETo) data and crop coefficients published for strawberries grown in California and Florida leads to an estimated demand of less than 7000 m^3 ha^{-1} (700 mm) (Clark, 1993; McNiesh, 1985; Snyder and Schulbach, 1992; Hansen and Bendixen, 2004; AgriMet, 1975). Excessive irrigation probably leads to significant nitrate loss by leaching, which may explain why farmers apply nitrogen doses up to 600 kg N ha^{-1} (Cárdenas Navarro, personal communication), against 50 to 250 kg ha^{-1} in the United States and Spain (Voth, 1991; Hochmuth et al., 1996; Miner et al., 1997; Cadahia, 1998).

Many techniques exist to monitor the water status of horticultural crops but most producers do not use them. The "Wetting Front Detector" is a new device that may help growers better manage water and fertilizer (Stirzaker, 2003, Stirzaker and Hutchinson 2005). During each irrigation event, water infiltrates into the soil forming a wetting front, which is the boundary between the wetted bulb (i.e., a volume of soil below the water source with a water content higher than field capacity) and the rest of the soil. The Wetting Front Detector is composed of a funnel buried in the ground. When the wetting front reaches the funnel, the water flow concentrates until the retention capacity of the soil is saturated and free water gathers at the base, moves through a filter and is collected in a reservoir. The depth the wetting front reaches before becoming undetectable depends mainly on the amount of water applied and the initial water content of the soil.

In previous studies, the inventors of the Wetting Front Detector have proposed several protocols to manage irrigation (Stirzaker et al., 2004). The objective of the present work was: 1) to validate a protocol to manage irrigation in a strawberry crop, and 2) to verify whether this irrigation practice matched the demand of the crop by comparing its performance with 25% lower or 25% higher irrigations amounts.

Materials and Methods

The experiment was carried out in a field of the Instituto de Investigaciones Agropecuarias y Forestales, in the Posta Veterinaria of the Universidad Michoacana de San Nicolás de Hidalgo (Morelia, Michoacán, México). The soil was a swelling clay (62% clay, 20% silt, 18% sand). The strawberry plants (cv. Aromas) were planted on 15

October 2005, in double lines at a density of 10 plants per meter on 85 cm wide furrows. Nine experimental units with an area of 15 m^2 each (4 furrows of 85 cm, with the two lateral furrows used as borders) were delimited and distributed in a completely randomized design. In these 9 units, 3 irrigation treatments with 3 replicates were applied. Irrigation was applied daily with a drip line (1.6 l/h drippers 30 cm apart). Each experimental unit was equipped with three Wetting Front Detectors buried at 30, 45 and 60 cm depths (27 detectors in total). The detectors were checked twice per week (once per day during the first two month). During the first month, excess irrigation was applied to allow plant establishment, then irrigation was managed using the Wetting Front Detector. The amount of water required was estimated by the response of the detectors at 45 and 60 cm depths. The "control" treatment was generated by adjusting irrigation up or down depending on the Wetting Front Detector response to the previous irrigation. The control treatment aimed for a > 2/3 response rate at 45 cm, but less than 1/3 at 60 cm. The other two treatment were then given 25% more water ("excess") and 25% less water ("deficit") than the control.

In each experimental unit, the maximum depth reached by the wetting front was estimated as that of the deepest detector that responded. The average depth of the wetting front was calculated as the average of the maximum depth in the three experimental units of the same treatment.

In an adjacent parcel, a weather station (Davis, Vantage Pro) was installed that provided an estimate of the potential evapo-transpiration (ETo). The applied crop coefficient (Kc) was calculated as the ratio of irrigation by ETo. Mature fruits were harvested twice a week, and the total fresh weight of the crop was measured. At each harvest, the soluble solids content (°Brix) of 5 representative fruits of each experimental unit was measured with a hand-held refractometer (Leica 7531L). The yield (sum of the fruit weight harvested in both harvests of the same week), average fruit size (yield divided by the number of fruits harvested in both harvests of the week) and average °Brix (average of 10 fruit sampled in both harvests of the week) were calculated every week. The statistical analysis was performed by ANOVA with repeated measures design (with irrigation fully randomized within the each harvest date and the experimental unit as a repeated factor). Since the variance of plant dry mass, leaf area and fruit yield were approximately proportional to the value of these variables, the ANOVA was performed on the logarithm of these variables to comply with the condition of homogeneity of variances. The software used to perform statistical analyses was R (R Development core team, 2004).

Results

Irrigation management

The objective of the "control" treatment, which was to obtain a 2/3 response rate in the detectors at 45 cm depth, was achieved during almost the whole experiment (Figure 1.B), and the average depth of the wetting front remained around 45 +/- 10 cm (Figure 1.D). In addition, over the 38 times the detectors were checked, in a single occasion (3% of the cases) the average depth of the wetting front exceeded 60 cm, and in other four occasions (8% of the cases) it did not reach 30 cm (Figure 1.D). The response rate at 30 cm, also around 2/3 was more stable than at 45 cm depth (Figure 1.A). However this reflected the heterogeneity of the irrigation system rather than a response to the irrigation dose: the detectors that were immediately below a dripper responded most of the time, while those that were between two drippers almost never responded. At 60 cm depth (Figure 1.C), the detectors never responded, except during two short periods of over-irrigation (with response rates above 75% at 45 cm) at the end of January and during mid-March. The only time we failed to achieve the objective of 2/3 response rate at 45 cm in the "control" treatment was during the last month of the experiment, because of a problem with the quality of the fertirrigation solution that clogged the filters of the dripper lines in the "control" and "excess" treatments. In the "control" treatment the clogging started progressively in mid-March and went unnoticed for a month. In the "excess" treatment, the clogging was sudden and almost blocked irrigation for a week during mid-March, until the problem was corrected.

In contrast to the "control", in the "deficit" treatment the response rate at 30 cm fell down to less than 25% two month after planting (that is, when the "control" irrigation regime was fully established), and to almost nil at 45 and 60 cm depth. In the "excess" irrigation, the response rate at 30 cm (Figure 1.A) was similar to that of the "control" (again reflecting the heterogeneity of the irrigation system rather than a response to the irrigation dose). At 45 cm, the response rate was always above 75%, and higher than in the "control" (Figure 1.B). The "excess" treatment was the only one to show a significant response at 60 cm, with a response rate consistently higher than 50% (Figure 1.C).

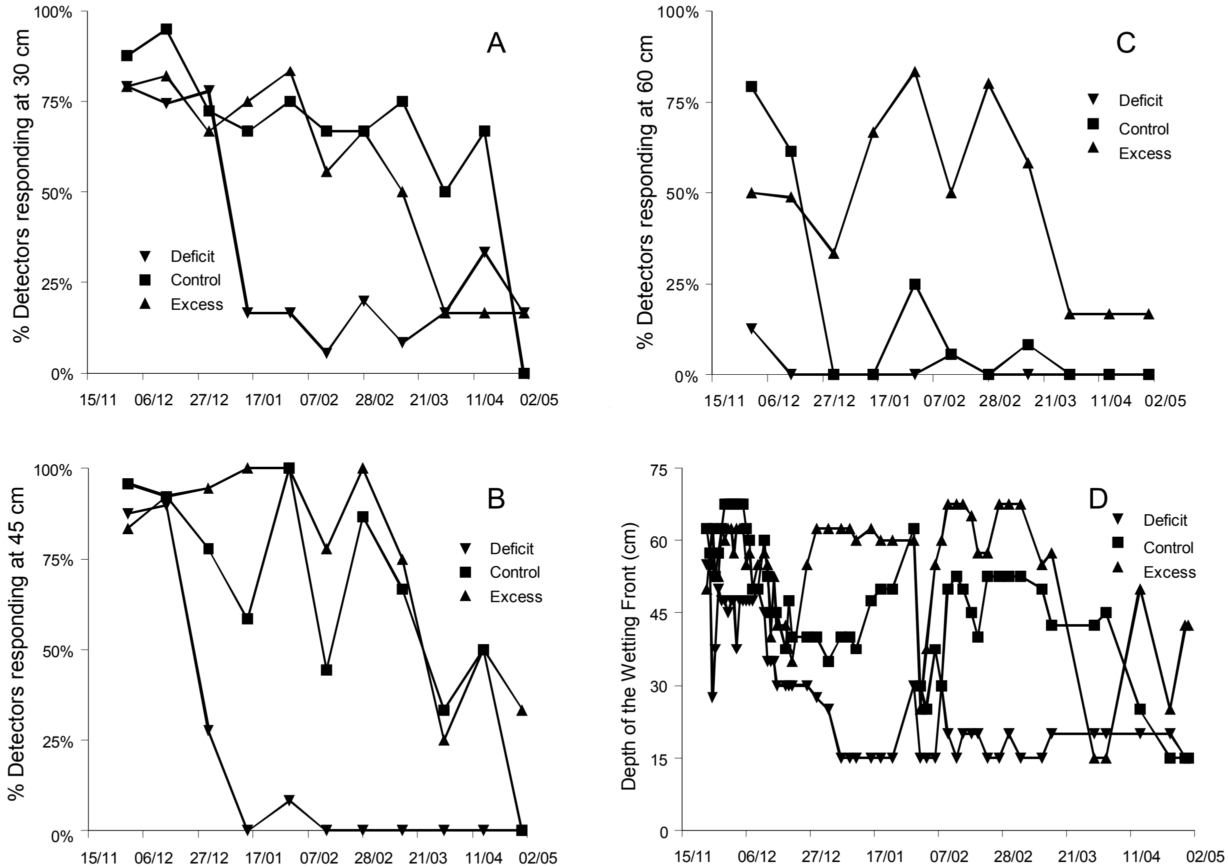


Figure 1. A., B., C. Percentage of the detectors that respond at 30 cm, 45 cm and 60 cm respectively, calculated as biweekly average (3 detectors over 4 observations), D. Evolution of the average depth of the wetting fronts (calculated as the average depth at which the deepest detector responds in three replicates explain in more detail) at each observation date. Irrigation in the ”control" treatment was managed using the WFD. The “deficit", and" excess" treatments corresponded to irrigation levels of 25% lower and 25% higher respectively than the “control”.

The irrigation amount applied in the “control” treatment increased regularly during the crop cycle, from approximately 2 mm/day in December to 4 mm/day in May (Figure 2.A). This corresponded to a variation of the applied crop coefficient (Kc) from 0.66 in January to 0.8 in May (Figure 2.B).

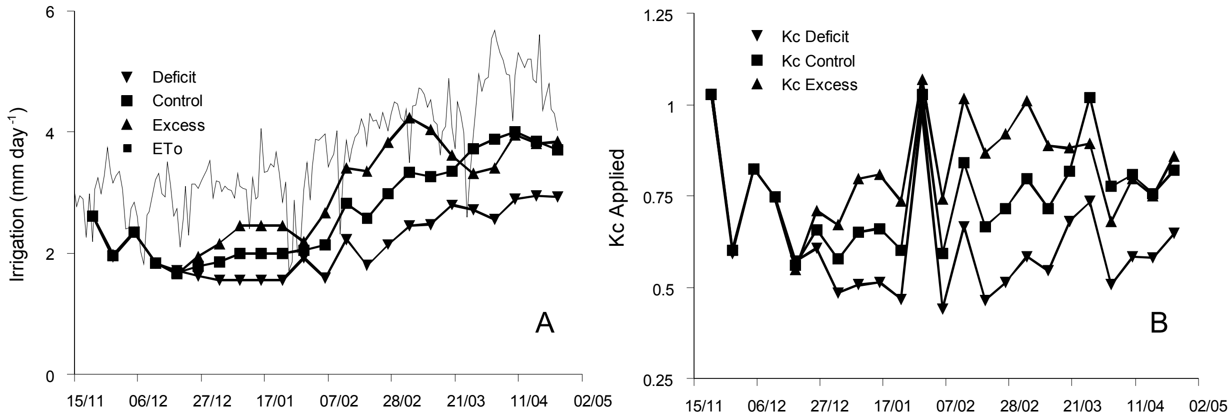
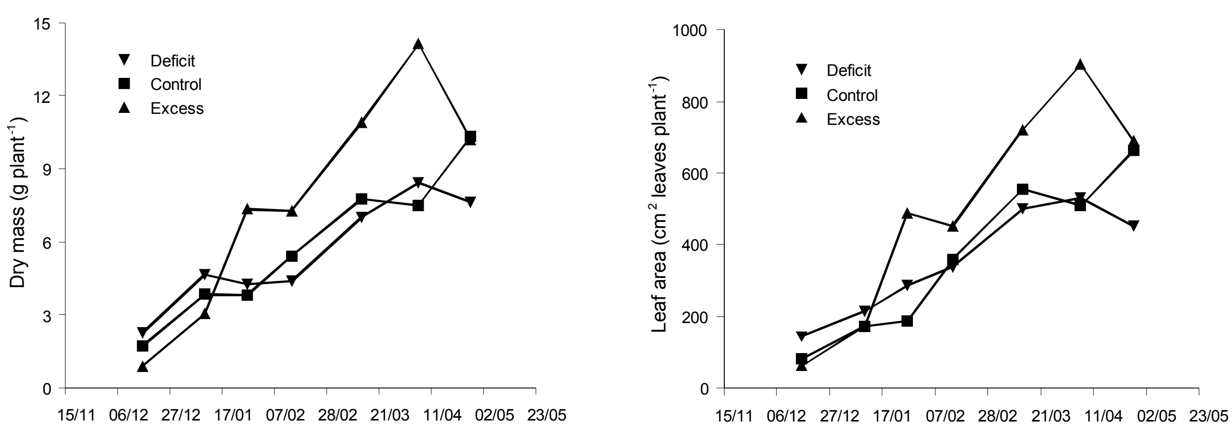


Figure 2. A) Evolution of reference evapo-transpiration (ETo, thin line) and irrigation dose in the three treatments during the crop cycle, B) Evolution of the applied crop coefficient (Kc). Irrigation in the ”control" treatment was managed using the WFD. The “deficit", and" excess" treatments corresponded to irrigation levels of 25% lower and 25% higher respectively than the “control”. The peak in the crop coefficient observed in February corresponds to a rain of 10.5 mm.

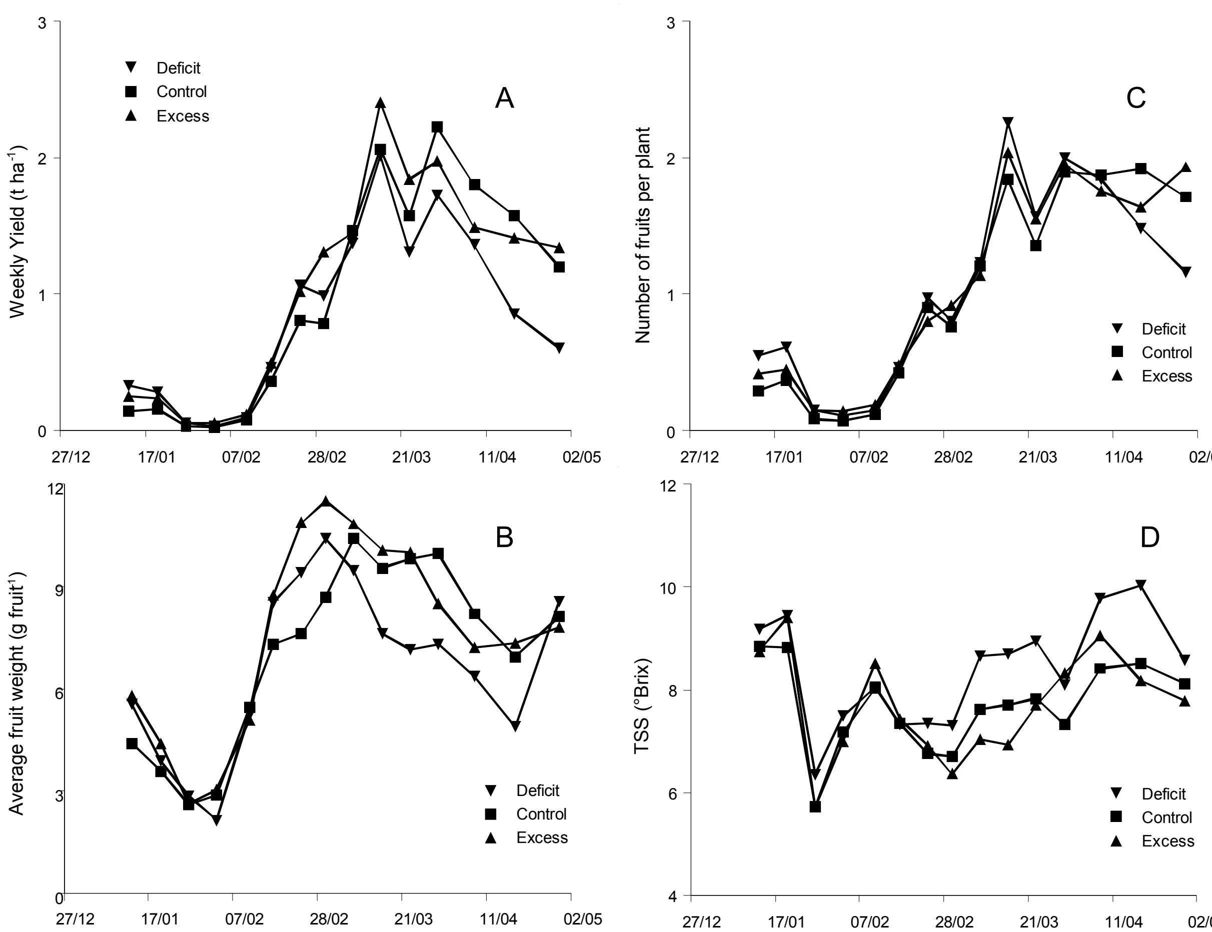
Crop performance

The behavior of the crop allowed to verify whether the irrigation applied in the “control” treatment was really optimum. In this case, no significant differences in crop performance should be observed between the “control” and the "excess" irrigation, while the “deficit" irrigation should affect the crop.



Figures 3. A. Dry matter accumulation and B. Leaf area increase per plant. Irrigation in the ”control" treatment was managed using the WFD. The “deficit", and" excess" treatments corresponded to irrigation levels of 25% lower and 25% higher respectively than the “control”.

Vegetative growth was apparently affected by irrigation, with higher leaf area and plant dry mass in the “excess” treatment. In the field, plants from the “deficit” irrigation also appeared to have a less developed canopy with smaller leaves. However, a careful ANOVA of these data revealed no statistical effect of irrigation (p > 0.15).



Figures 4. A. Yield, B. Average fruit weight, C. Number of fruits per plant and D. Total soluble solids content. Fruits were collected twice a week and both samples from the same week were pooled. Yield and

number of fruits are calculated as the sum of both harvests, fruit weight and TSS as their average. Irrigation in the ”control" treatment was managed using the WFD. The “deficit", and" excess" treatments corresponded to irrigation levels of 25% lower and 25% higher respectively than the “control”.

The irrigation affected fruit yield (Figure 3.A), as the repeated measures ANOVA revealed a significant interaction ($p < 0.05$) between the date and irrigation factors. Over the whole cycle, the cumulative yield in irrigation the “deficit” irrigation was 12.5 t ha^{-1}, against 14.3 and 15.4 t ha^{-1} in the “control” and “excess” irrigation respectively. This amounted to a 16% yield reduction in the “deficit” irrigation treatment, while no significant difference were found between the “control” and “excess” irrigations. This yield decrease was not due to a reduction if the number of fruits produced (Figure 3.C), where no significant effect of irrigation was found, but rather by their size (Figures 3.B), as indicated by a highly significant interaction ($p < 0.001$) between the date and irrigation factors.

Fruit quality was also affected (Figure 3.B.), with a significant effect of irrigation ($p < 0.05$). The average TSS was higher in the “deficit“ irrigation treatment, while no differences were observed between “control” and “excess” irrigation. It is interesting to note that the effects of irrigation on fruit yield, size and quality were noticeable only after mid February, that is during the period of peak production and/or higher evaporative demand, while no difference in were observed at the beginning of the cycle.

Conclusions

From a practical point of view, the Wetting Front Detectors worked as expected under our local conditions (furrows and swelling clay soil). The irrigation management protocol applied in the control achieved its objectives: it was easy to adapt irrigation time to maintain the depth of the wetting front around 45 cm. However, the proportion of detectors responding at 30 and 45 cm depths appeared to decrease slowly during the whole cycle. Apart for the clogging of the filters, an explanation of this decrease in the response of the detectors may be that during the last three month of the experiment, while the evaporative demand increased quickly, the adjustment of the irrigation time was done only twice a week, so that irrigation lagged behind the increase of evaporative demand by 3 to 4 days.

The protocol implemented to install the detectors and interpret their response was quite different from the one proposed by the inventors of the technique (Stirzaker at al., 2004). They suggested managing irrigation to keep the wetting front between two detectors installed approximately at half the depth of the root system, and immediately below the root system. For strawberry, with a root depth around 35 to 40 cm, this would have implied installing the detectors at 20 and 40 cm and maintaining the wetting front around 30 cm. However, previous experience with strawberries on the same soil has shown that this protocol led to insufficient irrigation. In the present experiment, the depth of the wetting front was maintained around 45 cm, which proved to be adequate. The reason why wetting fronts deeper than the root depth are needed is likely to be that the soil is a swelling clay with cracks and high macroporosity. During irrigation, the water infiltrates quickly through the macropores, and later redistributes by capillarity. In this situation, the water that will be used by the plant is likely to infiltrate deeper than the root zone before reaching the roots by capillarity.

When comparing “deficit” against "control" and “excess” irrigation treatments, a lower fruit yield was observed, while the “excess” irrigation did not significantly differ from the “control”. The fruits from the “deficit” irrigation, in addition to being smaller, also had a higher TSS content. In this case, higher TSS content should not be mistaken with higher fruit quality but rather revealed drier and less juicy fruits (as observed by tasting the fruits). These results confirmed that irrigation managed using the wetting front detector actually met the demand of the crop, at least within the +/- 25 % range tested: reducing irrigation affected yield and quality, while increasing it didn't bring any improvement.

The crop coefficient applied in the “control” irrigation treatment increased from Kc=0.66 two months after planting to Kc=0.8 at the end of the cycle. The only recommendations found in the literature for a fully developed strawberry crop vary between 0.6 in Florida (Clark, 1993), 0.7 (McNiesh, 1985; Snyder and Schulbach, 1992; Hansen and Bendixen, 2004) and 0.95 (AgriMet, 1975) in California. The value of Kc=0.8 we found for the fully developed crop under our conditions fits well inside this range. In contrast, the value of Kc=0.66 we found at the beginning of the experiment, when the crop was only two months old, seems quite high compared to crop coefficients of 0.2 to 0.4 given by the same authors in the early stages. The explanation may be in the principle of the wetting front detector itself: smaller irrigations (in the early stages of the crop) lead to weaker wetting fronts that are more difficult to detect than with bigger irrigations. Therefore, the detectors may have underestimated the presence of the wetting front and overestimated the irrigation requirement in the early stages of the crop.

In conclusion, the wetting front detector proved to be a viable alternative to other more complex and/or expensive techniques for the management of irrigation in strawberry, and in horticultural crops in general. In this experiment, irrigation was managed using only a set of 9 detectors installed at 45 cm depth. From our practical experience with the detectors, we suggest that a set of 4 to 6 detectors installed between 40 and 50 cm of depth should provide enough information to manage irrigation in a small field (up to 1 ha) with the protocol applied in this experiment. However, additional studies to further refine the interpretation of the wetting front detections and to validate these recommendations in commercial conditions.

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Monitoring and Management of Pecan Orchard Irrigation: A Case Study-Part II

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Summary

Pecan (*Carya illinoiensis*) production in the southwest US requires 1.90 m (75 inches) to 2.5 m (98 inches) of irrigation per year depending on soil type. However, for many growers, scheduling irrigation is an inexact science. Currently, there are several options available to growers, and some, such as soil moisture sensors and computerized data-collection devices have become inexpensive. With more growers using computers in their business, there is potential to improve irrigation efficiency using these new soil moisture monitoring tools. The objectives of this project were to introduce 2 low-cost soil monitoring instruments to a group of pecan producers, provide instruction on the use of internet-based irrigation scheduling resources, and provide assistance in utilizing these tools to improve their irrigation scheduling and possibly yield. The Doña Ana County Extension agent selected 5 small to intermediate-scale pecan farmers based on their expressed interest in improving soil moisture monitoring

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and whether they used a computer. Farmers were instructed on the use of the instruments and associated software, and received instruction on the use of climate-based irrigation scheduling resources found on the internet. All participants understood that better management of water inputs may translate into higher yields that could offset instrument costs. Three out of five growers indicated they used either the granular matrix sensors (GMS) or tensiometer to schedule irrigations, but compared to the climate-based irrigation scheduling model, all growers tended to irrigate later than the model's recommendation. Graphical analysis of time-series soil moisture content measured with the GMS showed a decrease in the rate of soil moisture extraction coincident with the model's recommended irrigation dates. These inflection points indicated the depletion of readily available soil moisture in the root zone. The findings support the accuracy of the climate-based model and suggest that the model may be used to calibrate the sensors. Four of the five growers expressed interest in continued use of the tensiometer, but only one expressed a desire to use the GMS in the future. None of the participants expressed interest in using the climate-based irrigation scheduling model. A series of nomographs relating time of years to days between irrigation bas on multiple years of climate and the irrigation scheduling model were then produced to try and simplify the irrigation scheduling process. These nomgraphs are currently be evaluated by a focus group to determine if this solution will overcome the limitations of soil moisture sensors or internet climate based irrigation scheduling The nomograph approach to irrigation scheduling is simpler but information is lost using average weather data than real time climate data. .

Introduction

New Mexico is one of the top three producers of improved variety pecans (*Carya illinoiensis*) in the U.S, . In 2005, New Mexico produced 28.6 million kg (62 million lb) of high quality improved variety pecans that garnered the highest price per pound in the nation (USDA National Agricultural Statistics).

Pecans naturally require large quantities of soil moisture to thrive (Sparks, 2002; Wolstenholme, 1979). In commercial pecan production, irrigation is one of the most important inputs affecting yield, especially in mature orchards (Garrot et al., 1993; Rieger and Daniell, 1988; Sparks, 1986; Stein et al., 1989). With all nutrients in sufficient supply it is ultimately non water-stressed evapotranspiration (ET) that contributes most to carbohydrate production (Andales et al., In press). The amount of irrigation water required to produce a crop of pecans ranges from 1.9 m to 2.5 m per year depending on soil type, with yearly ET measured at 1.31 m (52 inches) (Miyamoto, 1983) to 1.42 m (56 inches)(Sammis et al., 2004). In the interests of water conservation, the goals of growers and the research community have been to maximize irrigation application efficiency through proper design and operation of the irrigation system, and at the same time maximize water use efficiency and profitability through careful irrigation scheduling.

Under dead level flood irrigation farmers let water advance down the bordered plot until the water reaches ¾ of the distance from the end before closing the gate or they let the water reach the end of the border and then switch to the next border. This method typically over-irrigates the trees nearest the gate and may under-irrigate at the end of the run, although, application efficiencies in flood-irrigated orchards in the Mesilla Valley of New Mexico have been reported as high as 89% (Al-Jamal et al., 2001). By using soil moisture sensors in their irrigation program growers can better estimate when to schedule sufficient water to the end of the bordered plot and thereby increase water use efficiency.

For growers using computers for their operations there is potential to improve water use efficiency. Growers connected to the internet have access to real-time, relatively local scale climate information and can apply it with relative ease to estimate crop ET and soil moisture depletion using a climate-based irrigation scheduling model found on the New Mexico Climate Center website (http://weather.nmsu.edu). In recent years soil moisture sensors and automated data-collection devices have become inexpensive and accessible. Use of granular matrix sensors (GMS) has become a popular method for measuring soil water potential. Using a computer with both climate-based and soil-based scheduling tools, irrigations can be timed according to crop consumptive use, and site-specific water status.

Nomographs to schedule days between irrigations based on crop and soil type and local long term average climate conditions have been used successfully but information is lost when using average climate conditions (Henggeler 2006) .

The objectives of this project were to introduce two low-cost (< $250 for both) soil monitoring instruments, provide instruction on the use of internet-based irrigation scheduling resources, and assist a group of small to intermediate scale producers in utilizing these tools to facilitate more efficient irrigation scheduling. At the end of the growing season we would assess the performance of the sensors and determine if the farmers would adopt the technology. A second objective was to develop a simpler approach to irrigation scheduling by developing an irrigation nomograph.

Materials and methods

PARTICIPANT SELECTION AND STUDY LOCATION. The Doña Ana County Extension Agent selected five small to intermediate-scale pecan farmers based on their expressed interest in improving soil moisture monitoring, and whether they operated a computer as part of their farming operation. In February 2005, instruments were installed in each grower's orchard located in the Mesilla Valley from Vado, N.M., to north of Doña Ana, N.M.

INSTALLATION OF SOIL-BASED INSTRUMENTS. Each grower received two GMS sensors (Watermark, Irrometer Inc., Riverside Calif.), four data loggers (HOBO H08-002-02, Onset Computer, Bourne Mass.), and datalogger software (Boxcar 3.7, Onset Computer, Bourne Mass.). The extra data loggers pair remained dormant until launched and swapped with the field loggers as they were collected for downloading. Since these HOBO data loggers record a voltage signal, the input cable lead connected to the GMS (2.5 Stereo Cable, Onset Computer, Bourne Mass.) was modified by adding a large resistor to reduce the voltage drop across the sensor and minimize data logger battery drainage. A 10-kiloohm, 1/4 W, 0.1% tolerance metal film resistor (Mouser Electronics, Mansfield Texas) was soldered to the cable leads as described by Allen (1999).

The GMS sensors were buried according to the manufacturer's recommendations at approximately the middle of the root zone, 40 to 45 cm (16 to 18 inches) depth at two locations in each orchard. To assess the unevenness of the irrigations in a single bordered plot one GMS was installed between the first and second tree in a row closest to the irrigation turnout, and the other at the end of the plot between the last and second last tree in the same row. Interior rows were chosen to avoid edge effects. The sensors were placed equal distance between trees, approximately 4.6 m (15 feet) from the trunk.

Each grower also received one 45 cm (18 inch) tensiometer (Model R or LT, Irrometer Inc., Riverside Calif.), which was placed approximately 1 m (39 inches) from the GMS sensor at the end of the plot furthest from the turnout. Growers were given an estimated target soil moisture tension approximating 50 to 60% of field capacity (FC) based on the manufacturer's recommendations for soil texture, and on literature references (Curtis and Tyson, 1998; Paramasivam et al., 2000; Sammis, 1996a).

GMS DATA CONVERSIONS. The derivation of volumetric soil moisture from the data logger output requires three mathematical conversions: converting voltage to resistance, converting resistance to soil matric potential, and converting matric potential to volumetric soil moisture using pedotransfer functions (PTF) specific to soil texture classifications. The resistance of the GMS was calculated using equation 1:

$$R = 10 \times V/(2.5 - V) \qquad [1]$$

where R is the resistance produced by the GMS (kiloohms), and V is the voltage recorded by the HOBO data logger (volts).

The resistance of the GMS was converted to soil matric potential (kilopascals) using equation 2, developed by Shock et al. (1998):

$$\Psi_m = (4.093 + 3.213 \times R)/(1 - 0.009733 \times R - 0.01205 \times T) \qquad [2]$$

where Ψ_m is matric potential (kilopascals), R is the resistance of the GMS (kiloohms), and T is the average soil temperature (°C). We assumed that the soil temperature was approximately 20°C (68° F) for this region during the summer.

Farm soil texture classifications, on which water holding capacity and PTF were based, were determined by the growers, and verified using the Doña Ana County Soil Survey (Bulloch and Neher, 1980). However, typical of layered alluvial soils, considerable soil texture spatial variability, both vertically and horizontally, was observed within the plots at all locations. Soil pedotransfer functions were developed in the form described by van Genuchten (1980)

TECHNOLOGY TRANSFER. The growers were given oral instruction during demonstration, and a manual describing the steps to activate the data loggers, and to retrieve and import data logger text file information into a spreadsheet program that included the pedotransfer functions (Excel, Microsoft, Redmond Wash.). The manual also described the steps to enter the data logger information in the spreadsheet for converting the sensor voltage output into soil matric potential and soil moisture content. The manual contained blank worksheets for collecting tensiometer data, and listed contact information for the manufacturers of the equipment. The growers then received oral instruction, and demonstrations on how this file was to be used as a source in graphing soil moisture depletion through time, and how the HOBO voltage data was to be appended to the cumulative file by the grower as the data was collected over the season. The graph would allow the grower to extrapolate a future time when the soil moisture would reach a target of 50 to 60% of field capacity, and schedule the next irrigation. Growers were given the target volumetric soil moisture based on PTF for their soil texture.

The growers also received written instructions, and in some cases, a demonstration on their computer, on how to extract estimated pecan ET from the New Mexico Climate Center web site. Daily ET values listed on this site are computed from a climate-based model using Penman's reference ET, an empirically derived crop coefficient for pecan, and regional weather data (Sammis, 1996b; Sammis et al., 2004). Using modeled ET along with a texture-based estimate of soil water holding capacity within a root zone of 1 to 1.2 m (3 to 4 feet), growers could compute an estimated amount of soil moisture lost to ET each day, or since their last irrigation.

POST-SEASON DATA ANALYSIS. Irrigation dates were deduced from time-series GMS data sets from three of the five growers for which we had complete season-long information. The actual irrigation dates were entered in the climate-based irrigation scheduling model and compared with the model's predicted the irrigation dates. Model inputs and parameters were set to include soil water-holding capacity based on soil texture, root zone depth of 1.2 m (4 ft) , an estimated 11.9 cm (4.7 inches) of water applied at each irrigation, and a maximum allowable soil moisture depletion (MAD) of 45%. The model also had a soil moisture stress function that linearly decreased ET when the MAD was less than 45% (Andales et al., In press; Garrot et al.,1993). The cumulative difference between non-stressed ET and stressed ET was determined for each data set for the season and converted to yield loss using a water production function ($2.48 kg.ha^{-1}.mm^{-1}$) (Sammis et al., 2004), and revenue loss based on an average in-shell price of $0.49/kg ($1.08/lb).

To assess the calibration of the GMS sensors, the maximum measured soil moisture content at each irrigation was compared to the predicted FC moisture content based on the PTF for that particular soil texture. In addition, the GMS-measured soil moisture at the model-predicted irrigation dates were checked for consistency across irrigation cycles, and correspondence to the predicted moisture content at the 45% MAD. The GMS data used in the analysis was taken from sensors located at the end of the border, furthest from the irrigation gate. Data from sensors nearest the irrigation gate were not included since the gates tended to leak, resulting in perpetually high moisture levels and peaks corresponding to irrigation in adjacent borders.

Results and Discussion

TECHNOLOGY TRANSFER. The farmer participants in this study had diverse backgrounds, computer skills, and farming objectives. They owned and operated pecan orchards ranging from 4 to 112 ha (10 to 278 acres), providing up to 100% of their income (Table 1). Their average age was 48.5 years, and all had some college education. Most considered themselves proficient on the computer However, the degree to which they utilized computers to perform and track farm business activities varied and did not correlate with age or farm size. Most did not log inputs, such as irrigation dates or fertilizer applications with their computer.

Grower number	Age (yr)	Farming experience (yr)	Farm size (ha^z in pecan)	Farm revenue ($ x 1000)	Percent of personal income from pecan sales	Education level
1	48	27	64.8	> 100	100	Some college
2	22	7	4.9	10-30	<1	BS
3	54	20	24.3	>100	10-50	BA
4	55	5	4.2	10-30	25	BS, some grad.
5	64	35	112	>100	30	BSME

Table 1. Pecan farming experience, farm scale, and personal information of study participants.

All of the participants in this study had their own wells and could irrigate as needed, but when surface water was available there could be a delay of a few days from the time of placing an order with the irrigation district to the time of delivery. Previously, the growers had used calendar day, soil probe, and “moisture by feel” to schedule irrigations (Table 2). Some had previous experience using tensiometers, but none had used the climate-based model for estimating ET, even though it has been promoted and demonstrated at the Western Pecan Growers Conference held annually in Las Cruces, New Mexico and has been available on-line for more than four years.

Table 2. Pecan grower response to pre-season questions regarding irrigation scheduling and prior soil moisture monitoring instrument use, and post-season evaluation of the irrigation scheduling project.

Question	Response by grower				
	1	2	3	4	5
How have you previously scheduled irrigations?	Calendar, soil probe	Calendar	Calendar, moisture by feel	Calendar, soil probe	Calendar, soil probe
Had you ever used a tensiometer to measure soil moisture before?	No	No	Yes	Yes	No
Had you ever used the climate-based irrigation scheduling model before?	No	No	No	No	No

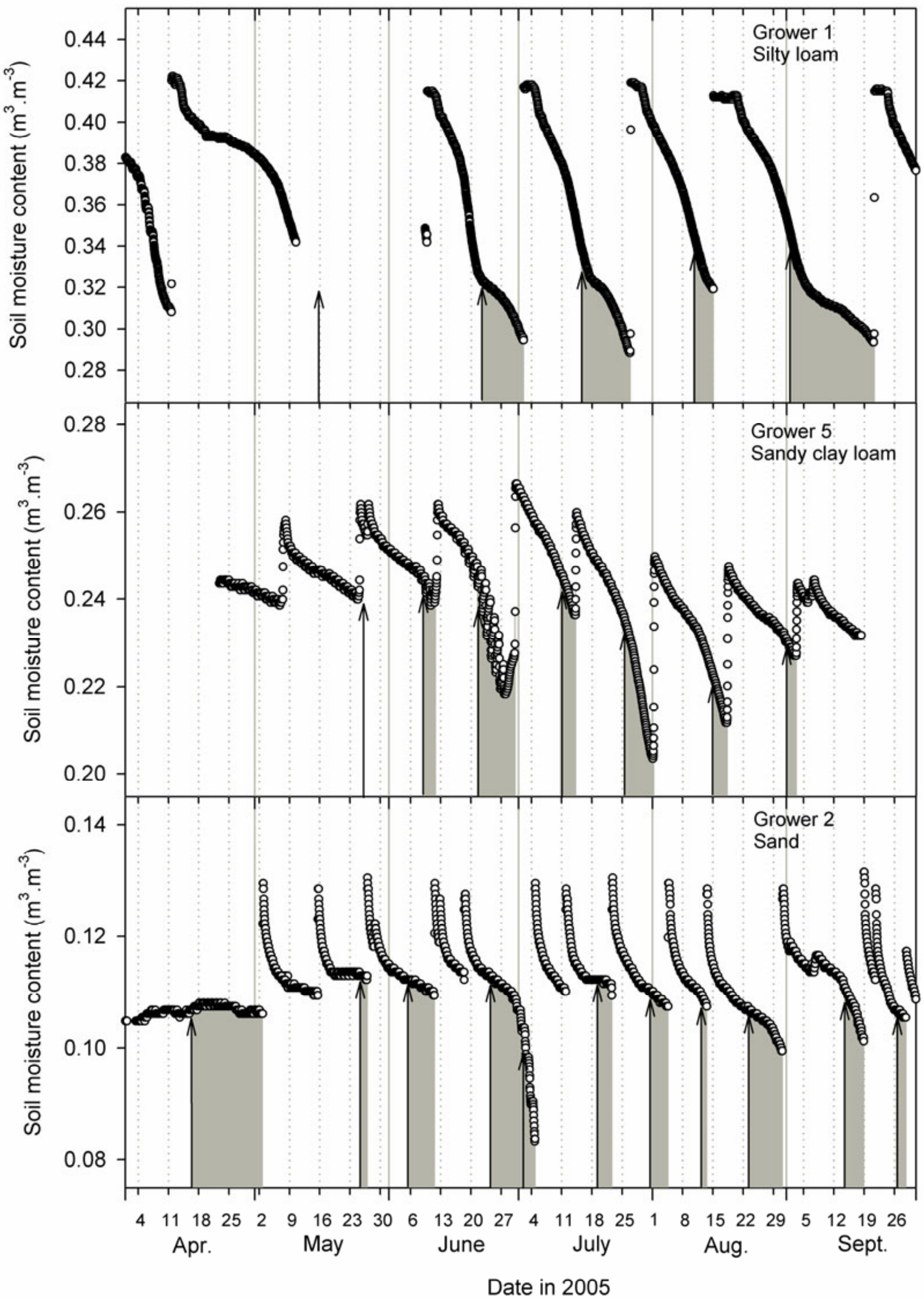
Did you use the GMS sensors with the datalogger to monitor soil moisture?	Initially	No	No	Yes	No
Did you use tensiometer to schedule irrigations?	Yes	Yes	No	Yes	No
Did you keep a record of the tensiometer readings?	Initially	No	No	No	No
Did you use the climate-based irrigation scheduling model?	Once	No	No	No	No
Did the person making the scheduling decisions also collect and analyze the soil moisture data?	Yes	Yes	No	No	Yes
Which instrument was most useful?	Tensio-meter & GMS	Tensio-meter	None	Tensio-meter	None[z]
Will you use any of these methods to schedule irrigations in the future?	Yes	Yes	No	Yes	Maybe
Were you satisfied with the training you received on operating the soil moisture monitoring equipment?	Yes	Yes	Yes	Yes	Yes
How much would you be willing to spend on soil moisture sensing equipment on an annual basis?	$200-800	$275	$0	$600	$500

[z] Deduced, since tensiometers were dry and the activated data loggers had not been downloaded for more than 6 weeks.

At the conclusion of the season growers expressed they had little time or patience to collect and manipulate GMS data on their computers, or to retrieve the estimated ET from the web site. Only one of five collected logged GMS data on a weekly or semi-weekly basis, graphically analyzed it, and used the information; two of five left the activated data loggers in the orchard for several months and never collected the data, even though they read the tensiometer adjacent to the GMS every few days. One of the growers was so frustrated and discouraged with his inability to manipulate data in a spreadsheet that he discontinued the project after 2 months. While three of five growers used the tensiometer information to aid in scheduling irrigations, none recorded the tensiometer readings, plotted the data on graph paper, or used the readings to predict a future date when the soil moisture potential would be at the prescribed target.

Even though the cost of the instruments used in this study was a fraction of the cost of more automatic systems, potential savings apparently did not provide incentive for growers to collect their data and do their own computational and graphical analysis. In cases where the tensiometer readings or GMS data were used, the timing of irrigations was allowed to go longer than the optimal interval predicted by the climate-based irrigation scheduling model (Fig. 1). Grower 1, who only used the tensiometer as an aid to schedule irrigations, was still 2 to 11 d late in scheduling irrigations, except in September when an entire irrigation was missed. The cumulative difference between non-stress ET and stressed ET was 280mm (11.0 inches), which translates to a theoretical yield loss of 694 $kg{\cdot}ha^{-1}$ (619 lb/acre), and revenue loss of \$340/ha (\$840/acre). Grower 2, who also used the tensiometer as an aid, irrigated at an interval consistent with the model during the beginning of the growing season. However, after May he was 4 d late, and appeared to have skipped an irrigation in late June. The cumulative difference in non-stress ET and stressed ET was 84mm (3.3 inches), equivalent to 208 kg·ha^{-1} (186 lb/acre) of lost yield, or $101/ha ($250/acre). Grower 5 used neither the tensiometer nor the GMS to schedule irrigations, and irrigated 2 to 8 d late for most of the growing season except in the month of May. The cumulative difference in non-stress ET and stressed ET was 137mm (5.4 inches), equivalent to theoretical lost yield of 340 kg·ha^{-1} (303 lb/acre) or $166/ha ($410/acre). Overall, the estimated loss in revenue exceeded by a factor of 4 to 14 the cost of the equipment or hiring a consultant to schedule irrigation at a fee of $24/ha ($60/acre).

Figure 1. Time series soil moisture content during the 2005 growing season at three pecan orchards measured with GMS sensors and HOBO data loggers. Open circles represent hourly soil moisture content readings from sensors located near the end of the bordered plot, furthest from the irrigation gate. Arrows indicate the next irrigation predicted by the climate-based irrigation scheduling model. Shaded areas represent periods of potential water-stress when soil moisture was below 45% MAD.


Grower 1
Silty loam
Grower 5
Sandy clay loam
Grower 2
Sand
Soil moisture content (m³.m⁻³)
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.14
0.12
0.10
0.08
4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19 26
Apr. May June July Aug. Sept.
Date in 2005

The reported overall in-shell yields for 2005 were 2595 kg·ha^{-1} (2315 lb/acre) for Grower 1; 1993 kg·ha^{-1} (1778 lb/acre) for Grower 2; 3004 kg·ha^{-1} (2680 lb/acre) for Grower 5. Local yields in mature, well managed, non-stressed orchards typically exceed 3700 kg·ha^{-1} (3300 lb/acre) in an "on" year. However, many factors affect actual yield including: alternate bearing, tree age, tree spacing, pruning regime, prior water or nitrogen stress, and disease. In this study, the yield for the bordered plot at Grower 1's orchard was at only 45% of the overall orchard yield. Trees in this block were over 30 years old, in need of pruning at the top of the canopy, and have recently produced low yields in both "on" and "off" years. Trees at Grower 2's orchard were severely water stressed in 2003 and 2004 to the point of early defoliation and severe branch die-back, and have yet to fully recover. In situations such as these, theoretical yield may not match the actual yield even with sufficient irrigation at optimal timing.

While some frustration with learning how to use the equipment and computer programs was expected, some of the shortcomings of this project were due to poor communication that may stem from a lack of incentive. By the end of the season it was apparent that most of the growers had difficulty with the instruments and spreadsheet manipulations, but during the season only two of the growers communicated any problems to the researcher or the county agent by phone or email. To minimize lost time and resources in future studies we recommend the following criteria for selecting grower participants:

1) Motivation to collect data needs to come from the grower's desire to increase profits, and the percent of personal income dependent on pecan sales should exceed 50%. 2) The person making the irrigation scheduling decisions needs to have demonstrated computer skills in spreadsheet programs. 3) Most importantly, future outreach programs should be less neutral with regards to rewards and expectations. If growers were actually paid a monthly stipend for gathering the data like a technician they would be obliged to record the data and solve the technical problems when they arose. The research community needs to include such stipends in grant proposals.

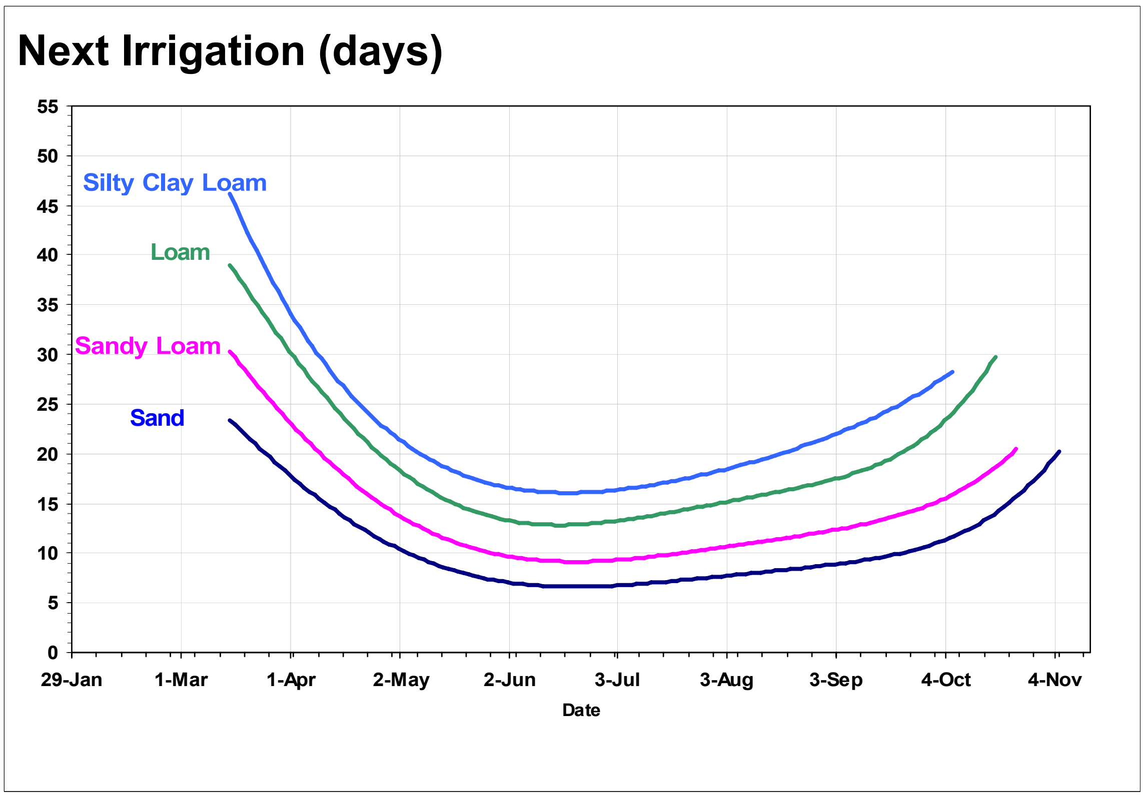
TECHNOLOGY ASSESSMENT.

Post-season analysis of the time-series GMS data (Fig. 1) indicated that, in many cases, the rate of soil moisture depletion slowed on or near the model recommended irrigation dates. If the actual irrigation was missed or delayed the rate of moisture depletion became more rapid as the moisture content decreased, suggesting that readily available soil moisture in the middle root zone (where the sensor was located) was depleted and the moisture gradient between the middle and lower root zone had increased. This correlation also implied that the model's parameters and assumptions were fairly accurate, which was further supported by the relatively consistent moisture content observed on all modeled irrigation dates. These results support our proposal that the model may be used to calibrate the sensors if the sensors are placed in the middle of the root zone and in a location where the moisture status is representative of the whole plot. However, given the sensitivity of the GMS to soil temperature (Shock et al., 1998) this calibration may need to be reset in the summer months.

Given outcome of this project and the comments from participants any improvement for future implementation of these tools needs to focus on simplicity. We suggest the following: 1) many data manipulation steps can be eliminated by developing template spreadsheets and macro programs that automatically convert logger voltage to volumetric moisture content and graph the time series data. The growers should only need to import, copy, and paste the data logger file into the template. 2) Information obtained from the on-line irrigation scheduling model could be more specialized. It was not clear whether the web site was too difficult to navigate, or growers had an inherent distrust of modeled values. To reduce the amount of information, an irrigation scheduling web page dedicated to Mesilla Valley pecan production using local weather data could be developed with fewer steps and menu options. An alternative way this information could be accessed by the growers is for a regular column to appear in the daily newspaper, written by the county extension office with crop irrigation information based on the irrigation scheduling model. Daily and cumulative ET for a variety of crops along with a recommended interval between irrigations for each crop in a few soil types could be reported in a table.

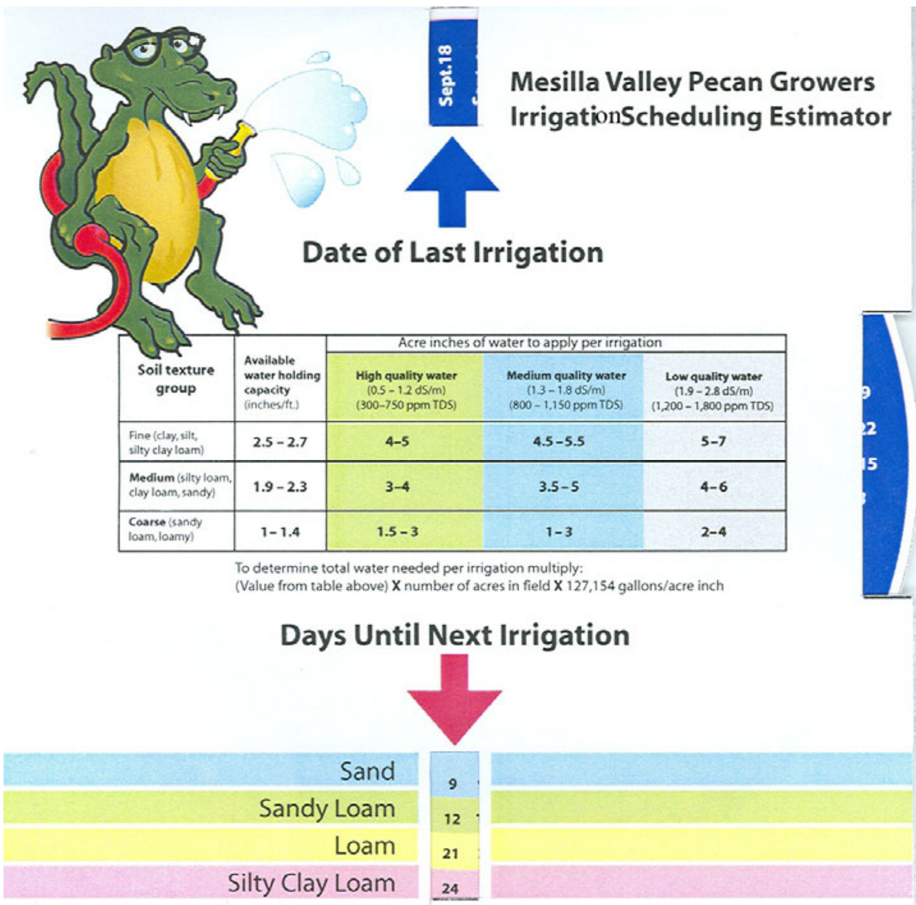
A second approach is to develop a nomograph that use average long term weather data to determine irrigation intervals days between irrigations depending on the soil type and month of the year (Figure 2).

Figure 2. Nomograph of pecan irrigation interval based on soil type and day of the year.



Nomographs can be built to present the data in figure 2 in a circular format like a circular slide rule (Figure 3) or in a standard slide rule format using different configurations. The different formats of the nomograph are currently being evaluated by a series of focus groups to determine the format of the nomograph that is preferred by a group of pecan farmers. The concept is that using the simpler nomograph approach to irrigation scheduling of pecans, information is lost but simplicity gained that will result in the use of the information where as soil moisture monitoring or internet irrigation scheduling approach to managing irrigations was not adapted.

Figure 3. Nomograph of pecan irrigation interval based on soil type and day of the year and presented in a circular nomograph format



Soil texture group	Available water holding capacity (inches/ft.)	Acre inches of water to apply per irrigation		
		High quality water (0.5 – 1.2 dS/m) (300–750 ppm TDS)	Medium quality water (1.3 – 1.8 dS/m) (800 – 1,150 ppm TDS)	Low quality water (1.9 – 2.8 dS/m) (1,200 – 1,800 ppm TDS)
Fine (clay, silt, silty clay loam)	2.5 – 2.7	4–5	4.5 – 5.5	5–7
Medium (silty loam, clay loam, sandy)	1.9 – 2.3	3–4	3.5 – 5	4–6
Coarse (sandy loam, loamy)	1 – 1.4	1.5 – 3	1 – 3	2–4

Conclusions

We had negligible success at transferring these cost-saving soil moisture monitoring technologies to growers because: a) many participants did not have the skills in spreadsheet programs as they had claimed; b) many participants did not have a substantial financial incentive to improve yield; c) most participants needed continued help the through the learning phase but did not communicate this with the research and extension community; d) there were too many steps involved in data procurement and analysis; e) the recommended target moisture content for scheduling irrigation based on PTFs did not agree fully with the GMS sensor output, creating added confusion about data interpretation. All of the growers in this study understood conceptually that better management of water inputs could translate into higher yields. While three out of five growers indicated they had used either a GMS or tensiometer to schedule irrigations, they all irrigated 2 to 11 d late throughout the season based on modeled ET dates. The estimated revenue lost based on theoretical yield exceeded the cost of the equipment or irrigation consultant fees.

A simpler approach to irrigation scheduling is needed and a nomograph although not as accurate as using a soil moisture sensor or internet real time irrigation scheduling may result in some form of irrigation scheduling where as the more sophisticated method will not be used.

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Kansas progress in ET based scheduling: Improvements in KanSched

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Written for presentation at the
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Abstract. *Irrigators in Kansas have increasingly accepted irrigation scheduling using climate-based ET information as a management tool. The primary scheduling tool used by individuals has been KanSched, a software package developed as part of the Mobile Irrigation Lab (MIL) project of Kansas State University Research and Extension. Producer survey and requests for additional features have been addressed by the development of KanSched 2. This paper will update the status of MIL programs and new KanSched 2 features.*

Keywords. Kansas, irrigation scheduling, ET, evapotranspiration, computer software

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Kansas progress in ET based scheduling: Improvements in KanSched

D.H. Rogers, G. A. Clark, M. Alam, and L. K. Shaw[1]

Abstract: Irrigators in Kansas have increasingly accepted irrigation scheduling using climate-based ET information as a management tool. The primary scheduling tool used by individuals has been KanSched, a software package developed as part of the Mobile Irrigation Lab (MIL) project of Kansas State University Research and Extension. Producer surveys and requests for additional features have been addressed by the development of KanSched 2. This paper will update the status of MIL programs and new KanSched 2 features.

Keywords: Kansas, irrigation scheduling, ET, evapotranspiration, computer software

Introduction: KanSched 2.0 is a program designed to help irrigators and water managers monitor the root zone soil profile water balance and schedule irrigation events on a field using evapotranspiration (ET) data. ET-based irrigation scheduling is a tool that can help you determine when and how much irrigation water to apply. The basic process involves using data on crop water use (crop evapotranspiration or ETc), rainfall, and soil water storage to assess when an irrigation event is needed and how much water to apply.

The original version of KanSched program was developed as part of the Mobile Irrigation Lab project, which is supported by a partnership between K-State Research and Extension, the Kansas Water Office with State Water Plan Funds, Kansas Water Resources Research Institute, and the Ogallala Initiative Project. This new release, KanSched2, offers some new features, in response to requests made by irrigators and crop consultants. These include additional crop options, including a built-in feature to account for cutting cycles on alfalfa, an irrigation forecast, irrigation fuel cost accounting, and a water record page for individual fields. Users of any of the KanSched 1.0 version series should find KanSched 2.0 familiar and have little or no difficulty in adapting to its use. KanSched2 will allow the import of field data saved in archive suing previous versions.

KanSched2

The background color scheme for KanSched2 was changed to help producers easily distinguish KanSched2 from the original KanSched, however the control buttons (now bars) still allow most of the functions to be controlled by placement of the mouse curser and clicking. Figure 1 shows the start page of KanSched2. Several of the internal improvements of KanSched2 include easier file transfer or sharing, and import and export of file information. Since KanSched has been in use by some producers for nearly ten years, the installation of KanSched2 does not automatically uninstall the original KanSched. While these files can be imported, if desired, it was thought this might be a producer preference. KanSched2 does require a few additional data entries than the original KanSched , so when the data is imported, some additional data entry is required to allow full use of KanSched2 options.

A new feature of KanSched2 allows the establishment of field collections. It is anticipated that this feature would be used by crop consultants or water mangers that may have multiple number of irrigation clients and would want to transfer information to clients individually, but not field information for other clients. Irrigators handling their own fields would most likely not want to divide their operation in this manner.

Once a field collection is made, the user of KanSched2 can start adding individual fields to the collection, using a series of input pages in the field set up option, shown in Figure 2. To help with this phase of data entry, the field inputs are broken down into a series of pages; general information, season dates, soils and roots, crop coefficients, and advanced. This allows on screen information to be provided to the user as needed. Drop down menus allow selection of crops, dates, and soil information to be selected without reentry. Once all required field set up information is activated, the other KanSched2 control buttons are activated and they then appear on the left hand side of the screen page. Notice in the Figure 2 example, a drop down calendar appears to let the user click on the desired date for entry. Nineteen different crop options are now included in KanSched2, meaning the crop coefficient information is built into KanSched for Kansas growing conditions. KanSched2 does allow additional entry of crop information in a new feature using an “add/edit custom crops” on the general information page.

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Alfalfa has also been added to KanSched2 . When alfalfa is selected as a crop, the budget page will have an additional column appear on the left to allow entry of the cutting date. Whenever a cutting occurs, KanSched2 will automatically reset the alfalfa crop coefficients. This allows the entire alfalfa growing season to be retained in one file.

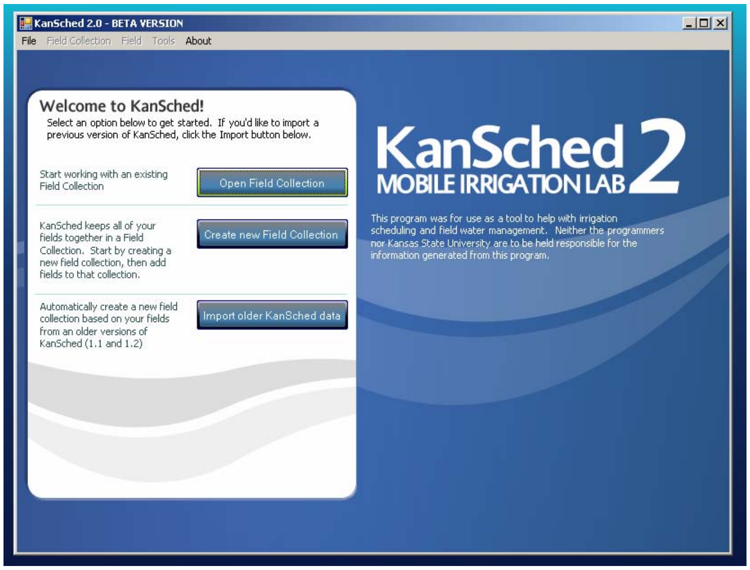

Figure 1: KanSched2 Start Page

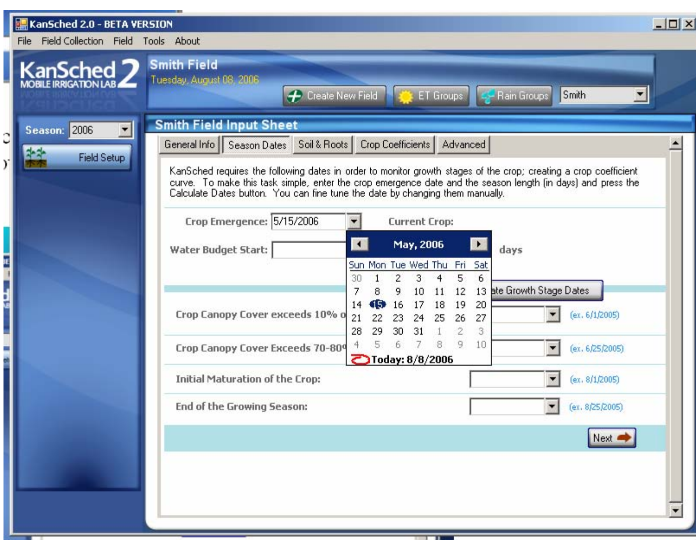

Figure 2: KanSched2 Field Set Up page

KanSched2 will also allow the water budget to begin before the emergence date of crop. Many producers with limited capacity wells in recent dry spring seasons have wanted to apply pre-season irrigation water and have the application recorded on the water budget and soil water chart pages (Figures 3 and 4).

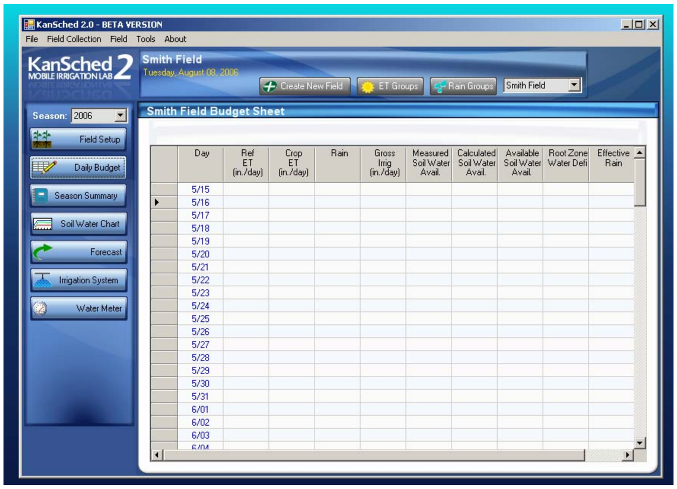

Figure 3: KanSched2 Water Budget Page

The water budget page follows the same format of the original KanSched. Daily entries of reference ET, rain, and irrigation are used to calculate the percentage of root zone soil water and the root zone soil water deficit. An entry column is available for any field observations of soil water. Any rain entry that exceeds the root zone storage capability is truncated to that amount and recorded as effective rain. Fields can also be grouped into ET groups. ET grouped fields are fields that use the same weather station source for reference ET information. Any update of the ET information in one field will result in the update of all fields within the group. Fields can also be grouped into rain groups, if one rain gauge serves more than one field.

The soil and root information, along with water budget soil water calculations, are plotted on the soil water chart. Rainfall and irrigation entries are also plotted, (Figure 4).

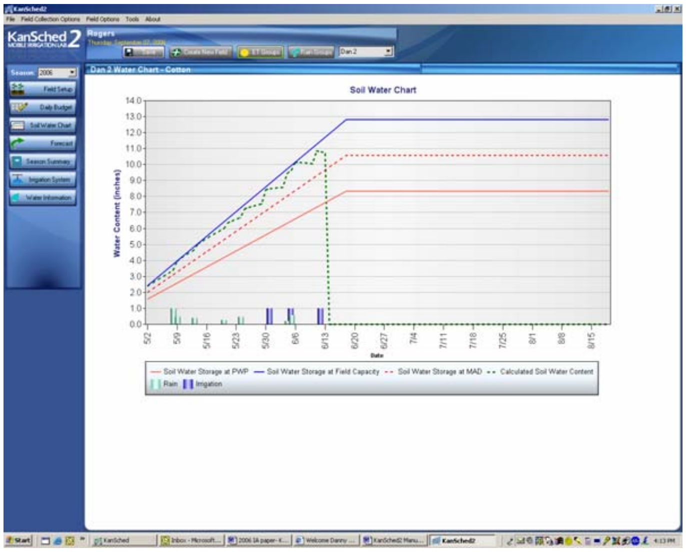

Figure 4: KanSched2 Soil water chart

Information from the water budget page is summarized and shown when the Season Summary control button is clicked. Season totals for reference ET, crop ET, rain, effective rain, gross irrigation, and net irrigation are totaled from the start of the water budget to the last entry date.

New KanSched2 Features

Three new control buttons have been added to KanSched2: Forecast, Irrigation System, and Water Records. The forecast control (Figure 5) lets the users look at the predicted soil water level five days into the future, based on the average reference ET for the previous five days and the future crop coefficients. A sliding scale allows the forecast to be made with reference ET values that are increased or decreased by up to 20 percent.

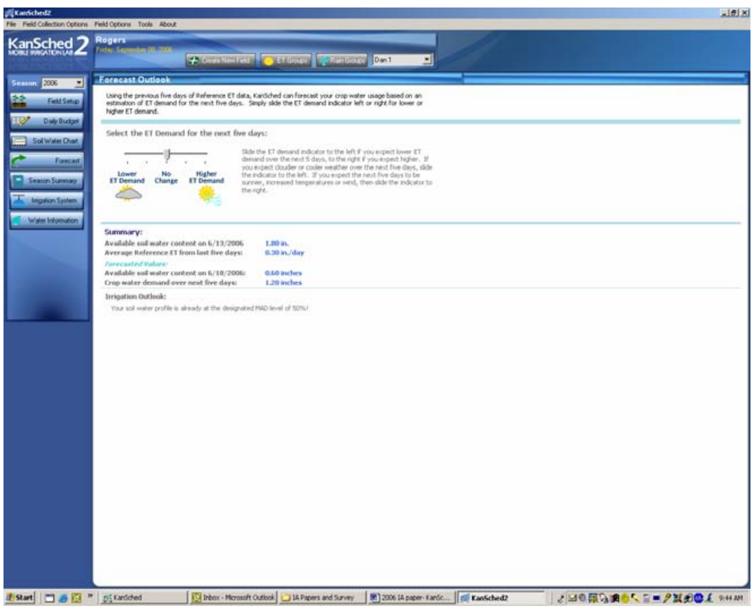

Figure 5: KanSched 2 Forecast Page

The Irrigation System page (not shown) allows the user to enter information about the pumping plant which results in an estimate of the irrigation pumping cost to be made. If this page is activated, the water budget page will show the accumulated fuel cost after each irrigation entry. Kansas irrigators have an annual water use reporting requirement. The Water Record page (not shown) allows information related to the water use report to be recorded in addition to water meter readings and any well water levels that may be taken during the year.

Summary

KanSched2 has been developed in response to Kansas producer requests and many new options and features have been added. However the new version retains the original "feel" of the original KanSched, meaning it is user friendly and easy to operate. KanSched2 will be available via the Mobile Irrigation Lab (MIL) website at www.oznet.ksu.edu/mil.

Acknowledgement: Support for the development of KanSched2 and the operation of other MIL activities has been provided by Kansas Water Plan Funds through the Kansas Water Office, USDA project 05-34296-15666, and the Ogallala Initiative.

Economics of Irrigation Ending Date for Corn[1]

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Troy J. Dumler, Danny H. Rogers, and Kent Shaw

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Summary

The results from a field study indicate that corn growers of western Kansas may cut back the last one or two irrigation events of the season without appreciable loss in production. This will improve the economic return by reducing input cost from water. Recent increases in energy costs for pumping water necessitated this study to compare the benefits of continuing irrigation until black layer formation. With the decline of Ogallala aquifer groundwater level and rising fuel costs, any reduction of pumping makes economic sense. Ending irrigation around August 10-15, corresponding to denting at 1/4 to 1/2 of starch-layer formation toward the germ layer, resulted in a yield reduction of 17 bushels per acre, compared with ending irrigation around August 21-22, corresponding to 1/2 to 3/4 of starch-layer formation toward the germ layer. Whereas, continuing irrigation until September 1, corresponding to the start of black layer formation improved yield by only 2.5 bushels per acre. Economic sensitivity tests show that irrigating until the formation of starch layer at 1/2 to 3/4 towards germ layer is feasible with a corn price of $2 per bushel and $8 per inch pumping costs. Irrigating past this stage of grain development is not economical, even with $2.75 / bushel of corn and pumping costs as low as $4 / inch.

Introduction

Crop production in western Kansas is dependent on irrigation. The irrigation water source is groundwater from the Ogallala aquifer. The water level of the Ogallala aquifer is declining, causing the depth of pumping to increase. The additional fuel consumption required for greater pumping depths and higher energy costs have resulted in increased pumping costs in recent years. Because of declining water levels and higher pumping costs, it is necessary to conserve water by adopting efficient water-management practices. Irrigation scheduling is an important management tool. Farmers are interested in information on optimum timing for ending the irrigation season. There are some misconceptions regarding the optimum irrigation ending dates. Some farmers believe that the corn crop must continue to have water to avoid eardrop. Over-application at the end of season, based on this perception, causes waste of water, increases cost of production, and may even cause degradation of the quality of the grain due to high humidity or disease. Most of all, the excess use of water may reduce the useful life of the Ogallala aquifer, which is a confined aquifer with little or no recharge. Depletion of the Ogallala

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aquifer will impact irrigated agriculture and the present economy of the area. The objective of the study was to determine the effect that irrigation ending date had on corn yield and economic return.

Procedures

A producer's field with center-pivot sprinkler irrigation was selected for the study. A Ulysses silty loam soil was selected, and the study was conducted for four years (2000-2003). Two sets of six nozzles were shut progressively after the formation of the starch layer in the corn grain. The first closure was done when the starch layer was 1/4 to 1/2 to the germ. This corresponded to August 10 to 15, depending on growing degree units. The second closure was done when the starch layer was 1/2 to 3/4 to the corn germ. This corresponded to August 21 to 24. The third closure occurred when the producer ended irrigation for the year. This happened during the first week of September.

Four random plots of 30 ft by 30 ft were identified within the center-pivot sprinkler circle, over which the selected nozzles would pass during an irrigation event. Ridges were built around the plots to prevent entry of water from the adjacent areas. Gypsum block soil water sensors were buried in the plots at 1, 2, and 3 ft below the soil surface. The soil of the test field is relatively dark, with a deep profile and good water-holding capacity, but the soil surface cracks when dry.

Corn ears were hand harvested. Four contiguous rows, measuring 10 ft each, were harvested at the middle of each plot to remove any border effect. Grain yields were adjusted to 15.5% moisture content.

In 2005, the study was moved to a field with loamy fine sand soil (Vona loamy fine sand) to evaluate irrigation ending date for a light textured soil with less water-holding capacity. The hypothesis is that the sandy soil may require continuation of irrigation, and irrigation ending date may be delayed, compared with a silty loam soil having greater water-holding capacity. The procedure followed was similar to the earlier study, in which two sets of six nozzles were closed progressively as the grain formed its starch layer.

Results and Discussion

Continuation of irrigation from the first ending date in early August (August 10 to 15) to the second ending date in the beginning of the fourth week (August 21 to 22) gave an increase averaging 17 bushels of grain per acre. The additional irrigation application amounted to 2.1 inches. The yield difference from the August 22 ending date to the ending date in the first week of September, as normally practiced, was only 2.5 bushels per acre, on average, over four years. The additional irrigation quantity for the period from the second ending to last irrigation date was about 2.5 inches. The yearly yields are shown in figure 1.

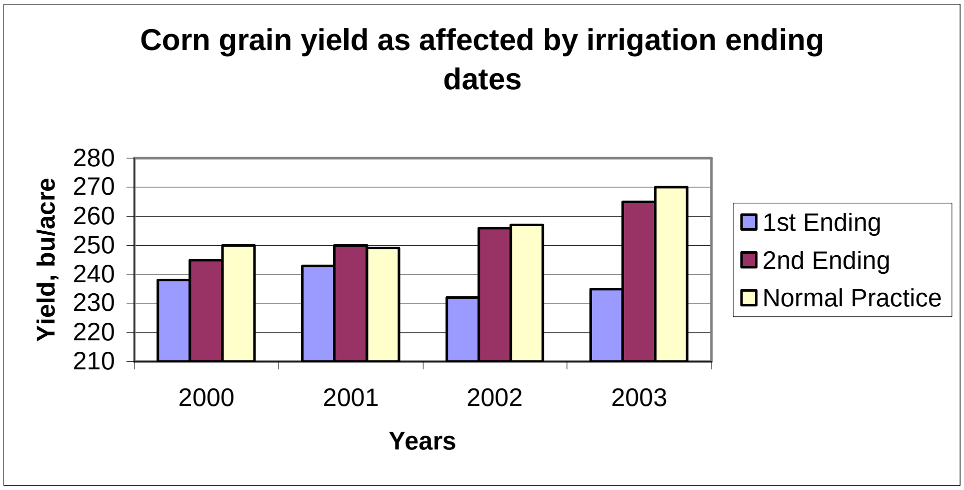

Figure 1: Yield of corn grain as affected by irrigation ending date at different growth stage on a silty loam soil, Stevens County, Kansas, 2000 to 2003.

The tool used to determine the optimum irrigation ending date was the marginal value vs. marginal cost analysis. In this analysis, corn prices ranged from $2.00 to $2.75 per bushel, and pumping costs ranged from $3.00 to $8.00 per inch. Positive returns indicate that the marginal benefit of continuing irrigation was greater than the cost of applying water.

Figure 2 shows that, under nearly all scenarios, irrigation remains profitable until the second ending date. Irrigation past this growth stage may not be profitable (Figure 3). Return becomes negative for corn at a pumping cost of $4.00 per inch, even at a corn price of $2.75 per bushel.

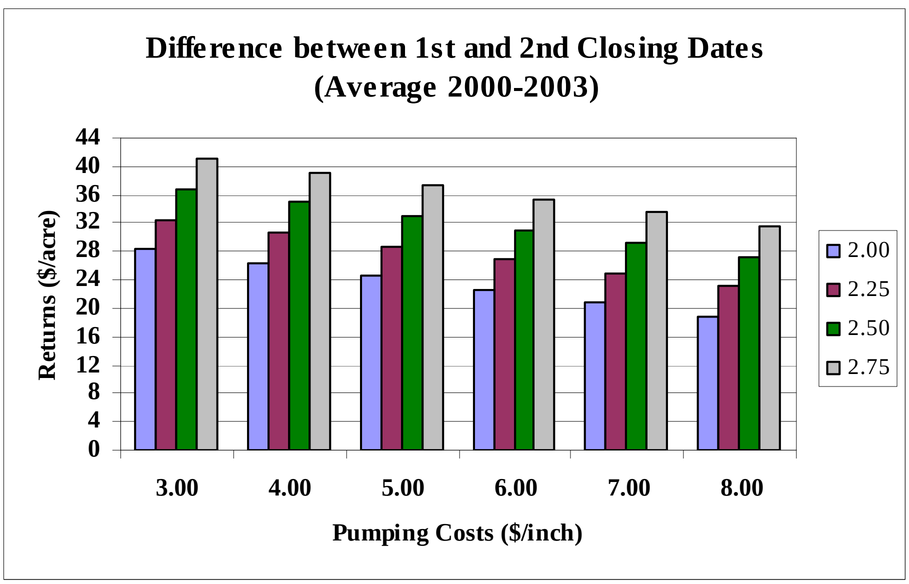

Figure 2: Returns at different levels of input cost and price of corn for difference between first and second ending dates

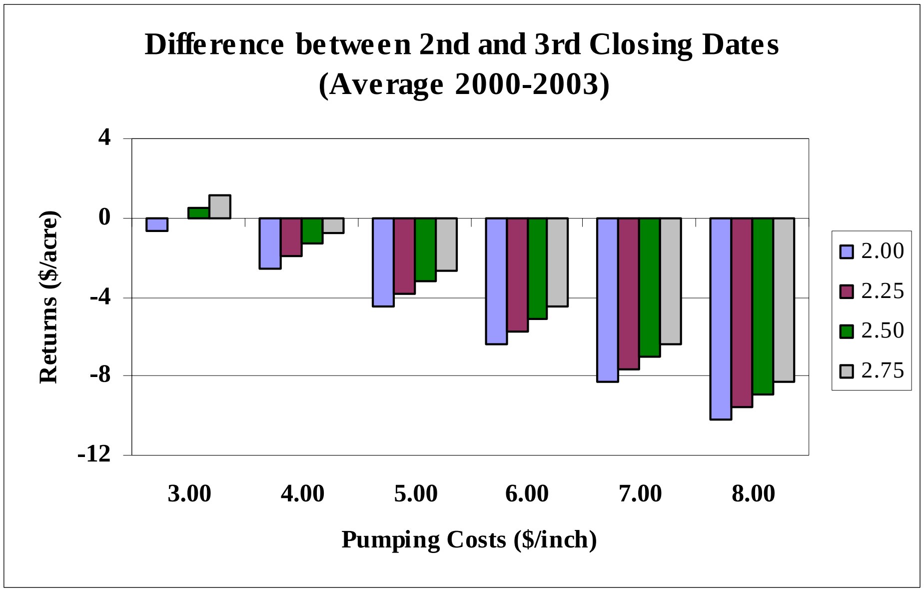

Figure 3: Returns at different levels of input cost and price of corn for difference between second and third ending dates

Kansas State University irrigation management bulletin number MF-2174: Predicting the Final Irrigation for Corn etc. presents a table showing normal water requirements for corn between stages of growth and maturity. The bulletin may be accessed at the website www.oznet.ksu.edu/mil under MIL Tool Kit & Resources. Corn grain, at full dent, will use 2.5 inches of water for the remaining 13 days before reaching physiological maturity.

The available water-holding capacity of the soil in the study field is estimated to be approximately six inches or more per 3 feet of root zone. It is expected that at a 50% management allowable depletion level, this soil will provide about 3 inches of water. This may be why there was no appreciable benefit from continuing irrigation past August 21 or after the starch layer has moved past 1/2 to 3/4 toward the germ layer. The soil water sensors indicated that the soil water condition was adequate to carry the crop to full maturity.

Figure 4 shows that the soil water at 1 and 3-ft depths were falling below Management Allowable Depletion (MAD) level for the first ending date, which caused a reduction in yield. Figure 5 shows that soil water in the top 1 ft started to decrease in the plots of the second ending date, but there was enough water at the 2- and 3-ft depths to carry the crop to maturity. At this site for some reason, the moisture level at 1 to 2 ft was at MAD levels at the beginning of the season. This changed as irrigation started.

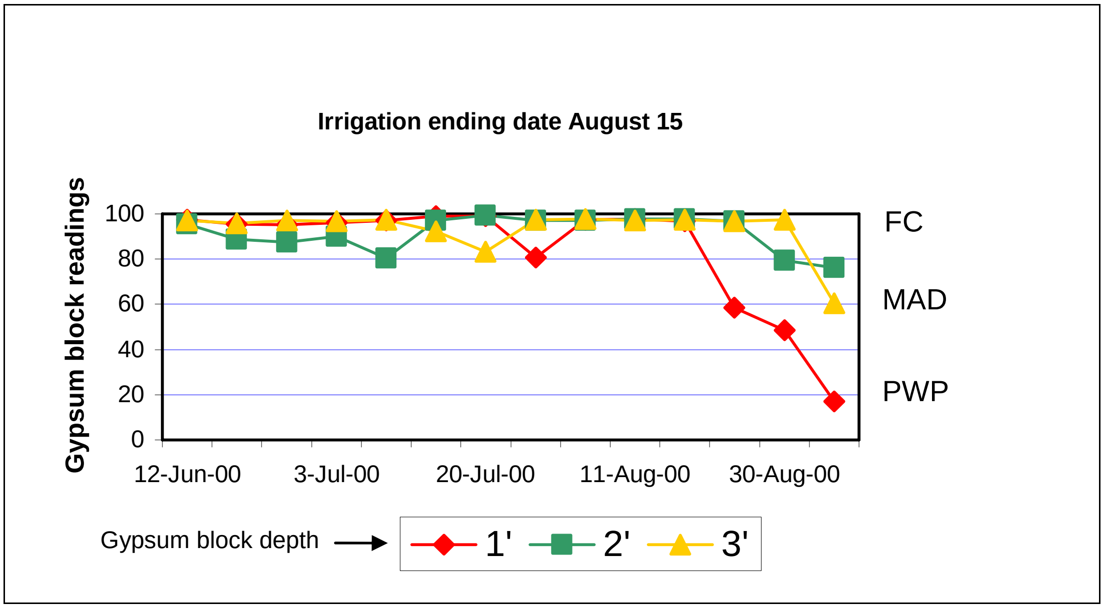

Figure 4: Soil water readings using gypsum blocks for first irrigation ending date (FC = Field capacity, MAD = Management Allowable Depletion, PWP = Permanent Wilting Point; these are to illustrate relative soil water status)

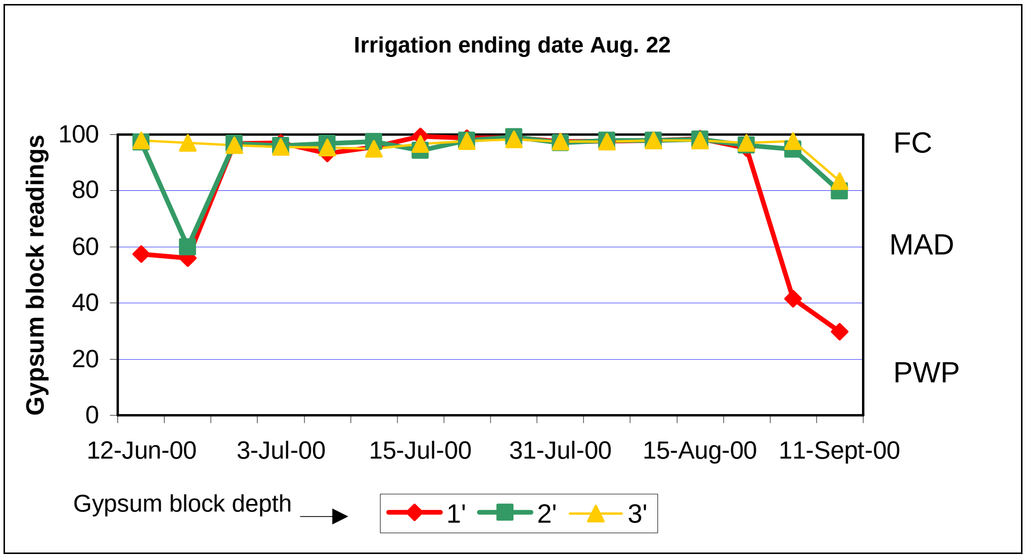

Figure 5: Soil water readings using gypsum blocks for second ending date.

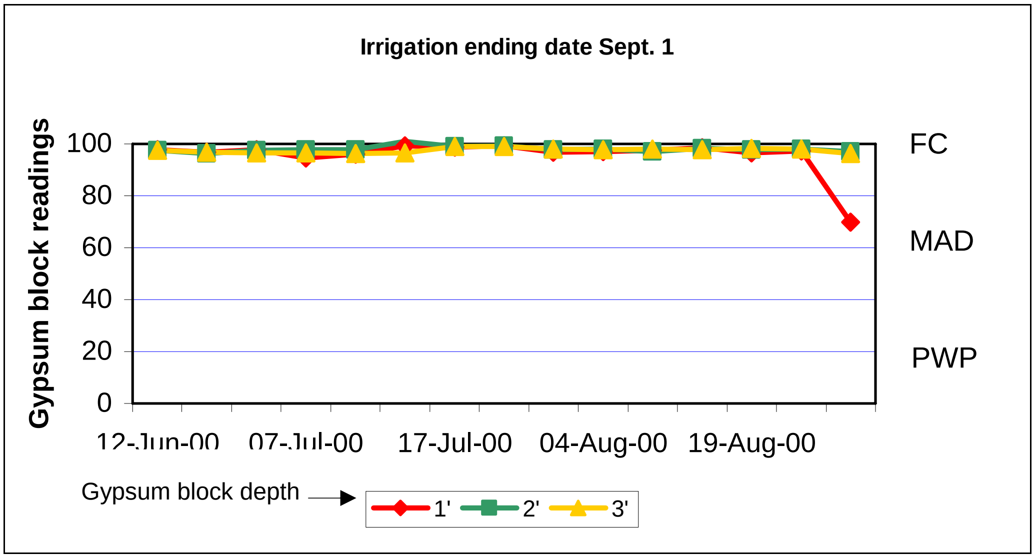

Figure 6: Soil water readings using gypsum blocks for last irrigation ending date

Figure 6 shows soil water readings taken until September 11 at the area where irrigation continued until September 1 under producers' practices; the readings indicate that soil water was almost at Field Capacity, except for the first foot of the profile. The crop was already mature, and there was no more water use. The profile was left with high water content over the winter. Most of the irrigated cornfields in western Kansas reflect this situation, and have little room to store winter and early spring precipitation. This causes double loss, from not taking advantage of natural precipitation and from leaching of nutrients with the deep percolation of excess water. A three-year study by Rogers and Lamm (1994) also indicated that the irrigation practices of corn producers of western Kansas leave approximately 1.4 inches of available soil water per foot of soil profile at harvest.

Producers using irrigated agriculture are continuously being educated on irrigation scheduling. Kansas State University Biological and Agricultural Engineering developed computer software called KanSched to provide the producers with an easy to use tool for irrigation scheduling. The irrigation events, rainfall, and crop water use (Evapotranspiration) data were entered to track the soil water depletion pattern, which is presented in Figure 7. Tracking of crop water use and irrigation applications show that the soil profile was pretty full at the end of the season when irrigation was continued until September 1.

System 12- Summer 2001

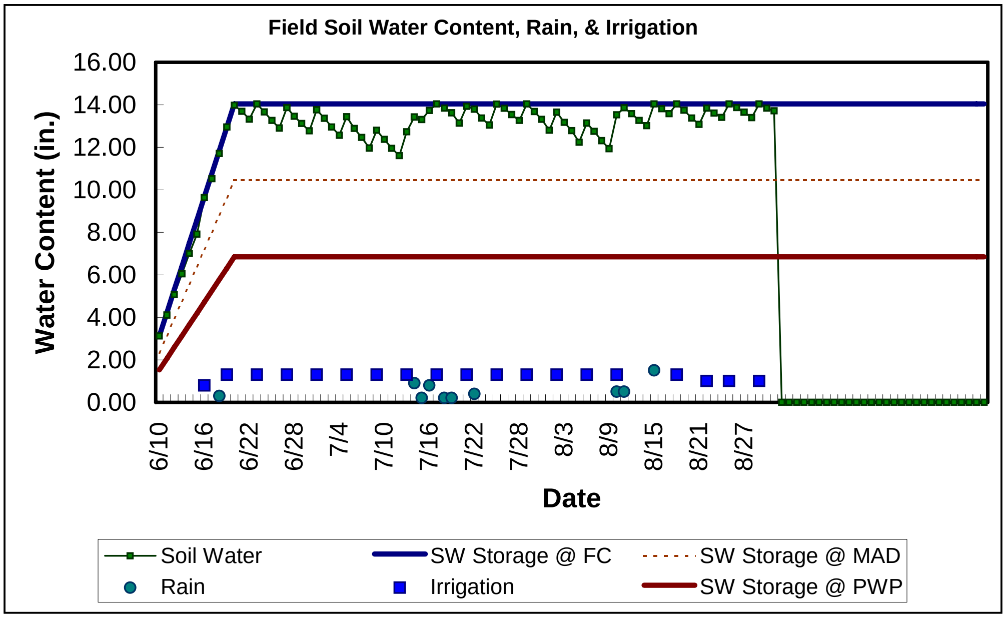

Figure 7: Chart showing water balance between soil water storage at field capacity and permanent wilting point. The dashed line in the middle represents management allowable depletion.

It would be worthwhile to mention that there was no appreciable eardrop observed in the field within the circular area having the first irrigation ending date, but the plants were dryer than plants in the rest of the field at the time of harvest.

The 2005 trial on Vona loamy fine sand needs to be continued to establish a trend, but the first-year results do indicate that the return remains positive at a pumping cost of $5.00 per inch, although the rate of return has been greatly reduced, Figures 8 and 9.

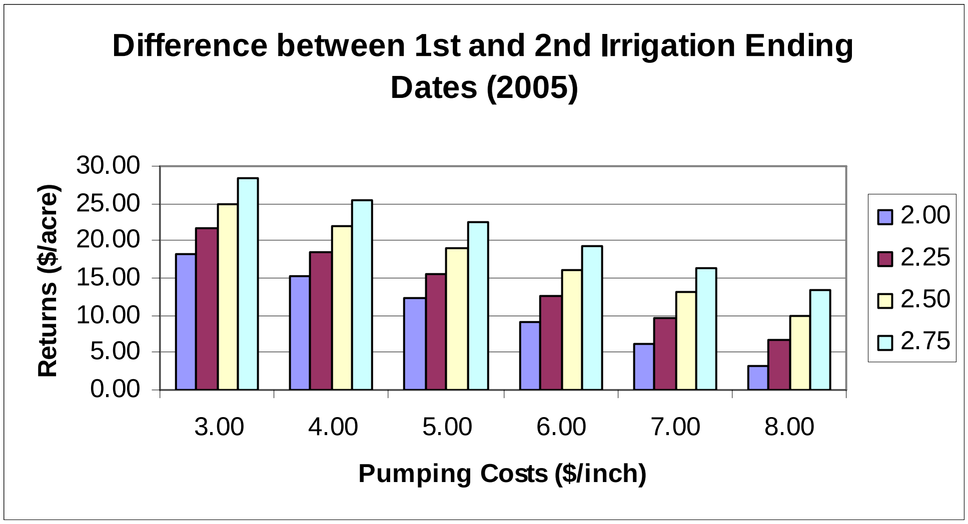

Figure 8: Returns at different levels of input cost and price of corn for difference between first and second ending dates.

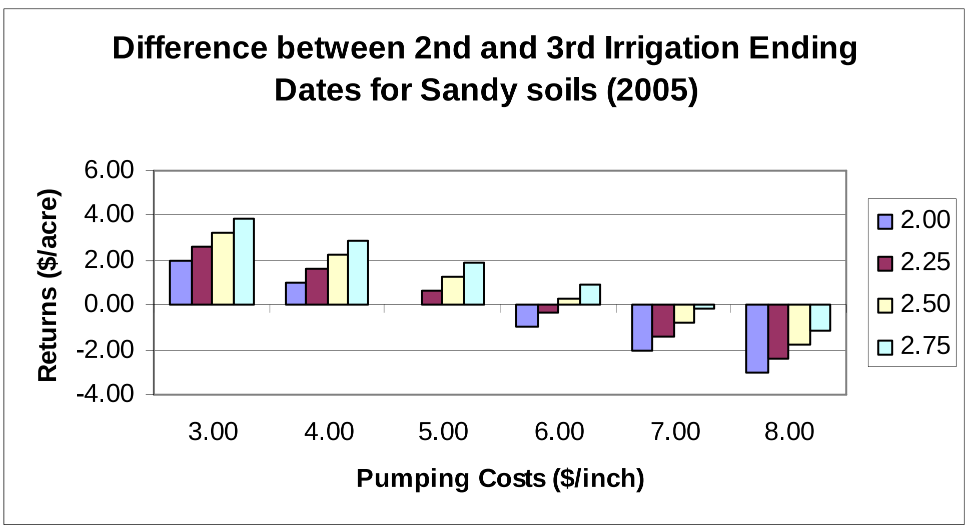

Figure 9: Returns at different levels of input cost and price of corn for difference between second and third ending dates

Concluding Remark

The four-year field study indicates that the present practice of irrigating until the formation of black layer in corn grain may not be economical. An earlier ending date for irrigation corresponding to the starch layer at 1/2 to 3/4 of the grain may help improve the economic return and best utilize the soil profile water in a silt loam soil. Using KanSched or Soil water monitoring by other means may help in the decision process. Earlier ending dates may require more cautious evaluation for a sandy soil because of its poor water-holding capacity.

Acknowledgements

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Termination of Irrigation on Corn

Jos. C. Henggeler[1]

ABSTRACT

A test was conducted for three years on the termination of corn irrigation in southeast Missouri (SEMO). Results showed that the location of the milk line can be an excellent tool of when to determine when to terminate irrigation. Based on the relative low cost of irrigation water in SEMO, corn should be irrigated past ½ milk stage and even as far as the ¼ milk stage.

INTRODUCTION

One of the most frequent questions that county extension agents are asked by local irrigators is when should irrigation be terminated on corn and other crops. Cutting off irrigation too early can reduce final yield by decreasing the overall weight of the corn kernels, which produces low *test weight,* (the number of pounds required to fill a bushel). The standard test weight of corn is 56.0 pounds per bushel. Test weight is hybrid-linked and data on it is normally provided by seed companies in their literature as a scale value from 1 to 9. Assuming correct population levels, lower then normal test weights are often associated with inadequate late-season irrigation.

Physiology of Corn

The number of ears per plant and number of kernels per ear are primarily determined during the vegetative stages of growth. Many of today's high-yielding hybrids are non-prolific (they tend to form single ears per plant), but the prolific varieties determine the number of ears per plant during R5. The potential size of the ear and the number of potential kernels, or ovules, down the ear is determined in V12. The final number of sites for kernels down the cob row is determined a week prior to silking in V17 stage. During silking (R1) the ovules which are fertilized can grow into kernels. The ultimate yield then is determined by the number of kernels per acre that exist times the average weight per kernel.

Thus, from ten weeks after emergence final kernel weight becomes the prime influence on yield. During the blister stage (R2) starch begins to accumulate. Towards the end of the dough stage (R4), as the starch levels begin to increase the kernels begin to dent on top as moisture level decreases in the kernel. The final stage prior to physiological maturity is the dent stage (R5) where starch accumulation and kernel drying continue occurring. The moisture level is at 55% as the beginning of dent stage. At physiological maturity (R6), also called black layer, the moisture level has decreased to 30-35% and no further starch accumulation occurs (Ritchie et al., 1993).

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During the six or seven weeks that transpire between the R2 and R6 stages kernel weight increases. If soil moisture becomes insufficient during this time yield decreases. The final irrigation should take place late enough in the season to ensure that the plant will have full potential to maximize the weight of the kernels. Management factors that must be accounted for is the tendency of root mass to diminish late in the season and the need of adequate hydration within the plant to allow for translocation of nutrients to the seed from other plant parts.

Early Work at Estimating Cut-off

Earlier attempts to ascertain when to end irrigation (e.g., Klocke et al., 1991) relied on a mass balance approach that used estimated soil moisture-holding capacity, rooting depth, and allowable depletion point to calculate a storage amount of water. Daily crop water use information from the tail-end of the season was then utilized to calculate an equivalent amount of water and the associated number of days back from black layer this point was reached. Several state Extension services followed this methodology in formulating their recommendations. Problems with the mass balance method was that it involved calculations and use of three tables (which might put off many farmers), plus it involved an estimation of current soil moisture status that the farmers might not have. In addition, the results did not always coincide with empirical studies (Alam, 2000), being too conservative and causing irrigation to be terminated too soon.

Henggeler (2002) developed a method of deciding when to terminate irrigation by soil type and irrigation method based on visual appearance of the corn ear, primarily milk line location. The procedure for this was based on the methodology of Klocke et al. (1991), but the rooting depth factor was reduced to only 1.5 feet, instead of 3.0 feet. This was done to reflect earlier water use studies of corn in SEMO that showed little water extraction beneath 18 inches. The impact of soil type was incorporated into the procedure by using irrigation deficit values used by the University of Arkansas (Ferguson et al., 1999) and from unpublished empirical studies by the University of Missouri.

METHODS and MATERIALS

A test was conducted for three years (2003-2005) on two separate soil types to determine when irrigation should be terminated on corn. The soils involved were a medium textured soil (Tiptonville silty loam) and a course textured soil (a Broseley Loamy Fine Sand and Bosket Fine Sandy Loam combination). The computer irrigation scheduling program, *Arkansas Scheduler* (Ferguson et al., 1996), was used to determine when to irrigate. Following the application of a new irrigation, a set of replicates was then excluded from receiving any additional irrigations. In this manner treatments were created based on when the last irrigation was applied. Replicate number was three or four depending on the size of the field available for the test.

The overall goal of the project was to develop visual keys based on the appearance of the crop for terminating irrigation for the season. In the first year of the study a single hybrid was used. In subsequent years four different hybrids were used to offset the possibility of results being skewed by innate traits one particular hybrid might possess. The ear with husk, stripped ear, cross-section of the ear, and crop canopy were photographed approximately every ten days starting about silking. Starting in 2004 kernel moisture and the position of the milk line was measured. The milk line was determined by inserting the end of a tack into the kernel to locate the demarcation between the solid starch area and the liquid portion of the kernel.

Yield was determined by harvesting two rows of corn with a plot combine. Test weight was measured by weight a know volume of seed. Both yield and test weights were adjusted to a 15.5 % moisture level. Relative yield was determined by dividing all yields by the highest yield from that test.

RESULTS

The 2004 year, which was an anomaly year for crop production in Missouri with historic yield levels in corn, soybean, sorghum, rice and cotton, was not used since the normal trends did not occur between yield and water applied.

The relative yields are shown plotted against the accumulative corn heat units (cHUs) (base = 50° and maximum temperature = 86°) from emergence to the last irrigation. The manufactures' estimate of cHUs required to reach black layer for the hybrids used was 2700-2800. The results (Fig. 1) tended to show that irrigation was often beneficial to about 2400 cHUs.

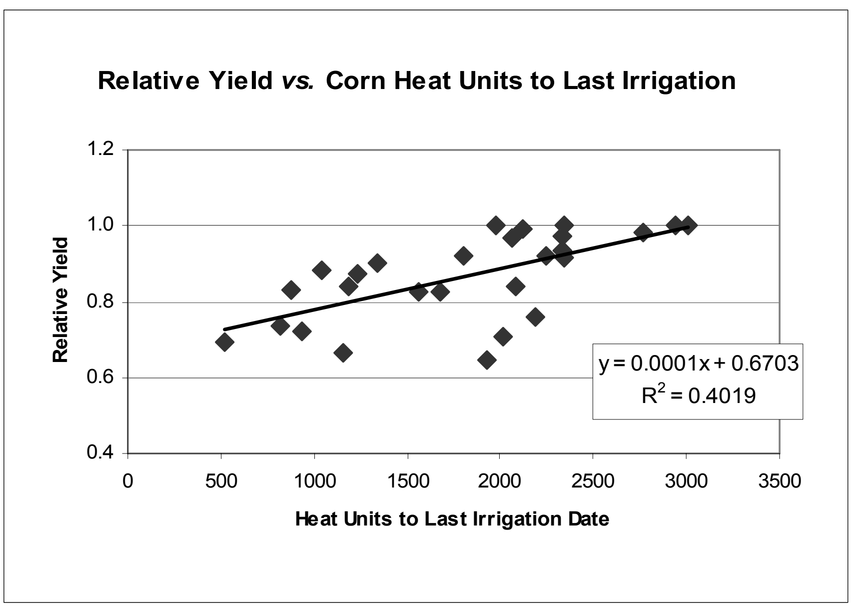

Fig. 1.—Relative yield versus corn heat units to the last irrigation.

The visible milk line was generally higher up the kernel then the actual milk line that demarks the solid and liquid area of the kernel, as shown in figure 2. The period of time it takes for the milk line to travel down from the crown to the tip of the kernel took longer then the time period of twenty or thirty days, which is often quoted in the literature (e.g., MSU, 2005). This commonly quoted rate change produces a percentage milk line change rate of about 4% per day. The study showed about a 2.2% rate change per day.

Fig. 2.—Cross-section of corn ear showing milk line. Percentage of milk line = l / L.

Many of the last irrigations in the tests were applied before R5 when the milk line has not yet been formed. Cutting off irrigation before the milk line appears is clearly too early and the average relative yield for these treatments was only 0.80. The average relative yield for all treatments where the last irrigation occurred once the milk line process was beginning was 0.90. .Figure 3 indicates that overall irrigation should continue until about 1/3 milk line remains.

This recommendation needs to take into account the cost of pivot irrigation. Currently, there is a large difference in cost between electricity and diesel/propane. The average cost for the electricity is about $2.40 per inch versus $4.20 per inch for diesel/propane. Growers will need to keep this in mind in determining when to apply the last irrigation.

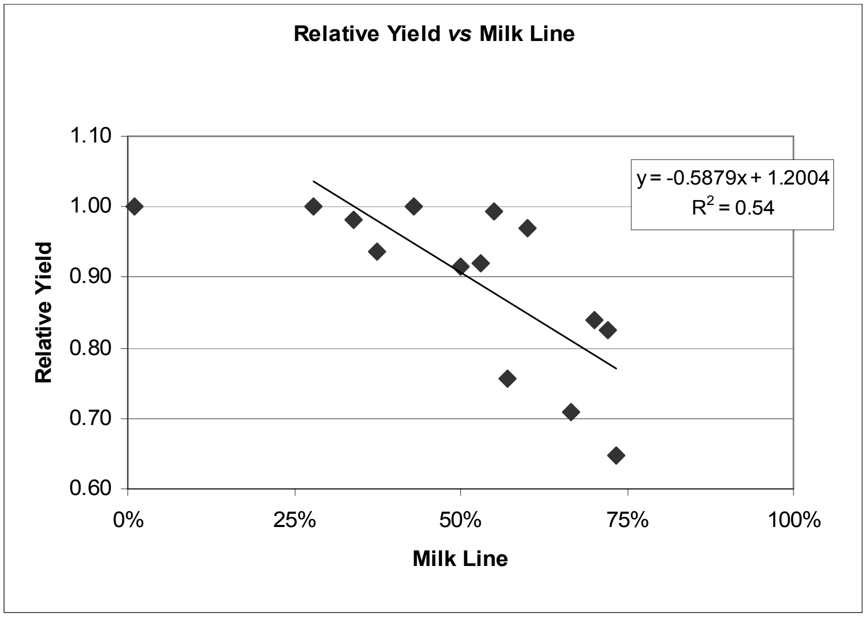

Fig. 1.—Relative yield versus position of milk line.

CONCLUSIONS

- The location of the milk line serves as a good indication of when to terminate irrigation.
- For Missouri conditions, irrigation should occur pass the 25% milk line for electricity users and pass the 50% milk line for diesel/propane users.
- The progression of milk line appears to take 40 to 50 days, and is slower then what is often reported (20 to 30 days).
- Test weight values can help determine if irrigation was carried long enough into the season.

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Crop Water and Irrigation Water Requirements of Cucumber (Cucumis Sativus) in the Loamy Sands of Kuwait

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Crop water and irrigation water requirements of cucumber have been estimated using the FAO CROPWAT model for the loamy sands of Kuwait. Agro-meteorological data for 43 years were used for this purpose. The crop water requirement (ETc), Irrigation requirement (IR) and Net Irrigation Requirement (NIR) of cucumber vary with the planting date. Water use of cucumber is the lowest with planting date of 15th October. The period 15th October to 15th November is suitable for cucumber planting. The ETc of cucumber crop vary from 537mm (15th October planting) to 948mm (5th January planting). The IR of cucumber varies from 428mm (25th October planting) to 876mm (5th January planting). Similarly the NIR of cucumber vary from 488mm (25th October planting) to 893mm (5th January planting). Cucumber planting in Kuwait may not be advanced beyond 15th November, in order to economise the water use. An irrigation schedule is also developed for cucumber for the loamy sands of Kuwait.

IRRIGATION SCHEDULING FOR SUGARBEETS GROWN ON A LOAMY SOIL UNDER VARIABLE CLIMATIC CONDITIONS

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Abstract

Irrigation schedule for sugarbeets grown in an experiment organized on a loamy soil in the continental part of Serbia, which is characterized by variable climatic conditions, has been determined on the basis of soil moisture readings obtained by the gravimetric method.
The experiment was conducted in the period 2002-2005, in which 2002 and 2003 were very dry and 2004 and 2005 were moderately dry. Irrigation was scheduled on the basis of two pre-irrigation soil moisture levels: A – 60-65% of FWC and B – 75-80% of FWC. The nonirrigated variant C served as control. The rainfall levels during the 2002-2005 growing seasons (April - September) were 274, 236, 442 and 530 mm, respectively. The rainfall distribution varied from year to year and between months in a single year. In variant A, 360 and 330 mm of irrigation water were applied in the two very dry years and 120 mm in each of the two moderately dry years. In variant B, 300 and 270 mm were applied in the very dry years and 150 mm in the moderately dry years.
The average yields of sugarbeet roots in variants A, B and C were 89.86, 94.44 and 75.36 t/ha, respectively. The respective average sugar contents were 14.62, 14.91 and 14.81%.

Key words: irrigation, climatic conditions, irrigation scheduling, yield, sugar content

Introduction

In the agricultural regions of Serbia, where the rainfall sum and distribution are highly variable from year to year and within a single year, irrigation is a supplementary practice. The average annual rainfall is about 600 mm, with variations from 360 to 940 mm. Variations are also large during the growing season, especially in July and August, from 0-160 mm. In 70-80% of the years the rainfall in July and August does not meet sugarbeet plant requirements and irrigation becomes necessary (Dragović *et al*., 2004).

Insufficient rainfall is particularly detrimental for sugarbeet, which is presently grown in Serbia at about 80-90,000 ha for the country's 11 sugarbeet refineries. The sugarbeet has a high water requirement because of its high production of organic matter per unit area. At the same time, it is a thrifty consumer of water. The well-developed root system takes up water from the depth of two meters. Under conditions of favorable soil moisture and fertility, it develops large leaf mass and a large storage root with a high percentage of sugar.

In climatic conditions where the amounts and distribution of rainfall are variable, as is the case with the agricultural regions of Serbia, sugarbeet yield performance is directly dependent on weather conditions and irrigation. Sugarbeet yields vary in conditions without irrigation not only from one year to another but also from one region to another within the single growing season. About 10-20% of the total sugarbeet requirement for water is supplied from reserve soil water, while the rest is provided by rainfall and irrigation (Maksimović and Dragović, 2004).

Depending on the conditions of growing, cultural practices applied, genotype properties and yield performance, sugarbeet water requirement ranges in Serbia from 500 to 700 mm, or 550-600 mm on the average. The most critical period for water supply are the months of July and August because that period accounts for 40 to 50% of the total sugarbeet requirement for water. As the amount of rainfall during growing season is from 350 to 450 mm, there is regularly a water deficit of 100-200 mm, which reaches 300 mm in some years (Dragović *et al*., 2003).

Material and Method

The trails were conducted from 2002 to 2005 at the experiment field of Institute of Field and Vegetable Crops in Novi Sad (northern Serbia), on a loamy chernozem soil with favorable chemical and physical properties. The experimental object was the sugarbeet variety Lara (NS-H-8R) developed at the Novi Sad Institute.

The experiment included the two irrigation variants, scheduled on the basis of pre-irrigation soil moisture level determined by a gravimetric method:

A – 60-65% of field water capacity (FWC)

B – 75-80% of FWC

C – nonirrigated-control

Sprinkling irrigation was used in the experiment.

Phosphorus and potassium were each applied in the amount of 90 kg/ha in the fall during primary tillage. Total nitrogen (140 kg/ha) was applied in 3 turns: during primary tillage, before planting and for top dressing.

The other cultural practices used in the experiment followed the recommendation for intensive sugarbeet production: plowing to the depth of 30 cm, seedbed preparation, herbicide application, crop protection against diseases and insects and between-row cultivation.

Results

Weather conditions and irrigation scheduling. The annual sums and distribution of rainfall varied considerably in the experiment years. The 4-year average rainfall during growing season was 370 mm, but the actual rainfalls differed from 236 mm in 2003 to 530 mm in 2005. The first two years (2002 and 2003) were very dry from the point of crop production, 274 and 236 mm, respectively (Table 1). Furthermore, the monthly distribution of rainfall was quite unfavorable in these years, so it was necessary to irrigate sugarbeets throughout the growing season. In 2002, the rainfalls in June and July were significantly below the long-term average. In 2003, below-average rainfall persisted in all months except in the second half of July when 54 mm of rain were received.

Table 1 - Total monthly and 10-day rainfall sums (mm) at the experiment field

Month	10-day period	Year				Long-term 1923-2003
		2002	2003	2004	2005	
Outside of the growing season		194	226	298	376	263
April	I	2	1	36	0	
	II	11	3	61	11	
	III	13	4	15	22	
	Sum	26	8	112	33	50
May	I	7	0	23	22	
	II	21	4	22	15	
	III	59	19	44	1	
	Sum	87	23	89	38	60
June	I	5	0	55	122	
	II	12	12	17	8	
	III	10	19	25	5	
	Sum	27	31	97	135	77
July	I	9	6	2	74	
	II	21	34	2	45	
	III	3	20	59	4	
	Sum	33	60	63	123	60
August	I	49	18	4	59	
	II	6	12	3	56	
	III	0	0	32	19	
	Sum	55	30	39	134	56
September	I	3	18	7	0	
	II	2	63	6	45	
	III	41	3	29	22	
	Sum	46	84	42	67	44
Growing season		274	236	442	530	348
Hydrologic year		468	462	740	906	611

The years of 2004 and 2005 had much higher rainfall sums, 442 and 530 mm, respectively, and much better distribution of rainfall during growing season. These sums were above the long-term average (Table 1). Precipitation was particularly abundant in 2005, both in the winter period (376 mm) and during the growing season (530 mm). The total precipitation of 906 mm for the hydrological year is near the absolute maximum ever registered in this region. Still, significant differences in monthly rainfall occurred in these years too (Figure 1).

Insufficient rainfall was supplemented by irrigation so that sugarbeets grow under optimum soil moisture throughout the growing season. Variant A (60-65% FWC) received 360 and 330 mm of irrigation water in 2002 and 2003, respectively. Six irrigations were performed in both years. Variant B (75.80% FWC) received 300 and 270 mm in 2002 and 2003, respectively, in nine irrigations each year. In 2004 and 2005, which had more favorable distributions of rainfall, 120 mm of water were added each year, in two irrigations, to variant A, and 150 mm, in five irrigations, to variant B (Table 2).

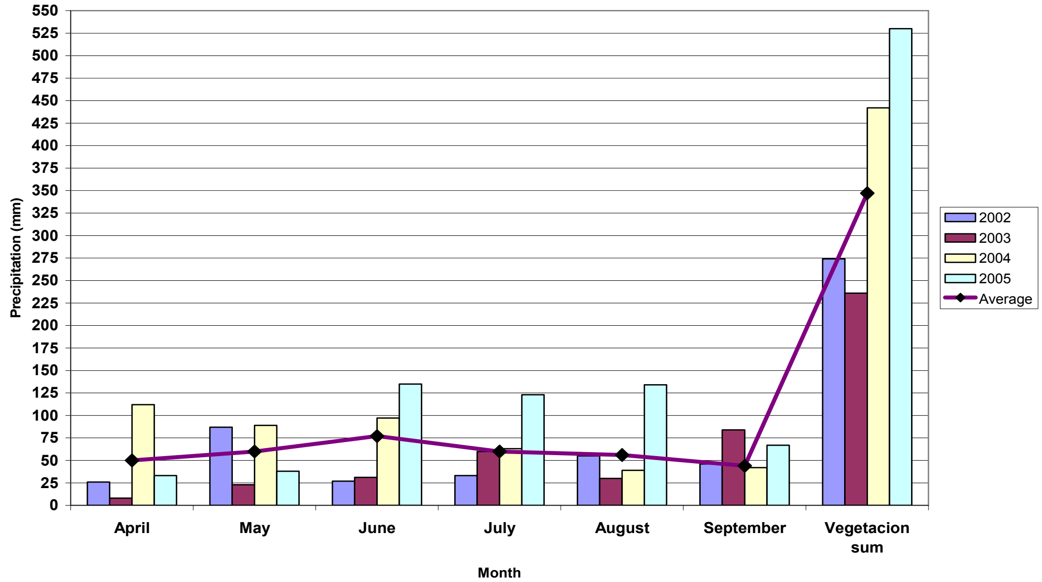


Figure 1 –Monthly and long-term average rainfall sums in the growing seasons

Table 2 – Irrigation schedule and rates (mm)

Year	Date of irrigation	Variant A: 60-65% FWC	Variant B: 75-80% FWC	Year	Date of irrigation	Variant A: 60-65% FWC	Variant B: 75-80% FWC
2002	19.06.	60	60	2004	30.06	-	30
	26.06.	-	30		08.07.	60	30
	28.06.	60	-		20.07.	60	30
	05.07.	-	30		24.07.	-	30
	13.07.	60	30		10.08.	-	30
	20.07.	-	30				
	30.07.	60	30				
	23.08.	-	30				
	28.08.	60	30				
	06.09.	60	30				
	Total	360	300		Total	120	150
2003	10.05.	30	30	2005	03.06.	60	30
	21.05.	-	30		21.06.	-	30
	03.06.	60	30		24.06.	60	-
	10.06.	-	30		30.06.	-	30
	13.06.	60	-		22.07.	-	30
	17.06.	-	30		29.07.	-	30
	30.06.	-	30				
	02.07.	60	-				
	08.07.	-	30				
	05.08.	60	30				
	15.08.	60	30				
	Total	330	270		Total	120	150

Air temperature had a significant effect on the intensity of evapotranspiration, therefore, on sugarbeet irrigation regimen. Average temperatures per 10-day period and per month are presented in Table 3.The average air temperature for the growing seasons of 2002-2005 was 18.7°C, the actual figures betwen years varying from 16.3 to 17.2°C. The long-term average for the growing season in this region is 16.8°C. In July and August, however, maximum daily temperatures typically exceed 30°C, frequently going above 35°C.

Table 3 – Mean daily air temperatures at the experiment field

Year	10-day period	Mean daily air temperature, ºC						
		April	May	June	July	August	September	Average
2002	I	8.3	18.3	18.8	23.8	23.2	21.3	
	II	12.6	19.6	22.9	24.8	21.0	15.8	
	III	14.2	19.4	23.7	22.2	22.3	14.1	
	Average	11.7	19.1	21.8	23.6	22.2	17.0	19.2
2003	I	5.9	22.3	24.7	22.1	24.4	17.1	
	II	12.1	19.5	24.2	21.9	24.8	16.9	
	III	14.8	20.1	23.1	23.6	24.7	17.9	
	Average	10.9	20.6	24.0	22.6	24.6	17.2	20.0
2004	I	11.4	15.8	18.5	23.0	22.3	18.1	
	II	11.2	14.3	20.3	21.1	22.5	16.8	
	III	14.8	15.5	20.7	21.9	20.4	13.9	
	Average	12.4	15.2	19.8	21.9	21.7	16.3	17.9
2005	I	10.8	14.3	15.2	19.8	18.9	19.5	
	II	12.3	14.9	20.0	21.1	19.1	17.1	
	III	12.4	21.2	22.8	22.2	20.2	15.2	
	Average	11.7	17.0	19.3	21.1	19.4	17.2	17.6
Mounthly average		11.7	18.1	21.2	22.3	22.0	16.9	18.7
Long-term average		11.3	16.7	19.7	21.3	20.8	16.8	17.8

Sugarbeet evapotranspiration. Sugarbeet evapotranspiration (ET) per test year and experiment variant was analyzed on the basis of water amounts received from soil reserve to the depth of 2 m, determined at the beginning of growing season, effective rainfall and irrigation.

The average ET in the variant of irrigation at 60-65% FWC (A) was 617 mm, 52 mm being supplied from soil reserve, 333 mm from effective rainfall and 232 mm from irrigation. The annual variation went from 552 mm in 2004 to 664 mm in 2003. Regarding water source, the variations were from 0 to 122 mm for soil reserve, from 212 to 477 mm for effective rainfall and from 120 do 360 mm for irrigation water. ET was similar in the variant of irrigation at 75-80% FWC (B). The average was 613 mm, with variations from 576 to 629 mm (Table 4). Regarding water source, the average values for soil reserve, effective rainfall and irrigation water were 63, 333 and 218 mm, respectively. The average ET in the nonirrigated variant (C) was 467 mm, with annual differences from 384 mm in 2003 to 565 mm in 2005. The high ET value in the nonirrigated variant was primarily due to water uptake from soil reserve (134 mm on the average), with annual variations from 76 mm in 2004 to 202 mm in 2002. Also, the abundant rainfalls in the 2004 and 2005 growing seasons contributed to the high ET values in the nonirrigated variant (Table 4).

Table 4 – Evapotranspiration of sugar beet including reserve of winter soil water to 2 m depth (mm)

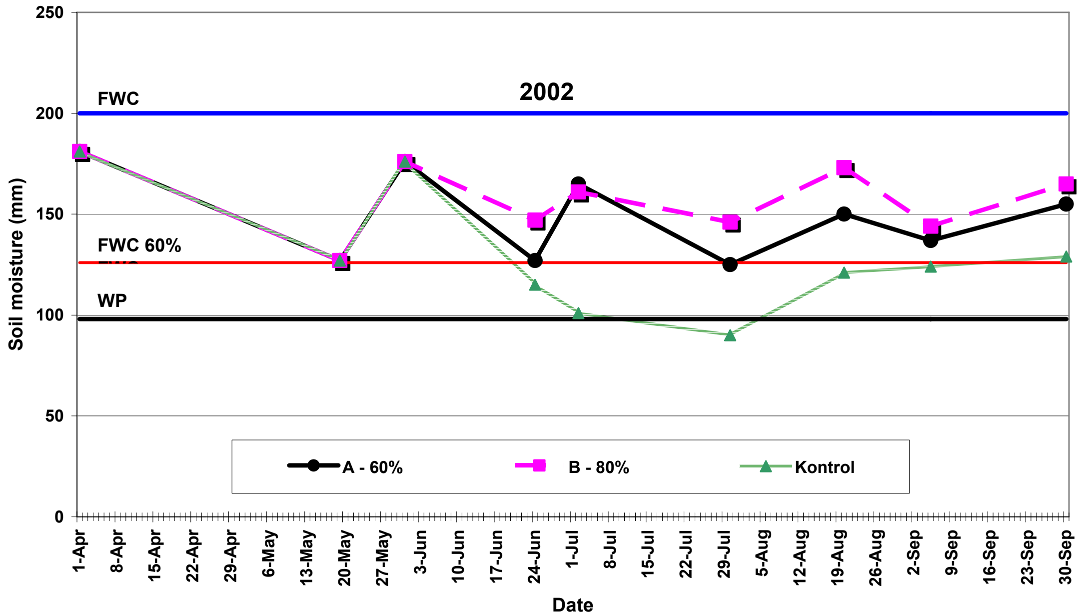
Year	Variant	Reserve of winter soil moisture	Sum of effective rainfall	Irrigation	Total
2002	A	51	245	360	656
	B	84	245	300	629
	C	202	245	0	447
2003	A	122	212	330	664
	B	142	212	270	624
	C	172	212	0	384
2004	A	34	398	120	552
	B	28	398	150	576
	C	76	398	0	474
2005	A	0	477	120	597
	B	0	477	150	627
	C	88	477	0	565
Average	A	52	333	232	617
	B	63	333	218	613
	C	134	333	0	467

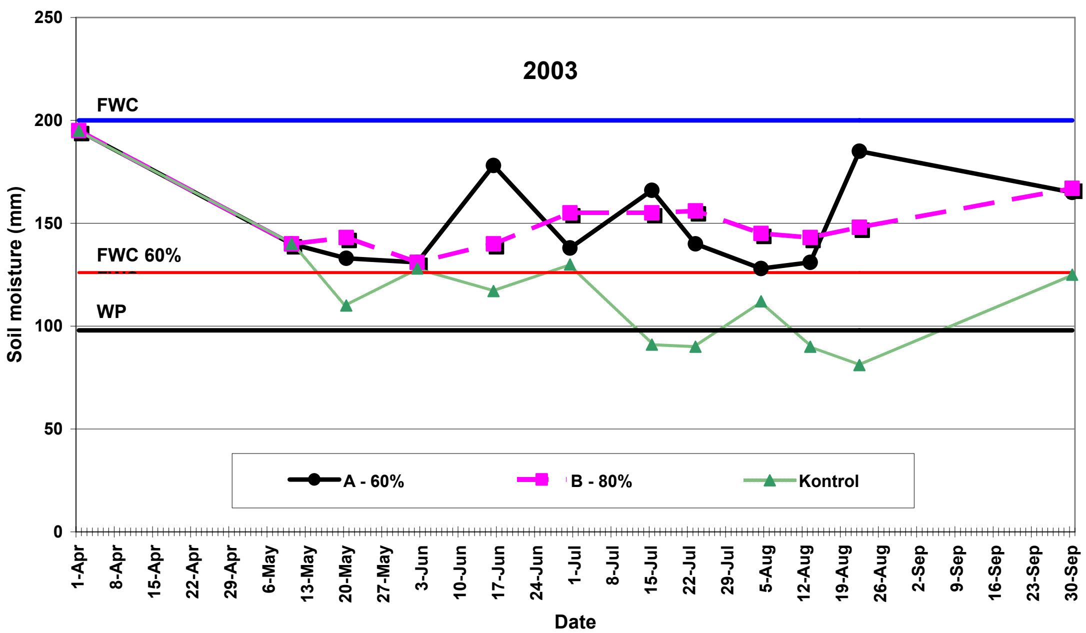
As the sugarbeets in the irrigated variants were provided with available water throughout the growing season, the average ET value for these two variants may be considered as the value of potential evapotranspiration of sugarbeet for the agroclimatic conditions of the region under study, which amounted to 615 mm.

Long-term studies (over 20 years) conducted in the same agroclimatic conditions indicated that the average sugarbeet requirement for water was 579 mm, with the annual variations from 530 to 625 mm depending on weather conditions during growing season. On the other hand, the actual evapotranspiration was considerably lower and it fluctuated significantly from one to another year. In warmer regions, such as Texas, USA, the requirement of sugarbeet is 1185 mm (Hilli *et al*., 1990). Ehling and LeMart (1979) report the requirement of 900 to 1195 mm for California.

Soil moisture determination. The irrigation schedule was made on the basis of soil moisture analyses. Soil moisture had been monitored throughout the growing season, at intervals of 10 or more days, depending on rainfall and air temperature. During the period of intensive growth of sugarbeet roots and high ET, soil moisture was monitored at 7-day or shorter intervals.

Before the beginning of irrigation, soil moisture values were similar in all variants so they were averaged across the variants. After the beginning of irrigation, soil moisture values were presented separately for each variant. At the beginning of the growing season, the average soil moisture in soil layer 0 - 60 cm ranged between 85 and 95% FWC. In the course of the season, the values changed in dependence of rainfall and irrigation schedule (Figure 2).


2002
FWC
FWC 60%
WP
Soil moisture (mm)
Date
A - 60%
B - 80%
Kontrol


2003
FWC
FWC 60%
WP
Soil moisture (mm)
Date
A - 60%
B - 80%
Kontrol

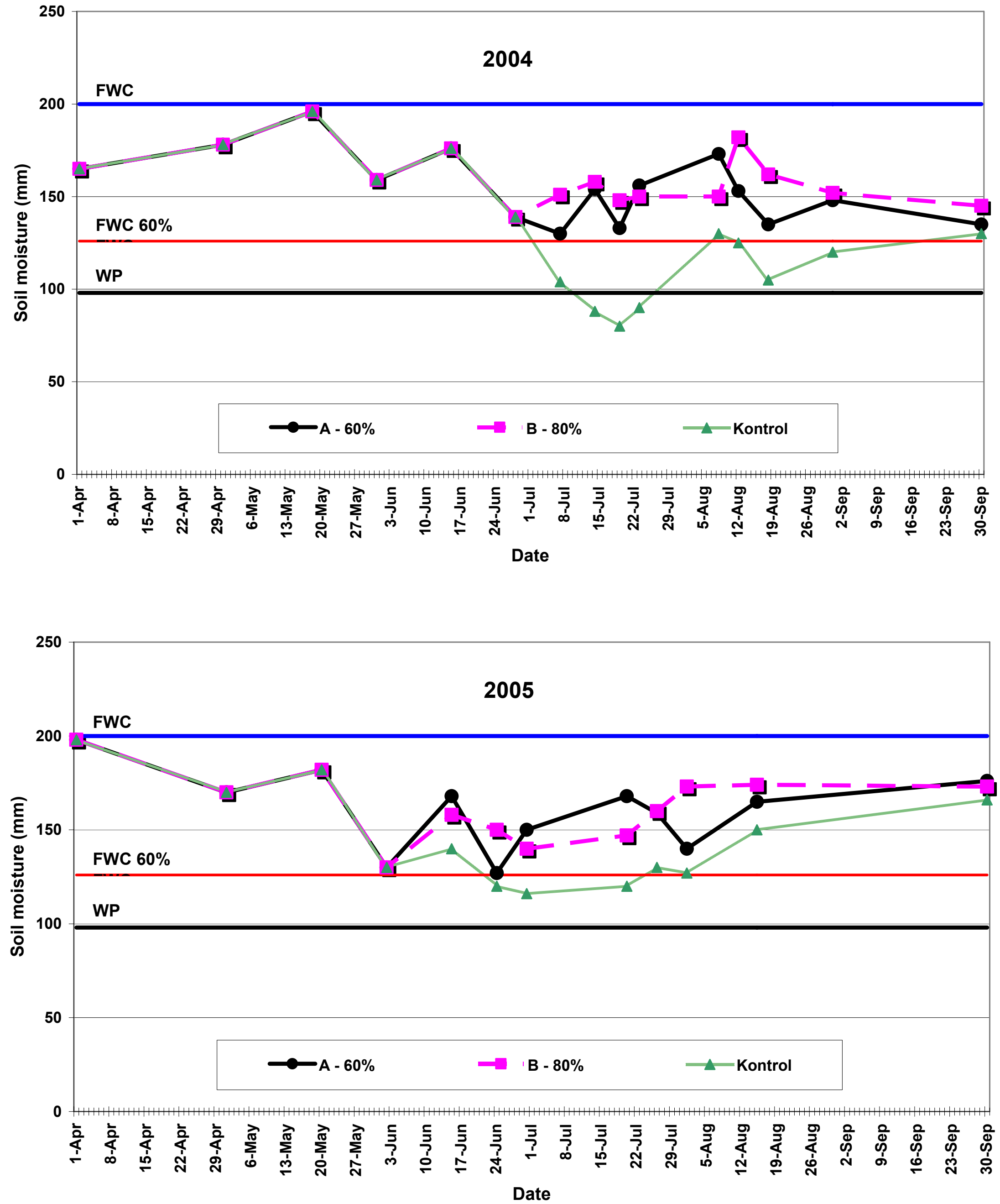


Figure 2 – Dynamics of soil moisture in the soil layer 0-60 cm in experimental years

In the nonirrigated control variant (C), soil moisture depended on rainfall and intensity of ET. In the very dry years (2002 and 2003), long dry spells brought the level of soil moisture to the wilting point or below it (Figure 2). During these periods, sugarbeet plants survived by taking up water from deep soil layers, 2 m or more.

Root yield. Effect of water scheduling on yield of sugarbeet differed in independence of rainfall and its distribution during growing season. Based on the calculated average values, the highest yield was in the variant of irrigation scheduling at 75-80% FWC (B) was 94.44

t/ha. The average yield in the variant of irrigation scheduling at 60-65% FWC (A) was 89.86 t/ha. The difference, 4.58 t/ha or 5.1%, was not statistically significant. But, in the very dry years of 2002, the differences in yield between these two variants were highly significant, 13.93 t/ha or 16.1%.

In 2004 and 2005, the effective rainfalls were 398 i 477 mm, respectively. These rainfalls were 110 mm higher than those registered in the previous two years. In 2004 and 2005, the average yields of sugarbeet in the two variants of irrigation scheduling were similar (Table 5).

Table 5 - Root yields depending on irrigation scheduling

Irrigation Sheduling A	Years B				
	2002	2003	2004	2005	*Average*
A-60-65% FWC	86.41	89.02	99.94	84.08	89.86
B-75-80% FWC	100.34	92.68	98.36	86.38	94.44
C-Control	64.36	63.56	87.12	86.38	75.36
Average	83.70	81.75	95.14	85.61	86.55
	A	**B**	**AxB**	**BxA**	
LSD 0.05	4.78	4.77	8.70	8.25	
0.01	7.24	6.44	12.26	11.15	

The average yield in the control variant was 75.36 t/ha. That was 16.79 t/ha or 22.3% lower than the average yield of the irrigated variants. However, differences were much larger in the very dry years of 2002 and 2003. Particularly high differences in these years were obtained in variant B, 35.98 and 29.12 t/ha or 56 and 46%, respectively. In the moderately dry year of 2004, the difference between variants B and C was mush lower, 11.24 t/ha or 13%. In 2005, which was favorable with respect to rainfall amount and distribution, especially in June, July and August, there was no significant difference in yield between the irrigated variants and the nonirrigated control. In 2005, variant A received 120 mm of water in 2 irrigation and variant B received 150 mm of water in 5 irrigations. Still, the irrigation practice showed no effect on sugarbeet yield.

The average yield of all variants in all years was 86.55 t/ha. The annual yields were similar, with the exception of 2004 which exceeded the average yields for the other three years by 11.63 t/ha or 13% (Table 5). This difference was high significant. Significant differences between years for sugarbeet yield without irrigation were also found. Berić (2000), reported that in the period 1990-1999 differences in the average yield of this crop ranged from 22.7 t/ha in a very dry year of 1993 to 46.62 t/ha in a rainy year of 1999.

In a previous study of the effect of soil water regimen on sugarbeet in reduced irrigation under variable climatic conditions, Dragović *et al*. (2003) found that irrigation increased sugarbeet yields from 4 to 90%. But in the years with moderate sums and relatively favorable distribution of rainfall, yields were 25% higher in irrigation than in the nonirrigated control (Dragović *et al*., 1999).

Analyzing data gathered over a 20-year period, Maksimović and Dragović (2000) found that the average yields of sugarbeet root in experiments without and with irrigation were 64.3 t/ha and 85.6 t/ha, respectively, the effect of irrigation being 33%. The annual yield variations were 40 to 94 t/ha and 64 to 124 t/ha, respectively. In very dry years, the average effect of irrigation was 190%, ranging in dependence of hybrid from 98 to 276% (Dragović *et al*., 1998).

Sugar content. Sugar contents in the root were similar in all variants. The average content was 14.78%. Some differences were observed among the test years, from 13.14% in 2002 to 16.96% in 2005 (Table 6). Long-term studies of the effect of irrigation on sugarbeet yield and sugar content in the root showed that in years with increased rainfall the irrigation practice reduces the percentage of sugar by 0.5 to 1% (Dragović *et al*., 2006). In this study, there was no significant difference in sugar content between the irrigated and the nonirrigated variants.

Table 6 – Effect of irrigation scheduling on sugar content (%)

Irrigation Sheduling	Years				
	2002	2003	2004	2005	*Average*
A-60-65% FWC	13.02	13.51	15.29	16.67	14.62
B-75-80% FWC	13.23	13.31	15.91	17.19	14.91
C-Control	13.17	13.71	15.35	17.03	14.81
Average	13.14	13.51	15.52	16.96	14.78

Conclusion

In changeable climatic conditions, with fluctuating rainfall, irrigation scheduling in dry years significantly affects sugarbeet yield.

In this study, the highest yield was obtained in the variant of irrigation at 75-80% FWC, 94.44 t/ha, which exceeded the yield in the variant of irrigation at 60-65% FWC by 5.1% and that in the nonirrigated control variant by 26%.

The annual yield fluctuations were high, especially in the nonirrigated variant, from 63.56 t/ha obtained in the very dry year of 2003 to 87.12 t/ha obtained in the moderately dry year of 2004.

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Advances in Using Center Pivots for Site Specific Management

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Summary: Historically center pivot irrigation has treated the entire field the same. Changes in technology have occurred which allow growers some limited ability to apply differing amounts of water and nitrogen fertilizer to different sectors of the field. This paper will discuss the currently commercially available options, their costs and their potential impact to growers. Also a brief discussion of the adoption of these options will be presented. Additionally the paper will present information on prototype site specific equipment and issues surrounding the broad adoption by growers and the needs for research seen before commercial products will be viable.

Introduction: Since the introduction of the center pivot in the mid 1950's, the mechanical move industry has continued to improve and develop products to better meet the needs of production agriculture. These improvements would be focused in four primary areas - drive train, structure, water application and controls. Overall goals were to provide uniform irrigation of the field with a specific application depth and at the same time in a cost effective fashion.

This has led to the development of changes in the water application devices and controls with the more recent focus on reductions in labor, water use and energy. Sector control has generally been limited to the endgun(s) on the center pivot. Some manufacturers offered specific special application sprinkler packages such as the Slurry Shooter™, Seedigator™ and Slurry Manager™ for special applications and to sequence sections of pivots on and off. Center pivot manufacturers developed sequencing packages (sector control of parts of the center pivot) with the introduction of corner arm options for center pivots to ensure as the corner arm extended and retracted water uniformity remained good. In the early to mid 1990's with the commercial introduction of automated controls for center pivots by the manufacturers it became easier to program a change of the ground speed of the center pivot for a specific area of the field. This speed change would result in a change to the applied depth of irrigation in a specific pie shaped area since the change in the water depth applied is directly proportional to the change of ground speed. However, in general the overall goal of the center pivot remained the same - to maintain uniformity of the application depth both along the center pivot and in the direction of travel.

Some cases did exist where farmers wanted to turn off the flow of irrigation to specific sections of the pivot due to a well head, wetland area or other reasons. The automated center pivot control panels made this easier as many had one or two auxiliary controls that could be programmed to turn a valve (or group of valves) on and off plus one or two endgun functions. Irrigation dealers and farmers took the lead creating some functional packages. A very small percent of center pivots have ever been operated in this fashion. Still overall the farmer treated the entire field the same – utilizing the same amount of seed, fertilizer, and other crop production inputs.

With the introduction of precision agriculture suddenly much more information was available for a particular field from yield, soil and fertility maps. Farmers now had data indicating the variability across the field that probably was already suspected. The challenge became how to use this data and how to make changes impacting different areas of the field. Fertilizer and chemical application equipment as well as planters have been equipped to make changes in rates or volumes across the field. As long as water for irrigation was plentiful and energy costs reasonably low the easiest management scheme for irrigating farmers was to put on 'a little extra' or not worry about an area receiving more than warranted by the yield.

This has all changed with droughts in the United States and other limits on the availability of water coupled with the recent rapid rise in energy and other crop production input costs. A number of questions begin to be asked:

- Can a farmer still irrigate the same way they always have and remain profitable?
- How much can a farmer justify spending on improvements to manage resources on a smaller scale than the entire field.

Objective: The goal of this project is to review the status of current research and commercial variable rate options, their costs and their potential impact to growers. Then the constraints to acceptance in the marketplace will be reviewed.

Discussion: Research into variable rate or site specific irrigation has been conducted at a number of locations across the United States by both Universities and USDA-ARS. These include but are not limited to Universities of Georgia, Idaho, Nebraska and Texas A&M and the USDA-ARS at Florence, SC and Ft Collins, CO. The first commercial marketed package has been jointly developed by the University of Georgia, FarmScan and Hobbs and Holder. These units have primarily been installed in the southeastern United States.

Valmont Industries has been evaluating the market opportunities and a concept unit for variable rate or site specific irrigation. The following is some of the initial analysis of the issues seen to adoption of site specific irrigation. Using some preliminary data Valmont has made the following estimates of costs and benefits. These are broken into two different broad examples – water / energy savings and nitrogen savings.

- Example #1
  - Assumptions
    - ¼ mile (395m) center pivot
    - 150ft (46m) pumping level
    - 800gpm (51lps)
    - 25psi at the pivot (17.6m)
    - 18in (457mm) per year

  - Savings potential – Let's just make some general estimates to determine the direct benefit to a farmer if site specific irrigation was utilized
    - If one could achieve a 10% reduction in water usage by applying water only to the specific areas of the field requiring irrigation, this would equal about a 234 ac-in reduction in the volume pumped
      - This would translate into a reduction in hours the pump is operated resulting in a savings in pumping costs of about $457 (electricity = $ 0.08 / kw-hr

    - As a second case, if one could achieve a 25% reduction in water usage by applying where needed, this would be equal to about a 858 ac-in reduction in the volume of irrigation pumped
      - In this case the savings due to the reduced volume of water pumped in energy costs would be about $ 1,142 (electricity = $ 0.08/kw-hr)

- Potential issues
  - One area of particular concern is the hydraulics of the entire irrigation system. As valves turn on and off, changing the volume being pumped there will be a potential impact due to the pump curve. With most pumps as volume changes so does the pressure. The entire system must be evaluated to determine if the changes will have a negative impact on the pipeline, center pivot or other components.
    - Two solutions could be:
      - Variable speed pump to maintain a constant pressure
      - Monitor the minimum volume pumped to ensure one does not exceed the hydraulic characteristics of the system
  - Another concern is feedback to determine that what is supposed to be happening in the field is what is happening. How does one monitor the field to determine each management zones status?
    - Solution - this is an area requiring more evaluation and research

- Example #2
  - ¼ mile (395m) pivot
  - 121ac (49ha)
  - Corn - typical nitrogen application
    - 230lbs per acre (257kg/ha)

  - Savings potential - Again let's just make some general estimates to determine the direct benefit to a farmer if site specific irrigation was utilized
    - Based on the established management zones we shall consider that a 10% reduction in nitrogen use could be achieved. This would equal about 2,800lbs of actual nitrogen applied.
      - This 10% reduction could save the farmer about $840 (Nitrogen at $0.30/lb)

    - Let's assume a 25% reduction in nitrogen use is possible based on the management zones. This would equal a savings in the amount of nitrogen applied of 6,950lbs.

      - The savings with a 25% reduction would be worth $2,085 to the grower (Nitrogen at $ 0.30/lb)

  - As in the case of the water delivery there are some potential issues.
    - Again the overall hydraulics are a concern as the nitrogen would be carried in the water and has the same issues as in example #1 above.
    - The additional complexity of the nitrogen delivery as one changes for the different zones and a variable rate pump is the most likely answer
    - Lastly the same monitoring issues exist as for the example above for each of the management zones.

- If one combines the potential savings of water, energy and nitrogen to evaluate the overall impact one finds:
  - With a 10% reduction
    - Water savings = 234 ac-in
    - Energy savings = $ 457
    - Nitrogen savings = $ 840
      - Total $1,297

  - With a 25% reduction
    - Water savings = 858 ac-in
    - Energy savings = $1,142
    - Nitrogen savings = $2,085
      - Total $3,227

The first question a farmer will then ask is great – I can potentially save some money but what would be the potential costs to achieve these savings?

Considering only the costs for the software and hardware for the modifications to the ¼ mile center pivot in the examples above, the estimates indicate farmer costs would be in the range of $18,000 to $25,000 for an installed package. Much depends on the irrigation equipment he already has and how much additional hardware is required.

An estimate of the payback would be:

A 10% reduction in water and nitrogen would require fourteen to nineteen years to payback the investment in the changes to the center pivot and this does not include any costs to modify the water pump or nitrogen injection system

If one could achieve a 25% reduction, the payback would be in the range of five to eight years. Again this excludes any costs to upgrade the water pump or nitrogen injection system.

This raises several questions:

- How is this going to accepted in the market place based on today's economics?
- How achievable would 10 or 25% reductions be?

Also no consideration is given to the possibility of the overall yield and/or crop quality being significantly improved which could also impact the farmer's bottom-line finances.

In the examples using commercially available packages, most utilize standard, proven components without making changes to new technologies.
Some use auxiliary control panels but the main changes are in software and how the information for the management zones is 'loaded' into either the auxiliary or center pivot control panel.

Based on the findings so far there are a number of areas requiring additional work and evaluation to help move site specific irrigation forward. Some of these would be (but not limited to):

- Optimum economic size of management zones
- Methods to efficiently provide the farmer easy control changes to the management zones
- Methods to obtain easy feedback from the management zones and incorporate into the farmer's decision making tools
- Impact to crop quantity and quality
- Methods to place a value on some of the possible soft benefits such as water savings, runoff, ground water impact and others

Conclusion: Historically center pivot irrigation has treated the entire field the same. Changes in center pivot control technology have occurred which allow growers some limited ability to apply differing amounts of water and products carried in the water to different sectors of the field. This paper has reviewed the commercial advancements and the current status of the market for site specific irrigation. Current hardware for center pivots is easily adapted for site specific use. Only in the area of software does there appear to be significant additional development requirements. Indications based on today's economics indicate payback in the best cases of five to seven years and possibly much longer. In this paper only the impact from the reduction in pumping costs and nitrogen required has been considered. Much more work is required to better develop the economic benefit of site specific irrigation particularly in the areas of monitoring the performance of management zones. Additionally consideration must be given to how one thinks of center pivot irrigation and the overall goal may not be to achieve general field uniformity but to apply the water and other crop inputs to the particular area of the field with the requirement.

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Evaluation of Collector Size for Low Pressure, Fixed-Plate Sprinklers for Center Pivots [1]

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Abstract

A lab study was conducted to evaluate the opening size of cylindrical collectors for use with measuring applications depths from low pressure, fixed-plate sprinklers used on center pivot irrigation systems. Four cylindrical collector sizes (52-mm, 101-mm, 148-mm and 198-mm in dia.) were evaluated for catch accuracy. Collectors were mounted on a moveable cart (trolley) in a randomized block design using six rows of the four collector sizes. The cart was pulled through various sprinkler patterns via a track and electric motor and winch system. Collected water depths were measured and compared using t-tests for paired comparisons of measured depths and F-tests for variance comparisons. Measured data were more variable for the sprinkler combinations that had low pattern breakup and distinct streams of water. While it would be convenient to use a reasonable size (<100 mm dia.) collector to measure application depths from center pivot systems with these types of sprinklers, the data from this study suggest that it is difficult to obtain consistent data even with collectors up to 198-mm in diameter.

Introduction

With a strong emphasis on irrigation scheduling, "just-in-time" applications, and as water supplies become more limited, irrigation systems need to apply water uniformly for optimal crop growth and development and proper utilization of applied cropping system inputs (seed, fertilizer, other crop chemicals). This requires an in-field assessment on the performance of the irrigation system. However, various sprinkler packages are used including fixed plate, rotating plate, and wobbling plate diffusers that can operate between 41 and 207 kPa (6 and 30 psi), be on 1.5 to 6 m (5 ft to 20 ft) spacings, and have vertical positions ranging from 0.3 to 2.4 m (1 ft to 8 ft) above the ground surface. The combinations of these diffuser plates, operating pressures, spacings and vertical positions result in a variety of application patterns and measurement conditions that do not conform to current measurement standards. This research will develop and test different techniques and procedures to measure and assess the uniformity of water application from center pivot irrigation systems.

Methods and Materials

Tests were conducted to evaluate different collector opening sizes for catch efficacy from low pressure, fixed plate sprinklers that are typically used on center pivot sprinkler systems. Four cylindrical collectors were tested that included inside diameters of 52, 101, 148, and 198 mm. All cylindrical collectors were made from PVC pipe, were 200 mm deep, and were constructed using

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the IrriGage design as reported by Clark et al. (2004). A wooden cart with dimensions of 1.2 m by 1.8 m (fig. 1) was constructed to hold the cylindrical collectors in a randomized block design. “Square” collectors (198 mm x 211 mm x 200 mm deep) were also used to characterize the sprinkler patterns (fig. 1).

Six different sprinkler combinations were evaluated (tab. 1) at 42 kPa (6 psi) of pressure. These combinations typically provided large streams or droplets with different patterns. Three sprinklers were located on drop tubes attached to an elevated PVC manifold and were spaced 1.5 m apart. The sprinklers were attached to 42 kPa (6 psi) pressure regulators and were positioned 1.1 m above the collector openings. The cart was pulled through the middle of the sprinkler pattern on a track made from aluminum channel attached to wooden blocks (fig. 1). The cart was moved by using a fixed speed electrical motor and cable system. The motor and cable drum were geared to pull the cart through the sprinkler pattern at a speed of 0.3 m/min. This speed is consistent with the mid-point tower speed on a 50 ha (125 acre; 1/4-section) center pivot system that is set to make 1 revolution in 60 hours.

At the beginning of each test, sprinkler collectors were set up as shown in fig. 1, the sprinklers were pressurized, and the cart pulley system was activated. All tests were conducted in the basement courtyard of Seaton Hall where wind effects were minimal. After the cart was pulled through the sprinkler pattern, collected water amounts were weighed and data were converted to depth units. Three test runs (reps) were conducted for each sprinkler combination (tab. 1) and collector arrangement (cylindrical or square). Data from the three test runs were summed for each unique collector size and location to simulate cumulative water collections from multiple runs in a field setting. This data averaging procedure helps to smooth out data spikes from single water streams.

Table 1. Sprinkler combinations used in the collector tests. All sprinklers were operated at 42 kPa (6 psi) of pressure.

Sprinkler Combination	Mfg.	Orifice Size (mm)	Plate Characteristics
S 16 1 Plate	Senninger	6.35	Single grooved disk plate; 33 grooves; concave pad
S 16 2 Plates	Senninger	6.35	Two grooved disk plates; 33 grooves each; concave pad and flat pad
S 20 3 Plates	Senninger	7.94	Three grooved disk plates; 33 grooves each; concave pad – flat pad – convex pad
N 32 Coarse	Nelson	6.35	Single grooved disk plate; 24 coarse grooves; flat pad
N 32 Medium	Nelson	6.35	Single grooved disk plate; 36 medium grooves; concave pad
N 32 Fine	Nelson	6.35	Single grooved disk plate; 30 fine grooves; flat pad

Results

The S_16_1 Plate, S_16_2 Plate, and N_32_Coarse Plate combinations resulted in larger droplets and distinct streams of water. The S_20_3 Plate, N_32_Medium Plate, and N_32_Fine Plate sprinklers resulted in smaller droplets and greater droplet breakup. These characteristics will be important in the analysis of the measured results.

Measured depths from the 52-mm, 101-mm and 198-mm collectors were generally lower than measured depths from the square collectors (tab. 2 and 3) while measured depths from the 148-mm collectors were typically greater than the square collector depths. Some of these differences were significant, but were also generally within ±6% of the square collector depths. It is not clear why some of these differences exist. The 101-mm collector has more statistically different depths and with greater differences than the 52-mm collectors; yet, they have nearly four times the surface area. Furthermore, the 148-mm collectors also have some relatively large differences in depths (tab. 3) but most of these differences are not significant.

Figure 1. Collector cart system with cylindrical containers (left) and "square" collectors (right).

Table 2. Average collected depths (mm) from all three runs for each collector. Cylindrical collector (52, 101, 148, and 198 mm) results were compared to the square collector results using a paired t-test. Values were significantly different at the 0.1 (*), 0.05 (**), or 0.01 (***) level of significance, or not significant (NS).

Sprinkler Combination	Collector				
	Square	52 mm	101 mm	148 mm	198 mm
S_#16_1 plate	21.4	19.7 *	19.1 **	22.8 NS	20.8 NS
S_#16_2 plates	33.4	32.0 *	30.0 **	31.3 NS	32.4 NS
S_#20_3 plates	48.6	48.3 NS	46.5 *	51.4 *	46.9 *
N_#32_Coarse	20.0	19.5 NS	17.4 *	21.2 NS	19.6 NS
N_#32_Medium	19.8	20.4 **	18.9 NS	21.2 NS	18.7 *
N_#32_Fine	33.8	31.4 ***	32.2 **	34.2 NS	31.9 ***

The variances of the measured values (tab. 4) along with the charts in figure 2 help to explain some of these measured depth differences. Variances associated with only two of the collector/sprinkler combinations (tab. 3)were significantly greater than the variances from the "square" collectors. Yet the level of variability of some of the data was high. The most variable sprinkler combinations were the S_16_1 plate, S_16_2 plate, N_32_coarse, and N_32_medium (top four charts in fig. 2 and fig. 3). The S_20_3 plate and N_32_fine sprinkler combinations resulted in greater droplet breakup and a more visually uniform pattern (lower two charts in fig. 2 and fig. 3).

Table 3. Relative depth of collected water with respect to the depth of water collected in the square collectors.

Sprinkler Combination	Collector				
	Square	52 mm	101 mm	148 mm	198 mm
S_#16_1 plate	1.00	0.92	0.89	1.07	0.97
S_#16_2 plates	1.00	0.96	0.90	0.94	0.97
S_#20_3 plates	1.00	0.99	0.96	1.06	0.97
N_#32_Coarse	1.00	0.98	0.87	1.06	0.98
N_#32_Medium	1.00	1.03	0.95	1.07	0.94
N_#32_Fine	1.00	0.93	0.95	1.01	0.94

The relative coefficient of variation (fig. 4) was determined as the ratio of the CV for a particular cylindrical collector to the CV for the square collectors. One would think that larger collector sizes would result in less variable data; however, the relative CV data (fig. 4) for the S_16_1 plate, S_16_2 plate, N_32_coarse, and N_32_medium sprinkler combinations do not support this hypothesis. The S_20_3 plate sprinkler has greater pattern breakup and relative CV does decrease as collector size increases. Collector size does not seem to make any difference with the N_32_fine plate sprinkler that results in small droplets without distinct streams (as with the other sprinkler combinations).

Table 4. Variances (mm^2) of collected water depths. Variances of cylindrical collectors were significantly different from variances with the square collectors at the 0.1 (*), 0.05 (**), or 0.01 (***) level of significance, or not significant (NS).

Sprinkler Combination	Collector				
	Square	52 mm	101 mm	148 mm	198 mm
S_#16_1 plate	11.0	14.0 NS	18.9 NS	40.8 *	12.5 NS
S_#16_2 plates	19.1	19.1 NS	25.6 NS	39.7 NS	14.0 NS
S_#20_3 plates	7.2	25.0 *	18.4 NS	13.5 NS	9.0 NS
N_#32_Coarse	42.3	100.8 NS	34.4 NS	57.6 NS	76.5 NS
N_#32_Medium	9.7	10.1 NS	6.3 NS	25.0 NS	10.1 NS
N_#32_Fine	34.1	34.8 NS	40.3 NS	50.8 NS	31.4 NS

Summary and Conclusions

Four cylindrical collectors (52-mm, 101-mm, 148-mm and 198-mm in dia.) were evaluated for catch accuracy of water applied by low-pressure, fixed-plate sprinklers. Measured data were more variable for the sprinkler combinations that had low pattern breakup and distinct streams of water. While it would be convenient to use a reasonable size (<100 mm dia.) collector to measure application depths from center pivot systems with these types of sprinklers, the data from this study suggest that it is difficult to obtain consistent data even with collectors up to 198-mm in diameter.

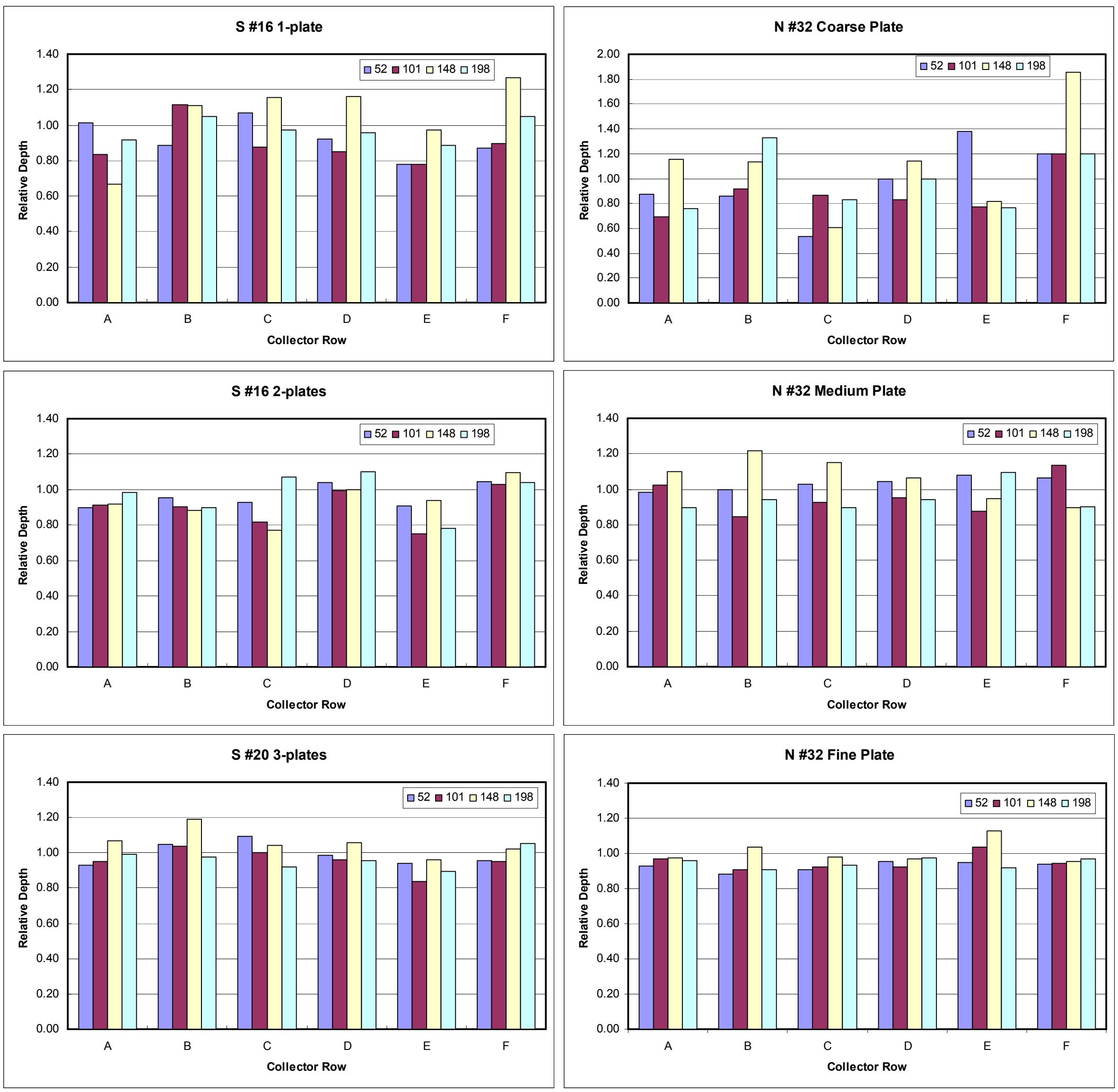


Figure 2. Relative depth distributions for the four cylindrical collectors (51-mm, 101-mm, 148-mm, and 198-mm) for each of the six collector rows on the cart for each of the six different sprinkler combinations.

Figure 3. Coefficient of variation (CV) of measured depths from the different sprinkler collectors for the six sprinkler combinations.

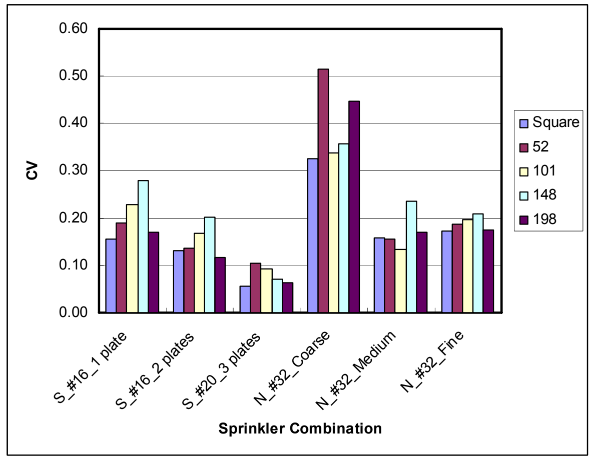
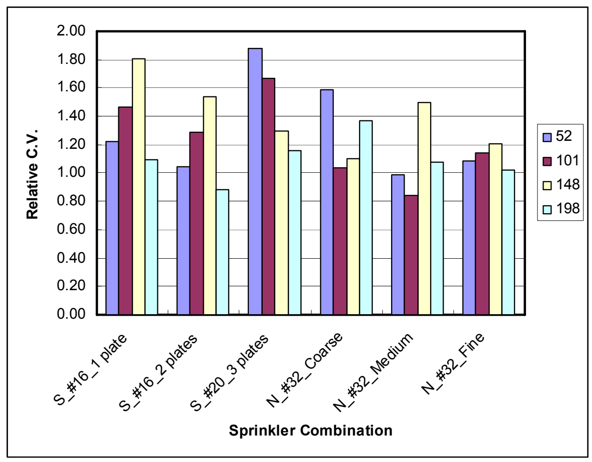


Figure 4. Relative coefficient of variation with respect to the "square" containers for the six sprinkler combinations.



Acknowledgements

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New Mechanized Irrigation Solutions for Small Seed Crops

By

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Summary

New advances have been made in mechanized irrigation structure and control technologies to meet the specific needs of small seed crops such as carrots, onions and others. Pre-germination, these corps require frequent, light water applications to provide an optimum environment for germination and control wind damage to the seedbed. Post germination, the need changes to a water application which will maintain soil surface moisture to avoid sealing and damage to the individual plants of the emerging high value vegetable crop. In addition control of wind erosion of the soil continues to be important. Previously, mechanized irrigation did not provide a good solution for these specific parameters. This paper will look at the specific needs for this application and discuss new advances created to solve these issues.

Objective

To discuss how modification of the typical center pivot was made to meet specific needs. In addition, a review of changes in control technology allowed for optimum flexibility to meet ongoing irrigation requirements.

Introduction

Mechanized irrigation has been a solution for many grower's irrigation needs for decades. Starting in the 1950's with the first commercially available center pivot and continuing though today, thousands of growers have increased efficiency while lowering operating costs by using this proven technology. One particular crop segment that has not widely adopted center pivots has been the carrot industry. The needs of this carrot crop are such that a standard center pivot is often not up to the task. The primary concern is the need for frequent, light applications immediately after planting to prevent the small, shallow planted seeds from blowing away. The current method for preventing this damage is to utilize aluminum hand-lines placed in the field. Water is rapidly cycled during germination so that any portion of the field may receive water every two and half (2.5) hours. This has traditionally not been an issue in the large carrot production areas as labor has been abundant for the laying out and removing of the irrigation pipe. A typical hi speed quarter (1/4) mile center pivot requires seven hours to make a complete revolution therefore not meeting the two and a half hour requirement. However, the economics of the labor force are putting pressure on the producers who have begun to look at alternatives to decrease labor costs. While center pivots drastically reduces the labor required, they have no been fast enough.

In addition, any leaking from the solid set sprinklers and draining from the sprinkler heads causes considerable crop damage. While the area of damage is relatively small, often only 1 foot in diameter centered around the sprinkler head, multiplied by the hundreds of heads typical for a field, this damage adds up. In addition, the weakened crop in this area is susceptible to disease pressures thus have the potential to harm the entire crop.

Discussion

The challenges of irrigating a small seed crop are many. The seeds are generally planted at a very shallow depth leaving them susceptible to be being blow away by wind. Because of the shallow depth, the soil moisture needed for optimum germination can quickly be lost to evaporation. Irrigating the crop can help with both of these issues but brings its own unique problems. If the irrigation frequency is not rapid enough, the soil will dry out and again be faced with wind issues. If the application rate of the water is too high, you have high potential for washing the seeds out and damaging the seed beds.

In the arid regions of the country where rapid evaporation and wind are a common factor, growers have traditionally utilized solid set sprinklers to irrigate these types of crops. With the ability to change the sprinkler blocks on a fast rotation time, they are able to water each section of the field ever two to three hours. Once the crop stand is established, the run time can be lengthened to provide adequate deep watering.

While effective, this method of irrigation has some drawbacks. The first is the investment in large amounts of irrigation pipe - typically aluminum. As the entire field must be covered in order to provide the needed coverage during germination, a large amount of pipe is needed for the growing operation. As that pipe is set out and picked up for each field, it is very susceptible to damage and must be maintained on a regular basis.

The labor requirement to set out this much pipe, move it for cultivations, and pick it up prior to harvest is also a concern. In addition, with so many valves to be operated during irrigation times, many workers are required to keep the operation moving. As labor has become more and more difficult to source, the labor cost for this type of irrigation has become increasingly more prohibitive.

Additionally, crop damage by any leaks in the sprinkler line can cause additional damage. If flying over a traditional solid set field, one can often see the discoloration of the crop near the sprinkler lines. This is the result of additional water from the leaking joints following the pipelines and leaching the nitrogen and other nutrients below the crops root zone. Sprinklers draining at the end of the irrigation cycle cause similar effects. Besides the issue of crop lost in these areas, the weakened crop is also more vulnerable to disease pressures which can affect the entire crop.

As the labor costs continued to rise, alternative solutions utilizing pivot irrigation were sought. With the main criteria being the need to make a circle in 2.5 hours, the initial thought was to create an ultra-high speed machine. While modern technologies make this approach theoretically possible, several potential issues remained. These include the complexity of the controls needed, the high potential of coasting or rolling ahead of the machine, and the high application rates required.

An alternative to overcome these issues was to look at placing two sets of center pivot spans on one center point. This had been done before in the Columbia basin of Washington State for onions. While effective for germination, it still had some shortcomings. It was not fast enough as the rotation of the pivot is seven hours for a complete circle. Even with the additional spans, this meant any portion of the field is 3.5 hours away from its next irrigation.

Also, this type of configuration did not allow any flexibility in operation. Each side of the machine always operated at 180 degrees from the other. This proved especially inconvenient for field operations such as planting, cultivating and harvest.

For a solution to this need, it was determined to utilize two complete machines affixed to one pivot point. Each side of the machine would have independent operation. To maximize flexibility, each side of the machine has a separate control panel will full programmability options. In addition, a sleeve style valve was installed on each side allowing independent water control.

With two machines operating in the same field, the potential for collision is obviously a concern. To address this, the machines were equipped with three levels of safety. The first is communication between the two control panels. As both panels have position information available, they are not allowed to operate within a set degree of each other. In case this fails, a set of mechanical switches is located on the pivot point again preventing the machines from getting too close. As a last resort, a set of auto stop arms is attached to one machine. If these arms come in contact with the other machine, they are both shut down.

The computer panels also offer the ability to water in different modes. These are independent full circle, independent part circle, or follow-the-leader. With the independent modes, each side of the machine is set to perform its own functions including depth, water statues, auxiliary statues, etc. In follow-the-leader mode, the speed is controlled by the primary machine. The secondary machine is given a distance to follow the first, say 90 degrees, and then adjusts its speed as required to maintain that spacing.

While this addressed some issues, the speed was still not fast enough to meet germination requirements. This was overcome by utilizing high speed center drives with the addition of a variable frequency drive. When the frequency is increased, it is possible to double the speed of the last drive unit. By using this method, the machines have a full rotation time of 5 hours. With the spans directly opposite of each other, any part of the field is at most 2.5 hours from receiving water.

One of the potential benefits to this new machines operation is the ability to apply chemicals in the leading machines. By using the independent full circle mode, the following machine can then water in the chemical. This reduces the amount of time needed to apply chemical in the field. "Growers also feel they are wasting water during traditional chemigation application." (Miller,2006)

Conclusions

With the continued growth in labor cost combined with labor shortages, growers of small seed crops need to find alternatives to current irrigation practices. Center pivots have helped other growers for decades with this very issue but until recently could not meet the demanding needs of these particular crops. With the changes outlined above, center pivots are now ready to meet the unique challenges of small seed crops.

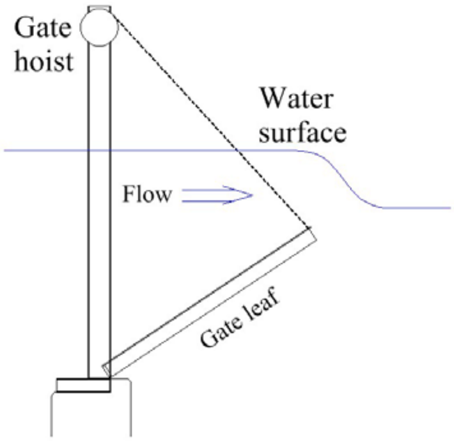
References

Miller, Terry and Miller, 2006, Applying Pesticides for Less, Potato Grower, Volume 35, no 2 Pg 12

Modernizing Canal Check Structures with BI-Fold Overshot Gates

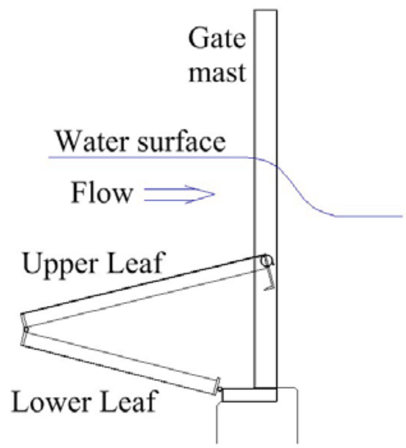
Ram Dhan Khalsa

[1]The Government Highline Canal is part of the Bureau of Reclamation's Grand Valley Project, located in Grand Junction, Colorado. The canal construction was started in 1913 and completed during the Great Depression. The canal extends 52-miles from the diversion dam on the Colorado River flowing westward through the Grand Valley. Two Federal environmental programs spanning a 25-year period have had a dramatic impact on the modernization of the Highline Canal. This paper discusses the use of bi-fold overshot gates in modernizing four existing canal structures and an application in a new pumping plant.



The classical canal overshot gate has a gate-leaf horizontally hinged near the bottom of the canal, with the gate-leaf extending downstream. Water flows over the gate-leaf, which acts as a horizontal weir. The gate actuator is a hoist mechanism that moves the downstream end of the leaf up and down, or in some designs an air bladder under the leaf is used to move the leaf.

The bi-fold overshot gate has a double leaf, horizontally hinged on the bottom and between the lower and upper leaf. The lower leaf extends upstream and is hinged to the upper leaf that folds over the top and is extending downstream. The hinged gate leaves form a horizontal upstream wedge, with the bottom hinge and the top of the leaf crest nearly in a vertical line. Because the gate-leaf and hoist mechanism are upstream of the mounting hardware, the gate can be mounted on the vertical upstream face of an existing canal structure, or in a rectangular concrete canal section.



The bi-fold gates used on the Government Highline Canal were invented by Peter Langemann. The Langemann Gate and controller were developed as a cooperative effort between the St. Mary River Irrigation District in Alberta, Canada and Peter Langemann.
The patented design is recognized and accepted for its simplicity, overshot technology, control capabilities, and low power requirements.

[1] Ram Dhan Khalsa, Civil Engineer, Western Colorado Area Office, U.S. Bureau of Reclamation

Before embracing the technology for other applications within the irrigation project, the decision was made to install and test one Langemann Gate in an existing three bay stop-log structure, six miles from the river diversion. The stop-log structure had three 7-foot wide bays that create a fore-bay pool for a hydraulic pump turnout. Significant flow changes in the canal required adding or removing stop-logs in an attempt maintain a stable water surface level in the fore-bay. This type of control was difficult. The original check structure was made by forming four massive vertical concrete gussets that create the three 7-foot wide bays. To help install the stop-logs, the stop-log slots and gussets were sloped.

To provide a vertical surface to mount the Langemann gate, the center two gussets were cut to create two vertical columns. A short concrete stem-wall was doweled into the base of the concrete structure.

The base beam sets on a stepped stem-wall and the hoist channels are supported by vertical steel angle sections bolted to the inside of the outside concrete gussets. The assembled gate was placed into the modified structure using a crane.

The gate functions as a vertically adjustable weir. The long horizontal gate-leaf slices through the canal current like a wing. The forces are somewhat balanced; the lower-leaf has an up lifting force that is countered by the downward force on the upper-leaf. With this “balanced” load it is possible to operate the gate hoist with a fractional-horsepower DC motor, which is powered by batteries. The batteries can be charged either by solar panels or an AC/DC battery charger.

Gate automation is accomplished with a Programmable Logic Controller (PLC), with open architecture, that can be easily programmed to run custom control algorithms. Standard control options for a Langemann Gates are upstream water level control and flow control, although the manufacturer will customize the control to the user’s need. In addition, this gate was supplied with an optical encoder to determine gate position, rather than the typical potentiometer indicator.

The purpose of this installation was to maintain a constant upstream water surface level in the pump fore-bay. The completed installation has a 25-foot wide automated bi-fold overshot gate, mounted in a modified 90-year old three bay concrete stop-log structure. The gate performs well, running on the manufactures automation software, and the decision to install four addisional gates on the irrigation project was implemented.

The second site is six miles downstream from the first gate. This structure contained a Waterman D-450 Amil gate and six stop-log bays, three on each side. The purpose of this canal check was to change and maintain the upstream water surface in the canal to prevent upstream freeboard encroachment at high canal flows, and to allow upstream turnout deliveries to be made during low canal flows. Although the structure was built in the 1990's, it was poorly designed and did not work. The Amil gate performed as expected but it was not the correct device for this application.

Amil gates have a trapezoidal gate-leaf and massive concrete buttresses. A large concrete saw was used to cut the buttresses from the floor of the structure. The Amil gate, the concrete buttresses, and one stop-log bay on each side of the of the buttresses were removed. A short concrete stem-wall was doweled into the floor of the check structure.

A 28-foot Langemann gate was installed in the open span. There is a small difference in water surface elevation across the gate-leaf, so that the hydrostatic pressures are nearly equal. Of the remaining stop-log bays, the two adjacent to the Langemann gate were fitted with manually operated electric sluices gates. These gates are open during high canal flows and closed during low flows. The outer most stop-log bays are only half the depth of the canal and the stop-logs are permanently in place. The automation at this canal check is accomplished by the Langemann gate, similar to the previous pump fore-bay Langemann gate.

The third gate was placed at the entrance of an 800 CFS siphon crossing the Colorado River. The purpose of this installation was to maintain automated flow control and flow measurement into the siphon.

Over 1600 CFS is diverted into the Highline Canal at high demand. A bifurcation five miles downstream in the canal splits the flow approximately in half. Originally the bifurcation was controlled using two radial gates, with hand-crank gate hoists. One radial gate controls the Highline Canal and the other controls the siphon. The gate on the Highline Canal had been rebuilt recently, and as part of the canal modernization, it was upgraded with an automated electric hoist. This radial gate controls the upstream water level in the bifurcation.

The Langemann gate, in the entrance to the siphon, is used to control flow. The installation was similar to the previous Langemann gates, but flow conditions were different. The entrance water velocity is over 6-feet/second and the water freefalls over the gate-leaf into the throat of the siphon. Even though the bi-fold leaf balances the approach velocity head on the gate, the hydrostatic difference across the leaf causes the gate to want to float.

To counteract this lift force, the bottom beam of the gate was securely anchored to the concrete stem-wall and the upstream side plates were bolted to the concrete side walls. The greater hydrostat force across the gate-leaf required high inrush current to the motor to start the gate moving. Because of increased the inrush current through the motor, the DC motor solenoids were replaced with a solid-state soft-start device. DC motor soft starters were installed on all five of the project gates, and are now standard equipment on Langemann gates.

One unexpected site improvement was a great reduction in the trapped air belching back from the siphon inlet. The high velocity discharge under the old radial gate pulled air into the siphon. The water velocity over the Langemann gate-leaf is reduced and the energy is dissipated in the siphon intake. The gate at this site is presently operated in local hand mode. When it is tied into the SCADA radio network, it will be locally automated and remotely operated.

The forth gate was placed downstream of an emergency siphon on a side-channel spillway from the canal. The purpose of this installation is to maintain an automated constant upstream water surface in the canal, and to measure the canal water administratively spilled into Highline Lake. Historically the siphon would be started by a high water level in the canal and then break suction when the canal water level was drawn down ½-foot. With the Langemann gate installed in the spillway, the three sluice gates in the bottom of the canal are opened and the siphon is inoperative.

This Langemann gate has the same hydraulic control challenges as the gate at the bifurcation siphon inlet. The lake spill is 44-miles from the canal diversion point, and there are a series of 14 canal check structures upstream from the spill. The canal checks are operated in upstream control mode, and the miss matches between canal diversion and irrigation deliveries are accumulated downstream at the Highline Lake spill. This gate is 13-feet wide and the spill flow ranges from 0 to 200 CFS. The gate must respond quickly to maintain the canal water surface level. The PLC algorithm control time step was shortened to make the gate move aggressively.

The fifth gate was placed at the entrance of the Highline Lake pump back station. The pump station is operated to supplement canal supply during short-term increases irrigation demand. The purpose of this gate installation is to prevent debris from building up on the pump screens when the pumps are not running. A trash rake cleans the screens when the pumps are operation. A low water level in the canal will cause the Langemann gate in the spillway to rise and stop the spill. If the canal water level falls below the pump target level, the pump PLC will lower the pump station Langemann gate in front of the screens prior to starting the pump. When the pumps stop, the gate is raised to block debris from entering the screens.

Conclusion: Canal modernization, with bi-fold overshot gates was very successful on the Highline Canal. The gates performance well in a variety of water control applications. These gates are custom engineered for each site and designed with the water control feature desired by the user. The low power requirement and the minimal concrete work needed for installations, makes the Langemann gate a versatile and economic tool for modernizing old canals or constructing new canals.

References: Personal contact with Gerald Robinson, R.E.T., Aqua Systems 2000 Inc.

Deficit Irrigation of Alfalfa as a Strategy for "Saving" Water

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Dan Putnam[2]
Rick Snyder[3]

ABSTRACT

Alfalfa is California's single largest agricultural water user due to its large acreage and long growing season, using 4 to 5.5 million acre feet of water each year. Because of this water use, the California Department of Water Resources is interested in deficit irrigation of alfalfa for providing water for transfer elsewhere. One strategy is to terminate irrigation during July and August when alfalfa yields are relatively small and use the "saved" water for nonagricultural uses. The amount of transferable water would be the difference in the evapotranspiration (ET_c) of a fully-irrigated field and that of a deficit-irrigated field; however, no information exists on the potential ET_c differences.

Evapotranspiration was determined in a commercial field using the eddy covariance and surface renewal energy balance methods in a fully irrigated part of the field, and the surface renewal method in the deficit irrigated part of the field. In addition, alfalfa yield, applied water, canopy coverage and plant height measurements were made in both parts of the field.

Deficit irrigation greatly reduce alfalfa yield in 2003, 2004, and 2005. Yield reductions due to deficit irrigation generally ranged from 41 to 88% of the fully-irrigated treatments. Cumulative ET_c in 2005 was 48.1 inches for the fully-irrigated treatment. Deficit irrigation (no irrigation) started on July 25. Cumulative ET_c between July 25 and December 6 (end of measurement period) was 20.8 inches for the fully irrigated treatment and 11.4 inches for the deficit irrigated treatment for a difference of 9.4 inches.

INTRODUCTION

Water transfers from the water-rich agricultural areas of northern California are

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being used by the California Department of Water Resources to supply water to areas with limited water supplies. The strategy is to fallow land and then transfer an amount of water equal to the seasonal evapotranspiration (ET_c) of the crop that would normally be grown in the fallowed fields. It is assumed that no ET_c occurs in the fallow fields.

Alfalfa is California's single largest water user due to the amount grown, typically about one million acres, and its long growing season. Seasonal alfalfa water use generally ranges from 4 to 5.5 million acre-feet per year. Because of this large water use, the Department of Water Resources is interested in transferring water from alfalfa production to other uses during periods of water shortage. A possible strategy is to deficit irrigate the flood-irrigated alfalfa fields during July and August, a period of time during which both alfalfa yield and water use efficiency (ratio of yield to ET_c) are relatively small. Deficit irrigation consists of terminating flood irrigations during those months.

Unlike a fallow field, deficit irrigated alfalfa can continue to transpire. The difference in ET_c between fully-irrigated and deficit-irrigated alfalfa is unknown because of this transpiration. Also unknown is the effect of deficit irrigation on subsequent yields of the following year. Thus, an experiment was conducted to determine the effect of deficit irrigation in the summer on the yield and ET_c of alfalfa and to determine the effect of the deficit irrigation on yield of the next year.

METHOD

A commercial field located near Davis, CA was selected for the fully-irrigated and deficit-irrigated treatments. The fully-irrigated alfalfa was irrigated according to the irrigator's normal practices. In 2003, 2004, 2005, and 2006, the deficit-irrigated treatments consisted of no irrigation during July and August with no fall irrigation. Deficit irrigation started at about the end of June in 2003, 2004, and 2006, and at the end of July in 2005. In 2003 and 2005, a second deficit irrigation water treatment consisted of applying a September irrigation after the deficit irrigation. Each treatment consisted of three alfalfa checks with border checks between the irrigated and deficit irrigated treatments. The border checks were necessary to prevent water flow through cracks in the soil from the irrigated treatments into the deficit irrigated treatments. The field scale approach was used to obtain the field-wide conditions experienced by commercial agriculture. A randomized replicated experimental design was not feasible because of the constraints caused by the use of a commercial field. The same field was used in 2003, 2004, and 2005. A new site was selected for the 2006 experiment.

The experiment was initiated in 2003, but no ET_c measurements were made at that time. In 2004, the Bowen ratio energy balance method (Todd et al., 2000) was used to determine ET_c. However, the results from this method were unsatisfactory due to problems with the instruments used by this method. In 2005, ET_c was calculated from data measured by the eddy covariance (EC) energy balance method (Tanner et al., 1985) and the surface renewal (SR) energy balance method (Spano et al., 1997). The EC method was used in the fully-irrigated treatment and the SR method was used in the deficit-irrigated treatment with no fall irrigation. Calibration of the SR method was achieved by installing an SR system near the EC system in the fully-irrigated treatment and using the EC data to calibrate the SR method for alfalfa. SR calibration coefficients generally ranged between 0.3 (just before harvest) to 0.4 (just after harvest).

Yield and yield quality were determined by sampling at nine locations in each treatment. In addition, canopy coverage, plant height, and soil water tension were also measured. Canopy coverage was measured with a digital infrared camera (Dycam, Inc., Woodland Hills, CA); soil water tension was measured with Watermark® electrical resistance blocks (Irrometer, Inc., Riverside, CA).

RESULTS/DISCUSSION

Alfalfa Yields

Alfalfa yields of the different treatments are shown in Tables 1, 2, and 3 for 2003, 2004, and 2005, respectively. The yields of 2006 are being analyzed. In 2003, yields of the fully irrigated treatment decreased over time during the period of deficit irrigation (Table 1). Deficit irrigation was imposed starting in July. Yields of the deficit irrigation treatments were substantially smaller than those of the full irrigation, particularly for the 4^{th} and 5^{th} harvests of both deficit treatments. For the 6^{th} harvest, yield of the deficit treatment with a September irrigation was higher than those of the earlier harvests under deficit irrigation. Yield of the 6^{th} harvest of the deficit treatment with no September irrigation also was higher than the earlier yields of that treatment, reasons for which are unclear. However, yields of less than 0.5 tons/acre are uneconomical to harvest, therefore, in reality, the yields of the deficit irrigated treatments were zero except for the 6^{th} harvest of the deficit (September irrigation) treatment.

Table 1. Treatment yields of 2003. The 4th, 5th, and 6th harvests occurred on August 6, September 8, and October 23, respectively. The numbers in the parenthesis are the yield reductions in percent of the full yield.

	Yield (tons/acre)				
	4th Harvest	5th Harvest	6th Harvest	Total	Yield Reduction
Full	1.56	1.35	0.58	3.49	
Deficit (no Sep. irrig.)	0.35 (78)	0.25 (82)	0.43 (26)	1.03	2.46
Deficit (Sep. irrig.)	0.28 (82)	0.16 (88)	0.96	1.40	2.09

Yields of 2004 also decreased over time during the measurement period for the fully irrigated treatment (Table 2). Deficit irrigation, which started at the end of June, resulted in a substantial yield reduction for the 6th and 7th harvests. The practical yield of these harvests was zero since yields less than 0.5 tons/acre are uneconomical to harvest. The September irrigation was omitted this year.

Table 2. Treatment yields of 2004. The 5th, 6th, and 7th harvests occurred on July 16, August 16, and September 24, respectively. The numbers in the parenthesis are the yield reduction in percent of the full yield.

	Yield (tons/acre)				
	5th Harvest	6th Harvest	7th Harvest	Total	Yield Reduction
Full	2.21	1.56	1.14	4.90	
Deficit (no Sep. irrig.)	1.96 (11)	0.25 (84)	0.19 (83)	2.21	2.69

The yields of 2005 of the fully irrigated treatment decreased over time (Table 3). Deficit irrigation started on July 25. Yields of the deficit irrigation were considerably smaller than those of the full treatment. The September irrigation increased the yield of the 7th harvest compared to the deficit (no September irrigation) treatment.

Table 3. Treatment yields of 2005. The 6th and 7th harvests occurred on August 23 and October 6, respectively. The numbers in the parenthesis are the yield reduction in percent of the full yield.

	Yield (tons/acre)			
	6th Harvest	7th Harvest	Total	Yield Reduction
Full	0.65	0.44	1.08	
Deficit (no Sep. irrig.)	0.23 (65)	0.26 (41)	0.61	0.47
Deficit (Sep. irrig.)	0.32 (51)	0.52	0.85	0.23

Crop Evapotranspiration

ET_c increased over time during the first part of 2005 as the climate became warmer (Fig. 1). However, considerable variability existed in the data as a result of day-to-day climate variability. The first harvest occurred on or about April 14 and the last harvest on or about September 30. Just after harvest, daily ET_c decreased to values between 0.08 inches/day to 0.15 inches/day. However, the day-to-day variability sometimes masked the harvest effect, particularly early in the year. Maximum daily ET_c between harvests was about 0.30 to 0.35 inches/day during the summer months. After September 15, ET_c decreased over time.

No irrigation occurred after July 25 for the deficit-irrigated treatment (no September irrigation). ET_c of this treatment continued to decrease over time until about August 25 (Fig. 1). Thereafter, a trend of relatively constant ET_c was found over time. Values of the deficit treatment were similar to those of the full treatment after September 30.

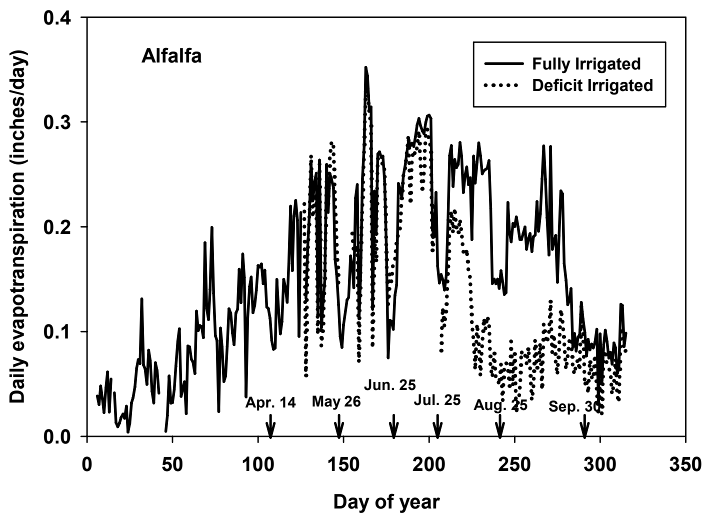

Figure 1. Crop evapotranspiration of fully-and deficit-irrigated alfalfa. The arrows are the harvest dates.

The day-to-day variability in the ET_c data makes it difficult to identify trends in the data. Thus, the data were smoothed using a 3-term moving average (Fig. 2). While the smoothing distorted the data to some degree, the effect of harvest on ET_c is clearly shown. During each harvest, ET_c decreased substantially even though the reference crop evapotranpiration (ET_o) remained high. After September 30, values of ET_c and ET_o were similar.

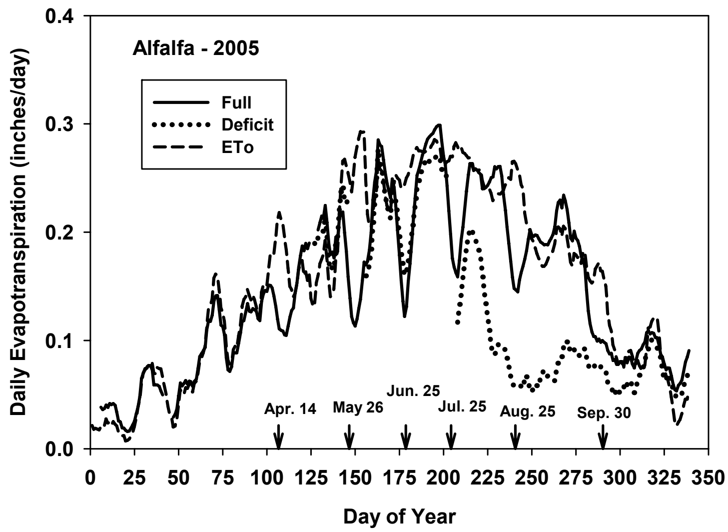

Figure 2. Smoothed crop evapotranspiration using a three term moving average. The arrows are the harvest dates.

Seasonal 2005 ET_c of the full treatment was 48.1 inches. Between July 25 and December 6 (end of measurement period), ET_c of the full treatment was 20.8 inches and that of the deficit treatment was 11.4 inches. The difference was 9.4 inches.

Cumulative ETc at the end of July 2006 was 32.2 inches. The difference in ET_c between the fully-irrigated and deficit-irrigated treatments for July 2006 was 2.6 inches.

Canopy Coverage and Plant Height

Canopy coverage of the 2005 fully irrigated treatment varied from between 20 and 40 % just after harvest to between 90 and 100 % just before harvest except after the last harvest (Fig. 3). During the period of deficit irrigation, maximum canopy coverage between harvests was between 55 and 65 %. After the last harvest, canopy coverage of the fully-irrigated alfalfa was about 70% and that of the deficit irrigated area was between 45 and 55 %.

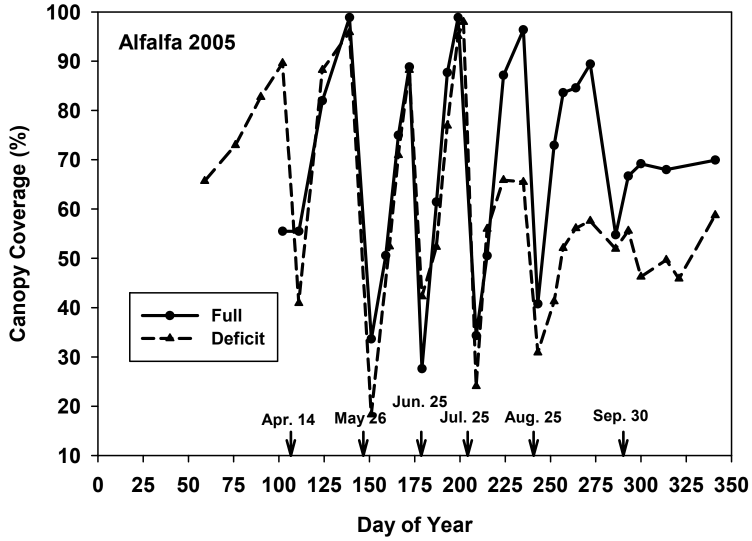

Figure 3. Canopy coverage of the 2005 fully-and deficit-irrigated alfalfa.

Plant height (Fig. 4) showed a behavior similar to that of the canopy coverage with values ranging from less than 5 inches just after harvest to generally between 18 and 23 inches just before harvest (data not shown). During the period of deficit irrigation, maximum plant height was less than 12 inches.

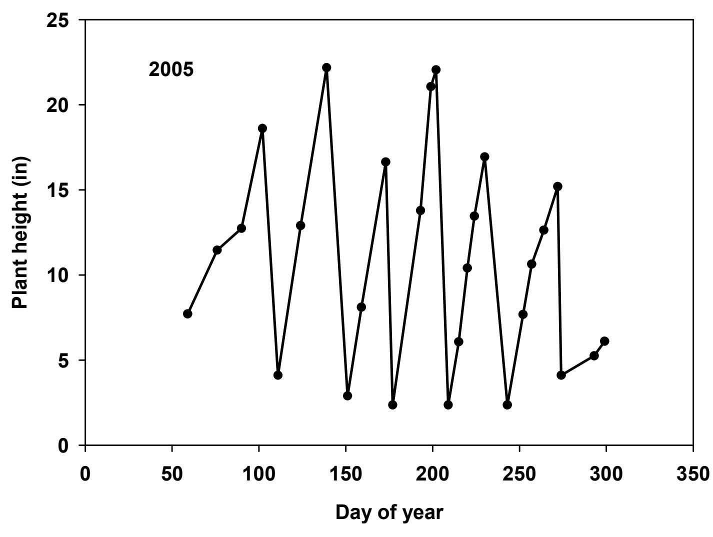

Figure 4. Plant height in 2005.

Crop Coefficients

Substantial fluctuation in the 2005 crop coefficients occurred up to the 100th day of the year (DOY100) with many values exceeding two (Fig. 5). Substantial fluctuations also occurred near the end of the measurement period. The average crop coefficient prior to DOY100 was 1.00. Values exceeding 1.5 were eliminated. After DOY100, the harvest schedule affected the crop coefficients over time. Just after harvests, crop coefficients ranged from about 0.3 to 0.5. Maximum coefficients between harvests were about 1.2 (excluding extreme values).

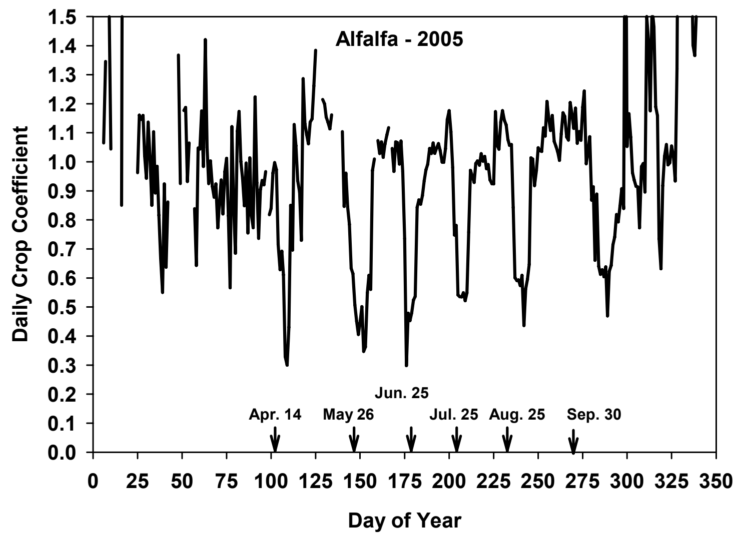

Figure 5. Daily crop coefficients of fully irrigated alfalfa in 2005.

Soil Moisture Tension

Soil moisture tension was less than about 50 centibars for the fully irrigated alfalfa until the end of September (Fig. 6). Soil moisture tension then increased with time because the last irrigation occurred near the end of September. Soil moisture tension in the deficit irrigated treatment increased with time during August, followed by a slight decrease at the end of August (reasons for which are not clear). Thereafter, soil moisture tension increased over time; however, the tension levels were greater than those of the fully irrigated treatment.

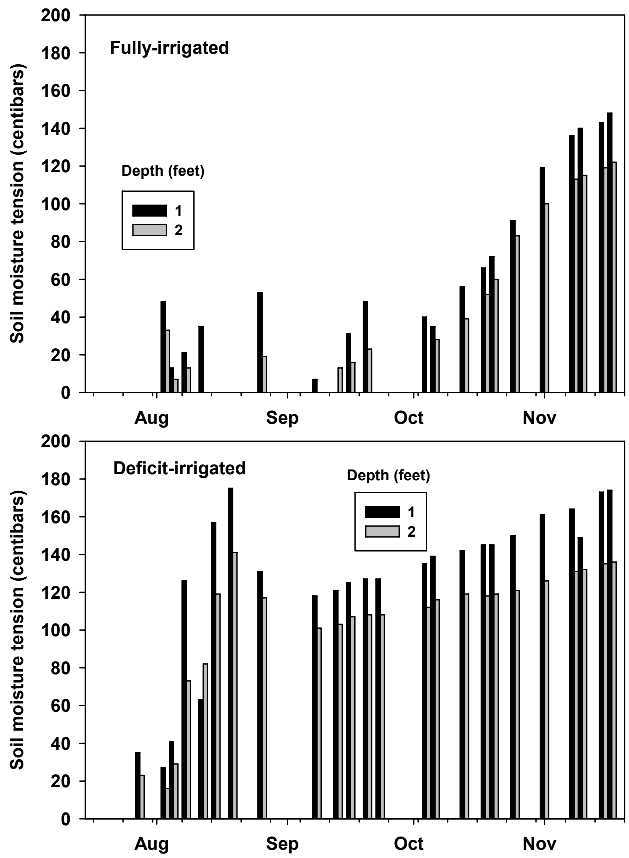

Figure 6. Soil moisture tension of fully and deficit irrigated alfalfa.

CONCLUSIONS

Deficit irrigation of alfalfa during July and August greatly reduced crop yield. Yields reductions of the deficit-irrigated treatments ranged from 41 to 88 % of the fully-irrigated alfalfa yields. In some cases, the yield was uneconomical to harvest. Deficit irrigation imposed at the end of July 2005 reduced the seasonal crop evapotranspiration by 9.4 inches. Deficit irrigation also reduced the maximum canopy coverage and plant height. Based on visual observations, deficit irrigation in a given year did not adversely affect the following year's yield.

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Soil Water Evaporation and Residue Management in Sprinkler Irrigation

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Introduction:

Soybean and corn growers who irrigate in the Great Plains face restrictions in available water, either from lower well capacities or from water allocations, and rising energy costs. They need management practices to manage water supplies for useful grain production. Water savings, even a few inches, can convert water into yield increases. Research (Schneekloth et al., 1991) has shown that each acre-inch of water captured or saved in the root zone potentially can be transformed into soybean yield through transpiration at the rate of 4 bu/ac. The same is true for corn at a rate of 12-14 bu/ac for each acre-inch.

Evapotranspiration is a two part process. Transpiration, or water consumed principally by evaporation near leaf and stem surfaces is used productively to produce grain. Non-productive soil water evaporation process vaporizes water directly into the air with little utility. Soil water evaporation rates are controlled by two factors. After wetting, atmospheric energy that reaches the ground drives evaporation rates (energy limited). As the surface dries, evaporation rates are limited by the movement of water through the soil to the surface. Generally, energy limited evaporation rates are more than soil limited rates during the growing season. Crop residues on the surface can influence energy limited evaporation by reducing energy reaching the ground.

Measuring methods to reduce wasteful soil water evaporation is the goal of this project. Past projects have demonstrated that reducing soil water evaporation under irrigated corn canopies is possible with flat wheat stubbles on the soil surface (Todd et al. 1991). Irrigators need to know what value crop residues, including corn stalks and standing wheat stubble, have for reducing soil water evaporation. They need concrete measurements of the soil water evaporation rates in soybean canopies with crop residue and irrigation management techniques.

Objectives:

Determine the water savings value of crop residues in irrigated corn and soybean production.

1. Measure soil water evaporation beneath crop canopy of fully irrigated and limited irrigated corn and soybean production.

    a. Measure evaporation from bare soil
    b. Measure evaporation from soil with no-till corn residue
    c. Measure evaporation from soil with standing wheat residue

2. Calculate the contribution of evaporation to evapotranspiration, based on mini-lysimeter and soil water balance techniques.

3. Predict potential savings in evaporation due to crop residues to equivalent grain yield gains and economic impacts in water limited areas in western Kansas.

For presentation at the Irrigation Association's 27th Annual International Irrigation Show, Nov. 5-7, 2006.

Methods:

Soil water evaporation was measured during the summer of 2003, 2004, and 2005 at Kansas State University's Research and Extension Center near Garden City, Kansas. Mini-lysimeters were used for the primary evaporation measurement tool. They contained undisturbed soil cores 12 inches in diameter and 5.5 inches deep. The soil cores were extracted by pressing PVC tubing into the soil with a custom designed steel bit. The PVC tubing became the sidewalls for the mini-lysimeters. The bottom of the cores was sealed with galvanized discs and caulking. Therefore, water could only escape from the soil by surface evaporation, which could be derived from daily weight changes of the mini-lysimeters. Weighing precision produced evaporation measurements with a resolution of $\pm$ 0.001 in/day.

Volumetric soil water content was measured bi-weekly in the field plots to a depth of 8 ft in 1 ft increments with neutron attenuation techniques. The change in soil water, form the start to the end of the sampling period, plus measurements of rainfall and net irrigation were the components of a water balance to calculate crop evapotranspiration (ETc).

Two mini-lysimeters with the same surface cover treatment were placed in a diagonal pattern between adjacent 30-inch rows under the crop canopy. There were four replications of bare, corn stover, or wheat stubble surface treatments in each of two irrigation treatments in 2004 and 2005 (high and low frequency irrigation), but only the high irrigation treatment was conducted in the 2003 soybeans. High frequency irrigation was managed to meet atmospheric demand for water (full ETc). The low frequency irrigation treatment received approximately half the amount of water as the high treatment.

A hail event on July 4, 2005 completely destroyed the soybean crop and damaged the corn. Therefore, an additional non-field experiment was conducted with soil surfaces partially covered with crop residues. The objectives were to (1) quantify the relationships between surface cover dry matter and soil water evaporation without a crop canopy, and (2) quantify the relationship between percentage of surface cover and soil water evaporation. A controlled area was established for the experiment where the mini-lysimeters were buried in PVC sleeves at ground level, but they were arranged adjacent to one another in a geometric pattern. Rain-out shelters were available to exclude rain from the mini-lysimeters. The movable shelters covered the mini-lysimeters during rainfall but were open during other times. There was no crop canopy and the mini-lysimeters were surrounded by clipped, irrigated grass. The mini-lysimeters were weighed daily. Two irrigation treatments, that approximated the companion field study, were imposed with once and twice per week watering.

Partial cover treatments with 25%, 50%, and 65% of the surface covered with corn stover were established by placing the material on undisturbed bare soil mini-lysimeter cores. The percentages of surface covered were confirmed with the line transect method by counting the presence of residue at intersections of a grid. The 100% corn and 89% wheat treatments used mini-lysimeters from the field experiment. Evaporation results were normalized with reference ET (ETr) which was calculated with on-site weather factors and an alfalfa referenced ETr model. (Penman, 1948).

Results:

Within Canopy Field Results

Trends in dry matter and crop residue coverage may help explain the following discussion of soil water evaporation. Corn dry matter and surface coverage, both sampled from the actual mini-lysimeters, were similar in 2003 and 2004 (table 1). Decreases in corn residue coverage corresponded to less dry matter. The protocol in this experiment was to obtain the maximum possible coverage from corn stover. The intent was to find the maximum potential influence on soil water evaporation by the corn stover. The wheat stubble dry matter and coverage decreased each year (table 1). The effects of wheat planting immediately following a summer annual crop may have been responsible for this trend. The wheat was planted on approximately November 1, which was 40 days later than wheat planted following fallow. The 2005 wheat crop was especially short in stature due to less fall growth.

Table 1. Crop residue mass and percentage cover at the end of the growing season for mini-lysimeters in soybean and corn field plots during 2003, 2004, 2005 near Garden City, Kansas.

Surface Cover	Dry Matter tons/ac	Residue Coverage* %
-------------------2003---------------------		
Bare	0.0	0
Corn	10.4	100
Wheat	15.2	N/A
-------------------2004---------------------		
Bare	0.0	0
Corn	7.3	97
Wheat	9.8	98
-------------------2005---------------------		
Bare	0.0	0
Corn	9.5	100
Wheat	6.3	91

*Percentage of soil surface covered by residue as determined by the line transect method.

The effects of surface cover type on soil water evaporation were analyzed in the soybean and corn crops (tables 2 and 3). The high frequency irrigation treatment in soybeans was imposed during 2003 and 2004, but the low frequency treatment was only used in 2004. Both irrigation frequency treatments were used in both years in corn. Both water treatments and all three vegetative growth observations were averaged together to obtain the results in tables 2 and 3. Average soil water evaporation for the bare surface treatments were significantly different from the two residue covered treatments in the corn and soybean crops in all years. Corn stover behaved somewhat differently in both crops except under soybeans during 2004. More dry matter for the wheat stubble in the 2003 lysimeters under soybeans promoted less evaporation losses. Less wheat stubble led to more evaporation, compared with the corn stover, in the corn crop during 2005

The crop ET, measured with soil water balance techniques, was the same for all surface cover treatments for each year, since all other treatments were averaged over surface cover. The 2004 cropping year was cooler and had more rainfall than 2003 and 2005. This is reflected in the ETc values for each year and crop. The ratios of E and ETc become a direct result of E. These results show the relative influence of surface residues coverage on soil water evaporation. The crop residues reduced the evaporation approximately by half compared with a bare surface.

Table 2. Average soil water evaporation (E), crop evapotranspiration (ETc), and evaporation as a ratio of crop evapotranspiration for all bare soil and soil covered with crop residues under a soybean crops during 2003 and 2004 in Garden City, KS.

	------------2003------------			------------2004------------		
Surface Cover	Average Evaporation --in/day----	ETc --in/day---	E/ETc*	Average Evaporation --in/day----	ETc --in/day----	E/ETc
Bare	0.080a	0.23	0.37a	0.06a	0.19	0.36a
Corn Stover	0.044b	0.23	0.21b	0.03b	0.19	0.18b
Wheat Straw	0.038c	0.23	0.18b	0.03b	0.19	0.18b
$LSD_{.05}$**	0.0005		0.03	0.0016		0.02

*E/ETc is the ratio of soil water evaporation and crop ET, measured with the water balance method.
**LSD is the least significant difference.
Means with same letters in the same columns are not significantly different for alpha=.05.

Table 3. Average soil water evaporation and evaporation as a ratio of crop evapotranspiration (ET) for all bare soil and soil covered with crop residues under a corn crop canopy during 2004 and 2005 in Garden City, KS.

	------------2004------------			------------2005------------		
Surface Cover	Average Evaporation --in/day----	ETc --in/day----	E/ETc*	Average Evaporation --in/day----	ETc --in/day----	E/ETc
Bare	0.07a	0.21	0.37a	0.06a	0.27	0.23a
Corn Stover	0.04b	0.21	0.19b	0.03c	0.27	0.12c
Wheat Straw	0.03c	0.21	0.17b	0.04b	0.27	0.14b
$LSD_{.05}$**	0.003		0.05	0.0002		0.01

*E/ETc is the ratio of soil water evaporation and crop ET, measured with the water balance method.
**LSD is the least significant difference.
Means with same letters in the same columns are not significantly different for alpha=.05.

Comparing soil water evaporation rates from one growth stage to the next can elucidate the influence of crop canopy development. The expected trend in energy limited evaporation is to decrease as shading increases until the crop starts to mature and lose leaf area. Concurrently, evaporative demand on the crop increases from planting through mid-season and then decreases later in the growing season.

Tables 4 and 5 summarize average soil water evaporation and crop ET by growth stage. Data for these tables were averaged over cover type and irrigation frequency. The soybean study in 2003 did not include irrigation frequency as a variable. Soybean results (table 4) are similar for both years, except during the pollination periods. Ten more days of data were collected during the pollination period in 2003, which may have influenced the outcome. Also, ETc was less during the 2003 pollination period, which further influenced E/ETc.

Results for E and ETc in the corn canopy (table 5) followed predictable patterns. E decreased as the crop developed and ETc increased from vegetative growth to pollination and decreased from pollination to seed fill. The proportion of E to ETc declined during the growing season when the two factors were combined.

Table 4. Soil water evaporation and evaporation as a ratio of crop ET during the growth stages of soybeans for all mini-lysimeter treatments during the 2003 and 2004 growing seasons at Garden City, KS.

Growth Stage	Measurement Periods	Average Evaporation	ETc	E/ETc
2003	2003	--in/day--	-in/day-	
Vegetative	Jul 18-31	0.067a	0.227a	0.31b
Pollination	Aug 1-20	0.065a	0.181b	0.36a
Seed Fill	Aug 21- Sep 6	0.027b	0.238a	0.12c
$LSD_{.05}$		0.005	0.016	0.04
2004	2004			
Vegetative	Jul 13-Aug 9	0.064a	0.131b	0.51a
Pollination	Aug 10-21	0.026b	0.208a	0.13b
Seed Fill	Aug 22-Sep 20	0.028b	0.212a	0.13b
$LSD_{.05}$		0.002	0.009	0.02

Means with same letters in the same columns for the same year are not significantly different.

Table 5. Soil water evaporation and evaporation as a ratio of crop ET during the growth stages of corn for all mini-lysimeter treatments during the 2004 and 2005 growing seasons at Garden City, KS.

Growth Stage	Measurement Periods	Average Evaporation	ETc	E/ETc
2004	2004	--in/day--	-in/day-	
Vegetative	Jun 30-Jul 19,	0.071a	0.21a	0.36a
Pollination	Jul 20-Aug 12	0.04b	0.23a	0.23b
Seed Fill	Aug 13-Sep 20	0.027c	0.18b	0.15c
$LSD_{.05}$		0.003	0.02	0.049
2005	2005			
Vegetative	Jun 21-Jul 19	0.046b	0.26b	0.18a
Pollination	Jul 20-Aug 3	0.053a	0.31a	0.17a
Seed Fill	Aug 4-Sep 2	0.03c	0.23c	0.13b
$LSD_{.05}$		0.002	0.013	0.01

Means with same letters in the same columns for the same year are not significantly different.

Cover type and growth stage variables were averaged to more easily explain the irrigation frequency variable (tables 6 & 7). Only 2004 soybean crop results were analyzed because 2003 did not have a water variable. More frequent irrigations led to more soil water evaporation and ETc in the high frequency than low frequency water treatments (table 6). Combining these two factors led to slightly less E in proportion to ETc for the high frequency irrigation treatment. The leaf area index (LAI) was not significantly different for the two irrigation frequencies.

Table 6. Soil water evaporation and evaporation as a ratio of crop ET for low and high frequency irrigation for all mini-lysimeter treatments in soybeans during the 2004 growing season.

Irrigation Frequency*	Average Evaporation --in/day--	ETc -in/day-	E/ETc	LAI**
Low	0.038b	0.173b	0.25a	4.7a
High	0.040a	0.205a	0.23b	5.1a
$LSD_{.05}$	0.0012	0.0063	0.02	0.34

*Number of irrigation events—4 for Low and 7 for High.
**LAI is leaf area index (leaf top surface area/ground area)
Means with same letters in the same columns are not significantly different.

Peak LAI shows the effect of the hail damage on the corn crop in 2005 (table 7). LAI was reduced in 2005 compared with 2004. During 2004 average E, ETc and E/ETc were more in the high irrigation frequency treatment than the low frequency treatment. Results in 2005 did not suggest a clear trend in average E and ETc. Again, ETc was more in the high frequency treatment than the low frequency. More ETc in 2005 may reflect more evaporative demand due to loss of leaf area from hail damage.

Table 7. Soil water evaporation and evaporation as a ratio of crop ET for low and high frequency irrigation for all mini-lysimeter treatments for corn during the 2004 and 2005 growing seasons.

2004 Irrigation Frequency*	Average Evaporation --in/day--	ETc -in/day-	E/ETc	LAI**
Low	0.042b	0.194b	0.22b	3.9b
High	0.05a	0.218a	0.28a	4.9a
$LSD_{.05}$	0.002	0.02	0.04	0.28
2005				
Low	0.046a	0.242b	0.185a	3.0b
High	0.042b	0.29a	0.143b	3.8a
$LSD_{.05}$	0.002	0.01	0.01	0.18

*Number of irrigation events—__ for Low and __ for High.
**LAI is leaf area index (leaf top surface area/ground area)
Means with same letters in the same columns for the same year are not significantly different.

Partial Cover Results from Control Area

Average daily evaporation decreased with increasing percentage of surface coverer (SC) and increases in surface cover dry matter (DM) (figures 1 and 2). There was a closer correlation of average E with dry matter than percentage of surface cover.

Twice per week irrigation frequency (high) produced 15% more evaporation than the once per week frequency (low) (table 8b). These data were from all surface cover types including bare and crop residue covered. Energy limited evaporation may have played a different roll in the types of surfaces.

The entire experimental period was subdivided into watering cycles consisting of approximately one week intervals. The data show some differences in average daily evaporation across the experimental period, but they also show the precision for the measurement process through the small significant differences that can be identified. Except for the first cycle, reference ET was consistent during the experimental period.

Table 8. Soil water evaporation study for full and partial crop residue surface covers conducted during September 7-October 6, 2005 at Garden City, Kansas.

		Average Evaporation	E/ETr*	Surface Cover Dry Matter
a. Surface Cover		--in/day--		--tons/ac---
Bare 0%		.054b	0.2b	0.00f
Corn 25%**		.066a	0.26a	0.51e
Corn 50%		.052c	0.19c	2.28c
Corn 65%		.065a	0.24a	1.64d
Corn 100%		.031e	0.12e	8.83a
Wheat 89%		.039d	0.15d	7.06b
$LSD_{.05}$		0.0016	0.0047	0.32
b. Irrigation* Frequency**				
Low		.055a	0.20a	
High		.048b	0.18b	
$LSD_{.05}$		0.0009	0.0027	
c. Water Cycle****				Reference ET -----in/day---
	1	.057a	0.16d	0.35
	2	.051c	0.21b	0.24
	3	.047d	0.19c	0.25
	4	.047d	0.17d	0.28
	5	.054b	0.24a	0.23
	6	.051c	0.19c	0.27
$LSD_{.05}$		0.0016	0.0047	

*Reference ETr (alfalfa based) from weather station data.
**Percent surface covered by residue found from line-transect (visual) methods.
***Once (low) and twice (high) per week irrigation frequency.
***Irrigation cycles were approximately one week in duration during Sept. 6 through Oct. 7, 2005.
Means with same letters in the same columns for the same variable are not significantly different.

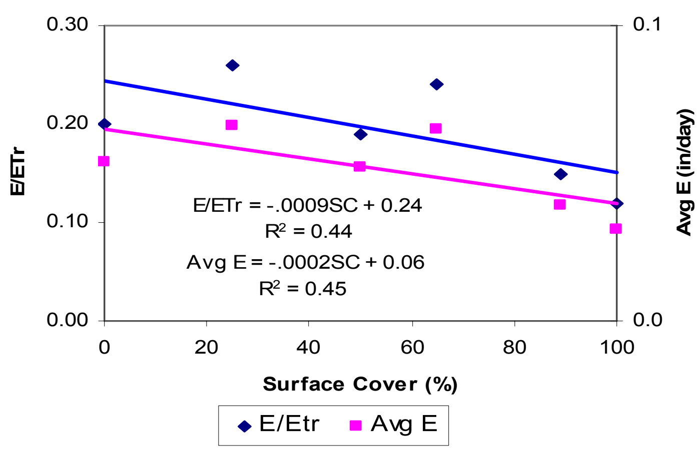

Fig. 1. Average soil water evaporation (AvgE) and E/ETr correlated with surface cover (SC) for corn stover and wheat straw residues on mini-lysimeters during Sept. 7-Oct. 6, 2005 near Garden City, KS.

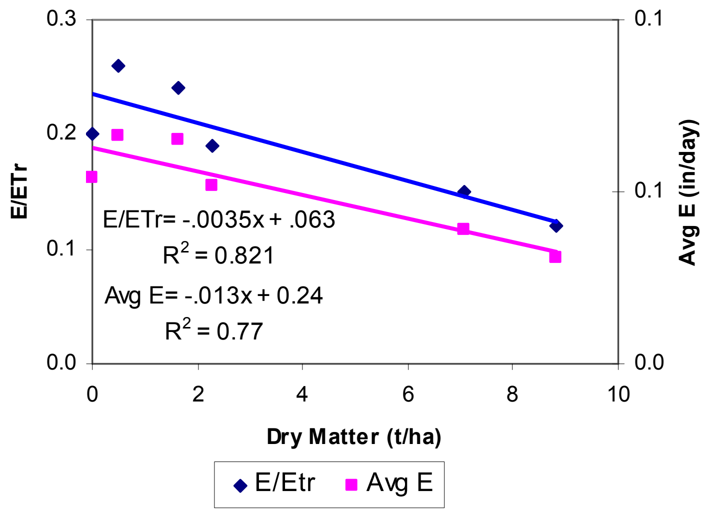

Fig. 2. Average soil water evaporation (AvgE) and E/ETr correlated with dry matter (DM) of corn stover and wheat straw residues on mini-lysimeters during Sept. 7-Oct. 6, 2005 near Garden City, KS.

Significance of Results:

The research showed that soil water evaporation in sprinkler irrigation could be reduced by crop residues by approximately 18% of ETc in soybeans and 9-11% in corn (tables 2 and 3). Because these measurements were collected from late vegetative to late seed fill growth stages, whole growing season savings would be more. Average growing season ETc for soybeans and corn would be 21 and 24 inches, respectively, in western Kansas. Over 120 day growing seasons, water savings could be 3.8 and 2.4 inches for soybean and corn, respectively.

If crop residue management techniques were adopted across all irrigated fields in western and central Kansas, very significant economic gains are possible. There were 139,000 ac of irrigated soybeans in the western third of Kansas and 227,300 ac in the central third for a total of 366,300 ac as reported in 2005.

Recent reports show that center pivots irrigate 80% of total irrigated land. If this holds true for soybean production in western 2/3 of Kansas, 293,000 acres could benefit from this research.

These water savings would have two major impacts on profitability. Irrigation pumping costs for average well depths in western Kansas have risen to $5-$9/ac-in recently, which means the operating cost of the evaporation savings would be impacted by $15-$27/ac. For irrigators with limited water supplies the water savings translates into crop production because the water becomes available to the crop. For top producers, an inch of water could be translated into 4 bushels of soybeans or 12 bushels for corn if water is a limiting factor. This would convert into an extra 15 bu/ac of soybeans and 29 bu/ac bushels of production from management of crop residues for evaporation suppression.

Assuming that soybean production in western Kansas is predominately in 30-inch rows, the overall economic impact of this research, if adopted, could be significant. For those fields with adequate well capacity, the economic impact of this research would be the pumping cost reduction. Assuming half the acreage in western Kansas has adequate well capacity, the pumping cost savings on 146,520 acres would be approximately $2.2 to $3.9 million annually. For the remainder of fields with inadequate well capacity, the economic impact from this research would be 12 bu/ac at $5/bu over 146,520 acres for a total of $8,791,000 annually.

Non-growing season benefits combine with the growing season benefits of crop residues for soil water evaporation suppression, infiltration enhancement, runoff reduction, soil erosion reduction, water quality enhancement, fertilizer savings, and snow entrapment. Dryland research indicated that off-season water conservation benefits from crop residues are worth at least 2 inches annually in the central plains states. These benefits all add to the growing season advantages of crop residues studied in this project.

The project gives irrigators concrete data to justify saving crop residues on the surface for suppression of soil evaporation. Also, water policy makers will have documented information on the economic impact of crop residues on water savings from irrigation in western Kansas. This will be important to justify funding for conservation programs and realistic water allocation programs in the future.

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The Effect of Dropping Water Tables on Center Pivot Performance

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INTRODUCTION

Irrigation in the Central Plains began in the 1930's and 1940's when farmers began drilling wells. The area was coming out of the dust bowl years and farmers were searching for ways to increase production in the semi-arid areas in the Central Plains. The irrigation in the area increased as a result of the deep well turbine pumps. Aluminum was used for both gated pipe and hand move sprinkler irrigation systems to encourage the irrigation development. The 1960's saw rapid irrigation development, as the center pivots became a proven technology. The growth has been quite slow since the 1980's when the drilling of wells has been controlled. There is a continual increase in drawdown of the water table in many areas of the Central Plains.

McGuire, 2004 published a Fact Sheet presenting the water-level changes in the High Plains Aquifer. Two periods were highlighted, predevelopment to 2003 and 2002 to 2003. McGuire reported that in 1949 there was 2.1 million irrigated acres compared to 13.7 million acres in 1980. The irrigated area peaked at 13.9 million acres in 1997 and reduced to 12.7 million acres in 2002. Ground water withdrawals increased from 4 to 19 million acre-feet from 1949 to 1974. The withdrawals exceed the recharge and the pumping lifts are continuing to increase. The objective of this paper is to discuss the effect the continuing decrease on water levels have on center pivot irrigation systems. Area weighted average water level changes are -1.0, -1.7, and -1.3 feet in the states of Colorado, Kansas and Nebraska. The 2002-2003 water level changes varied from a rise of 9 feet to a decline of 14 feet. There were significant areas that had ground water declines in excess of 5 feet in a one-year period. Southwest Kansas had areas of greater than 50 feet decline in water levels from the predevelopment to 2003. Obviously, much of this occurred in the later years with the increased irrigation development. Pumping of air is a major problem that is readily observed. It is the gradual decline in the water table and the decrease in irrigation uniformity that is not as easily observed.

ANALYSIS OF INCREASED PUMPING DEPTHS

The analysis of center pivot performance is made using a computer simulation program (CPED). The program simulates the application depths for the center pivot irrigation system. The input to the program includes the pump characteristics, the sprinkler package and lateral dimensions. The pumping level or total dynamic lift (TDL) is input to the program. The program solves the hydraulics of the center pivot system and pumping plant to determine the total discharge and pressure on the center pivot system. The problem of pumping air cannot be analyzed with the simulation analysis. It is assumed that the pump has sufficient net positive suction head to prevent air entrainment as it is lifted from the ground water and pressurized for the center pivot. The increase in TDL is assumed to be at least 10 feet and that it could easily approach 50 feet over just a few years, much less than the life of a center pivot system.

CENTER PIVOT AND PUMP SYSTEMS

Four center pivot systems are used to illustrate the characteristics of various pump and sprinkler packages. Table 1 summarizes the variables of each of the systems simulated. Assuming a change in the number of pump stages are used to illustrate their effect on the adequacy of an existing system. Each of the systems with pressure regulators had big guns with booster pumps at the end of the lateral. Changes in the pressure and operating point on the pump curve with changes in TDL are a function of the unregulated big gun sprinkler head pressure until the pressure was below the regulator pressure. The analysis assumes that the sprinkler packages provide uniform irrigations when adequate pressure is maintained. The data are from systems installed in the Great Plains.

Table 1. A brief description of the systems used for illustrating the effect of changes in the total dynamic lift (TDL).

System	H	P	B	K
Towers	7	7	8	14
Length, ft.	1287	1260	1491	2584
Sprinkler type	Iwob	Impact	Rotator	Spray
No. of Sprinkler	123	42	170	206
Sprinkler spacing, ft	18/9	30	9	18/9
Pressure Regulator	Yes	No	Yes	Yes
Pump stages, no.	3/2	7/3/2	1/2	4/3
Topography, differential ft.	20	0	0	3
TDL, ft	90- 190	90- 350	20-150	78- 128

System H

The first system simulated is a low pressure system with inverted wobbler[1] nozzles. Pressure regulators are installed on all application devices except for the big gun on the end of the system. There is 20 feet of elevation change along the 1300 foot lateral. The system was installed with a three stage pump that can accommodate a 100 foot increase in TDL and still maintain sufficient pressure. This example demonstrates an over-design where one stage could be removed and still meets the demands with the existing sprinkler package. Figure 1 illustrates the elevation and pressure head distribution at each of the towers. The minimum elevation and pressure head requirements at the end of the system is approximately 231 feet which is at least 10 feet less than provided with a 190 ft. TDL.

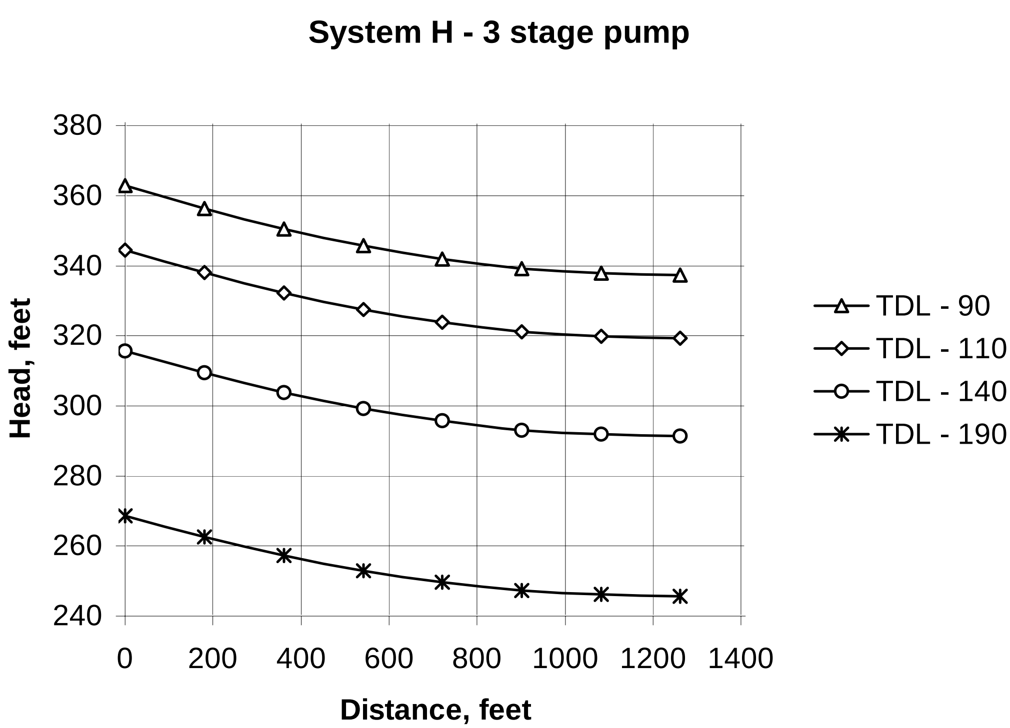

Figure 1. Lateral pressure head curves for System H (three stage pump) as installed with increases in total dynamic lift from 90 to 190 feet. Elevation and pressure head at end of system must equal 231 feet to meet minimum pressure requirements for installed sprinkler package.

[1] Mention of reference to a particular model of brand name is not an endorsement but is only for information that may be useful to the reader.

Figure 2 is the same center pivot system but with one stage removed from the pump. The lower curve is the elevation of the center pivot pad and each of the towers. The difference between this and the elevation and pressure head distribution in the curves for the different TDL's, demonstrates the need for pressure regulation. The curves for the TDL of 90 and 110 ft. meet the minimum pressure along the entire length of the system. However, with the increase in drawdown of 50 feet (TDL=140), the pressure is no longer sufficient to meet the required minimum.

Table 2 and 3 summarize the operating conditions for the three and two stage pumps, respectively. For the three stage pump the change in total discharge is a result of the big gun without pressure regulation. The reduced application depth is due to the reduced application with the big gun at the outer end of the pivot. The KW demand decreases with an increase in TDL. This is due to a lower pivot pressure and decrease in the big gun discharge. The KW demand and the head/stage is nearly the same for all conditions.

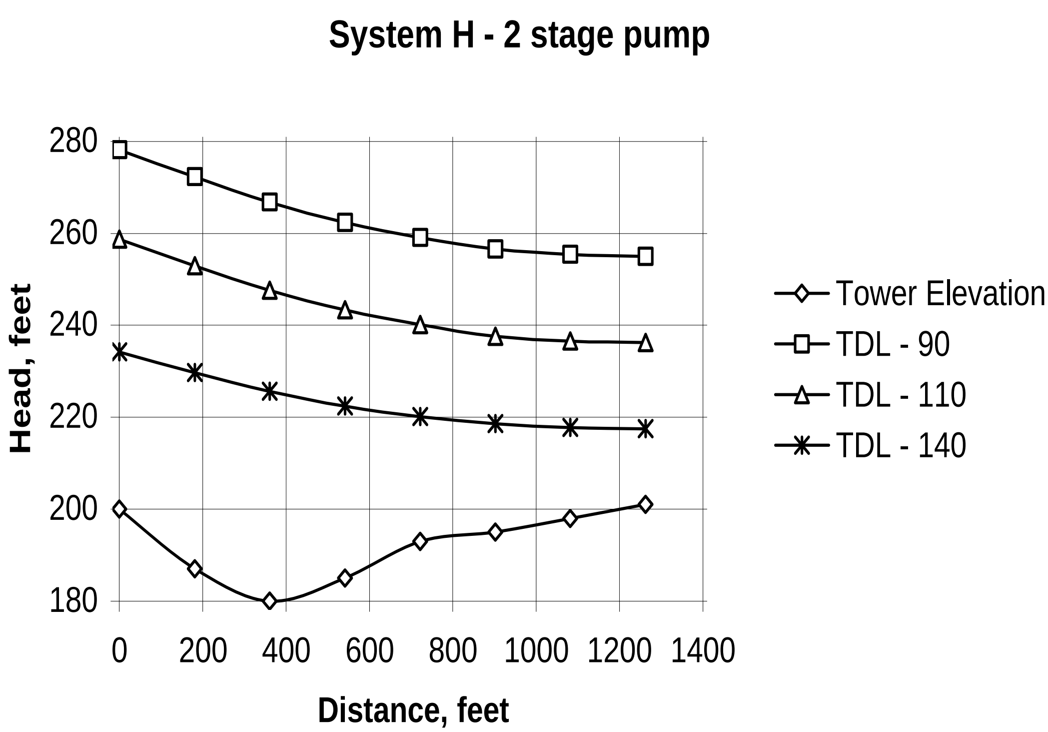

Figure 2. Lateral pressure head curves for System H (two stage pump) with increases in total dynamic lift from 90 to 140 feet. Elevation and pressure head at end of system must equal 231 feet to meet minimum pressure requirements for installed sprinkler package.

Table 2. Simulated operating characteristics for System H with three stage pump as was installed.

TDL, feet	90	110	140	190
Discharge,gpm	829	823	812	793
Pivot Pressure, psi	71	63	50	30
Irrigation depth, in.	0.77	0.77	0.76	0.75
Big gun, gpm	135	129	119	99
Head/stage, feet	88.0	88.5	88.9	89.8
KW	58.9	58.8	58.3	57.5

Table 3. Simulated operating characteristics for System H with two stage pump.

TDL, feet	90	110	140
Discharge,gpm	797	788	692
Pivot Pressure, psi	34	25	15
Irrigation depth, in.	0.75	0.74	0.66
Big gun, gpm	103	94	85
Head/stage, feet	89.6	89.8	92.2
KW	38.4	38.1	34.3

However, when one stage is removed, (Table 3) the big gun discharge is reduced as well as the application depth. A larger booster pump for the big gun could easily correct this. The head/stage is approximately the same as for the three stage pump. The final incremental increase in drawdown of 50 feet to a TDL of 140 does result in the pressure not being met at the outer ½ of the lateral length. The discharge decreased and the application depth decreased from 3/4 inch to 2/3 inch. The distribution of depths at the outer end of the system is illustrated in Figure 3. The application depths are identical until the big gun at 1288 ft, for all simulations except for the case of the TDL=140 ft and a 2 stage pump. The difference in application depth for the later case begins at approximately 600 feet from the pivot. This results with the much lower average application depth (Table 3). The four distribution curves (Figure 3) demonstrate the affect of the decrease in pressure and discharge of the big gun.

The differences in application rate pattern also demonstrates not only the reduced depth but also the reduced area that is adequately irrigated as the pressure decreases and the big gun discharge and pattern radius decreases. Figure 4 illustrates the change in discharge, pattern radius and area irrigated as a function of pressure. Assuming the effective wetted area equals 75% of the big

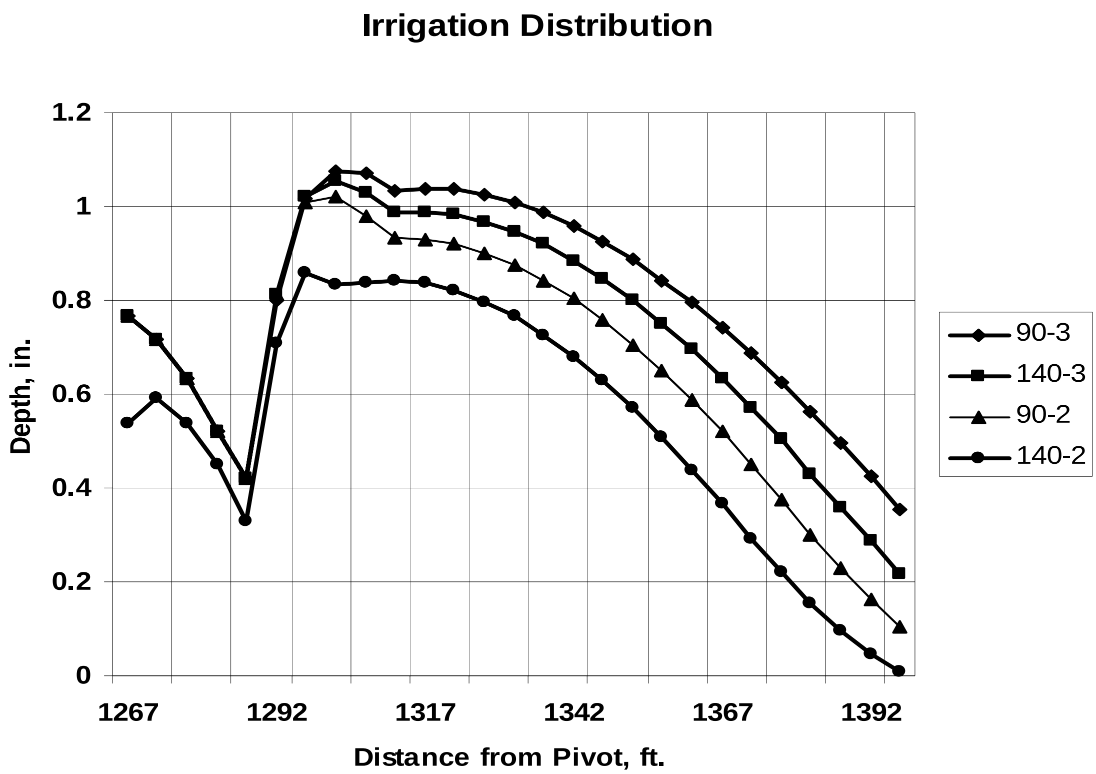

Figure 3. Irrigation Depth Distribution at the outer end of System H. Big gun is located at 1288 ft. from pivot. The legend is TDL-x where x is the number of stages.

gun radius, the irrigated area increases from 135.4 to 141 acres as the big gun nozzle pressure increases from 30 to 90 psi. This corresponds to a change in discharge from 80 to 140 gpm which is only slightly larger than the range in simulated discharge (85 – 135 gpm).

The major benefit of the two stage pump is the reduction of power requirements. Assuming a pump efficiency of 70%, the demand is reduced from 59 to 38 KW. Operating with the three stage pump will obviously provide for a larger safety factor that can accommodate a larger increase in TDL. However, the two stage pump can easily accommodate a 20 foot increase in drawdown, with the current design conditions. The irrigator can still consider a change to a three stage pump when water levels decline further.

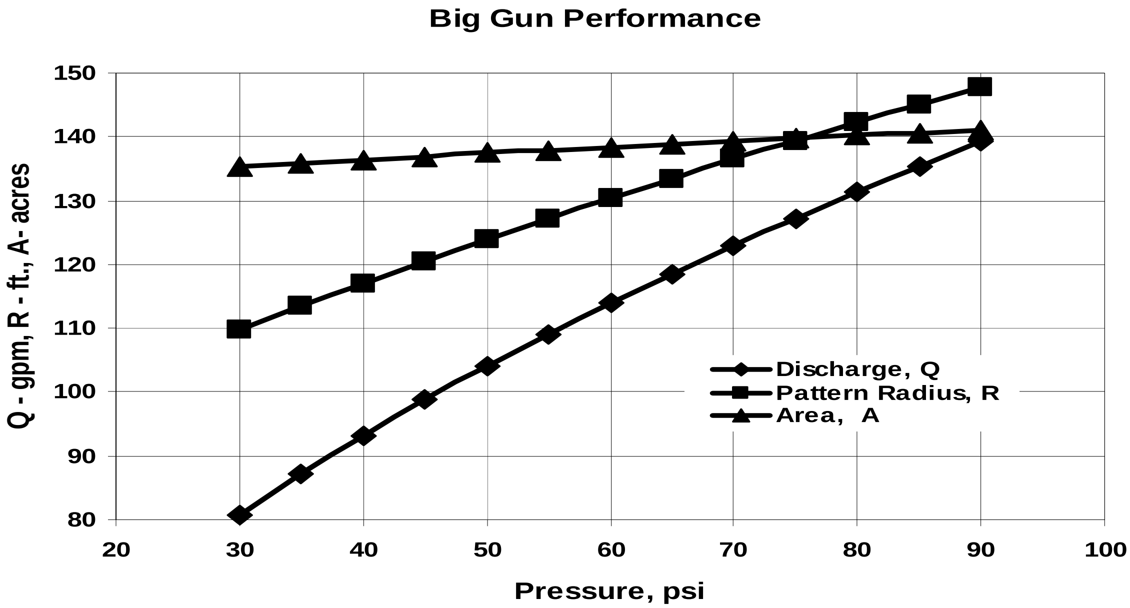

Figure 4. The effect of the pressure changes at the end of the lateral on the big gun discharge, pattern radius and the irrigated area for System H.

System P

System P is similar in length to System H but the sprinklers are high pressure impact heads. The system is assumed to have no topography change along the lateral. The system is simulated with three pump configurations having 7, 3, and 2 stages. It is the only system in this study that does not have pressure regulators along the lateral. The seven stage pump has a simulated TDL range from 300 to 350 feet. The simulated TDL range for the three and four stage pumps is 90 to 100 feet.

Figure 5 illustrates the pump curves for the 3, 4, and 7 stage pumps. The system operating points for the simulation are plotted on the pump curves. The discharge range for all simulations is between 600 to 800 gpm. The system without pressure regulators does exhibit a drop in the irrigation depth even with an increase in TDL by 10 feet (Table 4, 5). The Christiansen uniformity for each of the different pump configurations is 89 to 90%. An increase of 10 feet in the TDL for the four stage pump had a 0.02 in. decrease in application depth with a decrease in CU from 90 to 80%. The decrease in uniformity is primarily caused by the change in discharge and the pattern radius of the big gun. Comparing the three stage pump with TDL=90 and the seven stage pump with TDL=350 illustrates this fact. The pivot pressures are only 2% different but the CU is 11% different. Examining the depth data shows that the big gun has a major influence on the CU. CPEDlite used by the NRCS for EQIP funding does not include the big gun in the uniformity calculations. It is included here only to demonstrate the effect of changing TDL on the system performance. The take home message is that a 50 ft. increase in TDL can decrease the application depth by 10 – 15%.

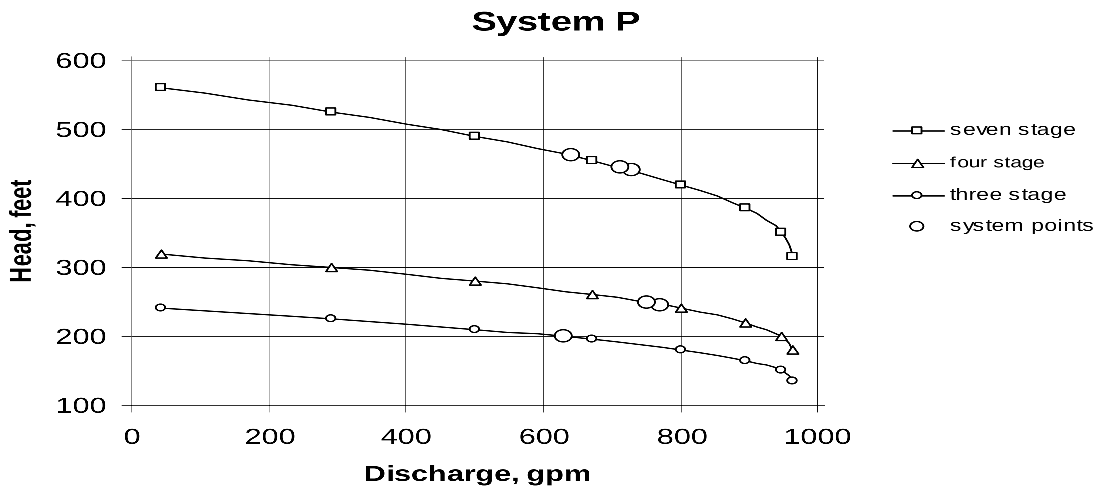

Figure 5. The pump curves for the different number of stages for System P. The operating points are for the ones included in the simulation analysis of this system.

Table 4. Simulated operating characteristics for System P with seven stage pump as was installed.

TDL, feet	300	310	350
Discharge,gpm	729	712	642
Pivot Pressure, psi	55	53	43
Irrigation depth, in.	0.77	0.75	0.68
Big gun, gpm	32	31	28
Head/stage, feet	63	63.6	66.1
KW	86.5	85.3	79.9
CU	89	89	78

Table 5. Simulated operating characteristics for System P with three and four stage pump to illustrate the lower power requirement.

Pump stages	3	4	4
TDL, feet	90	90	100
Discharge,gpm	630	769	751
Pivot Pressure, psi	41	61	59
Irrigation depth, in.	0.67	0.81	0.79
Big gun, gpm	27	33	33
Head/stage, feet	66.3	61.4	62.3
KW	33.7	50.8	50.4
CU	89	90	80

System B

System B is a pressure regulated system with a rotator sprinkler package. Both a single and double stage pump are used in the simulations. The system is also assumed to be operating on a level field. Figure 6 shows the pump curves and simulated operating points for the single and double stage pumps. Again the two pump curves are used to illustrate the effect of TDL changes over different ranges. The one and two stage pumps used a TDL range from 0-50 feet and 90-150 feet, respectively (Table 6). The one stage pump with TDL=0 feet and the two stage pump with TDL=90 have nearly equivalent pressure and discharge for the center pivot system. The pivot pressures vary only by 1 psi. In each case the head/stage is equal to 86.7 feet, thus the pressure difference is the difference between the TDL and the head/stage. The simulations demonstrate that a delta change in TDL has the same effect on the center pivot pressures whether the TDL is small or much larger. The increased TDL requires additional stages be added to the pump. The pump head for a two stage pump is double that of the single stage and the KW is linearly related to the number of stages. This conclusion assumes that the same pump characteristic for the single stage is used as stages are added. This is often the case where the discharge is used to select the pump.

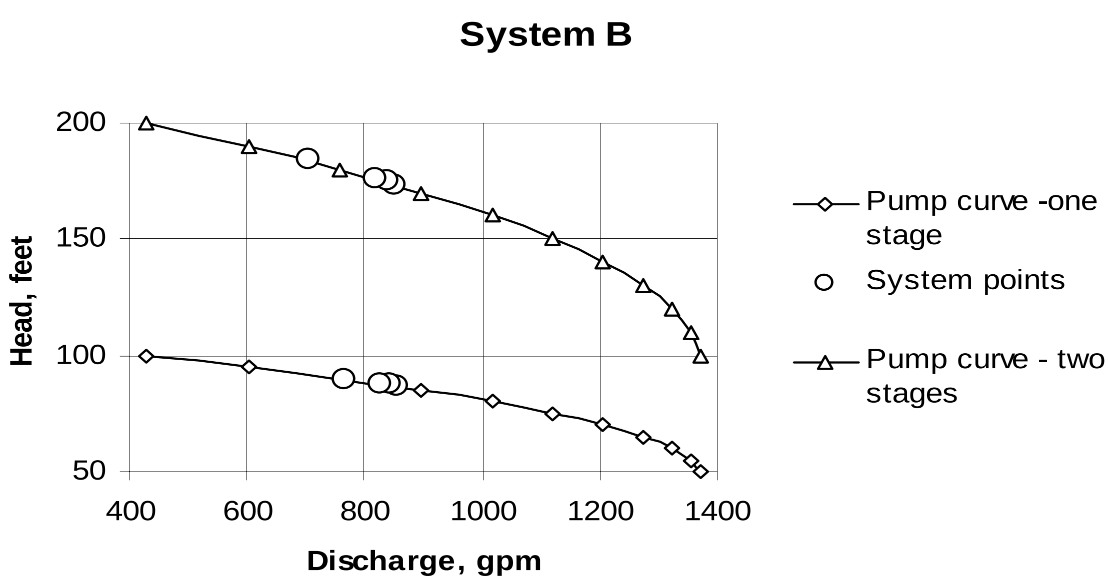

Figure 6. System B operating with single and two stage pump shown with simulated system points.

Table 6. Simulated operating characteristics for System B with a single and two stage pump.

	One stage pump				Two stage pump			
TDL, feet	0	20	40	50	90	110	130	150
Discharge,gpm	855.1	841.8	827.1	767.7	853	840	816.9	704.5
Pivot Pressure, psi	33.9	25.5	17.2	13.7	32.5	24.4	16.3	11.1
Irrigation depth, in.	0.6	0.6	0.6	0.6	0.6	0.6	0.59	0.51
Big gun, gpm	134	121	106	103	132	119	105	100
Head/stage, feet	86.7	87.3	88.1	90	86.7	87.4	88	92
KW	20.0	19.8	19.6	18.6	39.8	39.5	38.7	34.9

Another observation that can be illustrated with this system is the effect of pressure regulators. Figure 7 shows the center pivot hydraulic characteristics for System B assuming there are no pressure regulators with the same sprinkler package. Different pivot pressures were used to simulate the four points on the curve. The regulated system point (Fig. 7) has the same discharge as the first point on the curve. This emphasizes the influence of pressure regulators on a system. Regulators control the nozzle pressure for all heads when the pressure exceeds the regulator pressure along the lateral. The pivot pressure for the unregulated system is one-half that of the regulated system and the application depth decreases with distance from the pivot. The effect of drawdown on a regulated system is best observed by decreased pivot pressure as TDL increases. Systems with big guns are affected by a decrease in discharge as TDL increases. The big gun discharge decreased approximately 10% when the TDL increased 50-60 feet.

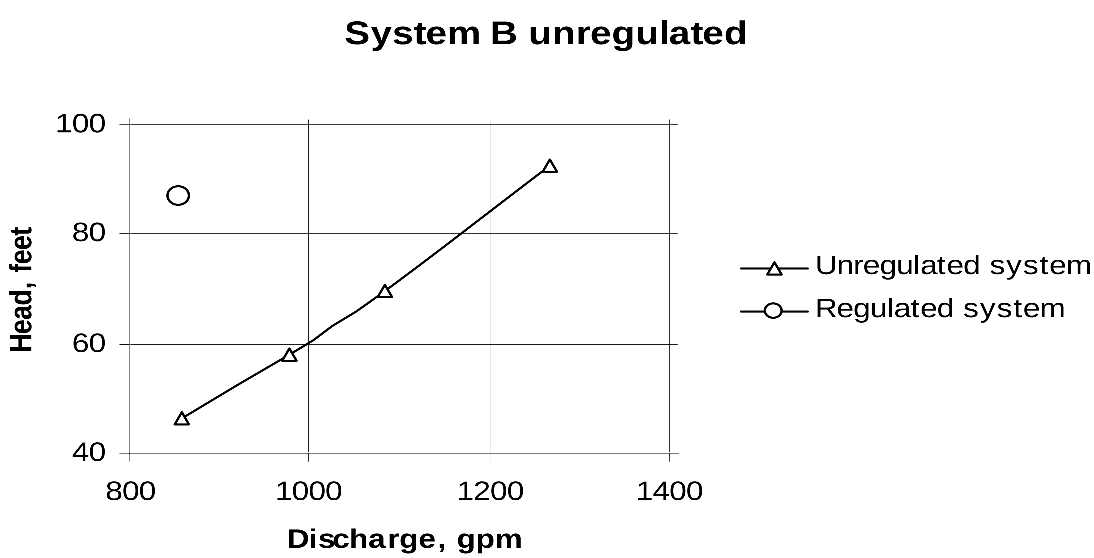

Figure 7. System B center pivot system hydraulic demand curve operating without pressure regulators

System K

System K is an illustration with a much longer lateral length (2584 feet) than previous systems. The topography change is about 3 feet along the entire lateral. Three and four stage pumps were used for the simulations comparing TDL's of 78 and 128 feet. Figure 8 shows the three and four stage pump curves and the simulated operating points. The discharges are almost double from the previous systems to irrigate the larger area. The operating characteristics are show in Table 7. The pivot pressure for the three stage pump and a TDL=128 feet is below that required for the lateral pressure to exceed the pressure regulator settings. The average irrigation depth is reduced by 8%. Figure 9 shows the application depths for each of the simulations. The depth is the same for all simulations up to 1600 feet from the pivot. The reduction in depth results from the smaller depths from this point on to the end of the pivot lateral. The system is not meeting the design but would be difficult to evaluate with catch cans. The application depth is 13% less at the outer end of the system. The best procedure for monitoring systems would be to measure the pivot pressure and compare to minimum pressure required at the time of design.

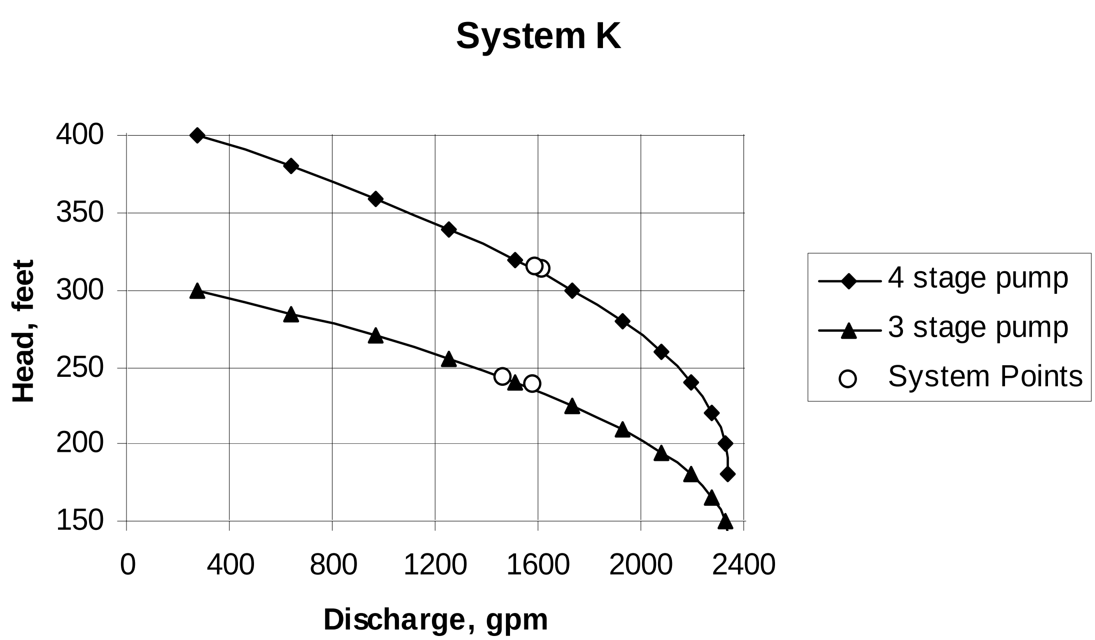

Figure 8. System K operating with three and four stage pumps shown with simulated system points.

Table 7. Simulated operating characteristics for System K with a single and two stage pump.

	four stage pump		three stage pump	
TDL, feet	78	128	78	128
Discharge,gpm	1617	1596	1583	1465
Pivot Pressure, psi	94	73	61	43
Irrigation depth, in.	0.38	0.39	0.39	0.36
Big gun, gpm	156	135	122	105
Head/stage, feet	78.3	78.8	79.3	81.2
KW	68.1	67.7	101.3	96.0

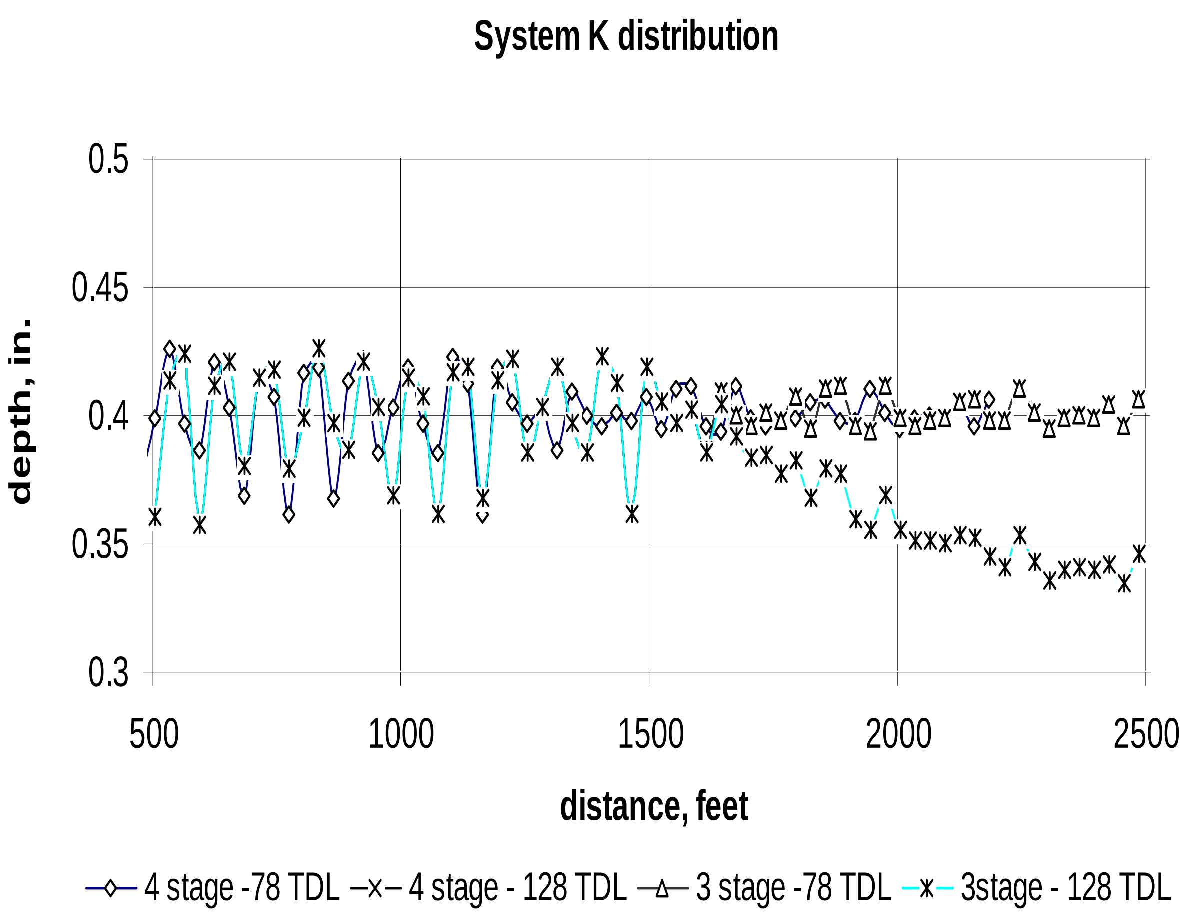

Figure 9. Simulated depths for the System K for the combinations of TDL and pump stages.

SUMMARY

The continual increase in drawdown in the Central Great Plains requires that producers monitor their water table depths and center pivot system operation. The data used for the simulation analysis indicated that many systems are designed to have considerably more pumping capacity than needed. This will automatically provide a factor of safety as the water table drops. The cost of operation of these systems is more expensive since many systems operate with pressure regulators. The excess pressure is dissipated in the regulator before reaching the nozzle and the energy is wasted. It is recommended that each system be analyzed to assure a pumping capacity that meets current needs plus an estimated increase in future water table depths. Monitoring wells in an area provides some guidance for the amount of anticipated increase in TDL requirements.

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USING TECHNOLOGY TO DEVELOP INTEGRATED WATER RESOURCES MANAGEMENT SCHEMES

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ABSTRACT

The State of Florida, like many states and nations around the world, will be facing critical choices regarding the future of its natural resources and economy in the next decade. Manatee County is one of eight (8) Florida counties included in the Southern Water Use Caution Area designated by the Southwest Florida Water Management District in 1992, indicating that the aquifer is under severe overuse. Manatee County is interconnecting three regional wastewater treatment plants to provide a 32-mile distribution system for urban and agricultural irrigation needs called Manatee Agricultural Reuse System (MARS). The Florida West Coast Resource Conservation and Development (RC&D) Council has developed the MARS Farm Connection Grant Program to connect farmers to the main distribution line. In addition to providing funding for connection, the RC&D will demonstrate a farm-scale integrated water resources management system that includes multiple interconnected sources of water to maximize both economic and environmental benefits.

The stress on the Floridian aquifer and the economic pressure on agriculture in Manatee County require new approaches to managing water resources. Minimizing aquifer withdrawals will require the use of alternative sources such as MARS reclaimed water, surface water, and aquifer withdrawals to meet crop and freeze protection demands. However, the quantities, quality, and seasonal availability of these sources of water present a challenging and potentially risky water management scheme for farmers. Using technology and automation in a farm-scale water management system has the potential to facilitate farmer acceptance of the complex integrated water management approach that will be needed to reduce aquifer withdrawals and keep farming viable in our communities.

To integrate various source of water and quantify the use of each water source, wireless data loggers will be installed at the farmer's wells and reclaimed water connections to transmit meter readings to a central computer which will geospatially represent this data. Recent developments in communication technologies and computer hardware/software will allow us to economically gather data and automatically update consumption information. Furthermore, data can be available on real time basis, if such information is needed. The different water sources on the farm can be interconnected through automation

technologies so that the use of water for the farmer is virtually seamless. Remote data collection and analysis will allow water use assessment and assist farmers with problems identification.

Use of technology in assisting farmers and communities with meeting their natural resource management objectives is one step towards facilitating sustainability and understanding barriers to conservation. Information collected will also help agencies develop programs to help farmers better manage their irrigation scheme and adopt efficiencies.

This approach will be part of a demonstration project which can promote an Integrated Water Resource Management Program for sustainable development. The more we understand our natural systems and their limitations, planning for water resource management can be better balanced with population growth, expansion and sustainability.

Quantifying resources through the use of technology and geospatially representing data can be made available to the various agencies and citizens to better see their individual and collective roles in creating sustainable communities where resources will be available for generations to come.

INTRODUCTION

The State of Florida, like many states and nations around the world, will be facing critical choices regarding the future of its natural resources and economy in the next decade. Three interrelated factors are contributing to the urgency of this problem: water use patterns and aquifer depletion, an important agricultural economy, and immense population growth. Although Florida is not typically considered an arid state, there are many complex water resource issues, including areas in the state that have been identified as having water supplies that are at risk due to overuse. Florida ranks number 2 nationally in production of fresh vegetables with 2002 sales of $1.4 billion and number 9 nationally in the value of farm products with $6.85 billion in sales for 2002. Additionally, the U.S. Census Bureau reported in April of 2005 that current projections indicate Florida, California, and Texas will account for 46 percent of the total U.S. population growth between 2000 and 2030, and that Florida will move from the fourth to the third most populous state, behind California and Texas. The Census Bureau also predicts that Florida will add more than 12 million people between 2000 and 2030.

The combination of aquifer depletion, water for food production, and population growth has urged many counties in Florida to plan for sustainable water resources. Manatee County located just south of Tampa Bay, is one such county. Since the mid 1980s, Manatee County has been planning and developing its reclaimed water system, the Manatee Agricultural Reuse System (MARS), to supply farms and landscape areas with reclaimed water. To connect the farmers to the reclaimed water system, the Farm Connection Grant Program is being implemented by the Florida West Coast Resource Conservation and Development (RC&D) Council.

The Florida West Coast RC&D Council is a local U.S. Department of Agriculture sponsored 501(c)(3) organization specializing in community leadership capacity building in the areas of sustainable economic and community development, natural resources use and conservation, sustainable agriculture, and healthy community food systems. The RC&D Area (Figure 1), authorized by the Secretary of Agriculture in 2001 includes Hillsborough, Manatee, Pinellas and Sarasota Counties, on the central southwest coast of Florida, serving a population of approximately 3 million people (Community Survey of the U.S. Census Bureau, 2003).

Figure 1 – Location of Manatee County, Florida within the Florida West Coast Resource Conservation and Development (RC&D) Area

Sustainability has been at the core of the RC&D concept since the inception of the program by the Department of Agriculture in the 1960s when the USDA program was created to address rural poverty in the United States. Assistance from USDA was provided to help local people build sustainable natural resource-based economies that would improve their quality of life. RC&D is very much like many community or economic development non-governmental organizations around the world, using natural resources, ingenuity, and partnerships to empower people to make their lives better.

The involvement of the Florida West Coast RC&D Council in the MARS project has created an opportunity to implement water resources management schemes on farming operations.

Sustainable Food and Water Balance

The Food and Agriculture Organization (FAO) of the United Nations has reported extensively on the relationship to food production and water resources (UNESCO, 2003). One trend that exists globally and at a local level in Manatee County is that agriculture accounts for up to 70 percent of the world's water withdrawals from surface and groundwater[1]. Up to 300,000 cubic meters (80 million gallons) of water per day are pumped from the Floridian Aquifer for agricultural irrigation in Manatee County (approximately 85% of total usage) and an additional 45,000 cubic meters (12 million gallons) are pumped per day for

[1] In the United States 190 billion m^3/yr (50 billion gallons/yr) of fresh water is used for irrigation; 25 million hectares (62 million acres) are irrigated, 47% by flooding, 46% by sprinklers, and 7% by micro-irrigation.

residential use. Irrigation efficiencies worldwide are approximately 40 percent, with 60 percent of the water drawn being lost to evaporation, deep infiltration, runoff, or weed growth. Irrigation efficiencies in Manatee County vary widely depending on the type of irrigation system, maintenance of the system, and the commitment to irrigation water management to maximize the system's efficiency.

Manatee County is one place where the importance and future of agriculture is in question. Manatee County, like many urban-edge areas, is facing agricultural land conversions to residential and commercial uses. The county's status in the ranks of agricultural production implies that the natural resources situation in Manatee County is favorable for economically viable agriculture and that water resource planning should address the economic importance of agriculture as well as contributing to a local food system. However, state legislation requires regional water management districts around the state to plan for allocation of scarce water resources to meet population needs for potable consumption, natural systems, agriculture and industrial users in that order. Florida counties, under the jurisdiction of regional water management districts, are required to follow these regional plans in planning for their own water supplies.

Non-sustainable Water Resource Consumption

Manatee County is one of eight (8) Florida counties included in the Southern Water Use Caution Area (SWUCA, Figure 2) designated by the Southwest Florida Water Management District (SWFWMD) in 1992. A "water use caution area" is an area where water resources are or will become critical in the next 20 years. The implication of a water use caution area is that the use of water exceeds recharge, or in other words, the use is not sustainable.

The SWUCA is a 5,100-square-mile area in southwest Florida where water resources are already critical. Within the SWUCA, the Eastern Tampa Bay Most Impacted Area (ETB MIA) extends along the coast of southern Hillsborough, Manatee, and northwestern Sarasota counties, where there is the greatest concern for saltwater intrusion as a result of depressed aquifer levels. Depressed aquifer levels not only allow saltwater intrusion, but also contribute to reduced flows in the rivers and lowered lake levels in some areas.

To work towards stabilization of groundwater levels, permitted groundwater withdrawals from the Floridian aquifer in the ETB MIA have not increased since 1990. However, this effort alone is not enough to offset increases in groundwater withdrawals in the Floridian aquifer as a whole, due to increased demand from rapid population growth in the state.

The SWUCA Recovery Strategy, developed by SWFWMD and currently in draft form, is designed primarily to manage groundwater withdrawals to achieve and sustain the Floridian aquifer saltwater intrusion minimum aquifer level. There are numerous sub-strategies in the SWUCA, including the incorporation of water reuse measures and providing financial incentives to develop alternative supplies such as reclaimed water projects. However, very few of the sub-strategies come without actual costs, opportunity costs, or other material and non-material implications.

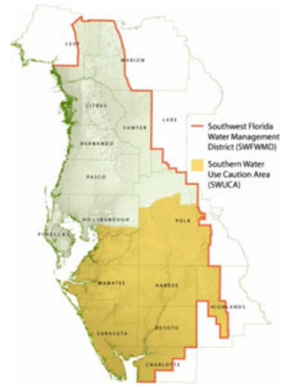

Figure 2 – The Southern Water Use Caution Area (SWUCA) of the Southwest Florida Water Management District (SWFWMD). Graph source: SWFWMD.

Continued development of reclaimed water projects has been established as a priority for the state by the Florida Reuse Coordinating Committee and the Water Conservation Initiative Water Reuse Work Group in their June 2003 report *Water Reuse for Florida.*

The Manatee Agricultural Reuse System (MARS) project is part of this larger regional strategy to reduce aquifer withdrawals through treated wastewater reclamation and recycling, designed to pipe reuse water from urban areas to rural areas for use in agricultural irrigation as an alternative to groundwater use.

The MARS Project

Manatee County has completed interconnection of three regional wastewater treatment plants to provide a 32-mile distribution system for urban and agricultural irrigation needs. Manatee County has been working on the main transmission pipeline for approximately five years with a budget of about $55 million, which includes three booster pumping stations to convey reclaimed water throughout their transmission line.

The RC&D will provide funding and technical assistance to link Manatee County's MARS main transmission line to the farmer's agricultural irrigation system using funds obtained through Congressional direct appropriations, which now total $8.5 million. The RC&D has developed a three phase MARS Farm Connection Grant Program to carry out this objective. The first two phases consist of connecting the farmers to the reclaimed water system and to create a smooth technological transition from fresh or well water to reclaimed water use by the farmers.

Phase III was developed for the RC&D to play a community role through the implementation of demonstration projects and incentives that address reclaimed water quality, seasonality of rainfall and reclaimed water availability, and water conservation.

Presently, connecting farmers and nurseries to the MARS transmission pipe is underway.

Integrated Water Resources Management

Food and Agricultural Organization of the United Nations defines Integrated Water Resources Management (IWRM) as a process that promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. It is also a political procedure with long-term gains that are vital to the sustainability of the resource base (Global Water Partnership).

Practically all of the materials found on the Internet related to IWRM discuss policies, management, and procedures on the subject of Integrated Water Resources Management issues.

The approach RC&D will be taking in IWRM is two fold: application of technology to maximize efficiency for the management of water and other resources on agricultural land, and to tap into the knowledge and skills of farmers, manufactures, policy makers, water district agents, regulators, governmental agencies, NGOs, and other stakeholders by bringing them together in a partnership towards addressing the many issues related to water resources management.

Farm-Scale Integrated Water Resources Management

The stress on the Floridian aquifer and the economic pressure on agriculture in Manatee County require new approaches to managing water resources. Additionally, many residents, decision-makers, and consumers are not aware of the importance of agriculture to the economy of Manatee County and to the security of the food system in their local area. That places additional pressure on finding ways to assist farms with water conservation as agriculture consumes the largest volume of water, as in most areas of the world.

Minimizing aquifer withdrawals requires the use of alternative sources such as MARS reclaimed water, and surface water, in addition to some aquifer withdrawals to meet crop and freeze protection demands. However, the quantities, quality, and seasonal availability of these sources of water present a challenging and potentially risky water management scheme for farmers. Using technology and automation in a farm-scale water management system has the potential to facilitate farmer acceptance of the complex integrated water management approach that will be needed to reduce aquifer withdrawals and keep farming viable in our communities.

The different water sources on the farm can be interconnected through automation technologies so that the use of water for the farmer is virtually seamless. Remote data collection and analysis will allow water use assessment and assist farmers with problems identification.

METHODOLOGY

The implementation of the MARS Farm Connection Grant Program provides an opportunity to address integrated water management schemes by using various techniques and technologies to create efficiencies and conserve water and other resources.

One of the goals of the program is to measure the reduction of Floridian Aquifer pumping from agricultural lands where the MARS reclaimed connection will be made. Wireless transmitters will be installed at the master meter reclaimed water connection and at the wells on the farmer's property. The data will be collected on a central computer and geospatially mapped on a Geographic Information System map.

Another goal of the program is to demonstrate by integrating the various water conservation techniques the reduction in water consumptions and address water quality issues. To achieve these goals, RC&D is utilizing technology and automation means to develop on farm integrated water resources management schemes.

Water Meter Data Collection

For RC&D to be able to quantify the reduction of aquifer withdrawal, a remote meter readings program is being implemented. Flow meters installed downstream of the reclaimed water connections and those next to the farmer's well will be collecting and forwarding this data to a central computer wirelessly.

Presently, as it is in most other parts of the world, water meter data is read by the farmer and forwarded to a monitoring agency or it is read by a county/water authority representative, usually once a month.

The technology for remote meter reading already exists. Utility departments across the country are using Automatic Meter Reading (AMR) technologies to read water, electric and gas meters. Currently, approximately 20 percent of the water utility market in the U.S. is engaged in using the AMR technology.

A drive-by meter reading was developed several years ago whereby a meter transmits a low frequency signal to a drive-by utility personal. Once the data is collected from an area, the information is downloaded to the utility department's computer for processing and billing.

A more recent technological development is a fixed area network method, where meters transmit data to a collector, in a grid wide network using low power radio transmitters. The data collector forwards this information to a central computer using land line or cellular technology. Other than the advantage of reducing the collection costs associated with reading meters, it creates a medium for an efficient and continuous transfer of meter reading data into central software for billing purposes.

Similar technologies can be adapted at regional levels to collect water consumption readings for agricultural water meters at wells, lakes, reservoirs and rivers to monitor pumping volumes. Data can be transmitted using a cell phone, land lines, or satellite transmission to a central location where the information is stored, and managed by computer networks. Having continuous and real time access to this type of data can assist in developing security strategies for the protection of the water resource as well.

Having a remote meter data collection network in place, addition of a rain tipping bucket and a soil moisture sensor at farms can provide an added advantage to the farmer, who will be able to evaluate water consumption and can address control measures for water conservation. Other than being able to monitor their water consumption, farmers will be able to log on to their account and evaluate if a given rain event has adequately recharged to the desired soil moisture levels, and only apply the balance of irrigation water needs for their crop. In this way farmers become partners in reducing their water consumptions as a result of data availability to decide how much irrigation water is needed for their crops.

Data collected from water meters and rain tipping buckets can be interfaced with Geographic Information System (GIS) software for planning, evaluation and analysis. GIS mapping provides the users with the advantage of spatial data management and its mapping. Historic data can be analyzed, and geographic patterns can establish relationships between features. The results of this analysis can be displayed as a map, values in a table, or in a chart format. Water consumption and rain fall data mapped in GIS will provide the data needed to implement conservation practices.

For the MARS farm connection program, a number of AMR systems have been evaluated and are being installed on an experimental basis. A coordinative effort between Manatee County and RC&D is being developed for both parties to have access to the meter reading data. The goal is not only to collect, map and report reclaimed water consumption and aquifer pumping data for program evaluation purposes, but also to take the program to another level by demonstrating the use of technology for water consumption data collection in farming operations.

Having access to continuous and accurate flow of data from water meters, as opposed to once a month reading, with possible inaccuracies, can open new doors towards water resources management and conservation program development.

MARS Demonstration Sites

Observing farming practices in Southwest Florida indicates that isolated efforts are made by the farmer to improve irrigation efficiencies. Rain sensors may be used to shut down irrigation once a pre-defined rain event is reached, weather stations may be used to gather hydrological data, soil moisture sensors may be used to determine moisture levels, drainage improvements may be adopted to control water table and convey water away from a portion of a farm, runoff collection ponds may be constructed to reduce nutrient loadings and recalculate water on the farm, and poor water quality may be treated with chemicals.

One of the objectives of the MARS demonstration sites is to demonstrate by integrating the various efforts and use technology and techniques to reduce water consumption and conserve resources. In this way sustainable resource management programs are developed in partnership with the farmers.

To achieve this objective a continuous system of monitoring and real time evaluation will need to be set up so that irrigation decisions are made based on existing variables and conditions, and resource are efficiently allocated to respond to demand. Examples of such an approach are discussed below.

Water Quality Issues

Water sources available on farms in the Manatee County can consist of deep well aquifer water, shallow well brackish water, municipal treated reclaimed water, storm water runoff, and tail water collection system. Since it is the goal of the Manatee County's MARS program to reduce pumping from the Floridian Aquifer and use reclaimed water in its place, the quality and availability of reclaimed water has to be taken into consideration.

During the planning stages of the MARS transmission pipe, efforts were made to design the system so that farmers could benefit from the reclaimed water discharged from the three interconnected wastewater treatment plants. Not all farms in the County are located next to the transmission pipe and with the recent expansions in urban sprawl, only pockets of farms and nurseries in the area are candidates for connecting to the MARS pipe. More significantly, the reclaimed water quality may present a challenge to nurseries and crops sensitive to salts and other minerals.

Recent reports are indicating that intrusion of brackish water into the sewage collection system in the coastal areas of Manatee County has resulted in undesirable chloride levels in reclaimed water. Manatee County's wastewater treatment facilities meet the minimum requirements for the State of Florida discharge guidelines. Removal of salts can be a complex process which may require advanced treatment facilities. In lieu of this challenge, it may be possible to mix reclaimed water with other water sources that may be available on a farm. If storm water and/or tail water recovery measures are put in place, it may be possible to mix the incoming reclaimed water in order to improve water quality.

Another measure could be treating part of the reclaimed water with a small onsite reverse osmosis plant and then mixing the higher quality of water with the reclaimed water. Although this approach may be feasible for a small scale farming operation, costs for such a treatment process could be impractical for some of the farms thousands of acres in size. Also, even though reverse osmosis has proved to be a viable alternative for water treatment, especially with the drop in manufacturing costs of membrane production, disposal of the reject water generated by this treatment process may present a challenge to the farmer and permitting agency.

Implementing Irrigation Techniques for Water Conservation

At the heart of an integrated water resources management scheme on farms is the ability to access data on the environmental conditions and address the crop water needs on a real time basis. Many automation and control technologies are presently available to deal with the growing concerns of farmers for irrigation, water resource and environmental management of their crops, albeit, many farmers elect to address some of the issues, given the limitations in understanding the technologies involved and the costs associated with their implementation.

RC&D's goal is to implement, through demonstration, automation techniques that can integrate the many factors involved in water and other resource management, and to provide the farmer with on going support and expertise needed to show their effectiveness. As part of an automation technology, a controller may be able to activate an irrigation cycle by first sensing existing conditions, and then irrigate based on crop water needs, thus effectively reducing aquifer pumping, and conserve energy. As a back up strategy, in times of power failure, solar or battery back up systems can continue with system operation.

The following scenario is an example of a nursery that can benefit from using technology to develop management schemes. Presently, piped fresh water from the County supplies the irrigation needs of the nursery. On the average the nursery pays $5,000 for its monthly water bills. Part of the stormwater runoff is collected on site. Fertilizer enriched irrigation water runoff is also partially collected on site and is pumped back into the irrigation system after disinfection using chlorine.

The nursery is located next to the MARS transmission line, but the owner is concerned about the quality of reclaimed water and its availability. Also, for propagation purposes, the nursery will need to apply fresh water during the early growing stages of the plants.

As an integrated approach to water quantity and quality for this nursery, water pressure, Electrical Conductivity (EC) and chloride levels at the reclaimed water connection can be measured. Fertigation can be minimized since nutrient rich reclaimed water is being used. If the chloride levels prove to be too high, water from the stormwater runoff can be pumped into the irrigation system. Also, if the incoming reclaimed water pressure is low for the efficient operation of the irrigation system, pumped water from the on site reservoir can boost this pressure.

Tailwater recovery can be extended to collect all of the runoff water from both irrigation and stormwater runoff in the on site reservoir. Since the reservoir and reclaimed water is used in this scenario, nutrient rich irrigation water runoff from the site will be minimized.

Overhead sprayers presently used to irrigate the various horticultural plants can be replaced with pressure regulated in-pot sprayers, thus water is only applied at the root zone level. Pressure regulation will ensure uniformity of water application, resulting in uniform growth of the plants, so long as the soil medium and other conditions remain the same. Soil moisture sensors can be utilized to ensure adequate water is applied as part of the irrigation cycle. Precautionary measures to flush out the excess salt build-ups in the root zone by over irrigating can be considered.

Phase III of the MARS project may also implement solar energy to run electric pumps and controllers to supply desired water quantities and qualities using variable frequency drive pumps to adjust flow and pressure demands automatically, and minimize on site pressure reductions downstream of the system.

Florida has been coined as the lightening capital of the world since it experiences significant lightening forces during the hot and humid summer months. Many of the automation technologies discussed here will require sensitive electronic and computer equipment that can be damaged every year during the summer irrigation cycles. Auto system shut downs during storms is an important factor in an automation process in Florida so that the farmer can depend on their systems after the passing of storms.

Florida coastal areas, along with other coastal areas around the world, give possibility to use wave energy converters to generate either electricity or desalination of water to be used for agricultural purposes and possibly mixing with brackish water. This concept may be gaining greater attentions in the years ahead and will need to be addressed at a regional policy level.

From RC&D's perspective, use of technology and transfer of technology, the knowledge base, is an important ingredient in the long term sustainability of our projects. The economics and affordability of the technology is also an important element in technology transfer and will have to be taken into consideration during its planning, execution and management stages.

MARS Program Complementing IWRM Strategies

Southern Florida Water Use Caution Area (SWUCA) recovery strategy has been developed by the Southwest Florida Water Management District (SWFWMD) as an integrated strategy to address the diverse issues, policies and management of water resources in the south west region of Florida.

Since the early 1990s, the Governing Board of SWFWMD has been engaging the various stakeholders to address regulatory and non-regulatory components of the recovery strategy. In their recent draft of this strategy (March 2006), they have addressed issues related to the present water supply plans, provides descriptions of the various conservation initiatives and projects that are part of the strategy, discusses existing and planned water resources development projects, provides regulatory components of the strategy and the financial tools available to achieve the goals of their strategy. These integral elements in the water resources management are ingredients for region wide Integrated Water Resource Management (IWRM) schemes.

As part of these schemes, SWFWMD has been funding various projects to promote development and use of reclaimed water by the counties and municipalities in the SWUCA area. Construction of the MARS transmission pipeline and the three pumping stations to supply reclaimed water in Manatee County are being partially funded by SWFWMD as part of their region wide strategy to reduce Floridian Aquifer pumping.

A significant component of the District's effort is to enhance agricultural water use efficiency by funding technology and best management practices (BMPs) research for farm irrigation and management. Along with research, normally conducted by the Institute of Food and Agricultural Sciences (IFAS) at the University of Florida, educational programs are carried out in each county under the extension arm of IFAS.

Phase III demonstration projects that RC&D is planning to carry out may compliment the efforts towards SWUCA strategy. As farmers partner with RC&D

in the Phase III program for demonstrating the techniques and automation technologies, it will be possible to use their operations as sites where the various stakeholders come together to observe results of the water management and conservation schemes.

CONCLUSIONS

Advances in low cost wireless radio communication, computer technologies and sensing equipment provides an opportune time in the field of agriculture to develop technologies that can assist a farmer with managing their water and other interrelated resources in a sustainable manner.

Partnering with the farmers, RC&D’s role will be to demonstrate that these technologies can be part of an integrated management of water resources on farms that not only conserve these vital resources, but also address the many complex issues as part of region wide IWRM policies and programs that water agencies and their partners have been developing for decades.

Two goals of RC&D are to develop remote water meter readings and to integrate technologies for the management and conservation of water and other resources on farms connected to the MARS reclaimed water program.

Collection of water meter reading and rain data on a continuous basis can address the goals of IWRM strategies by providing the information a water authority and their partners need to develop area wide realistic goals, establish short and long term plans, and target farming areas to promote water conservation and efficiency improvement programs. Real time and accurate collection of data opens up much possibility for water resources management and conservation planning.

Integrating techniques and technologies to conserve water and other resources will benefit from the research work done by the many institutions worldwide and IFAS at the University of Florida to address the many complex and interrelated concerns of water resources management in Manatee County.

Success of a technologically oriented project can be measured by the sustainability and long term positive effect it will have on a population it is serving. The approach in the three phases of the MARS reclaimed water program will be more than just connecting pipes and instruments and linking them with computers, it will focus on developing partnerships with the farmers, transferring knowledge and putting in place functional systems that will be affordable, economical, and address water conservation issues. This program will also develop a partnership with Manatee County, Southwest Florida Water Management District and other stakeholders in exchange of ideas and lessons learned from the demonstration of integrating water resources management programs on the farms.

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Determination of the Optimal Date for Sowing of Wheat in Canal Irrigated Areas using FAO CROPWAT Model

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ABSTRACT

Mismatch between available water supplies and crop water requirements both, in terms of quantity and timing are a major cause of low water use efficiency in canal irrigated areas in India. FAO CROPWAT model adequately predicts the effects of water stress on yield. The applicability of the model was studied with the help of operating schedule data of a small *Noorpur* distributary of Western *Yamuna* Canal system. The expected yields of wheat under different sowing dates, during a large period of sowing followed by farmers in north Indian Plains (First week of November to third week of January), were estimated corresponding to the most probable canal operation schedule. Third week of November was found to be the optimal sowing period for wheat. This paper concludes that CROPWAT is a powerful tool to simulate different crop water need scenarios under different planting dates and thus enables the user to select most optimal sowing date to realize higher yields and water use efficiencies by matching the probable canal water supplies with crop needs.

Key words: CROPWAT, Canal command, Wheat, Sowing date;

INTRODUCTION

Growing competition for water from domestic and industrial sectors is likely to reduce its availability for irrigation. The need to meet the growing demand for food will require increased crop production from less and less water. Achieving greater efficiency of water use is a a challenge in the near future and will include the employment of techniques and practices that deliver a more accurate supply of water to crops.

Crop growth simulation models and hydraulics of water movement in crop root zone help in making predictions for irrigation scheduling under different conditions of water supply. The CROPWAT model developed by the FAO Land and Water Development Division (FAO, 1992) is based on simple water balance principle that allows the simulation of crop water stress conditions. It also helps in estimations of yield based on well established methodologies for determination of crop evapotranspiration and yield responses to water. Smith and Kivumbi (2002) described in detail the use of CROPWAT model in management of deficit irrigation situations. Marica and Cuculeanu (2000) and Tuinea and Palade (2000) found CROPWAT model useful in assessment of impacts of draught.

In north Indian plains, wheat is a predominant crop grown in *Rabi* season. It is sown from first week of November to First week of January. Crop sown on different dates require different irrigation schedules. Operation of canals somehow, is independent of agricultural; operations in their command area. Crops grown on different dates experience water stress of different magnitudes in areas under exclusive command of canals, consequently, wheat sown on different dates result into different yields and water use efficiencies (Rajput and Patel, 2005).

Canal delivery schedules are seldom prepared on the basis of the actual water requirements of the command area. Also, the canal operation schedules are rarely adhered to the fixed pattern. This result into mismatch between water needs and canal water availability. Consequently the water use efficiency in canal command areas is very low. Determination of probable canal operation schedules and matching the crop water needs with it by appropriately selecting the crop planting date may help in achieving high water use efficiency as well as high yields. Water needs of crops grown on different dates may be simulated and resulting desired irrigation schedules may be compared with the availability of canal water with a view to achieve highest water use efficiency.

MATERIALS AND METHODS

In the present study, CROPWAT model was used for determining irrigation schedule for wheat sown on different dates under the agro climatic conditions of western Uttar Pradesh, India Villages Lakhan and Masauta, District Ghaziabad were selected specifically because they provided a unique opportunity to study different scenarios of irrigation water availability including exclusive canal irrigated areas, exclusive tube well irrigate area as well as areas with both canal and tube well irrigation facility, in the close proximity, for comparisons. Resulting irrigation schedules were then compared with the probable canal water supplies to determine optimal sowing dates for wheat to match water needs with likely water availability with a view to achieve maximum yields. In case of fields exclusively irrigated by tube wells and both with canal as well as tube wells also were considered and appropriate wheat sowing dates were in those situations were also determined.

The study area falls within the command area of Noorpur distributary of Western Yamuna canal system. Though rotational water distribution system (*warabandi)* is said to be in vogue on the canal system but last 20 years data of operation pattern of the distributary indicated no fixed pattern of its operation. Based on the frequency of operation weeks of the distributary in different years a most likely operation schedule during *Rabi* season was developed (Table 1).

CROPWAT is a computer program for irrigation planning and management, developed by the Land and Water Development Division of FAO (FAO, 1992). Its basic functions include the calculation of reference evapo-transpiration, crop water requirements and plan irrigation. Based on daily water balance, the user can simulate crop yield under different water supply conditions and estimate yield reductions and water use efficiencies. Typical applications of the water balance include the development of irrigation schedules for various crops.

The critical soil water content varies for different crops and different crop stages and is determined by the rooting density characteristics of the crop, evaporation rate and, to some extent, by the soil type. Further reduction in soil moisture results in reduction in evapotranspiration that directly influences the crop yield.

The average monthly values from 19 years data of the study area (1983 to 2002) were calculated from daily meteorological parameters like maximum temperature, minimum temperature, relative humidity, wind speed and sunshine hours and are tabulated in Table 2. Penman-Montieth equation was used in ETo calculations with the following values for Angstrom's Coefficients: a = 0.25, b = 0.5. Effective rainfall values were determined to assess the net irrigation water requirements. Fig. 1 represents the monthly variations in rainfall and effective rainfall for the study area.

Soils of the study area were loamy sand (medium) with total available soil moisture of 240.0 mm/m depth. Maximum infiltration rate was 40 mm/h and the root-restricting layer was located at 0.90 m depths. Winter wheat was taken as the test crop with the following parameters (Table 3). Irrigation at 45% of readily soil moisture depletion was considered as the criteria for irrigation.

Nine different sowing dates namely, November 1, November 8, November 15, November 22, December 1, December 8, December 15, December 22 and January 1, were simulated for estimating their schedule for irrigation and expected yields. The simulations using CROPOWAT model were done for all the nine sowing dates under the exclusive canal irrigated area.

RESULTS AND DISCUSSION

Most probable operation schedule of Noorpur distributary for *Rabi* season was developed and is presented in Table 1. In exclusive canal irrigated areas, irrigation water is available only at per the canal operation schedule, irrespective of the actual crop water requirements. Wheat sown on different dates are likely to receive different number of irrigations from canal water supplies (Table 4). Estimated values of reference crop evapo-transpiration, effective rainfall, and net irrigation water requirement and likely number of canal irrigations, expected yield and resulting water use efficiency in exclusively canal irrigated area resulting from the use of CROPWAT model are presented in Table 5. Values of total evapo-transpirational water requirement steadily increased with the increasing delay in sowing of wheat from November 1 to January 1. The probable canal pattern indicated possibility of only four irrigations except for wheat sown during November 15 to December 1, when five canal irrigations would be possible. It was assumed that about 40 mm depth of irrigation water would be available per canal irrigation.

In all cases of wheat sowing dates, actual evapo-transpirational water requirements were higher than the expected canal water supplies (Table 5). It may also be noted from Table 5 that deficit of canal water in meeting crop water needs of wheat progressively increased with increasing delay in wheat sowing. Wheat sown on November 22 resulted in maximum wheat yield (4.0 t/ha) and also in highest water use efficiency (2.0 Kg/m^3). Yield of wheat sown a week after and a week earlier resulted in the next best yields (3.8 and 3.6 t/ ha, respectively) and water use efficiencies (1.9 and 1.8 Kg/m^3, respectively). Wheat sown between November 15 and December 1 is likely to receive five canal irrigations and consequently result in higher yield and water use efficiency.

Fig. 2 presents a comparative picture of the expected wheat yields and water use efficiencies under different situations of availability of irrigation water for wheat sown on different dates between November 1 and January 1. The figure 2 indicates that in general, appropriate date for wheat sowing falls between November15 and December 1

CONCLUSIONS

November 22 to December 1 was found to be the most appropriate sowing date for wheat in exclusive canal irrigated areas. The study confirmed that CROPWAT is a potent tool to determine optimal sowing date of crops with a view to maximize the crop yields and water use efficiency.

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Table 1 Probable operation schedule of *Noorpur* distributary during *Rabi*

S N	**Month**	**Week**
1	November	1-8
2	December	8-15
3	January	15-20
4	February	8-15
5	March	1-8
6	April	1-8
7	May	8-15

Table 2 Meteorological Data (19 years average)

Months	Max Temp (°C)	Min Temp (°C)	Relative Humidity	Wind speed (km/d)	Sunshine hours	Evapo-transpiration* (mm)
January	20.5	6.4	70.3	80.4	5.8	1.83
February	23.3.	8.9	66.0	100.6	7.0	2.67
March	29.4	13.7	57.0	110.4	8.0	4.06
April	36.1	18.7	45.8	115.7	9.3	5.70
May	39.8	24.2	42.9	145.3	8.1	6.70
June	38.2	26.6	53.2	165.4	6.5	6.28
July	34.9	26.8	70.6	134.9	5.3	4.84
August	33.3	26.0	75.8	103.3	5.3	4.22
September	33.8	24.2	70.2	93.4	7.1	4.29
October	33.0	17.4	60.5	58.1	7.9	3.35
November	28.1	11.3	60.6	45.9	7.2	2.17
December	22.6	7.1	67.5	60.1	5.5	1.66

Table 3 Crop parameters

Growth Stages	Initial	Development	Mid	Late	Total
Stage Lengths (days)	30	45	45	25	145
Crop Coefficients (K_c)	0.70	0.70	1.15	0.40	
Rooting Depths (m)	0.35	0.70	0.90	0.90	
Depletion Levels (P)	0.50	0.70`	0.50	0.80	
Yield Factors (K_y)	0.40	0.60	0.80	0.40	1.00

Table 4 Water use efficiency under exclusively canal irrigated area

S N	Sowing date of wheat	Durations of probable canal supplies	No. of expected canal irrigations
1	November 1	Dec 8-15, Jan15-20, Feb 8-15, Mar1-8	4
2	November 8	Dec 8-15, Jan15-20, Feb 8-15, Mar 1-8	4
3	November 15	Dec 8-15, Jan15-20, Feb 8-15, Mar 1-8, Apr 1-8	5
4	November 22	Dec 8-15, Jan15-20, Feb 8-15, Mar 1-8, Apr 1-8	5
5	December 1	Dec 8-15, Jan15-20, Feb 8-15, Mar 1-8, Apr 1-8	5
6	December 8	Jan15-20, Feb 8-15, Mar 1-8, Apr 1-8	4
7	December 15	Jan15-20, Feb 8-15, Mar 1-8, Apr 1-8	4
8	December 22	Jan15-20, Feb 8-15, Mar 1-8, Apr 1-8	4
9	January 1	Jan15-20, Feb 8-15, Mar 1-8, Apr 1-8	4

Table 5 Water use efficiency under exclusive canal irrigated area

Date of sowing	ETc during the crop period (mm)	Effective rainfall, (mm)	No. of likely canal irrigations	Expected amount of canal water supplies (mm)	Expected wheat yield (t/ha)	Water use efficiency (Kg/m^3)
Nov 1	262	43	219	160	2.8	1.75
Nov 8	269	43	226	160	2.9	1.80
Nov 15	325	43	282	200	3.6	1.80
Nov 22	347	43	304	200	4.0	2.00
Dec 1	337	43	294	200	3.8	1.90
Dec 8	373	47	326	160	2.9	1.81
Dec 15	403	51	352	160	2.9	1.81
Dec 22	469	58	411	160	2.6	1.62
Jan 1	507	67	440	160	2.6	1.62

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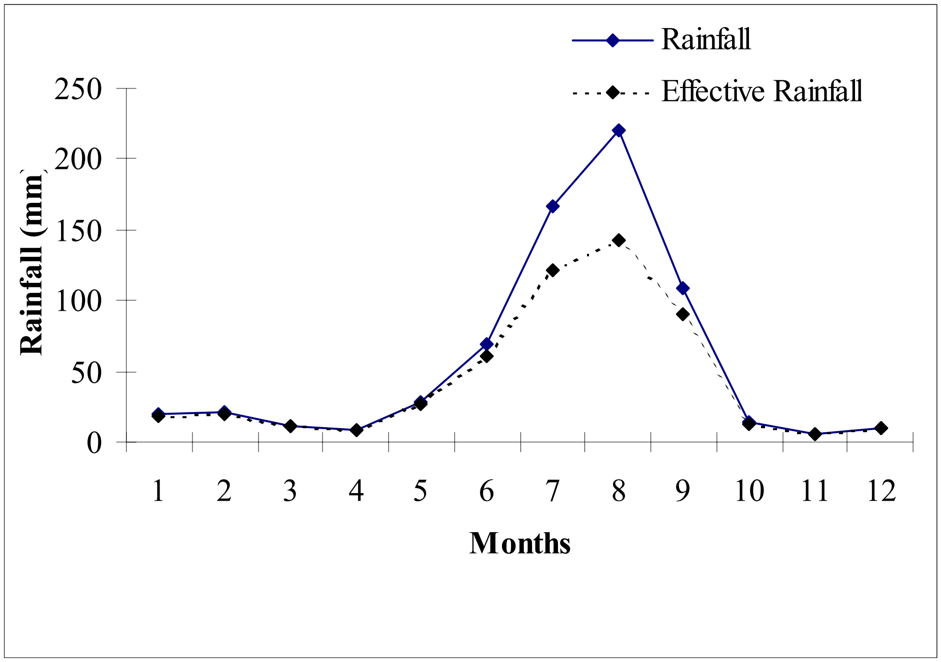

Fig. 1 Monthly variation in rainfall and effective Rain in the study area

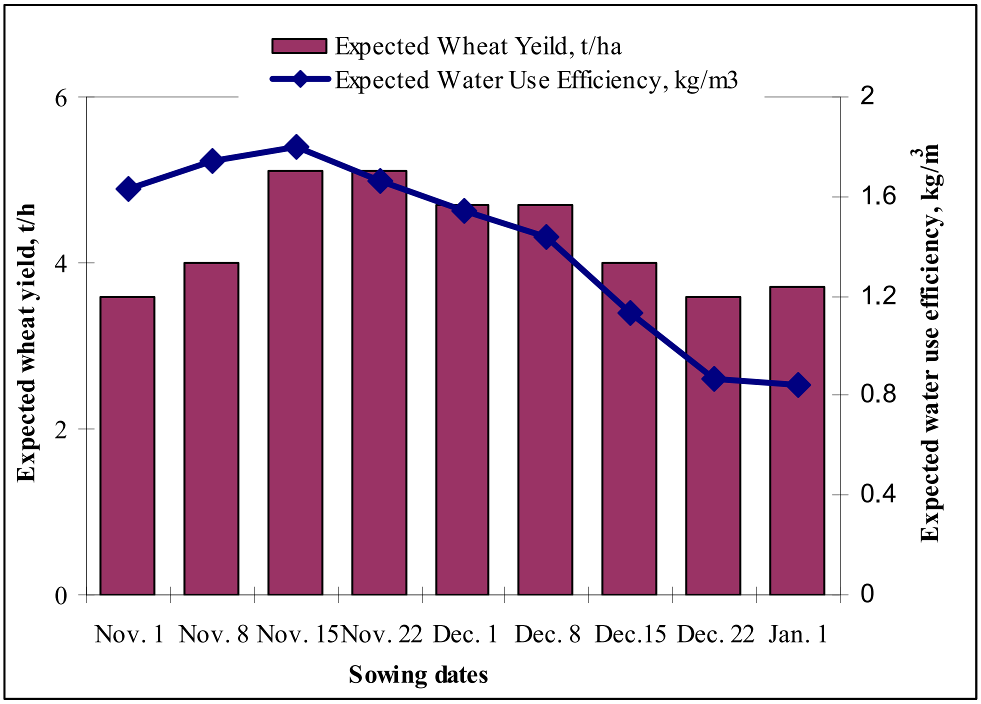

Fig. 2 Effect of sowing date of wheat on its yield and water use efficiency

Innovative subsurface drip irrigation (SDI) alternatives for on-site wastewater disposal in the Alabama Black Belt

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Topic areas: 1) SDI and wastewater effluent 2) GIS and environmental analysis

Abstract: More than 75% of the Blackland Prairie area of Alabama is unsuitable for conventional septic systems due to high clay content. An innovated integrated soil moisture controlled subsurface drip irrigation (SDI) is proposed as an alternative to conventional septic systems. This study evaluates the ability of an integrated treatment/disposal system to increase the hydraulic disposal rate of primary septic tank effluent on a Blackland Prairie soil to maintain favorable aeration for nutrient removal. Other objectives of the study include GIS evaluation of existing soils in the region and modification of an existing SDI system to dose wastewater based on volumetric soil moisture. A lab scale SDI prototype has been assembled for field evaluation in summer 2006. Results can be used to provide design information for alternative wastewater treatment and disposal in heavy clay soils in Alabama and elsewhere.

Introduction

Decentralized wastewater treatment methods are used where connecting isolated households to the existing sewer system is not practical and/or economical (Viraraghavan, 1986), or when expansion of the current municipal WWTP serving area is too costly. In the US, about thirty percent of households are using onsite sewage disposal, while in Alabama this number is 47 percent (Alabama Onsite Wastewater Association, 2005).

Conventional septic systems collect raw sewage from individual homes. The sewage goes through primary settling and biological reaction during its retention in a septic tank. Upon reaching a preset overflow level, the supernatant from the septic tank is disposed by gravity to a drain field where percolation through an unsaturated soil zone provides advanced aerobic treatment of the effluent. The environmental challenge for conventional onsite treatment is the system's almost complete reliance on soil properties (Oron, 1996). Overload to the drain field is a common cause of onsite system failure (U.S.EPA., 2002). Conventional onsite septic systems are a significant contributor of non-point source pollution. (Carroll and Goonetilleke, 2005; Charles et al., 2005; Lipp et al., 2001; Shaviv and Sinai, 2004; U.S.EPA., 2002). Therefore, a carefully scheduled dosing strategy becomes important in controlling the hydraulic and nutrient impact to the environment (Cote, 2003).

Pradhan (2004) reported the average nitrogen concentration of septic tank effluent to be 40-80mg/L, among which 75 percent is ammonium nitrogen and 25 percent is organic nitrogen. Average phosphorous concentration was reported to be 3 to 20 mg/L, with about 85 percent as orthophosphate. An extensive septic effluent field survey in Australia (Charles et al., 2005) compared published regulations in Australia and the United States, and recommended that the 80^{th} percentile (250 mg TN/L and 36 mg TP/L) of effluent survey values should be adopted as design guideline by new regulations to minimize drain field overloading. Lipp (2001) demonstrated the pathogen impact from onsite sewage systems to the coastal community. Carroll (2005) confirmed that a high system density (290 units/sq.km) can significantly impact shallow groundwater systems. Incidences of poor management of onsite systems, particular conventional septic systems, are quite common (Carroll and Goonetilleke, 2005). In Alabama the average onsite system failure rate is 20 percent (U.S.EPA., 2002).

Background Analysis

A series of Geographic Information System (GIS) analyses were conducted to evaluate the environmental risks associated with conventional onsite septic systems in the Alabama Black Belt area (Figure 1). Results indicate that approximately 77 percent of the study area is rated as unsuitable for conventional onsite septic systems due to high clay content soils. According to the 2000 US census, about 12 percent of the rural census block groups have an average system density larger than 15 units/sq.km, with a maximum of 212 units/sq.km (Figure 2). Approximately 99 percent of the rural census block groups have an average system size smaller than 3 persons/unit (Figure 2). As to 2000, more than 97 percent of the rural census block groups had a weighed average system age of more than 20 years (Figure 3). GIS ranking analysis (Figure 4) revealed several census block groups close to cities with a comparatively high environmental risk. The GIS analysis revealed that not only are the majority of soils in the Black Belt area unsuitable for conventional onsite systems, but that high system density in certain areas is also responsible for high environmental risk. Therefore, for areas with high system density, small community based onsite systems are a potential alternative technology. For areas with low system density but poor soil properties, improving the management (dosing strategy) and/or upgrading existing systems is more practical.

Integrating drain field conditions with a more uniform temporal water distribution increases the drain field utilization rate while reducing the environmental risk of overload. The system proposed in this study adopts real-time drain field soil moisture content into the dosing strategy, along with an integrated seasonal cropping system for optimum moisture and nutrient uptake. Subsurface drip irrigation (SDI) is used to distribute the wastewater more evenly in the drain field. By integrating the two components together, the innovative system overcomes the shortcomings of conventional onsite systems and is better suited to high clay soil areas. Plant uptake in the drain field is optimized to increase the water and nutrient uptake during different seasons, utilizing wastewater as a natural fertilizer for plants in the drain field.

Objectives

The purpose of this research is to optimize the onsite wastewater dosing rate in a selected high clay soil in Alabama Black Belt area through an innovative onsite system which integrates agronomic water and nutrient uptake with soil-moisture based dosing of pre-filtered septic effluent. The goal of this research is not necessarily to maximize waste disposal, rather to develop an innovative treatment and beneficial reuse of effluent using environmentally friendly plant uptake systems at sustainable loading rates in marginal clay soils. Results can be used to provide design information for alternative onsite wastewater treatment and disposal systems in heavy clay soils in Alabama and similar areas. Although the cost of these integrated seasonal cropped systems may be prohibitive for single home owners, this research may provide a viable option for decentralized sewage system managers, or existing community systems looking for increased treatment and disposal capacity.

Methods

Soil Moisture Control Interface

A data logger controller (DeltaT, UK) and a sanitary drip irrigation control unit (Geoflow, CA) were modified and integrated to add soil moisture based dosing control to an existing drip irrigation control unit. The data logger/controller receives input from two soil moisture sensors and uses the feedbacks to control an external circuit (Figure 5). The external circuit controls an intermediate relay which is wired in series to the tank low water float switch. When the soil moisture feedback is below a preset threshold, the external circuit will close the intermediate relay and the existing irrigation control system will response as long as there is sufficient water in the 350-gallon test tank. If there is enough water in the tank, the SDI dosing pump will operate at a preset sequence. If there is not enough water in the tank, the dosing pump will not be activated. When soil moisture feedback is above a preset threshold, the external circuit will break the intermediate relay and the in-series the low water level float circuit, cutting irrigation just as if there was not enough water in the tank. At this circuit interruption, the dosing pump is set to off. As described, the soil moisture sensor works in tandem with the low water float switch to control irrigation dosing to turn off the dosing pump temporally when the drain field is near a preset moisture level or there is not enough water in the tank. The preset moisture level in this study, which uses a synthetic secondary-treated wastewater effluent, is set to approximate field capacity.

Field Experiment

The SDI application in this study is conceived to be for a small community-based system. The design flow rate is set to 1022 liters/day/household (270 gpd/household). A test site at the Black Belt Research and Extension Station in Marion Junction, Alabama was selected for the field experiment. Soil sampling was conducted at the field site in December, 2005 at the site. The soil in the proposed drain field is Houston clay. Textural soil properties are listed in Table 1, below.

Table 1. Soil properties of Houston soil, Black Belt Research and Extension Station, Marion Junction, Alabama

Horizon	Lower Depth	Particle Size Distribution		
		Sand	Silt	Clay
	cm	%		
Ap1	23	7.09	39.63	53.28
Ap2	42	8.26	38.04	53.70
BA	63	10.17	33.38	56.45
Bkss1	88	3.50	35.93	60.57
Bkss2	152	3.10	25.80	71.10

* Source: Auburn University Pedology Laboratory

The designed hydraulic loading rate applied to the drain field was set to 2.04 liter/m^2/day (0.05 gal/sq.ft/day). A 3.78 m^3 (1000 gallon) tank was used in the field as the water reservoir. A 0.37 KW (1/2 horse power) submersible pump working at 1.26 liters/sec (20 gpm) supplies water from the tank to a $18.3m \times 27.4m$ ($60' \times 90'$) SDI drain field (Figure 6). Ryegrass (cool season) and Sorghum (warm season) are planted over the drain field to increase water and nutrient uptake. The drain field is divided into two subplots, a clean water subplot and a nutrient subplot. Each subplot has 15 drip laterals at 2 feet spacing. The clean water subplot in this study accepts clean water and regular surface-applied fertilizer, and the nutrient subplot accepts synthetic wastewater (250 mg TN/L and 36 mg TP/L) only. An open field beside the drain field study area is also planted with ryegrass and sorghum as a control plot, but no irrigation is carried out except for regular fertilizer. Two soil moisture sensors are buried in the middle of the drain field to monitor the real-time drain field soil moisture content. The data logger/controller, located beside the drain field, is pre-programmed to control the pump run time sequence based on soil moisture sensor feedback. With the exception of the nutrient injection pump, the entire system has been installed at the experimental site (Figure 7). Since the experimental system is currently operating with clean water, initial comparisons will be made between the clean water subplots and the open field control.

The field data, including plant water uptake, soil moisture content, rainfall, soil temperature, pumping rate and volume, dosing frequency and dosing time, will be continuously logged at 15-minute intervals. Crops will be harvested during the end of each growth season to quantify the nutrient uptake from the drain field.

HYDRUS-2D, developed by U.S. Salinity Laboratory, U.S. Department of Agriculture, will be used to simulate the seasonal water and nutrient profile in the drain field using collected field data as input.

Expected Results

The recorded dosing time and flow rate of the SDI system will be used to quantify the seasonal average dosing rate and the total mass of nutrients entering the drain field. The nutrient mass in the harvested plant will be used to quantify nutrient uptake. The difference between nutrient input and uptake approximates the amount of nutrients remaining in the drain field, lost due to runoff, leaching, de-nitrification or other transformations. Environmental risk to the nearby water bodies from surface runoff and leaching should be minimized by soil-moisture based dosing. The mechanism by which this functions is to reduce the potential of wastewater overdosing during saturated field conditions. HYDRUS-2D will be used to simulate seasonal water and nutrient profile in the drain field, including plant uptake. Results from HYDRUS-2D will be used to assess the environmental impact from nutrient and water, optimize the field seasonal dosing rate for different seasonal conditions, and provide optimized hydraulic dosing rates and dosing strategies. The differences between the three treatments (nutrient subplot, clean water subplot, and open field) will be statistically evaluated in terms of plant growth through ANOVA.

Conclusion

The pilot system evaluated in this study overcomes the shortcomings of conventional onsite systems and focuses on sustainable hydraulic loading rates on the high clay soils. The system integrates real-time drain field soil moisture content into a dosing control strategy and utilizes select crop species capable of maintaining consistently high seasonal water and nutrient uptake. Since the system is based on real-time field conditions, the reliability of the control strategy must be evaluated through multi-year field tests. The proposed system can be used as the basis for 1) an alternative to conventional decentralized secondary treatment systems; 2) a supplement to existing decentralized secondary treatment systems; or 3) a supplement to an existing municipal WWTP.

Acknowledgements

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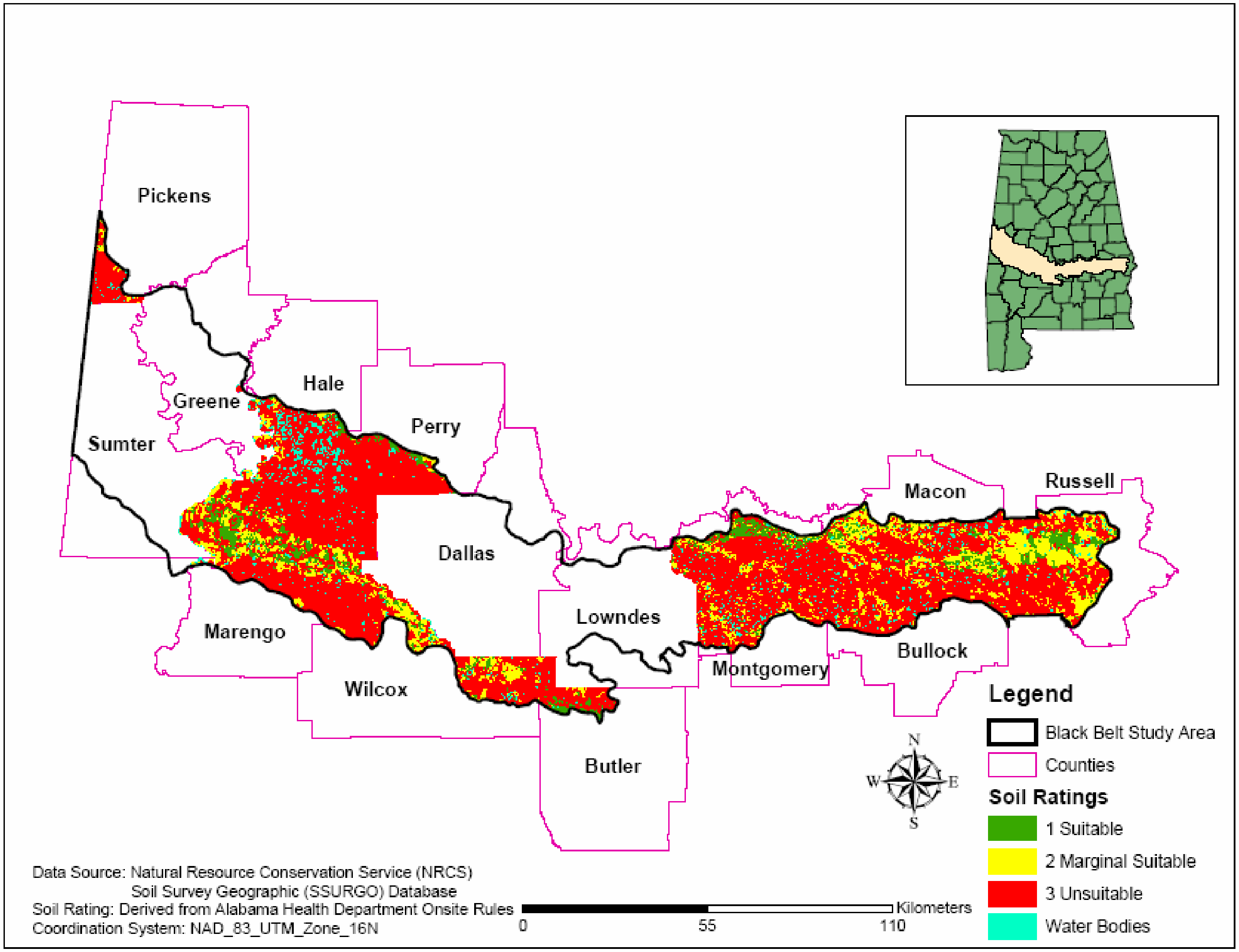

Figure 1: The study area and the soil ratings

Note: Soil survey data not currently available for Sumter, Greene, and Lowndes Counties.

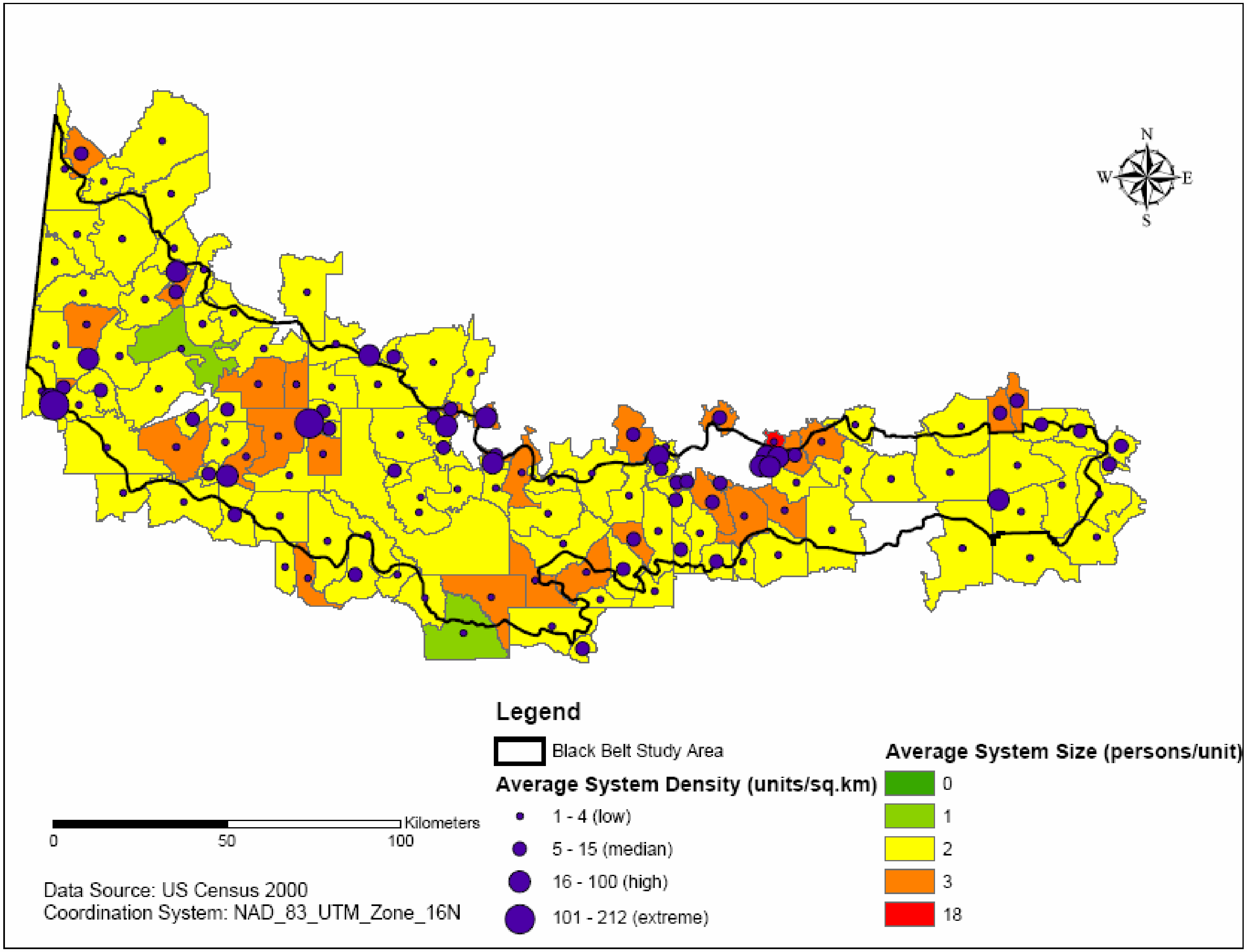

Figure 2: Onsite system density and size in rural areas of the Alabama Black Belt by census block group

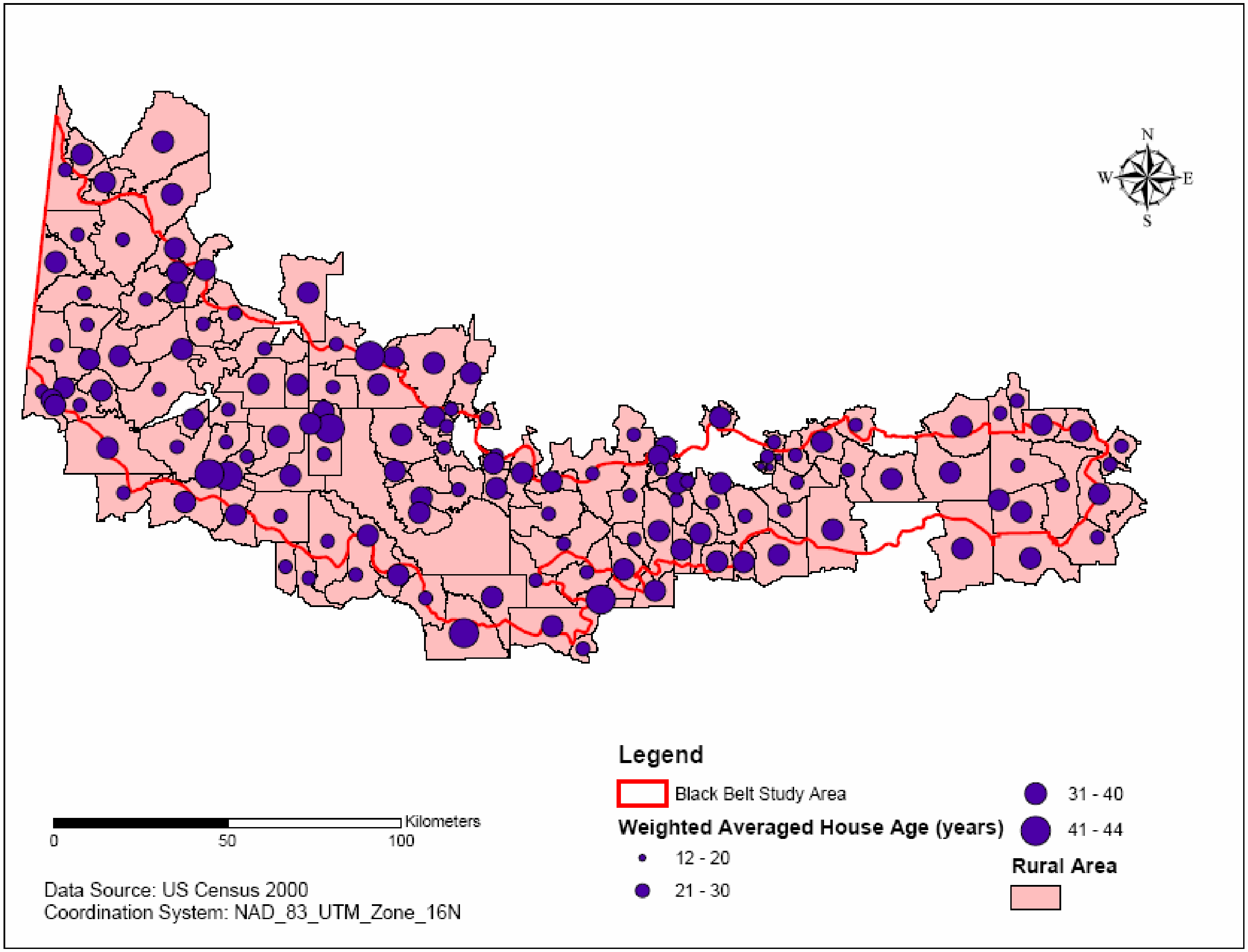

Figure 3: Weighted average house age in rural areas of the Alabama Black Belt by census block group

Note: Soil survey data not currently available for Sumter, Greene, and Lowndes Counties.

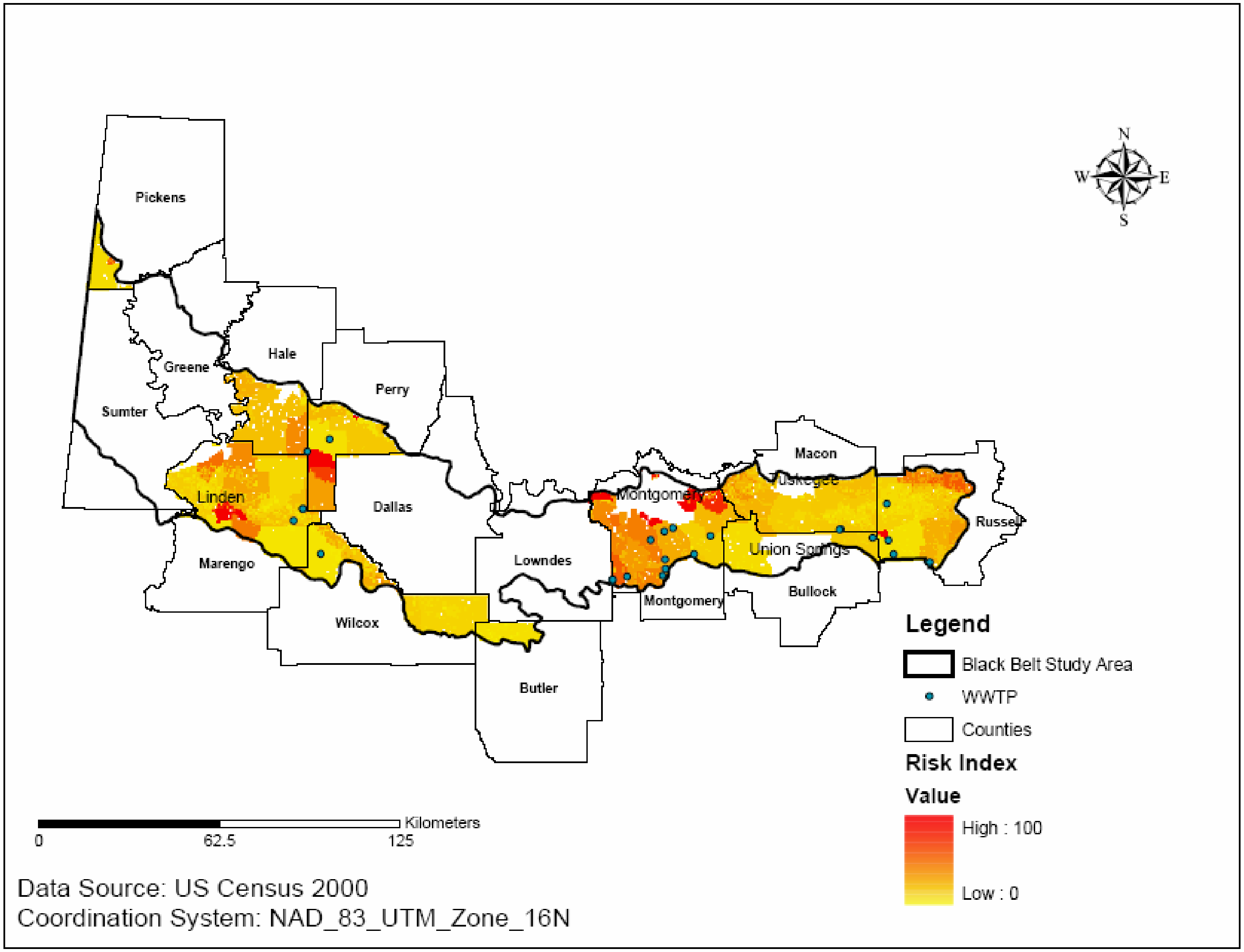

Figure 4: Environmental risk from conventional septic systems in the rural Black Belt area

Note: Soil survey data not currently available for Sumter, Greene, and Lowndes Counties.

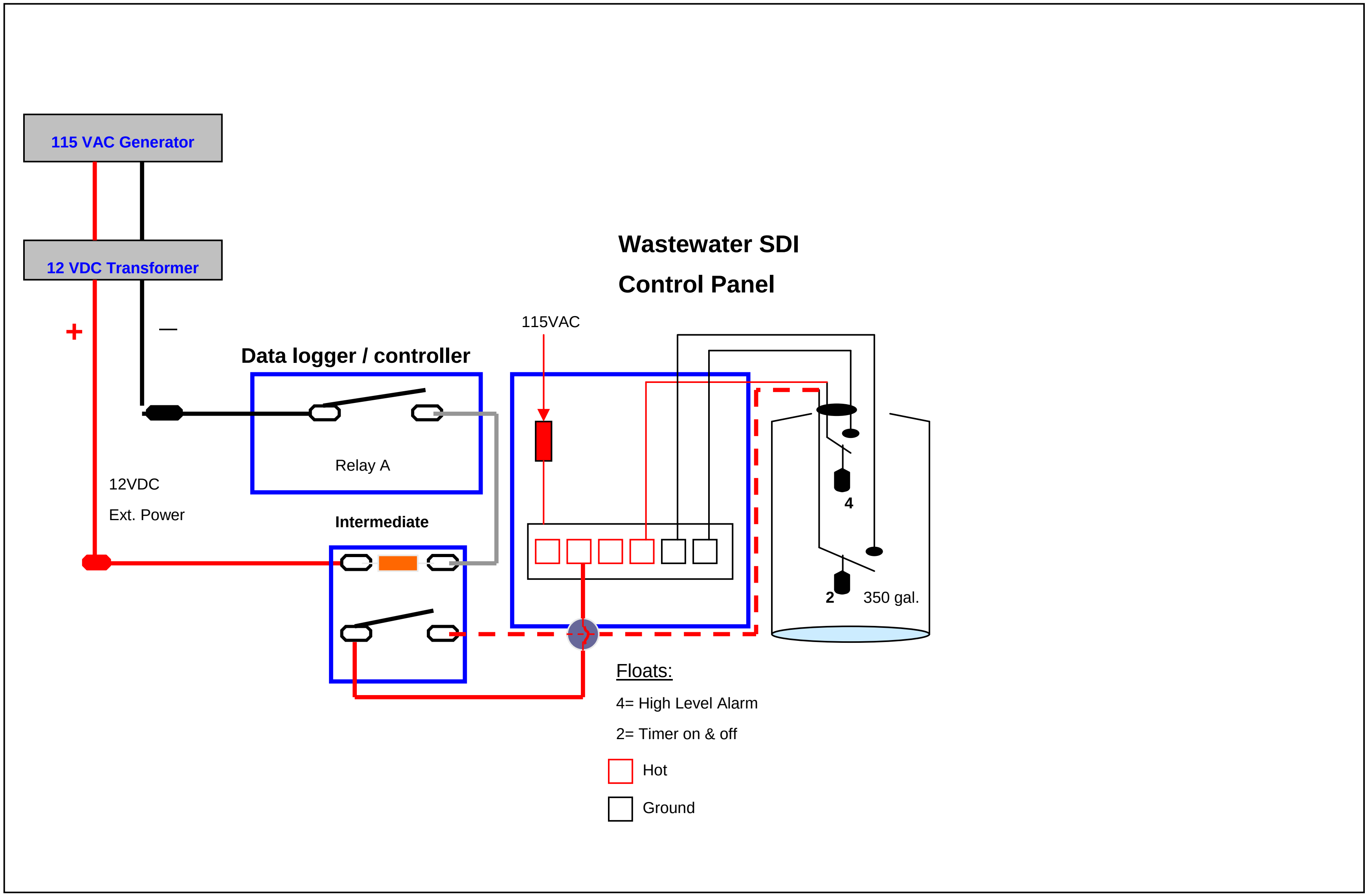

Figure 5. Electric connection diagram illustrating interface of soil moisture sensors and control to existing float / irrigation dosing system. (Adapted from Dynamax, Inc. and Geoflow, Inc.)

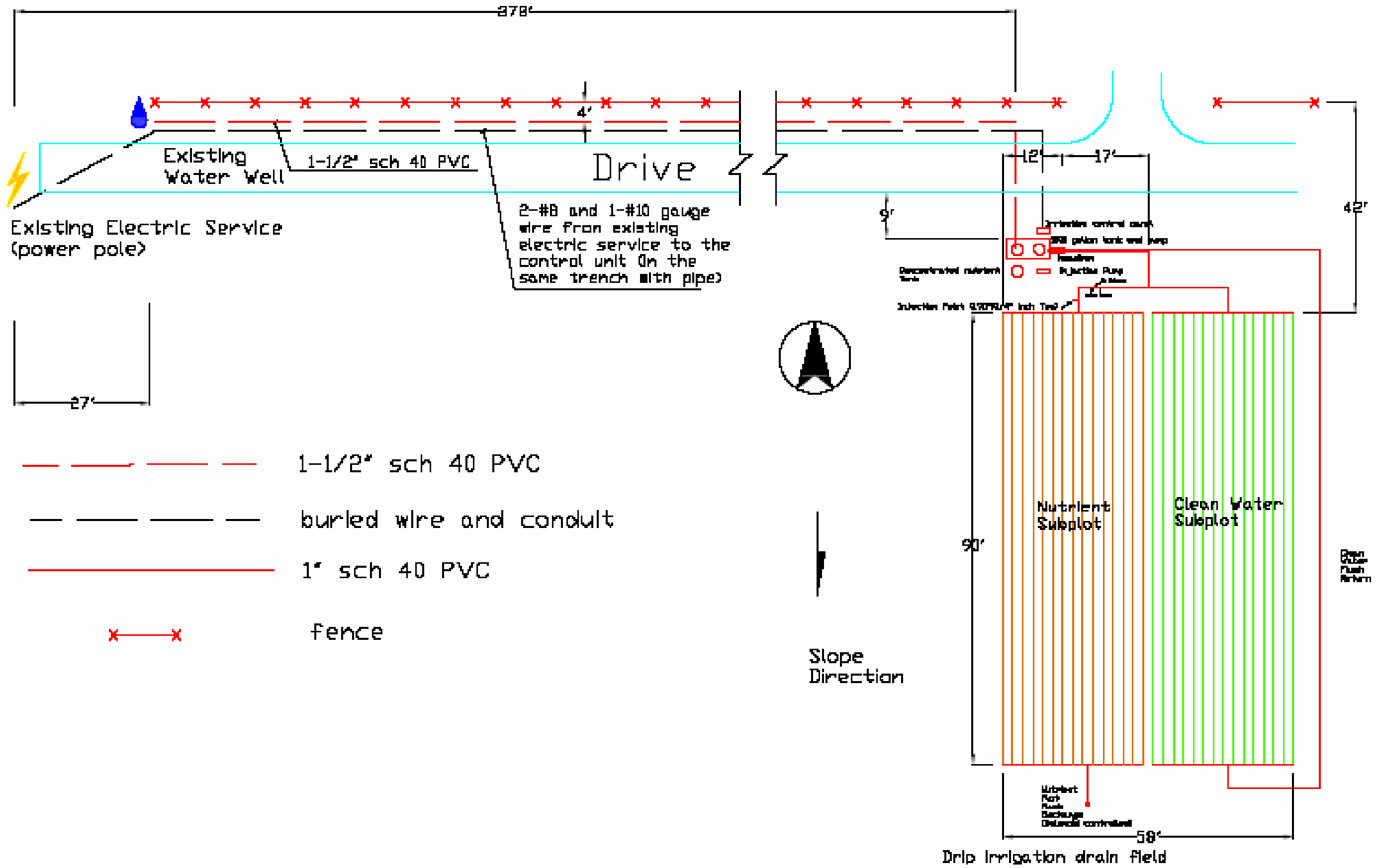

Figure 6. Field sketch of the proposed field experiment at Black Belt Research and Extension Station, Marion Junction, Dallas County, Alabama.

Figure 7. Finished field experimental system (Datalogger and Control box) at Black Belt Research and Extension Station, Marion Junction, Dallas County, Alabama.

APPLYING SWINE EFFLUENT WITH SDI AND LEPA SPRINKLER IRRIGATION

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ABSTRACT

A two-year study was initiated in the spring of 2000 at the Northwest Research-Extension Center, Colby, Kansas (USA) to compare the application of swine effluent through subsurface drip irrigation (SDI) and simulated low energy precision application (LEPA) sprinkler irrigation. Results suggest both methods can be successfully used, obtaining crop yields of approximately 250 bu/acre with good nutrient uptake. Averaged over the two years of the study, SDI produced 10-20 bu/acre greater than LEPA sprinklers for equivalent effluent applications. Plant uptake and residual soil nitrogen were also greater with SDI, suggesting that appreciable N-losses were occurring with volatilization or leaching with LEPA.

INTRODUCTION

The use of livestock effluent through agricultural irrigation systems can have positive or negative impacts on the environment, depending on the method and intensity of use. The effluent can also be an inexpensive fertilizer resource for crop producers, providing nutrients in a timely fashion to the crop in a readily plant-available form. Subsurface drip irrigation (SDI) has been shown to be technically feasible with beef feedlot runoff effluent in K-State research performed in western Kansas (Trooien et al., 2000; Lamm et al., 2002). The use of SDI with effluent brings many potential advantages but a scientific comparison of SDI to sprinkler (such as low-energy precision application, abbreviated LEPA) application of effluent has not been performed previously. Use of swine effluent through SDI may or may not bring real environmental advantages in the form of reduced nutrient accumulation at the soil surface or in or below the root zone. Sprinkler irrigation is currently the common practice for effluent application in the Great Plains.

The overall objective of this project was to compare the environmental, cropping, and irrigation system impacts of swine effluent applied with SDI or simulated LEPA sprinkler irrigation. The specific questions to be answered were: 1) What are the environmental impacts of swine effluent when applied with SDI or LEPA irrigation, specifically in terms of nutrient utilization and redistribution in the soil profile? 2) What are the crop impacts of swine effluent application through SDI compared to LEPA irrigation? 3) Is swine effluent use through SDI technically feasible?

METHODS

Research plots were established at the Northwest Research-Extension Center at Colby, Kansas in the spring of 2000. The study was conducted for crop years 2000 and 2001. The deep silt loam soil can supply about 17.5 inches of available soil water for an 8-foot soil profile. The climate can be described as semi-arid with a summer precipitation pattern with an annual rainfall of approximately 19 inches. Average precipitation is approximately 12 inches during the 120-day corn growing season.

Swine effluent was hauled to the site from Premier Pork, Scott City, Kansas. The logistics of hauling sizable quantities of effluent necessitated relatively small research plots. The plots were 15 ft wide accommodating 6 corn rows and 54 ft long. Buffer areas of irrigated corn (50 ft wide) surround the plot area to minimize the effect of wind and heat on the plot area. Each treatment was replicated 3 times in a complete randomized block design. Since livestock effluent can rapidly experience volatilization losses and other transformations when transferred from larger lagoons into smaller tanks, the application methodology was restricted to two 2-day application periods during mid to late June and early July. The water was hauled to the site and immediately applied during a two-day period.

The treatments were as follows:

1. SDI control treatment (No application of effluent, but SDI fertigation of commercial fertilizer, 200 lbs N/acre inseason through dripline.)
2. Application of 1 inches of effluent per year with SDI, 0.5 inch per application.
3. Application of 2 inches of effluent per year with SDI, 0.5 inch per application.
4. Application of 0.6 inches of effluent per year with simulated LEPA.
5. Application of 1 inches of effluent per year with simulated LEPA, 1 inch per application.
6. Application of 2 inches of effluent per year with simulated LEPA, 1 inch per application.

The effluent/fertigation for treatments 3 and 6 were applied in two separate periods approximately 2 weeks apart (Table 1). An application period for SDI was two consecutive daily events of 0.5 inches (1 inch in 2 days). The application period for LEPA was initiated at the same time but just consisted of a single 1 inch application. Additional freshwater irrigation was scheduled as needed using a calculated water budget approach. Weather data were collected with an automated weather station approximately 0.5 mile from the research site to schedule irrigation. SDI and LEPA irrigation capacity was limited to 0.25 inches/day that approximates full irrigation in the majority of years in Northwest Kansas. Irrigations were scheduled when the calculated soil water depletion exceeded 1 inch for a given treatment. The SDI treatments received as-needed irrigations of 0.5 inches every two days while the LEPA had 1-inch applications on a 4-day schedule. Soil water measurements were made in one ft increments to a depth of 8 ft with the neutron attenuation method on a weekly basis to determine crop water use but were not used to adjust irrigation schedules.

The plot area had 5 ft spaced raised beds with two corn rows centered on the shoulders of the bed. This is the traditional "K-State bed system for SDI" (Lamm, 2001). The driplines with a 12-inch emitter spacing were spaced 60 inches apart with an installation depth of 17 inches. Each dripline was centered between two corn rows spaced 30 inches apart on the 60 inch crop bed (Figure 1). The nominal flow rate was 1 gal/min for each 100 ft of dripline. This is a higher than typical dripline flowrate for the region, but was selected so that the application period could be minimized, thus helping to avoid further effluent losses and transformations. There were three driplines in each plot and each whole plot was 54 ft long. Each plot was instrumented with a municipal-type flowmeter (nutating disk) to record total accumulated flow. The LEPA plots also had driplines because the study area was developed in the spring of 2000. The installation period required some freshwater application, so the addition of driplines to the LEPA plots allowed equal soil water conditions at the beginning of the actual study.

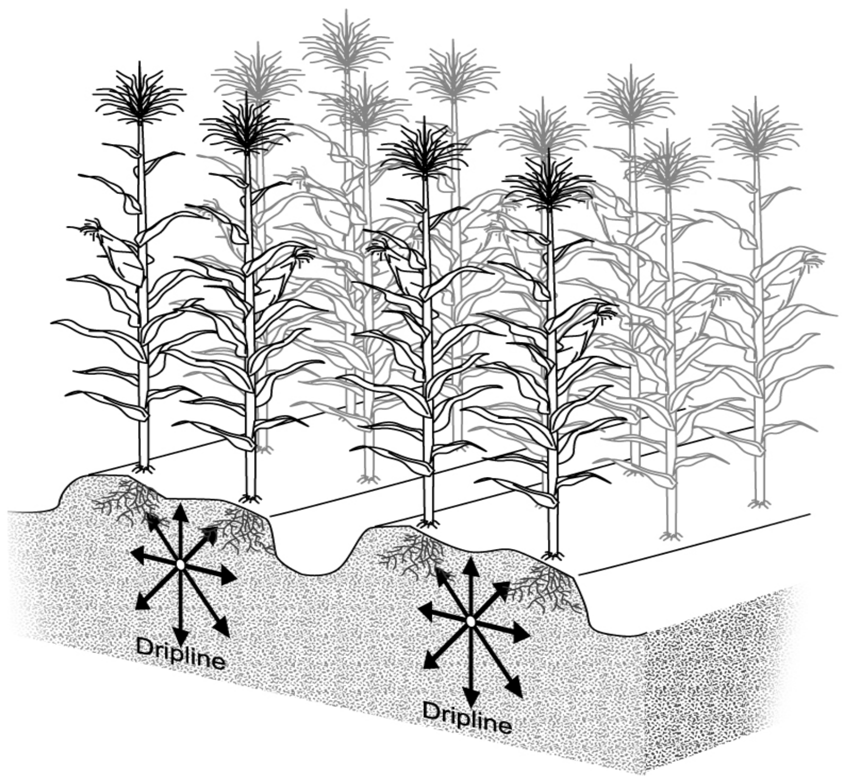

Figure 1. Physical arrangement of the subsurface dripline in relation to the corn rows.

The simulated LEPA was accomplished by applying equal amounts of water to furrow basins between adjacent pairs of corn rows. Equal amounts of water are accomplished by delivering water to each furrow basin through a small-diameter irrigation tube connected to a flow divider (Figure 2). This differs from surface drip irrigation in that the application time is much less. The application time for the 1-inch application is approximately 45 minutes, similar to LEPA irrigation, rather than as much as 20 hours for surface drip irrigation. The geometry of the irrigation delivery points for the SDI and LEPA systems allows that the edge rows in the LEPA plot do not receive an adequate irrigation amount. Periodic surface irrigation amounts were supplied to these LEPA edge rows to alleviate this problem, yet not influence the center two plot rows being utilized for sampling.

Table 1. Amounts of seasonal irrigation, applied nitrogen and the source for corn in a biological effluent study, Colby, Kansas, 2000-2001.

Irrigation System & Effluent Amount	Irrigation	------------- Nitrogen fertilizer, lbs/acre, in the indicated source -----				
	inches	Starter	Effluent 1st App	Effluent 2nd App	Irrigation	Total
Year 2000						
SDI, Control	19.5	30	0	200*****	14.6	245
SDI, 1.0 inch effluent	19.5	30	184	0	14.6	229
SDI, 2.0 inches effluent	19.5	30	184	159	14.6	388
LEPA, 0.6 inches effluent	20.0	30	110	0	15	155
LEPA, 1.0 inches effluent	20.0	30	184	0	15	229
LEPA, 2.0 inches effluent	20.0	30	184	159	15	388
** Control commercial fertilizer applied June 26, 2000*						
SDI effluent applied June 15-16, and June 29-30, 2000, 0.5 in/day						
LEPA effluent applied June 15 and June 29, 2000, 1.0 in/day						
Year 2001						
SDI, Control	18.0	30	0	200*****	13.5	244
SDI, 1.0 inch effluent	18.0	30	165	0	13.5	209
SDI, 2.0 inches effluent	18.0	30	165	147	13.5	356
LEPA, 0.6 inches effluent	18.0	30	99	0	13.5	143
LEPA, 1.0 inches effluent	18.0	30	165	0	13.5	209
LEPA, 2.0 inches effluent	18.0	30	165	147	13.5	356
** Control commercial fertilizer applied June 22, 2001*						
SDI effluent applied June 22-23, and July 5-6, 2001, 0.5 in/day						
LEPA effluent applied June 22 and July 5, 2001, 1.0 in/day						
Sum of both years 2000 - 2001						
SDI, Control		60	0	400	28	488
SDI, 1.0 inch effluent		60	349	0	28	437
SDI, 2.0 inches effluent		60	349	306	28	743
LEPA, 0.6 inches effluent		60	209	0	29	298
LEPA, 1.0 inches effluent		60	349	0	29	438
LEPA, 2.0 inches effluent		60	349	327	29	744

Pioneer[1] corn hybrid 3162 was planted at approximate seeding rates of 29,000 and 34,000 plants/acre on April 27, 2000 and April 30, 2001, respectively. This hybrid is a full season hybrid for the region with an approximately 118 day comparative relative maturity requirement. Pest (weeds and insects) control was accomplished with standard practices for the region. The corn rows were planted parallel with the dripline with each corn row approximately 15 inches from the nearest dripline. A raised bed was used in corn production. This allows for centering the corn rows on the dripline and limits wheel traffic to the furrow. This controlled traffic can allow for some shallow cultivation procedures.

Figure 2. Flow divider with tubes used to deliver irrigation water to individual furrow basins.

A starter fertilizer was band-applied at planting to all plots in the amount of 30 lbs N/acre and 45 lbs P_2O_5/acre. Additionally the fresh irrigation water was sampled to determine its contribution of N. The swine effluent was monitored and analyzed as it came out of the lagoon and as it was actually applied to insure that it was physically, chemically and biologically representative of a typical effluent application. The nutrient conditions at the time of application were the values used to compare applied to recovered nutrients.

Initial soil sampling of each plot was used to determine baseline N, P, EC and pH conditions for the plot area. There was no reason to believe that there would be any stratification in any horizontal direction at the initiation of the study, so only one sampling hole for each plot was utilized. Samples were taken in 6-inch increments in the top 3 ft and 1 ft increments in the 3-8 ft depth range (18 plots x 11 depth increments = 198 samples).

Soil sampling after harvest (Fall 2000 and 2001) was as follows for N, P, EC and pH

- LEPA: 0 to 1 ft in 3-inch depth increments, 1-3 ft in 6-inch depth increments, 3 to 8 ft in 1 ft depth increments, with horizontal locations at the middle of bed, 7.5 inches from middle of bed, corn row, 7.5 inches from middle of furrow, and corn furrow (9 LEPA plots x 5 horizontal locations x 13 depths = 585 samples)
- SDI: 0 to 2 ft in 3-inch depth increments, 2-3 ft in 6-inch depth increments, 3 to 8 ft in 1 ft depth increments at distances from dripline of 0, 3, 6, 10, 15, 20 and 30 inches (9 SDI plots x 7 horizontal locations x 15 depths = 945 samples)

The soil samples were dried and finely ground to pass through a 2 mm sieve and then sent to the KSU Soils Laboratory for chemical determinations.

Whole corn plant sampling at physiological maturity was used to determine biomass, and the N-P-K uptake of above ground dry matter. Corn grain yield and yield components were determined from hand harvesting a 6 m long section of crop row at physiological maturity.

Analyses to be discussed here include corn grain yield and yield components, nutrient uptake by crop, water use and soil profile distribution, water use efficiency, residual N and distribution patterns in soil, and comparisons of applied nutrients to those recovered in crop and soil.

RESULTS AND DISCUSSION

Irrigation and water use

Cumulative precipitation and corn evapotranspiration for the 120-day corn growing period at Colby, Kansas from May 8, 2000 through September 4, 2000 was 6.18 inches and 25.85 inches, respectively. Similar extreme drought conditions existed in 2001 with cumulative precipitation of 6.95 inches and corn evapotranspiration of 26.04 inches for the period May 13 through September 9. The long term average (1972-99) precipitation and corn evapotranspiration for the more typical 120-day period running from May 15 through September 11 is 12.61 inches and 22.56 inches, respectively. Thus irrigation requirements were much higher than normal (19.5 inches for the SDI and 20.0 inches for the LEPA irrigation in 2000 and 18.0 inches for all treatments in 2001).

Water use was significantly higher (P=0.05) for the LEPA sprinkler irrigation plots as compared to the SDI plots in 2000 averaging approximately 3 additional inches of use (Table 2). Since irrigation was only 0.5 additional inches for the LEPA sprinkler irrigation plots, this extra water use came by decreasing soil water storage. This extra water use was visually evident near the end of the cropping season because there was increased early senescence for the LEPA sprinkler irrigation plots due to decreased soil water reserves. It is not clear why the LEPA sprinkler irrigation treatments had higher total water use in 2000, but a partial reason may be increased water losses from evaporation from the soil surface or deep drainage. Drier soil surfaces with SDI can reduce soil evaporation while smaller SDI applications can also decrease deep drainage. In 2001, there were no statistically significant differences in water use between irrigation systems but LEPA treatments tended to have slightly higher water use. When averaged over the two years, water use for LEPA treatments had approximately 2 inches greater water use than SDI which was statistically significant (P-0.05).

Table 2. Yield component and water use data for corn in a biological effluent study, Colby, Kansas, 2000-2001.

Irrigation System & Effluent Amount	Irrigation inches	Applied N[1] lb/a	Grain yield bu/a	Plant Pop. plants/a	Ears /plant	Kernels /ear	Kernel Wt. g/100 krnl.	Biomass ton/a	Water use[2] inches	WUE[3] lb/acre-in
Year 2000										
SDI, Control	19.5	245	253	26136	1.04	570	41.4	10.6	30.1	472
SDI, 1.0 inch effluent	19.5	229	252	27297	0.97	595	40.6	11.4	30.4	464
SDI, 2.0 inches effluent	19.5	388	260	26717	1.04	573	41.4	10.9	29.5	492
LEPA, 0.6 inches effluent	20.0	155	237	26717	0.98	595	38.6	10.9	33.2	399
LEPA, 1.0 inches effluent	20.0	229	250	26717	0.99	603	40.0	11.1	32.8	427
LEPA, 2.0 inches effluent	20.0	388	246	27007	0.98	600	39.4	10.7	33.2	415
LSD P=0.05			NS	NS	NS	NS	1.6	NS	1.5	51
Year 2001										
SDI, Control	18.0	244	262	32960	0.97	561	37.1	11.5	28.5	517
SDI, 1.0 inch effluent	18.0	209	270	32525	0.94	598	37.4	12.4	27.4	553
SDI, 2.0 inches effluent	18.0	356	267	32525	0.94	597	37.2	11.5	28.1	531
LEPA, 0.6 inches effluent	18.0	143	214	33251	0.95	525	32.9	8.9	28.2	427
LEPA, 1.0 inches effluent	18.0	209	251	32815	0.95	557	36.9	10.2	28.7	493
LEPA, 2.0 inches effluent	18.0	356	237	33225	0.97	494	37.9	10.0	30.3	439
LSD P=0.05			22	NS	NS	63	2.6	NS	NS	53
Mean of both years 2000 - 2001										
SDI, Control			258	29548	1.01	565	39.3	11.1	29.3	495
SDI, 1.0 inch effluent			261	29911	0.96	596	39.0	11.9	28.9	509
SDI, 2.0 inches effluent			263	29621	1.00	585	39.3	11.2	28.8	512
LEPA, 0.6 inches effluent			225	29984	0.96	559	35.7	9.9	30.7	413
LEPA, 1.0 inches effluent			251	29766	0.97	580	38.4	10.6	30.8	460
LEPA, 2.0 inches effluent			241	30116	0.97	547	38.7	10.4	31.7	427
LSD P=0.05			20	NS	NS	NS	1.4	NS	1.0	35

1 Total applied N-P-K from the three sources: starter treatment at planting (30 lbs N/acre + 45 lbs/a P205), wastewater application, and the amount naturally occurring in the irrigation water (0.75 lbs/acre-inch).

2 Total of seasonal change of soil water storage in the 8 ft profile plus irrigation and precipitation.

3 Water use efficiency (WUE) is defined as grain yield in lb/acre divided by total water use in inches.

Corn yields and yield components

There were no significant differences in corn yields due to irrigation method or effluent application in 2000, though SDI yields tended to have slightly higher yields (Table 2). Grain yields were similar with commercial fertilizer or effluent for the SDI treatments at approximately 255 bu/acre. The smaller 0.6 inch effluent amount applied with LEPA had an appreciably lower grain yield (237 bu/acre), perhaps indicating some crop nutrient stress. There were no significant differences in kernels/ear, but LEPA treatments tended to have greater numbers than SDI treatments in 2000. This may be related to the extreme drought conditions which have reduced kernels/ear for SDI in some years (Lamm, 2004). Kernel weight at harvest was significantly affected (P=0.05) with the LEPA plots generally having lower kernel weight. This reduction in kernel weight may be reflecting the previously mentioned crop water stress that was apparent on the LEPA plots near physiological maturity. Final kernel weight for corn is usually set just prior to physiological maturity in mid to late September in this region (Northwest Kansas).

In 2001, grain yield, kernels/ear and kernel weight tended to be higher with SDI than with LEPA (Table 2). Grain yield averaged approximately 268 bu/acre for the two SDI effluent treatments (1 and 2 inch effluent applications) and approximately 244 bu/acre for similar LEPA treatments. Although extreme drought conditions continued in 2001, the number of kernels/ear tended greater with SDI than with LEPA. The LEPA treatment with the smaller 0.6 inch effluent application had significantly lower yields, which was further indication of the apparent combination of increased nutrient and water stress for the LEPA treatments compared to SDI.

There were no statistically significant differences in biomass at physiological maturity as affected by irrigation method or effluent application in either year although SDI tended to have greater biomass in 2001. Dry above-ground biomass was approximately 11 tons/acre at physiological maturity (Table 2).

Water use efficiency

Water use efficiency is defined as the crop yield per unit of total water use and thus can combine treatment effects related to grain yield and water use. As discussed earlier SDI yields tended higher and LEPA water use tended higher, so it was not surprising that water use efficiency was higher with SDI in both years (Table 2). Averaged over the two years of the study, SDI produced approximately 65 lbs more grain for each inch of total water use for similar effluent treatments. This is probably a combination of better nutrient utilization and less crop water stress for the SDI treatments.

Nutrient utilization and soil residual N

There were no significant differences in above-ground biomass nitrogen uptake in 2000 related to irrigation method or applied effluent but there was a slight trend for higher uptake with SDI and for increasing effluent rates with the LEPA treatments (Table 3). In 2001, there was a stronger trend towards higher crop N uptake with SDI and the lower 0.6 inch effluent application had significantly lower crop N uptake. There were no differences in plant uptake for the SDI treatments probably a good indicator of N sufficiency in the soil profile, but plant uptake increased with higher rates of effluent for the LEPA treatments, probably indicating some N losses due to volatilization or possibly leaching. The principal source of nitrogen in the swine effluent at application time is ammonium nitrogen which is subject to rapid volatilization losses when applied to the soil surface under hot weather conditions. The application of the effluent subsurface with the SDI system may have reduced or eliminated such losses.

Table 3. Applied nitrogen, plant uptake and change in residual soil nitrogen in a biological effluent study, Colby, Kansas, 2000-2001.

Irrigation System & Effluent Amount	Irrigation inches	Applied Nitrogen lbs N/a	Plant Uptake lbs N/a	Change in Residual Soil N (8 ft)			Nitrogen Balance[1] lbs N/a
				NH4-N lbs N/a	NO3-N lbs N/a	NH4-N plus NO3-N lbs N/a	
Year 2000				*Spring 2000 to Fall 2000*			
SDI, Control	19.5	245	234	21	-17	4	7
SDI, 1.0 inch effluent	19.5	229	246	23	21	2	-19
SDI, 2.0 inches effluent	19.5	388	236	5	74	79	73
LEPA, 0.6 inches effluent	20.0	155	206	13	-112	-100	49
LEPA, 1.0 inches effluent	20.0	229	225	1	-73	-72	76
LEPA, 2.0 inches effluent	20.0	388	231	4	-49	-45	202
LSD P=0.05			NS	NS	NS	NS	
Year 2001				*Fall 2000 to Fall 2001*			
SDI, Control	18.0	244	277	-39	-25	-64	31
SDI, 1.0 inch effluent	18.0	209	276	-33	-35	-68	1
SDI, 2.0 inches effluent	18.0	356	274	-8	91	83	-2
LEPA, 0.6 inches effluent	18.0	143	150	-37	-31	-67	60
LEPA, 1.0 inches effluent	18.0	209	218	-27	-46	-73	64
LEPA, 2.0 inches effluent	18.0	356	265	-32	64	31	60
LSD P=0.05			79	NS	NS	NS	
Sum of both years 2000 - 2001				*Spring 2000 to Fall 2001*			
SDI, Control		488	511	-18	-42	-60	37
SDI, 1.0 inch effluent		437	522	-10	-14	-66	-19
SDI, 2.0 inches effluent		743	510	-3	165	162	71
LEPA, 0.6 inches effluent		298	356	-24	-143	-167	109
LEPA, 1.0 inches effluent		438	443	-26	-119	-145	140
LEPA, 2.0 inches effluent		744	496	-28	15	-14	283

[1] Nitrogen balance as defined here is the total applied nitrogen minus the total of the quantity, above-ground biomass N uptake plus the soil residual nitrogen in the upper 8 ft soil profile. Positive values indicate losses primarily through volatilization or leaching, while negative values indicate increase in recovered nitrogen, probably due to mineralization that was not accounted for in the analysis.

There were no statistically significant differences in the change in residual soil N levels between any of the sampling periods, but there was a trend towards slightly lower losses of both ammonium nitrogen (NH4-N) and nitrate nitrogen (NO3-N) with SDI than with LEPA (Table 3). As effluent application increased to the highest level, soil residual N actually increased in storage for the SDI treatment (162 lbs N/a) and was only a small loss (14 lbs N/a) for the LEPA treatment when compared over the entire study period.

A comparison of the nitrogen balance of applied minus recovered nitrogen (Table 3) indicates that SDI recovered more nitrogen in plant uptake and the residual N than LEPA. When examining the total study period, the 1 inch effluent application with SDI resulted in 19 lbs additional N being recovered than was applied while the same effluent application on the LEPA treatment resulted in losses of 140 lbs N/acre. This further supports the statements about increased volatilization or leaching losses with LEPA.

At the end of the study (Fall 2001) after two years of treatments, the SDI treatments had more nitrate-N dispersed in the soil profile than the LEPA treatments and increasing levels of applied effluent also resulted in higher levels of nitrate-N (Figures 3-8.). The levels of nitrate-N for the 2-inch swine effluent with SDI (Figure 5) are tending to be excessive which indicates that effluent applications could be reduced with SDI and still maintain good corn yields (Table 2).

SUMMARY AND CONCLUSIONS

Each irrigation system produced excellent corn yields, but SDI gave significantly greater yields in 2001 and for the two-year average. Increased water and nitrogen stress may have played a combined role in reducing LEPA sprinkler yields. Plant nitrogen uptake for equivalent effluent treatments was numerically greater for SDI in both years and statistically significantly greater in 2001. Higher levels of nitrate-N existed in the soil when using the SDI method which suggests that effluent application amounts may need to be reduced when using this irrigation method. N losses for LEPA sprinkler were probably primarily ammonium-N volatilization losses due to the summer fertigation and possibly some leaching.

Environmentally, SDI has some advantages in that it can reduce odor and ammonium – N losses and still produce excellent corn yields. However, there are some logistical disadvantages that could important to the effluent generator. Some feedlots are more interested in effluent disposal than utilization. These results indicate more land resources would be needed for proper nutrient application with SDI. Additionally, the SDI system is permanently tied to the land source, whereas center pivot sprinklers can be moved to alternate disposal sites if nutrient loading of the original site becomes excessive.

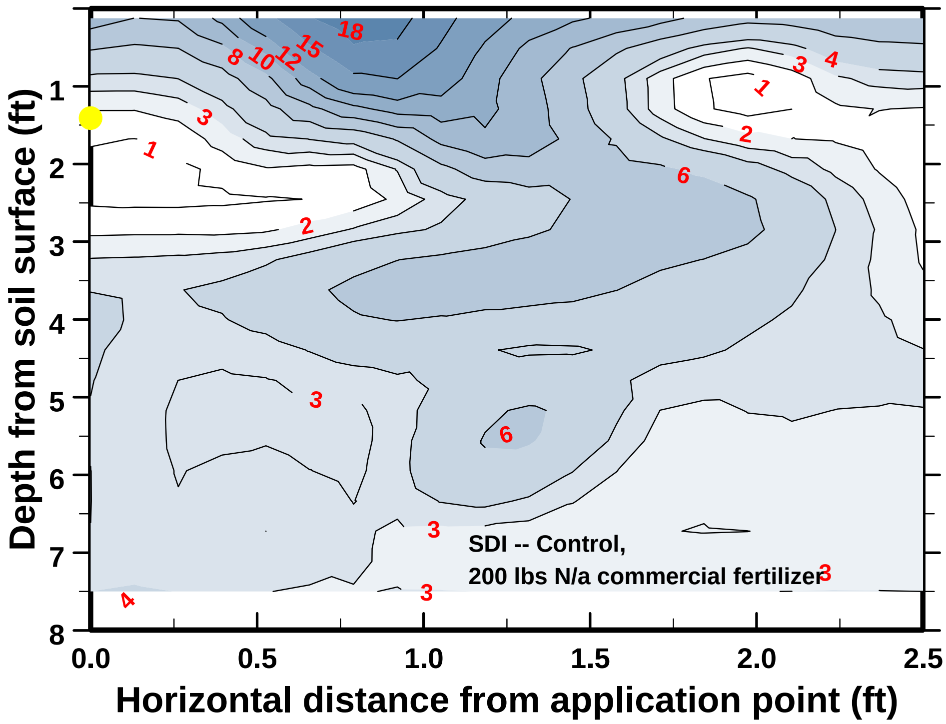

Figure 3. Nitrate-N concentrations, ppm, in the soil profile at specific depths and distances from the subsurface dripline (yellow dot) for the commercial fertilizer treatment in the fall of 2001, KSU Northwest Research Extension Center, Colby Kansas.

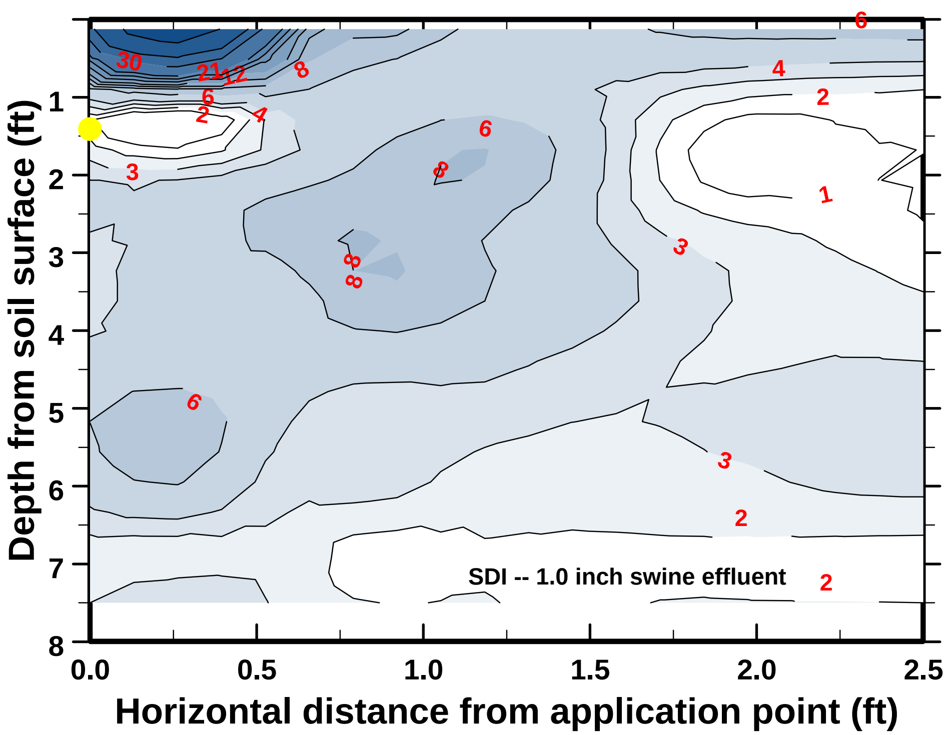

Figure 4. Nitrate-N concentrations, ppm, in the soil profile at specific depths and distances from the subsurface dripline (yellow dot) for the 1-inch swine effluent treatment in the fall of 2001, KSU Northwest Research Extension Center, Colby Kansas.

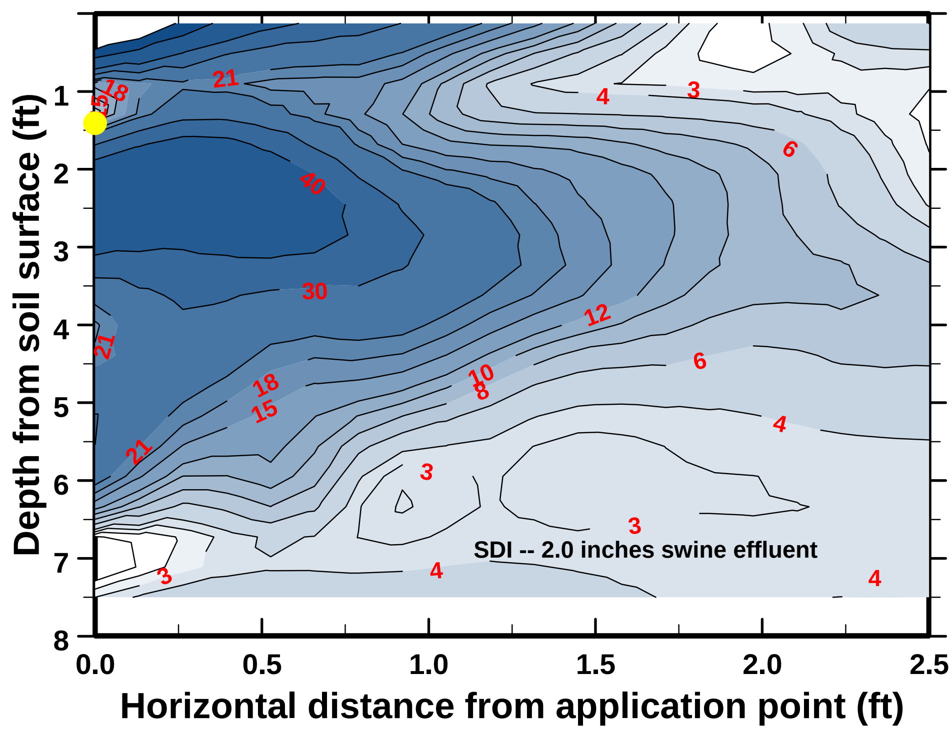

Figure 5. Nitrate-N concentrations, ppm, in the soil profile at specific depths and distances from the subsurface dripline (yellow dot) for the 2-inch swine effluent treatment in the fall of 2001, KSU Northwest Research Extension Center, Colby Kansas.

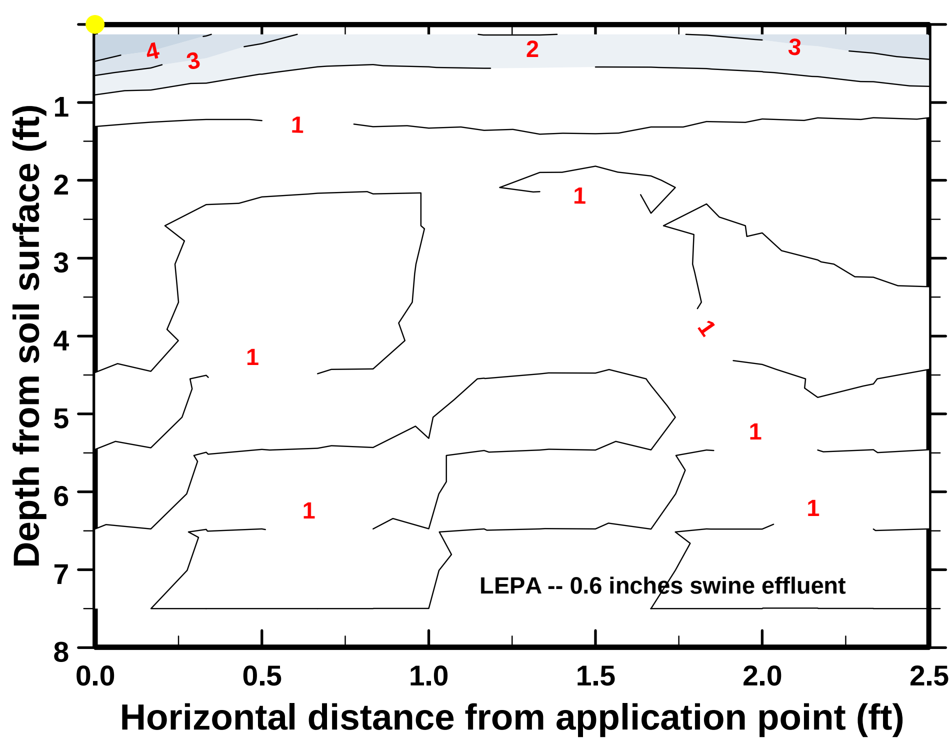

Figure 6. Nitrate-N concentrations, ppm, in the soil profile at specific depths and distances from the LEPA sprinkler (yellow dot) for the 0.6-inch swine effluent treatment in the fall of 2001, KSU Northwest Research Extension Center, Colby Kansas.

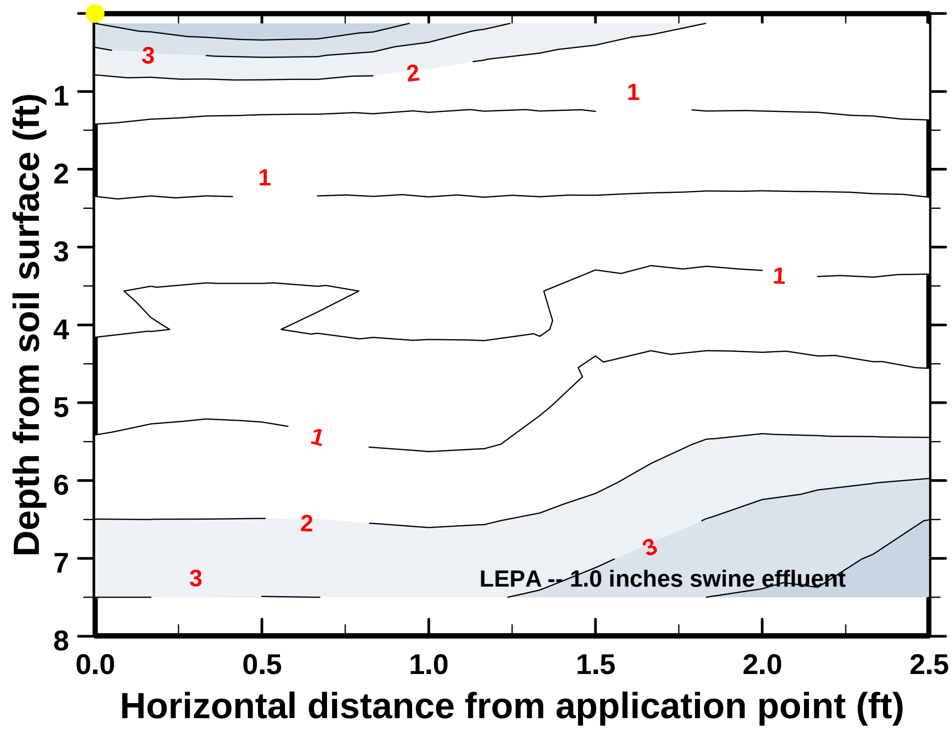

Figure 7. Nitrate-N concentrations, ppm, in the soil profile at specific depths and distances from the LEPA sprinkler (yellow dot) for the 1.0-inch swine effluent treatment in the fall of 2001, KSU Northwest Research Extension Center, Colby Kansas.

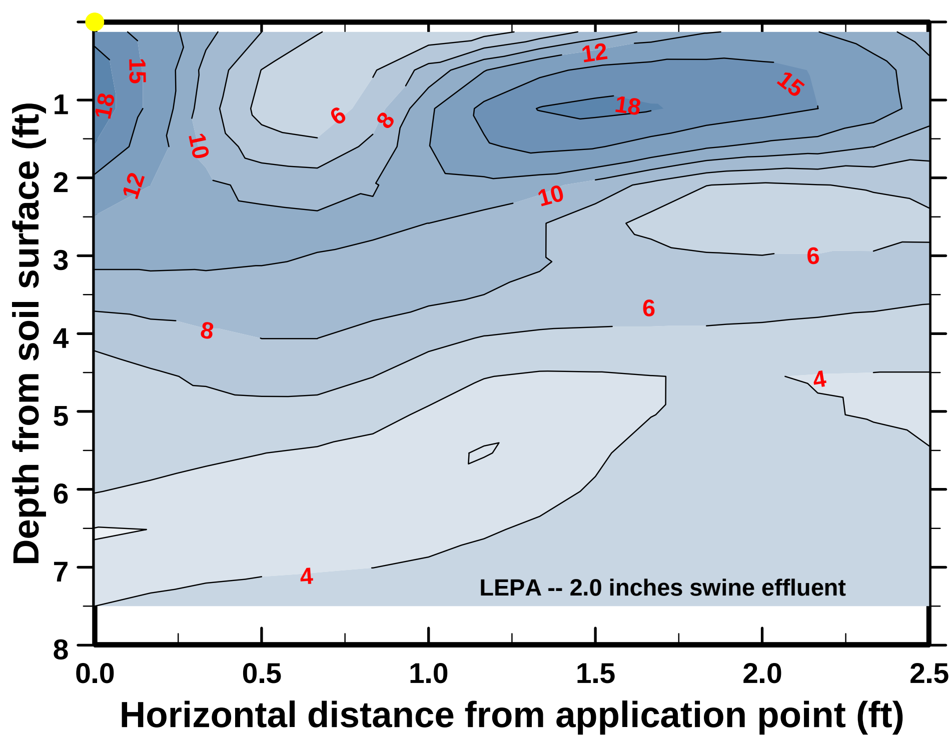

Figure 8. Nitrate-N concentrations, ppm, in the soil profile at specific depths and distances from the LEPA sprinkler (yellow dot) for the 2.0-inch swine effluent treatment in the fall of 2001, KSU Northwest Research Extension Center, Colby Kansas.

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[1] *Mention of tradenames is for informational purposes and does not constitute endorsement of the product by the authors or Kansas State University.*

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Safe Reuse of Treated Wastewater for Inedible Seed Production

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Abstract

Four years of successful environmental wastewater treatment at Sadat Pilot Site, western desert of Egypt, safe production of inedible seeds was realized. Mixed domestic and industrial wastewater was treated through, oxidation pond; polishing pond then constructed gravel wetland cultivated with different types of water reeds. Three types of inedible seeds were produced and analyzed for heavy metal content. Vegetable seeds of Onion, Celery and red Turnip, cut flowers; Chrysanthemum and, potato marigold. Decorative plants; Coreopsis, Alyssum and Santorum were selected after several trials, of successful production under local environmental conditions of soil, water and climatic norms prevailing in the area. Heavy metal contents of the produced seed indicated safe use of those seeds for producing safe crops if cultivated in other areas. Dilution of heavy metal pollutants was calculated and proves safe use of the produced seeds. Water quality of primary treated wastewater expressed as EC of 1.58 ds/m, pH of 7.92 and BOD of 89.0 while after tertiary treated wastewater (wetland) EC of 2.70 ds/m, pH of 8.6 and BOD of 16.0, heavy metal content, i.e. Cd, Pb, were 0.02 and 0.27 ppm respectively in primary treated, while 0.01, and 0.16 ppm respectively in the tertiary treated, wastewater. On the other hand heavy metal content i.e. Cd, Pb, Ni in the produced seeds were 0.00, 0.00 and 50.90 in Onion seeds and were 0.00, 0.50 and 30.00 ppm in Alyssum seeds while 0.00, 2.35 and 12.50 ppm in Celery respectively. .

Keywords wastewater reuse, inedible seeds, arid climate.

INTRODUCTION

Water has been a scarce resource in the Middle East since early civilizations. Water resource allocation continues to be the most urgent and pressing issue for the region. Today, water shortage in the Middle East has forced countries to reuse treated wastewater for agriculture, industry, recreation and to recharge aquifers (Asano & Mills, 1990). Due to the increasing demand for water use in the arid region wastewater reuse is recognized as one of the rising alternative water resources.

Wastewater has been extensively reused as a source of irrigation water for centuries in water shortage countries, since irrigation water does not usually require high grade water quality compared to drinking water, (Asano and Levine. 1996).

Reuse of reclaimed water for irrigation enhances agricultural productivity: it provides water and nutrients, and improve crop yields However; it requires public health protection, appropriate wastewater treatment technology, treatment reliability, water management and public acceptance and participation. It must also be economically and financially viable, (Bahri, 1999). Various physical, biological and chemical treatment processes that can be applied in wastewater treatment have been reviewed by (APHA 1995), In addition, the sustainability of wastewater for irrigation is determined by the amount and kind of salts present as well as its potentials to causing problems. Various soils and cropping problems were reported when using wastewater.

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Those problems related to usage of poor quality wastewater include salinity, permeability and toxicity among others. While the wastewater reuse for agriculture has the advantage of securing alternative water resources with economically, high concentration of nutrient and other constituents may bring adverse effects on environment soils, crops and irrigation water management, (Shainberg and Oster, 1978). The most significant wastewater reuse takes place in arid region, where other sources of water are not enough, (Harovy, 1997). High levels of nitrogen in wastewater may result in nitrate pollution of groundwater sources used for drinking, which could lead to adverse health effects. Accumulation of heavy metals in soils and its uptake by plants is another risk associated with wastewater irrigation (Khouri, Kalbermatten and Bartone 1994). Distribution of wastewater on the soil may be repeated for at least 3 – 5 years without encountering significant problems. (Cox L. etal. 1997). The removal of nitrogen was more effective than that of phosphorus in the agal ponds studied by LI et al., (1991) with efficiencies up to 99.3 % for nitrogen and 48.1 % for total phosphorus. Health risks associated with the agricultural application of reclaimed wastewater involve farmers / agricultural workers and consumers (Crook, 1991). Other environmental concerns are also important, particularly the fate of toxic substances (such as heavy metals) or Endocrine Disrupting Substances. The treatment methods alone (including or not effluent disinfection) or in combination with the proper irrigation techniques should eliminate the health and environmental risks involved.

In Egypt late of 1990's the ministry of agricultural issued a decree forpedden the reuse of reclaimed wastewater for irrigation of food and fiber crops, but only for wood trees production. Therefore the aim of this research is evaluate the safety reuse of the reclaimed wastewater for producing some inedible seeds as a more economic alternative rather than poor wood trees production under arid climatic conditions in the western desert of Egypt.

MATERIAL AND METHODS

The research was carried out in the desert adjacent to Sadat city, Egypt using treated wastewater to produced inedible seed production. The WHO, 1989 code of irrigation water quality of was considered in addition to the Egyptian code.

Six crops have been selected for seed production; Vegetables seed crops (onion and celery), out door plant species (Coreopsis and alyssum) and cut flowers species (Chrysanthemum and potato marigold). Two types of treated wastewater were used; polishing pond (secondary treated) and wetland (tertiary treated) effluents Fresh under ground water was used as control. Table (1) Each plot area was 70 m^2; each crop cultivated in seven rows. The length of each row is 10 m and spacing between rows is 1 m. Each treatment was replicated three times and arranged to comply with the statistical design of randomized complete block design with three treatments; polishing, wetland effluents and freshwater used for irrigation as a control. Seeds were cultivated for two growing winter seasons of 2004 / 2005 and 2005 / 2006 all types of seeds were planted in a soil irrigated with wastewater for 5 years, some physical and chemical soil analyses are shown in Table 2&3 at 50 cm spacing and 1 meter raw spacing. Therefore the number of plants per plot was 140. The plantation was completed through 10^{th} to 20^{th} 2004 and around the same dates of 2005of October. All the experimental plots received only organic manure at soil preparation stage with about 1/2 liter per plant along the dripper. Standard agronomic practices were applied for irrigation and plant protection during the two growing the spring and the summers of 2005 and 2006. Seeds were hand picked, sun dried and manually cleaned. Seed yield was determined as grams per meter of irrigation pipes, germination tested were performed in Petry dishes. Heavy metals contents of some seeds were determined using standard chemical analyses method using Atomic Adsorption Spectrophotometer, Model Perken Elmer 3110.

Some data were analyzed, for Onion and Coreopsis through ANOVA to determine the effect of treatments and Tukey's studentized range (HSD) tests were performed to determined the statistical significance of the differenced between means of treatment.

Table (1): Wastewater analyses before and after reclamation treatments. Date of sampling

Parameters	**Inlet** *(oxidation pond effluents)*	Polishing pond Effluent	Wetland bed Effluent	Fresh water
PH unit	7.23	7.94	6.42	7.91
Total Alkalinity mg/L	265	310	340	358
Total suspended solids mg/L	105.5	77.1	50.1	ND
Total dissolved solids (TDS) mg/L	954	1022	505	ND
Biochemical oxygen demand (BOD_5) mg/L	80.8	32.3	16.7	ND
Chemical oxygen demand (COD) mg/L	166.5	105.4	45.6	ND
Ammonia-Nitrogen (NH_4-N) mg/L	3.2	2.6	4.91	ND
Nitrate-Nitrogen (NO_3-N) mg/L	3.3	1.85	0.32	ND
Total phosphorus(T-P)mg/L	8.9	3.9	3.7	ND
EC dS/m	1.43	1.6	2.6	0.69
Cl me/l	6.7	8.1	8.8	3.6
Fe *ppm*	6.75	8.8	7.95	0.0
Cu *ppm*	1.66	1.48	1.20	0.0
Zn *ppm*	0.0	0.0	0.0	0.0
Mn *ppm*	1.30	0.2	0.62	0.0
Cd *ppm*	0.0	0.0	0.0	0.0
Pb *ppm*	0.80	0.38	0.20	0.0
Ca me/L	6.3	8.1	8.95	8.19
K me/L	0.8	0.9	0.91	0.31
Na me/L	7.8	7.6	10.0	7.9
HCO_3 me/L	8.91	7.4	8.73	5.3
Mg me/L	2.1	2.0	2.3	3.5

Table (2) Effect of reused wastewater on some top soil characteristics.

Profile	Soil depth(cm)	pH	EC (dS/m) 1:2	Soluble cations and anions (meq/l)					
				Ca	Mg	Na	K	HCO_3	Cl
Wet.	(0-10)	9.9	1.08	2.3	1.28	5.65	0.85	2.94	5.22
	(10-20)	9.8	0.55	1.17	0.65	2.88	0.43	2.8	1.8
	(20-40)	10.1	0.39	0.83	0.46	2.04	0.31	2.11	1.08
Fresh	(0-10)	8.5	3.06	6.52	3.62	16	1.02	1.54	6.19
	(10-20)	8.4	1.34	2.85	1.59	7.01	1.06	0.84	3.96
	(20-40)	8.56	0.77	1.64	0.91	4.03	0.61	1.18	1.08
Pol.	(0-10)	9.71	0.96	1.78	0.45	4.84	0.38	1.48	3.76
	(10-20)	9.6	0.74	1.58	0.88	3.87	0.58	1.43	2.34
	(20-40)	8.6	1.56	3.32	1.85	8.16	1.23	0.73	1.35

RESALT AND DESCUTION

The main objective of this research is to delete the environmental wastes to reduce the risk of the concentration of the environmental pollutants particularly the heavy metals. Meanwhile to realize an economically feasible reuse of the reclaimed wastewater in agriculture production of inedible seeds is a good and economic agricultural activity if it is technically viable and safe regarding the heavy metals concentration not necessarily in the seeds but in the propagated plants there after. This experiment was carried out in a soil received reclaimed wastewater for irrigation along the past five year. The seed yield and germination rates were determined for the tested plants of various types, namely Onion, Celery and red turnip (Vegetables), Chrysanthemum and Potato marigold (cut flower) and Coreopsis, Alyssum and Santorum (decorative plants). Table (4) indicated the average seed yield of the tow growing season 04/05 and 05/06, the average germination rates for some of the tested crops were 75% for onion, 40% for Celery, 74% for Coreopsis and 31% for chrysanthemum, but low for other seeds, therefore the statistical analysis was performed only for Onion and Coreopsis. Data indicated clearly that the seed yield of most tested plants was affected by the irrigation water quality and also with soil characteristics. However some plants such as Coreopsis produce similar yield. Therefore two crops were selected for statistical analysis using ANOVA. Data of the statistical analysis indicated that significant differences in the seed yield production for Onion, F value 0.0015, however the germination rate was not affected significantly due to the prolonged irrigation by reclaimed wastewater, F value = 0.3011.

Table (4): Average of Seed Yield

Crop Type	Seed Yield of 04/05 g/m* for different treatment			Seed Yield of 05/06 g/m for different treatment		
	Fresh	Wetland	polishing	Fresh	Wetland	polishing
Onion	7.14	3.33	5.40	5.90	4.10	4.17
Celery	8.00	4.00	5.40	6.00	4.70	5.00
Coreopsis	16.13	18.20	20.00	12.5	22.0	18.18
Santorum	11.11	13.50	13.00	8.30	10.4	15.2
Chrysanthemum	40.00	58.30	48.60	39.4	48.15	43.8
Mary Gold	33.33	44.44	44.12	33.3	44.0	43.7

* g/m gram per meter of drip line

Regarding the coreopsis, both seed yield and germination rates were not affected significantly due to (F values 0.1272 and 0.0830), Peratlta et al (2000) indicated that seed germination of alfa alfa is seriously affected by concentration of Cu, Cd, Cr and Ni. Some other concentration has no or stimulated effect on seed germination and growth. It seems that Onion seed production affected negatively by the levels of heavy metals in the top soil. Kuo et al (1983). Other soil characteristics may also influenced the growth and seed yield and quality such as the soil salinity which increased due to the prolonged use of reclaimed wastewater in irrigation. Quality of reclaimed wastewater used for irrigation was the major factor affect the soil characteristics of the top soil, crop growth as well as the quality of produced seeds. However the economic value of the produced seeds still more better than other uses such as low quality wood trees. Seed quality was almost the same in both plots irrigated with wetland and polishing effluents however much better quality seeds produced using fresh water for irrigation as indicated from the weight of the same number of seeds.

Table (5): Heavy metal analyses for soil of Wetland, Polishing and fresh experimental plots.

Cd	Pb	Ni	Cu	Zn	Mn	Fe	Soil depth(cm)	
g/Kg soil								
-	2.28	1.59	7.53	8.53	11.90	17.67	0-10	Wetland
-	2.13	1.24	7.48	8.18	9.63	17.89	10-20	
-	1.05	0.92	4.13	5.53	8.63	13.43	20-40	
-	0.96	0.73	2.11	3.31	4.80	14.87	40-80	
-	5.36	3.25	13.89	15.18	21.23	29.13	0-10	Polishing
-	5.28	3.12	13.87	12.74	19.64	26.24	10-20	
-	3.24	2.81	8.23	9.31	17.35	25.76	20-40	
-	2.21	2.04	5.62	5.68	11.78	22.39	40-80	
-	0.00	0.19	0.23	0.94	0.86	8.54	0-10	Fresh
-	0.00	0.15	0.24	0.44	0.56	8.41	10-30	
-	0.00	0.11	0.15	0.20	0.37	6.74	30-60	
-	0.00	0.06	0.09	0.12	0.98	4.48	60-90	

Data of heavy metals analysis of top soil layers of the experimental plots reveal that heavy metals contents of the experimental site soils are below the standard limits of both Holland, England and Germany as reported in the science, technology and environment agency, Ho Chi Minh City., Report of environmental activity (2000).
Table (6) heavy metal contents in produced plant seeds

	Type of plant	Heavy metal							
		Fe	Mn	Zn	Cu	Pb	Cd	Ni	Co
Fresh	onion	60	15.0	0	0	0	0	10.0	3.5
	celery	274	33.5	13.35	5.0	1.35	0	2.5	10.0
	coreopsis	250	4.7	3.2	4.0	0	0	2.0	2.5
	Alyssum	650	18.0	12.0	1.5	0	0.50	10.0	2.0
	chrysanthemum	ND	ND	ND	ND	ND	ND	ND	ND
	potato marigold	ND	ND	ND	ND	ND	ND	ND	ND
Wetland	onion	57.2	16.2	13.4	2.75	0	0	30.0	4.5
	celery	860	18.0	6.75	4.3	1.80	0	12.0	12.0
	coreopsis	370	5.5	3.1	4.0	0	0	2.5	3.0
	Alyssum	1560	38.5	18.0	2.6	0.95	0.55	35.25	5.0
	chrysanthemum	119.5	12.4	8.0	4.9	4.0	0	0.15	3.0
	potato marigold	105	49	19.0	4.2	2.5	0.40	2.1	ND
polishing	onion	82.3	17.5	16.20	4.9	3.75	0	40.0	4.5
	celery	1950	25.0	9.8	7.8	3.5	0	25.0	15.0
	coreopsis	760	15.0	10.0	5.0	0	0	4.0	5.0
	Alyssum	4200	20.0	20.0	4.6	1.30	0.56	33.4	4.0
	chrysanthemum	140.0	10.5	13.4	5.0	3.4	0	35.0	3.5
	potato marigold	115	16	13.2	5.0	4.7	0.35	5.0	4.0

However the produced seeds contain significant amounts of heavy metals as shown in table (6),. This may be attributed to the heavy metals in the reclaimed wastewater used for irrigation as indicated in table (1). The amount of heavy metals assimilated by plants dose not differ due to plant species, also the soil total content of heavy metals cannot be used as an explicit criterion for ecological evaluation of soils with regard to their exploitation for agricultural activities, Penka, et al (2004). It can be concluded that the quality of irrigation water is the most effective parameters determining the sees yield and quality. Therefore the produced seed should not propagated using the same quality water for the final stage for producing edible product. In this case very environmental safe dilution will realized due to the following calculation i.e for Onion seeds produced using polluted wastewater.

Table (7): Seed weight: average weigh of seed of some tested plants.

Type	No. of seeds	Weight/ g		
		Wetland	Polishing	Fresh
Onion	100	0.43	0.45	0.65
Celery	1000	0.48	0.50	0.57
Coreopsis	1000	0.25	0.30	0.36
Chrysanthemum	500	1.29	1.20	2.00

One seed contain 40.0 ppm of Ni if cultivated and irrigated with good quality water then produced an Onion pulp of 100g. One seed weights 0.0043g, as shown in Table (7) provided that all the Ni contaminate will accumulate in the onion pulp then the

40.0ppm concentration will diluted to 0.0043x 40/100 means that the Ni concentration the produced Onion pulp is $72x10^{-6}$ ppm. For the other seed produced the contaminant concentration will be much less as the seed Wight is extremely low. The germination rates were affected significantly with the irrigation water quality therefore it can be also concluded that crop selection tests should be performed using seed germination test as an explicit criterion. Following this sequence safe inedible seed production can be realized using treated wastewater for irrigation.

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Knifing versus Injecting Phosphorus with SDI Systems in Cotton

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Abstract

Presently, one of the problems farmers are facing in West Texas after continuously raising cotton for 10 years on previously installed SDI systems is the depletion of nutrients. Since SDI systems wet a portion of the soil forming a wetting bulb, most of the nutrients are absorbed from this portion where the water infiltrates. This process has depleted nutrients that otherwise would have been plentiful for uptake given that the soils are rich on them, mainly nutrients such as phosphorus (P) and potassium (K). In comparison, furrow systems wet a larger volume, which presumably would encourage roots to spread, providing a larger access to nutrients. Some SDI farmers have observed large increases on cotton lint yields just by the addition of small amounts of phosphorus. Several questions arise regarding these applications, such as what are the most appropriate rates or whether to split the rates between the phenological stages. Furthermore, there is uncertainty concerning the most efficient method to apply phosphorus and potassium. These nutrients can be either knifed into the soil, or injected through the irrigation system. SDI systems allow splitting injections during the growing season at a low cost. The effect of knifing versus injecting the phosphorus into the irrigation system in two applications was evaluated. The experiment was completely randomized with four treatments and four replications. The treatments were: 1) No phosphorus applications; 2) Knifing the phosphorus into the soil, 3) applying 15.1 L (4 gallons) of phosphoric acid in one application, 4) applying 15.1 L (4 gallons) of phosphoric acid in two applications. The phosphorus rates applied in both the knifing and injection applications were similar. Although not statistically different, the knifed phosphorus resulted in numerically higher seed cotton weights than the yield obtained with the injection of phosphorus through the subsurface drip irrigation system in 2004. Statistically, there was no difference between knifing or injecting the phosphorus during the first year of the experiment. The experiment got hailed out in 2005.

Introduction

The adoption of subsurface drip irrigation (SDI) for cotton production in Texas has increased dramatically in the last 10 years. In 1994, Henggeler listed the SDI cotton acreage to be about 3300 acres (10% of the irrigated acreage of St. Lawrence area). This year according to Bryan Frerich there are about 220,000 cotton acres with SDI in the state of Texas (Frerich, 2004). The most intensive area with cotton using SDI remains in the St. Lawrence area of Texas (Upton, Reagan and Glasscock Counties), and the Lubbock area. Declining water resources and small irrigation system capacities have pushed this trend up, and also perhaps the fact that irrigation efficiencies (defined as lint yield divided by gross irrigation applied) above 24 kg/ha-cm (55 lbs/ac-in) can be obtained with SDI systems (Enciso et al., 2002; 2003). In comparison, irrigation efficiencies of 15 kg/ha-cm (35 lbs/ac-in) are generally obtained with furrow systems.

One of the problems farmers are facing after continuous cotton production with SDI for 10 years is the depletion of nutrients. Since SDI systems wet a smaller volume of the soil, a smaller root zone would presumably result, and nutrients such as phosphorus (P) and potassium (K) are absorbed from a much smaller volume. With furrow systems, a larger volume is wetted, presumably resulting in a larger root volume and hence a greater access to soil nutrients. Some SDI farmers have observed large increases on cotton lint yields just by the addition of small amounts of phosphorus. Several questions arise regarding these applications, such as what are the most appropriate rates, or whether to split the rates between the phenological stages. Another question is what is the most efficient method to apply phosphorus and potassium. These nutrients can be applied on the surface and knifed into the soil to depths of approximately 10 cm, or injected through the irrigation system (fertigation). Considering that P is relatively immobile in the soil, injecting P into the soil through SDI may increase its distribution through mass flow of water and saturation of cation exchange points compared with knifing (Bar-Yosef, 1999; Lamm et al., 2006). The injection of P and K with SDI irrigation systems under high frequency has increased tomatoes yields considerably without increasing water use, resulting in higher water use efficiency (Phene et al., 1990). However, one of the challenges of phosphoric acid injection into the irrigation system in desert environments is that water generally is hard (high in calcium and magnesium), which can result in precipitation of phosphates and clog drip emitters if the irrigation water is not acidified (Burt et al., 1998). Alternatively, phosphoric acid could be injected at a sufficiently high rate so as to maintain irrigation water pH at approximately 4.0 or less.

We hypothesize that, despite some risks with emitter clogging by injecting phosphoric acid, cotton lint yields might be increased by fertigation relative to knifing. The objectives of this study were to evaluate the cotton yield response of phosphorus application through 1) knifing; 2) single large application of fertigation; and 3) two smaller applications of fertigation.

Material and Methods

The experiment was conducted on a farm owned by a cooperating cotton producer in St. Lawrence, TX during the 2004 and 2005 seasons. The cotton variety Deltapine[1] 488 BR was planted on 24 May, 2004 on raised beds with 1.02 m spacing. The soil was a clay loam soil with good drainage (29% sand, 42% silt, and 29% clay). Irrigation was applied using subsurface drip irrigation (SDI). The SDI system had emitters installed every 60 cm and each emitter had a discharge of 0.91 L/h. The drip-line was spaced every 1.02 m (beneath each planted bed) at a 30-cm depth. This resulted in an application rate of 0.15-cm h^{-1}. Tillage practices consisted of stalk chop and list, plant, and two applications of round up Ultra Max®.

The experiment was completely randomized with four treatments and four replications, with a total of 16 plots. Each plot consisted of four 290-m long cotton rows. The treatments were: 1) No phosphorus applications; 2) Knifing 33.6 kg ha^{-1} of P_2O_5 into the soil using ammonium polyphosphate (10-34-0); 3) Injection of 33.6 kg ha^{-1} of P_2O_5 in one application using phosphoric acid; 4) Injection of 33.6 kg ha^{-1} of P_2O_5 in two applications (16.8 kg ha^{-1} each) using phosphoric acid. Liquid nitrogen (UAN32) was injected through the irrigation system on 25 July 2004 at 127 kg ha^{-1}. (this was reduced to 117 kg ha^{-1} for the knifing treatment to account for the N present in the 10-34-0). The fertilizer 10-34-0 was knifed on 30 June 2004; the phosphoric acid was applied on 15 July 2004 in a single 15.1 L application, and on 15 July and 1 August 2004 for two 7.6 L applications. Watermark blocks were installed to qualitatively assess soil wetness by estimating soil matric potential. Rainfall and weather data were recorded daily.

Harvest data were gathered from within each plot mechanically by harvesting four rows. Seed cotton was weighed for each replication, and a portion (about 0.60 kg) was ginned at the Texas A&M Agricultural Research and Extension Center in Lubbock, TX. The seed cotton weight was analyzed with a general linear model (GLM) with mean separation by the least square difference (SAS Institute, 1991).

Results

During the 2004 season, 21.3 cm of rainfall received (Table 2). Preplant irrigation (15.3 cm) was applied depth from March 23 to May 6, and an in-season irrigation depth (26.4 cm) from May 21 to August 21. In 2005, preplant irrigation (9.9 cm) was applied from April 15 to May 24, and an in-season irrigation (26.4 cm) was applied from June 25 to August 15. A hail storm occurred on July 17 that severely damaged the plots and low cotton yields were obtained, therefore the results of 2005 are not reported.

[1] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by Texas A&M University or the USDA-Agricultural Research Service.

Table 2. Rainfall (cm) received during 2004 and 2005.

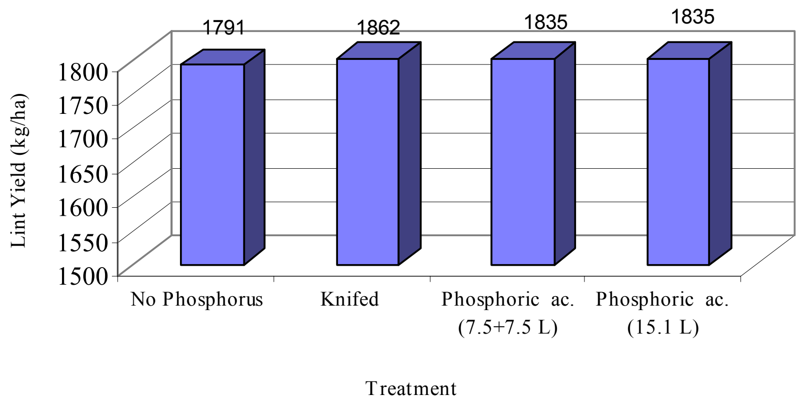
Month	2004	2005
Jan	2.1	0.7
Feb	1.9	6.9
Mar	5.9	6.6
April	8.5	0.2
May	0.2	11.1
June	18.4	6.8
July	5.4	9.5
Aug	12.0	46.6
Sep	12.2	0
Oct	0.3	17.8
Nov	0	0
Dec	0	0.04
Annual total	66.9	106.2
Preplant rainfall	10.9	7.0
In-season rainfall	35.8	65.5

There was not any statistical difference on lint cotton yield between the treatments of the experiment (Fig. 1). Although not statistically different, the knifed phosphorus resulted in numerically higher seed cotton weights than the yield obtained with the injection of phosphorus through the subsurface drip irrigation system. The average yield for the knifed phosphorus was 26.9 kg ha^{-1} (24 lbs ac^{-1}) higher than the injected phosphorus through the drip system and 70.6 kg ha^{-1} (63 lbs ac^{-1}) higher than the no phosphorus application treatment. These results do not support the hypothesis where the deeper placement of phosphorus through fertigation (approximately 30 cm) would improve cotton yields relative to the shallower placement of nutrients by knifing (approximately 10 cm). There was no difference between splitting the phosphorus in two applications or in applying it in only one application; the yields were similar for these treatments. It is important to obtain data for more years to draw any valid conclusions.

Conclusion

Statistically, there was no difference between knifing or injecting the phosphorus during 2004. In 2005, the experiment got hailed out. Another year is necessary to make conclusions.

Fig. 1. Cotton lint yield (kg/ha) response to different phosphorus applications in 2004.



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The Use of Multi-sensor Capacitance Probes as a Tool for Drip Irrigation Management in Humid Regions.

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Abstract.

Irrigation management in humid regions is more complex than in arid regions, and this is particularly so for drip irrigation under plastic mulch. Good measurements of soil water content can help. Multi-sensor capacitance probes (MCPs) measure soil water content simultaneously at discrete depths, and a new generation can also respond to salinity and therefore may be useful in nitrogen management. Replicated field studies on drip irrigated watermelon have been conducted in Delaware in which MCPs were used to monitor water content under different relative irrigation amounts. The objectives are to develop improved irrigation guidelines and to evaluate the potential for nitrogen management. Results indicate that MCPs may be an important tool, but there are many practical details to be considered, such as their placement and interpretation of the wealth of data they generate.

Introduction

Drip has become the preferred method of irrigation for some crops, (particularly high value vegetable crops) in the humid Eastern USA. For example, in Delaware most watermelon production now uses drip tape under plastic mulch. While this method is potentially very efficient in terms of water use, it is also complex in terms of soil water distribution and dynamics, particularly when rainfall during the season is significant.

The reasons for the complexity when compared to sprinkler irrigation include:

- Irrigation water is applied to only part of the field, and is applied as a line of equally spaced point sources rather than relatively uniformly to the entire field.
- The areal extent of the canopy is often not the same as the areal extent of the roots.
- Rain falling directly on the plastic mulch cannot infiltrate, but runs off to the edge. Rainwater is therefore concentrated at the edge, where it can infiltrate the soil but must then move laterally to contribute to soil water content under the mulch.
- Rain can enter the soil under the mulch through the planting holes (perhaps also channeled by stem flow) and through cuts and tears that may develop in the mulch, but this direct contribution to soil water content is difficult to quantify.
- Both the lateral and vertical root distribution relative to the drip tape may be affected by irrigation management itself.
- In sandy soils, downward movement of water below the drip tape may be significantly higher than lateral movement, making it difficult to adequately replenish the wetted soil volume without causing deep percolation.
- The evaporative component of evapotranspiration (ET) is suppressed by the plastic mulch.
- Nutrients are commonly applied through the drip tape (fertigation), and so will have the same distribution and dynamics as the irrigation water.

In terms of management, growers typically will tend to over-irrigate as insurance against under irrigation. This tendency may be exacerbated in mulched drip irrigation because the water is "out of sight" and because soil water content under the mulch cannot be readily assessed.

We have been conducting research in Delaware since 2004 using Multisensor Capacitance Probes (MCPs) to measure soil water content and dynamics under mulched drip irrigated watermelon. Watermelon may be particularly difficult to manage under humid conditions because of the wide row spacing typically used (therefore the fraction of the field under mulch is relatively low) and because the crop appears to have an agressive root system. Figure 1 shows a typical layout and probe locations.

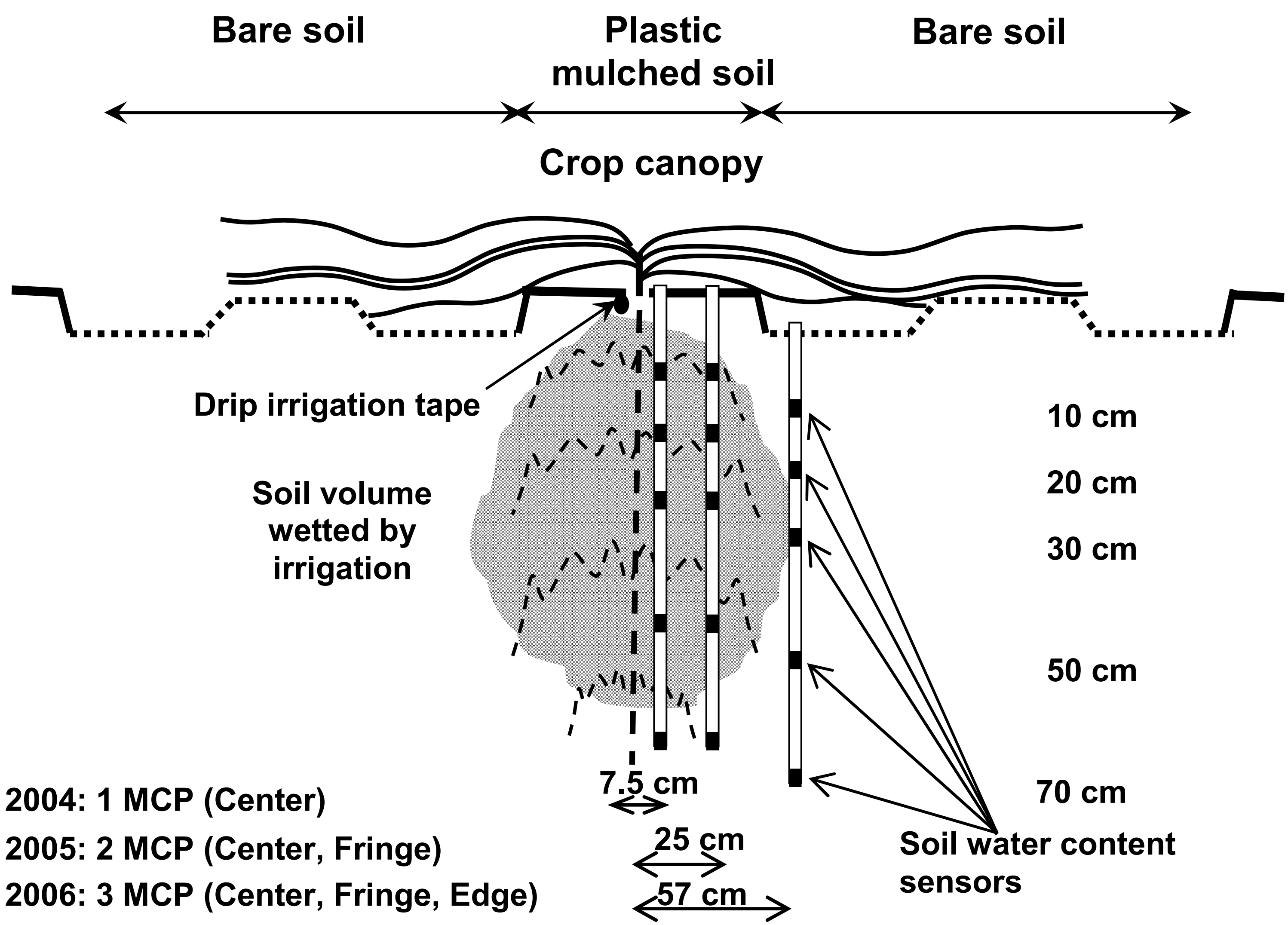


Figure 1. Plastic mulched drip irrigation of watermelon and layout of MCPs in 2004, 2005 and 2006. The center position and fringe position are in the mulched area, while the edge position is in the bare soil outside the mulch.

There are a number of soil water sensors available, each with advantages and disadvantages. Sensors that provide an electrical signal have the advantage of easy measurement, logging and data processing. Such sensors include those that measure the dielectric constant of the soil, which depends primarily on volumetric soil water content and electrical conductivity. Time Domain Reflectometry (TDR) and Frequency Domain Reflectometry (FDR) are the technologies currently being used. MCPs use a number of capacitance sensors (FDR) mounted on a probe that is inserted into the soil and remains in place for the duration of the period during which measurements are required. MCPs therefore measure volumetric soil water content at discrete depths based on the dielectric constant of the soil surrounding them. The MCPs we used were EnviroSCAN®[1] or TriSCAN® (Sentek Pty. Ltd., 77 Magill Rd, Stepney, South Australia 5069), in which up to 16 sensors can be placed on a single probe, with depth intervals set by the user in 10-cm increments. The probes are installed in access tubes that are inserted into the soil so as to make good contact with it. EnviroSCAN probes operate at a single frequency range chosen such that water content rather than electrical conductivity is the primary determinant of the dielectric constant. TriSCAN probes have similar sensors, but are dual frequency in that, in addition to the frequency used in EnviroSCAN probes, they also operate in a frequency range in which electrical conductivity (expressed as "Volumetric Ion Content" (VIC)) can be measured (Buss et al, 2004). In non-saline environments and sandy soils VIC can be related to soluble nutrient content. The zone of major influence of the sensors represents a cylinder of soil approximately 10 cm along the axis of the probe with a 10 cm ring around its 5-cm diameter PVC access tube (Paltineanu and Starr, 1997). Starr and Paltineanu, 1998; Paltineanu and Starr, 2000; Fares and Alva, 2000; and Starr and Timlin, 2004 have investigated Enviroscan MCPs.

Evett et al (2002) have compared measurements made using TDR and FDR instruments, including MCPs, with those made using a neutron probe, and conclude that the neutron probe has superior accuracy. However, while the neutron probe has the advantage of sampling a relatively large soil volume with perhaps greater accuracy than many other methods, it cannot be logged and, because it requires licensing, is unsuitable for direct use by growers. The accuracy of capacitance probes can be improved with on-site calibration, but it is not likely that many growers would do this before using them.

Methods

We conducted replicated studies in 2004, 2005 and 2006 on mulched drip-irrigated seedless watermelon (cv. Millionaire) at the University of Delaware Research and Education Center in Georgetown (38˚ 38' N 75˚ 27' W). The soil texture at this site is sand to loamy sand over sandy loam or sandy clay loam. Plant and row spacing were 0.91m (3ft) and 2.44m (8ft) respectively, following standard production practice in the region. A row of seeded watermelons (as pollenizers) were planted for every 2 rows of seedless watermelons. In all years seedlings were transplanted during the third week of May. The plots, which were 9.14m (30ft) long, were irrigated using drip tape (T-Tape, T-

[1] Trade names are used in this publication to provide specific information. Mention of a trade name does not constitute a guarantee or warranty of the product or equipment by the USDA or an endorsement over other similar products.

Systems) at one of three different rates, roughly corresponding to 50%, 100%, and 150 % of estimated ET (ratios of 1:2:3). These rates, (low, medium, and high) were imposed by varying the run time of the drip tape so that, for example, if it was determined that an irrigation of two hours duration was needed to meet ET (the 100% treatment), the 50% and 150% treatments received water for one and three hours respectively. While the run time for the 100% treatment varied during the season, the 50% and 150% ratios were always maintained. Anecdotal observations suggest that typical grower irrigation may be at least as much as the 150% treatment. The width of the raised bed covered by plastic mulch was approximately 76 cm (30 inches), and the spacing between the drip tape emitters was 30 cm (12 inches). Nitrogen was applied preplant at the rate of 56 Kg/mulched ha (50 lb/ mulched ac) and in two fertigations of 56 Kg/mulched ha (50 lb/mulched ac) area during the season. In each year ET_0 was estimated using the FAO-56 Penman-Monteith method (Allen et al, 1998) from data collected by a nearby automated weather station.

In each year of the study MCPs with sensors at 10, 20, 30, 50 and 70 cm depth were carefully installed to minimize air gaps, using a manufacturer supplied auger system and access tubes with cutting rings. Prior to installation each sensor on each probe was "normalized" by making measurements in distilled water and air using the manufacturer's default calibration. After installing the access tube silicone sealant was applied around it to prevent direct water infiltration between the tube and the plastic mulch. The MCPs were connected by cables to the logger, and logged at 10 minute intervals. However the number and location of MCPs differed each year (as shown in figure 1), as follows:

2004.

Four replications of the three irrigation rates were used (12 plots total). In each plot an EnviroSCAN probe was installed near the center of the raised bed (termed the "center" position) 15 cm (6 in) from an individual plant and 7.5 cm (3 in) from the driptape. The probes were not located relative to the emitters. There was thus 1 MCP per plot, 12 MCPs total with a combined total of 60 sensors.

2005

As in 2004, four replications of the three irrigation rates were used. In each plot an EnviroSCAN probe was installed at the center position but located relative to the emitters (midway between adjacent emitters at the closest available location to a plant). An additional probe was installed midway towards one edge of the raised bed (approximately 27 cm (10.5 in) from the drip tape, 19 cm (7.5 in) from the plant, and termed the "fringe" location) in order to assess lateral water movement from the drip line toward the edge of the raised beds. There were thus 2 MCPs per plot, 24 MCPs total, with a combined total of 120 sensors.

In addition, TriSCAN (dual frequency) probes were installed in the center and fringe positions in two replications of two treatments in an adjacent complementary study established to evaluate response to nitrogen. Irrigation and preplant nitrogen application was the same as the 100% irrigation treatment. One of the treatments received four fertigations of 28 Kg N/mulched ha (25 lb N/mulched acre) during the season while the other treatment received two fertigations of 56 Kg N/mulched ha (50 lb N/mulched acre). A total of 8 TriSCAN probes (40 sensors) were therefore used in addition to the 24 Enviroscan probes.

2006.

Probes were installed in the same two positions as in 2005 (center and fringe), with an additional probe installed in each plot outside the plastic mulch approximately 57 cm (22.5 inches from the plant, 64 cm (25.5 inches) from the drip tape), in what is termed the "edge" position. These probes was therefore in bare soil in the area where runoff from the mulch collects after rainfall. Probes were installed in 3 replications of the three irrigation treatments. There were thus 3 MCPs per plot for a total of 27 MCPs with a combined total of 135 sensors. The probes were located relative to the emitters as in 2005, but the seedlings were also planted relative to the emitters (adjacent).

In addition, two more irrigation treatments were instrumented in one replication. The treatments were no irrigation (0%) except for the two fertigations, and very high irrigation (250%). EnviroSCAN probes were installed in the center position in the 0% treatment, and in the center and fringe positions in the 250% treatment. The center position probe in the very high irrigation treatment had an additional sensor installed at 100cm to monitor infiltration to and water uptake from this depth. There were thus three additional MCPs with 16 sensors.

Eight TriSCAN probes (40 sensors) were also installed, as in 2005, to measure response to the same two fertigation treatments.

The amount of data generated in such experiments is considerable. For example in 2006 there were a total of 30 EnviroSCAN probes (151 sensors) measuring soil water content every 10 minutes to provide almost 22000 measurements per day. In addition the 8 TriScan probes (40 sensors) were logged every 30 minutes and provided almost 2000 additional measurements of soil water content per day along with the same number of measurements of VIC.

In drip irrigation, actual crop water use cannot be estimated by applying the same crop coefficient to ET_0 as with other methods of irrigation. Even with a full canopy, drip irrigated crops often have lower crop water use. Clark et al (1996) reported that irrigation of $0.3ET_0$ was sufficient for drip irrigated watermelon. We used ET_0 as a guideline for the 100% irrigation treatment, but assumed that the crop would use water only from the area under the mulch, which is about 30% of the total field area. Thus, irrigation was applied to replenish water only from this mulched area, and so was similar to the requirements reported by Clark et al.

Results and Discussion

Figure 2 shows daily and cumulative ET0 (a), daily and cumulative rainfall (b), irrigations (c) and the total measured soil water content in the top 70 cm in the center position for the 2006 plot that included the very high (250%) and no irrigation (0%) treatments in addition to the 50%, 100% and 150% treatments. Each measurement depth represents the range from 5 cm above to 5 cm below. For example the 20 cm measurement depth represents soil water content from 15 to 25 cm. The total water content was obtained by summing the water contents at the measurement depths and interpolating at the depths for which there was no direct measurement, ie between 30 and 50 cm, and between 50 and 70 cm. There was a large rainfall event early in the season that resulted in ponded water at the edge of the mulch, the effect of which can be clearly seen in the measured soil water content. The soil water content at the beginning of the measurement period (17 June) varies considerably, from about 100mm to 160mm. This difference may be real and due to spatial variability in soil type or water content, or it may be due to lack of calibration. Regardless of the reasons for the differences, the trends over time can be seen. The 0% treatment results in the lowest water content by the end of the season, and shows none of the responses to irrigation seen in the higher irrigation rates. However, rain did replenish soil water content. The rapid response to the large rain early in the season indicates that water likely entered through the planting hole, whereas the later rainfall event in the middle of the measurement period caused a more gradual rise, indicating lateral movement into the bed from outside. In the 150% and 250% irrigation treatments water content did not increase over time, indicating that the soil may have been at its maximum in both cases. It was thus not possible to distinguish between these two rates of over-irrigation with a probe at the center position. Water content in the 100% treatment declined during the first 3 weeks of July, indicating that irrigation was not sufficient to maintain it at a high enough level. Water content in the 50% treatment declined at about the same rate as the 100% treatment. There was also a spike in the 50% plot following a rainfall event that is not apparent in the 0% and 100% treatment. This spike indicating rapid infiltration of rainfall through the mulch either through the planting hole or in a possible leak around the access tube seal. The effect of slower lateral movement of water following the rainfall event is readily seen in the 0% treatment.

The replications of the 100% irrigation treatment showed that soil water content was being maintained in the 100% irrigation treatment. Unexpected leaks around a probe, unpredictable entry of rainfall through the planting hole, spatial variability of soil water content or plant water uptake, and differences between probes due to calibration, location and root density all suggest that it would not be wise to depend on measurements from a single probe to manage irrigation over an entire field.

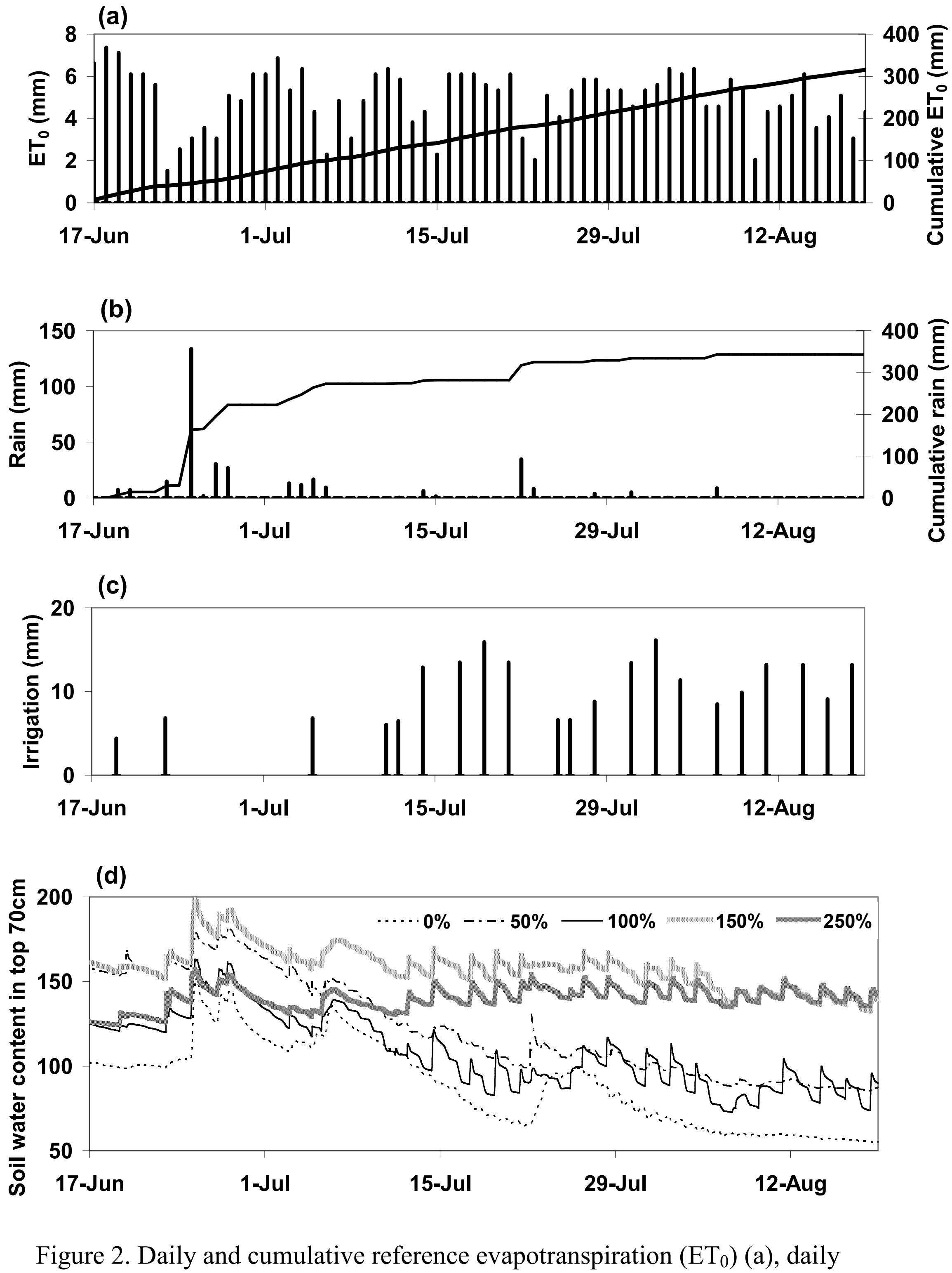
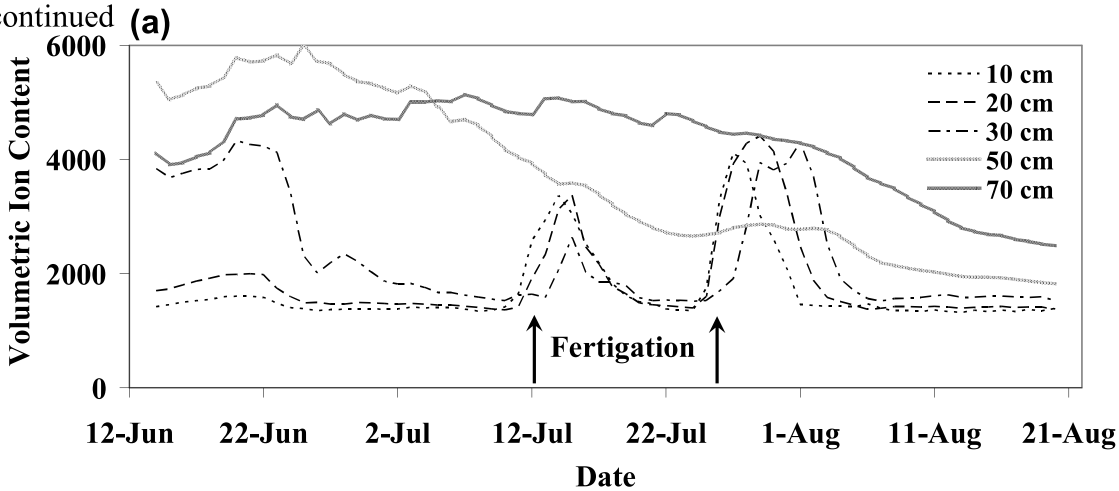


Figure 2. Daily and cumulative reference evapotranspiration (ET_0) (a), daily and cumulative rainfall (b), daily irrigation in the 100% treatment, and total soil water content in top 70 cm for the 0%, 50%, 100%, 150% and 250% irrigation treatments in one replication during the 2006 growing season.

Figure 3 shows an example of VIC (a) and soil water content (b) as measured at each depth in the center position of one plot that received 2 fertigations of 56 Kg N/mulched ha (50lb N/mulched ac). Early in the season soil water content was relatively high, and this apparently resulted in some leaching of pre-plant N to the lower depths. In particular during the last week of June there was a large drop in VIC at 30cm and a smaller more gradual increase at 50 and 70 cm. Before the 1st fertigation VIC levels at 10, 20 and 30 cm had dropped to relatively low and stable values, while at 50 cm it was steadily declining. The 1st fertigation caused VIC to progressively increase at 10, 20 and 30 cm, with the peaks occurring in sequence. After about 10 days VIC at these depths had declined to about the same as before the fertigation. At 50 cm, VIC briefly leveled out before continuing its steady decline. The 2nd fertigation caused a similar response at 10, 20 and 30 cm, but of a larger magnitude. It also caused VIC at 50 cm to level out and slightly increase rather than continuing to decline, indicating some movement of nitrogen to this depth. The duration of the response was about the same as to the 1st fertigation. VIC at 10, 20 and 30 cm then declined to the same relatively low level as before. By the end of the season VIC at 50 cm was also approaching the same level, and at 70 cm continued



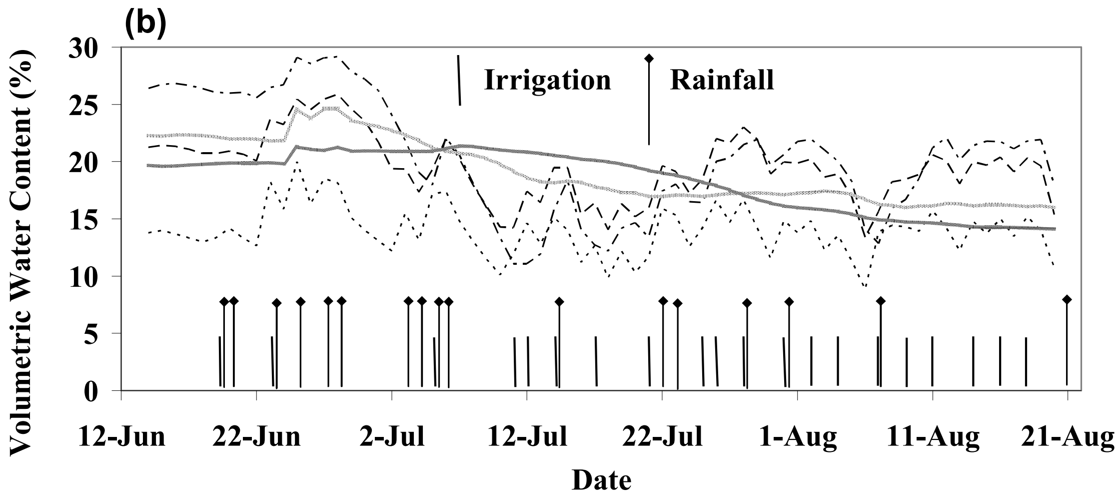


Figure 3. Volumetric Ion Content (a) and simultaneous volumetric soil water content (b) at 10, 20, 30, 50 and 70cm, measured in the center position of one plot that received two fertigations of 56 Kg N/Ha each. The timing (but not magnitude) of irrigation and rainfall events are also shown in (b)

to decline. Trends in soil water content from the beginning of July onwards showed neither consistent increases nor decreases, indicating that the 100% irrigation treatment approximately replaced crop water use from the center of the bed.

An important consideration if producers are to use MCPs (or any form of soil water measurement) is spatial variability of soil water content within a field. This variability is likely greater under drip irrigation because of the relatively limited volume of soil that is wetted. There are large differences in soil water content over a relatively small distance. Confounding the issue of actual variability in soil water content is the issue of differences in response between individual sensors, and differences in the relatively small volume of soil sampled by capacitance sensors. Figure 4 shows, as an example, the differences in measured values (averaged over one hour) integrated over the top 30 cm of soil for the 4 replications of one irrigation treatment (100%) during a two week period in 2005. While ideally measurements in all four replications would be similar, it can be seen that the measured absolute values are actually different. These differences may be real or may be due to the calibration of the sensors. However all four replications do respond to irrigations, and subsequent drainage and drying. Also visible is the “stair-stepping” that occurs when the crop extracts water during the daytime but not at night. Regardless of the source of the absolute differences, the trends can be very useful in irrigation management. In this example, there also does not appear to be a longer term trend of increasing or decreasing soil water content, indicating that irrigation approximately replenished crop water use.

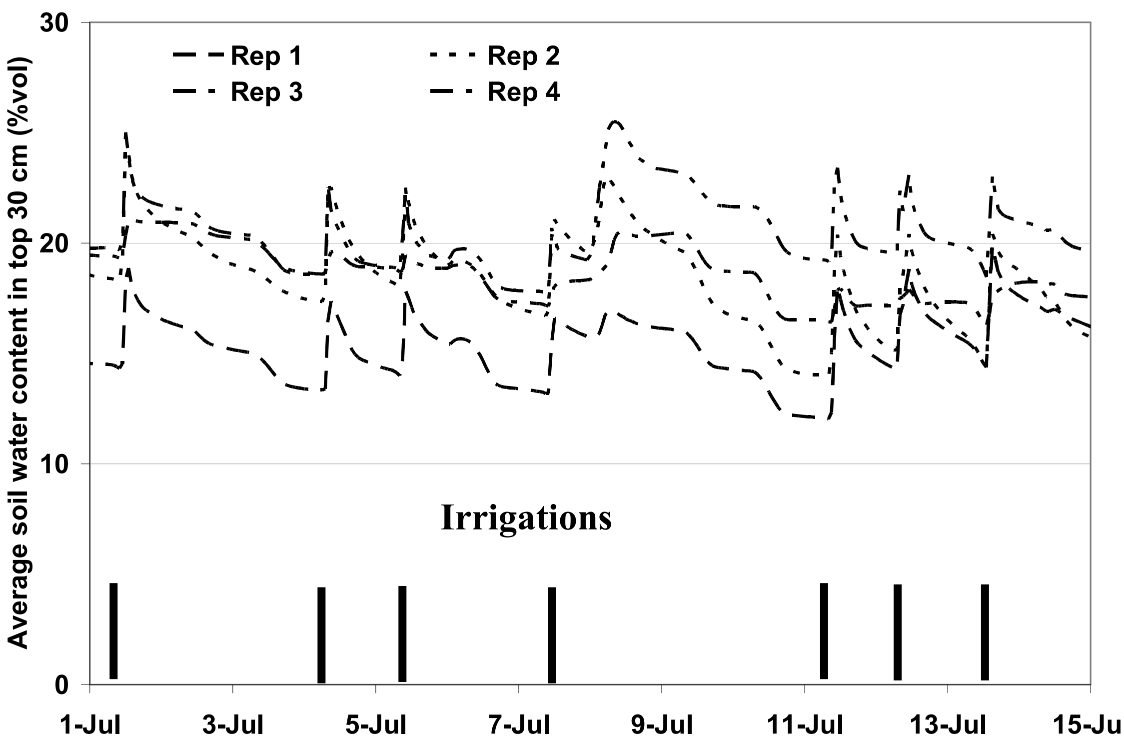


Figure 4. Soil water content in top 30 cm averaged from measurements at 10, 20 and 30 cm during a two week period in 2005, for the 4 replications of the 100% irrigation treatment.

Trends can be more easily seen if differences rather than absolute values are plotted. Figure 5 shows an example of the change in soil water content in one replication in 2006 relative to measured values on 1 July.

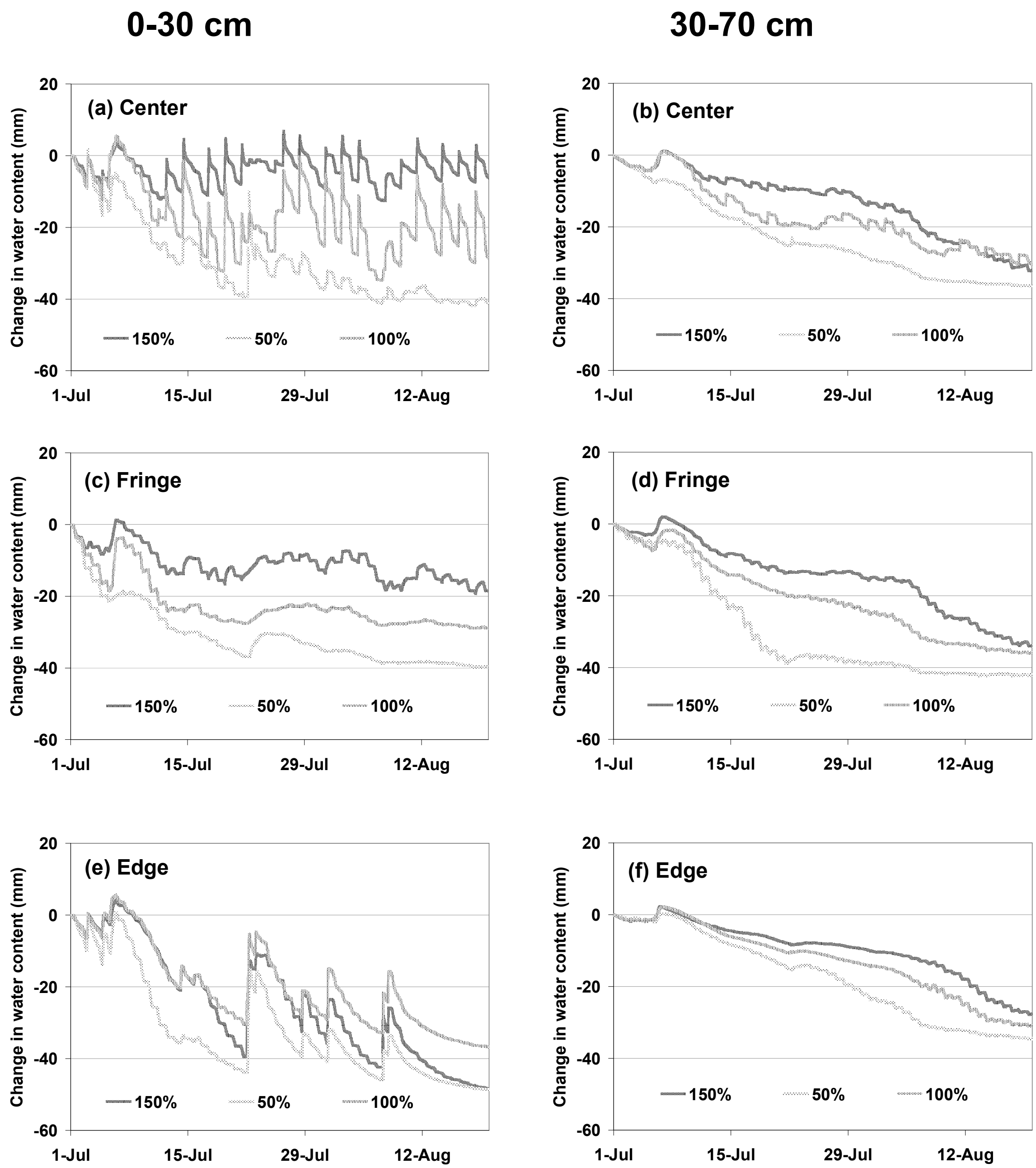


Figure 5. Changes in soil water content from 1st July 2006 in one replication for the 50%, 100% and 150% irrigation treatments from 0-30 cm for the center (a), fringe (c) and edge (e) positions, and from 30-70 cm for the center (b), fringe (d) and edge (f) positions.

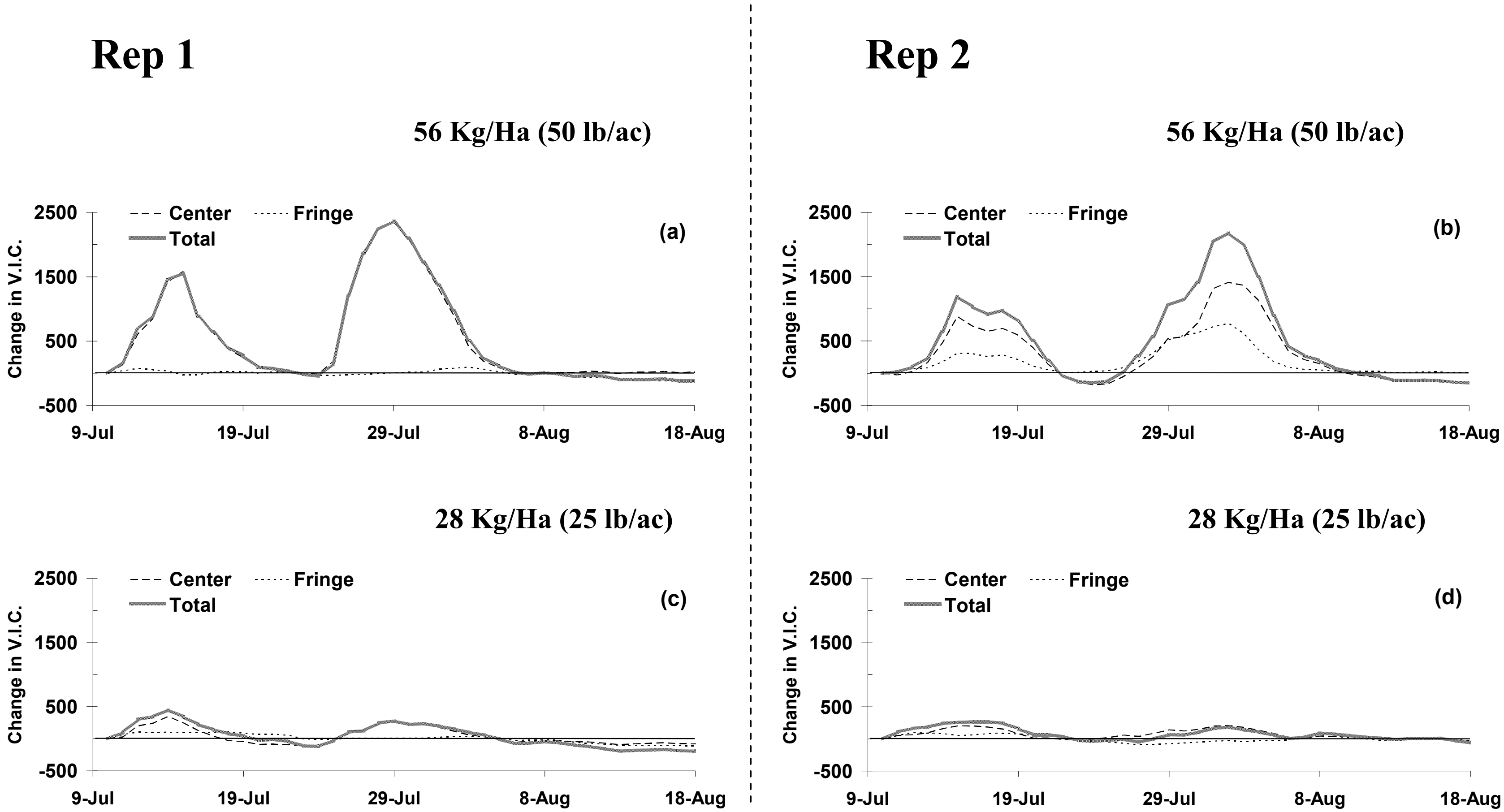


Figure 6. Change in average volumetric ion content in top 30 cm (12 in) compared to the value on 10 July (the day preceding the first fertigation) in the two instrumented replications for fertigations of 56 Kg/Ha (a and c) and 28 Kg/Ha (b and d)

Figure 6 shows the change in VIC relative to the values on the day before the first fertigation, for two replications in which there were two fertigations, either 56 Kg N/mulched Ha (50 lbs/ mulched ac) or 28 Kg N/mulched Ha (25 lb/mulched ac). The TriSCAN probes certainly responded to the fertigations. There was a disproportionately greater response to the higher fertigation rate, and a greater response to the 2nd fertigation at the higher rate. Only in the higher rate in replication 2 was there a significant response at the fringe position. The movement of the nitrogen depends on subsequent irrigation management and crop uptake. The relative VIC response over time can probably provide good information on N trends. For example, an increase at the deepest sensor can indicate leaching.

From a research perspective there is a wealth of information available in analyzing the dynamics of soil water content and VIC. For example, in figure 5 it can be seen that there is root water extraction from the edge position below 30 cm and that infiltrated rainfall does move laterally into the fringe position under the mulch. Root distribution and crop water use can be inferred from the daytime reduction in soil water content at each depth. Changes in VIC over time, combined with soil water trends, can indicate nitrogen movement and uptake.

From a growers perspective, to be useful in aiding irrigation decisions the information should be processed and presented in a way that condenses it and makes it intuitive. Also, from a practical point of view, installation of the MCPs must be easy and the information transmitted wirelessly. However, it is important that the probes be installed properly, with no air gaps. In a humid environment it is also important that rainfall does not concentrate on the plastic mulch around the probe and then infiltrate. A good seal between the probe or access tube and the mulch itself is important, otherwise rainfall will run down the probe and cause high measurements. Some rainfall will however run down through the planting holes, and this is a valid source of water that should be reflected in the measurements. The appropriate number of MCPs to use within a field and where to install them within the row also need consideration. Perhaps three MCPs would represent a reasonable balance between cost and the need to have enough "replication" in a typical field. Positioning MCPs relative to emitters is probably not practical for growers, but installation in the center position relative to plants and the dripline would be appropriate. The additional cost of dual frequency MCPs over single frequency MCPs is not large considering the additional information that is provided.

Conclusion

MCPs, if correctly installed and positioned, can provide valuable information to a grower in humid regions. Unpredictable crop water use and rainfall probably cause growers in such areas to err on the side of over-application more than growers in more predictable arid or semi-arid climates. The trends that can be observed over time with such instrumentation are important and, with some experience, a grower can "calibrate" the sensors for their particular conditions in terms of knowing what range of measured values represents the range of desirable soil water content.

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Near-surface soil water and temperature for SDI, LEPA, and spray irrigation[1]

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Abstract

Near-surface soil temperatures and volumetric soil water contents were compared for SDI, LEPA, and spray irrigation in a Pullman clay loam soil planted in cotton. Soil temperatures were measured by type-T thermocouples and volumetric water contents were measured by time domain reflectometry (TDR) installed in the center and sides of raised beds at 5-, 10-, and 15-cm depths. Irrigation was applied in alternate furrows, resulting in beds having an irrigated (wet) side and non-irrigated (dry) side. Greater soil temperatures were found in SDI compared with all other irrigation methods. Reduced soil temperatures were found on the wet side of LEPA beds compared with other methods. Volumetric soil water contents were compared following four irrigation events during July. Smaller bed-averaged soil water contents were found in SDI beds compared with other methods. Soil water variability within a bed was greater for SDI than for other methods.

Introduction

Subsurface drip irrigation (SDI) is being increasingly adopted by producers in the Texas High Plains, notably in the cotton producing area around Lubbock. There is a general premise that use of SDI results in greater crop yields, greater water use efficiency, better cotton fiber quality, and enhanced crop earliness compared with typical sprinkler packages used on center pivot irrigation machines (i.e., spray applicators or Low Energy Precision Applicators [LEPA]), which is partially supported by earlier studies of Segarra et al. (1999), Bordovsky and Porter (2003), and Colaizzi et al. (2005). This is thought to be related to reduced evaporative cooling and warmer soil temperatures during crop establishment. For some producers, these factors have justified the much greater cost and management requirements inherent in SDI, as well as the potential difficulties in crop germination for most High Plains soils if precipitation was inadequate prior to planting (Howell et al., 1997; Bordovsky and Porter, 2003; Enciso et al., 2005). New SDI installations in the Texas High Plains have been estimated at around 100,000 ha since 2000 (*J. Bordovsky, pers. communication*) in a region having approximately 1.86 million ha of irrigated area (TWDB, 2001). Continued SDI adoption is anticipated in

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response to intensifying drought, declining water resources, and greater energy costs to pump irrigation water. The northward expansion of cotton into areas where corn was traditionally produced (i.e., the Northern Texas Panhandle and Southwestern Kansas; USDA-NASS, 2005) may also stimulate SDI adoption if: i) warmer soil temperatures do result from use of SDI, ii) warmer temperatures do reduce the greater risk associated with cotton production in thermally limited environments (Esparza et al., 2006), and iii) alternative SDI designs do mitigate difficulties with crop germination (Colaizzi et al., 2006).

The objectives of this study were to compare near-surface soil temperature and volumetric water content under spray, LEPA, and SDI methods applied to raised beds planted with cotton in the thermally-limited climate of the Northern Texas High Plains. The 2006 cotton season was still underway when this report was produced; therefore, final lint yield and fiber quality data have yet to be obtained. Only crop emergence and total reproductive squares will be reported herein, in addition to soil temperatures (in terms of cumulative soil heat units) and volumetric water contents.

Procedure

The experiment was conducted in 2006 at the USDA Agricultural Research Service Conservation and Production Research Laboratory at Bushland, Texas (35° 11′ N lat., 102° 06′ W long., 1070 m elevation above MSL). The climate is semi-arid with evaporative demand of about 2,600 mm per year (Class A pan evaporation) and precipitation averaging 470 mm per year. Most of the evaporative demand and precipitation occur during the growing season (May to October) and average 1,550 mm and 320 mm, respectively. The climate is also characterized by strong regional advection from the south and southwest, with average daily wind runs at 2 m height exceeding 460 km, especially during the early part of the growing season. The soil is a Pullman clay loam (fine, superactive, mixed, thermic torrertic Paleustoll; USDA-NRCS, 2005), with slow permeability due to a dense B21t horizon that is 0.15- to 0.50-m below the surface. A calcic horizon begins at approximately 1.2 m below the surface.

Agronomic practices were similar to those practiced for high lint yield in the High Plains region of Texas. Cotton (*Gossypium hirsutum* L., Paymaster[3] 2280 BG RR) was planted on 17 May 2006 at 20 plants m^{-2} on east-west oriented raised beds spaced at 0.76 m. Furrow dikes were installed in the irrigated field after crop establishment to control runoff. Preplant fertilizer containing nitrogen (N) and phosphorous (P) (11-52-0) was applied at 18 and 83 kg ha^{-1}, respectively, based on a soil fertility analysis. Additional N (32-0-0) was injected into the irrigation water, resulting in 34 kg ha^{-1} prior to planting, and 45 kg ha^{-1} from first square to early bloom for full irrigation (deficit irrigation rates received proportionately less N in irrigation water). Treflan was applied at one time before planting at 2.3 L ha^{-1} to control broadleaf weeds.

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[3] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

The experimental design consisted of four irrigation methods (MESA, LESA, LEPA, SDI, described in more detail shortly), and five irrigation rates (I_0, I_{25}, I_{50}, I_{75}, and I_{100}). The I_{100} rate was sufficient to prevent yield-limiting soil water deficits from developing, and the subscripts are the percentage of irrigation applied relative to the full (I_{100}) irrigation rate. The I_{100} rate was based on soil water content determined using the neutron probe (NP) to the 2.4-m depth. Early in the season, irrigation water was applied when soil water contents indicated a deficit of 25 mm below field capacity in the I_{100} treatment. From first square to termination of irrigations, the appropriate irrigation amount was applied on a weekly basis. The statistical design was a variant of the split-block design (Little and Hills, 1978), where irrigation methods were in the direction of travel of a three-span lateral move irrigation system, and irrigation rates were perpendicular to the direction of travel. This sacrificed the power of comparing different irrigation rates, but was necessary to facilitate operation of the lateral-move system using applicators common in the Southern High Plains. Each span of the linear move system constituted a complete block (i.e., replicated three times), and irrigation methods were randomized within each block.

Mid-elevation spray application (MESA), low-elevation spray application (LESA), and low energy precision application (LEPA) irrigations were applied with a hose-fed Valmont (Valmont Irrigation, Valley, NE) Model 6000 lateral move irrigation system. Drop hoses were located over every other furrow at 1.52-m spacing. Applicators were manufactured by Senninger (Senninger Irrigation Inc., Orlando, FL) and were equipped with 69-kPa pressure regulators and #17 plastic nozzles, giving a flow rate of 0.41 L s^{-1}. The MESA and LESA spray heads were positioned 1.5 and 0.3 m above the furrow, respectively. A double-ended drag sock (A. E. Quest and Sons, Lubbock, TX) was used for LEPA irrigations. The subsurface drip irrigation (SDI) system consisted of Netafim Typhoon dripline (Netafim USA, Fresno, CA) that was shank injected in 1999 under alternate furrows at a 0.3 m depth below the surface (before bedding). Irrigation treatment levels were controlled by varying the speed of the lateral-move system for the spray and LEPA methods, and by different emitter flow and spacing for the SDI method. Additional details on irrigation equipment are provided in Colaizzi et al. (2004).

Soil temperature and volumetric soil water content were determined in the planted beds under the MESA, LESA, LEPA, and SDI irrigation methods at the I_{50} and I_{100} irrigation rates (eight plots) by arrays of type-T thermocouples and time domain reflectometry (TDR) probes. The thermocouples and TDR probes were placed on each side and in the center of each bed at 5-, 10-, and 15-cm depths (Fig. 1). (The thermocouple at the 15-cm center was omitted due to a limited number of double-ended channels in multiplexers). Each bed array was replicated three times in each plot, for a total of 24 instrumented beds, 192 thermocouples, and 216 TDR probes. The thermocouples were connected to multiplexers (model AM25T, Campbell Scientific, Inc., Logan, UT), which were controlled by two data loggers (model 21x, Campbell Scientific, Inc., Logan, UT) that recorded thermocouple readings every hour. The TDR system consisted of 20-cm long trifilar probes connected to coaxial multiplexers (Evett, 1998), a cable tester (model 1502C, Tektronix, Inc., Redmond, OR), and an embedded computer running the TACQ supervisory TDR system control and data acquisition program (Evett, 2000a; 2000b). The TDR waveforms were recorded every 2 h. The TACQ program determined bulk electrical conductivity and effective frequency from the recorded waveforms and used these data in a water content calibration equation that practically eliminates temperature effects at greater water contents (Evett et al., 2005). The TDR system accuracy (root mean squared error of calibration) is < 0.01 $m^3 m^{-3}$ in all three main horizons of the Pullman soil (Evett et al., 2006).

Soil temperatures were used to compute cumulative soil heat units (CSHU) (measured soil temperature minus the base temperature of 15.6 °C) for each location within a bed (i.e., wet side at 5 cm, etc.). The effect of irrigation method (MESA, LESA, LEPA, or SDI) on CSHU at each bed location was tested for differences using the SAS mixed model (PROC MIXED, Littell et al., 2006). Values of CSHU considered were on June 2 (16 days after planting, when crop emergence was recorded) and on August 20 (95 days after planting). In PROC MIXED, fixed and random effects are specified separately. Fixed effects were irrigation method, bed location, and irrigation method by bed location; the random effect was the bed replicate. The fixed effect "irrigation method by bed location" was tested for differences using least square means ($\alpha \leq 0.05$), with "bed location" as the slice parameter, by each irrigation rate (i.e., I_{50} and I_{100}).

Volumetric water contents from the TDR system were analyzed in a similar manner; however, only measurements following the four irrigation events in July were used in the present analysis, and these were the averages of the three measurements at 2, 4, and 6 h following each irrigation event (Fig. 2). Each measurement average following an irrigation event was specified as a repeated class in PROC MIXED. The TDR waveforms recorded earlier in the season often exhibited weak second reflections possibly due to high bulk densities, leading to errors in computing travel times, and require manual reinterpretation. Future analyses will consider continuous soil water dynamics to investigate relationships with soil temperature. Crop emergence on June 2 and reproductive squares (first and second position) on August 11 were also tested for differences between irrigation methods for irrigation rates (I_{25}, I_{50}, I_{75}, I_{100}) in a similar manner with PROC MIXED (see Colaizzi et al., 2004 for specific details).

Results and Discussion

The period from September 2005 to May 2006 was the driest on record at our location, with only 45 mm of precipitation. In 2006, only three rainfall events were recorded near the experimental site prior to planting (May 17); these were 3 mm, 2 mm, and 12 mm on March 20, April 23, and May 7, respectively. Consequently, 50 mm of preplant irrigation was applied in two 25 mm applications on May 1 and 4 to ensure adequate soil water during peak water use later in the season. A total of 198 mm of rainfall occurred during the 91 days considered in the present study (May 17 to August 16, Fig. 2). Most rainfall occurred during late June, early July, and mid-August, well after crop establishment. A total of 356 mm and 178 mm of in-season irrigation was applied to the I_{100} and I_{50} rates, respectively. These irrigation amounts will be the final seasonal totals because over 200 mm of rainfall occurred August 17-31.

Crop emergence was recorded on June 2 (DOY 153, 16 days after planting), and the effect of irrigation method within an irrigation rate was tested for differences using least squared means ($\alpha \leq 0.05$) in PROC MIXED. There were some significant differences between irrigation methods within an irrigation rate; however, these differences were not consistent from one rate to the next, and irrigation rate was not a significant covariate (Fig. 3). This result was unexpected because, in the absence of sufficient preplant or early season rainfall, SDI is well-known to have serious limitations in germinating a crop in the Pullman soil when laterals are installed in alternate furrows (Colaizzi et al., 2006). For now, we hypothesize that the influences of both irrigation rate and method on crop emergence were masked by preseason irrigation (50 mm) several weeks before planting, and perhaps a 6 mm rainfall event on May 25. This hypothesis will be tested after time domain reflectometry (TDR) waveforms during this period (May 17 to June 2) are reinterpreted. Observed crop emergence patterns may have also been confounded by soil temperatures (as influenced by soil water distribution), which are discussed next.

Cumulative soil heat units (CSHU, 15.6 °C base temperature) were computed beginning at the planting date (17 May) using temperatures determined at each location within a bed, and analyzed when crop emergence was recorded (June 2, 16 days after planting) and analyzed again on August 20, 2006 (95 days after planting). By June 2, CSHU did not vary a great deal for the I_{50} (Fig. 4) or I_{100} (Fig. 5) irrigation rates, with the exception of LEPA, for which CSHU tended to increase from the wet (irrigated) to the dry (non-irrigated) side. This may have resulted from greater conductive and evaporative cooling in and adjacent to the furrow irrigated with LEPA. Another exception was LESA (I_{100} rate only, Fig. 5), for which CSHU was less at all bed positions than it was for other irrigation methods (except for LEPA on the wet side of the bed). This also could have resulted from greater conductive and evaporative cooling distributed uniformly across the bed and furrows. As expected, CSHU decreased with depth for all irrigation methods due to attenuation of diurnal soil temperature amplitude. Crop emergence (Fig. 3) did not appear to be related to CSHU for the I_{50} rate (Fig. 4), but emergence did appear inversely related to CSHU on the wet side of the bed for the I_{100} rate (Fig. 5).

By August 20 (95 days after planting), the crop was past peak bloom and bolls were forming in both the first and second position. For the I_{50} (Fig. 6) and I_{100} (Fig. 7) irrigation rates, SDI resulted in greater CSHU than all other methods at all bed locations, and differences were often significant. Similar to the results of June 2, CSHU by August 20 tended to increase for LEPA (and to a lesser extend SDI) from the wet to the dry side of the bed; and for LESA (I_{100} rate only, Fig. 7) CHSU was less than for other methods at most bed locations.

Volumetric soil water was measured using time domain reflectometry (TDR) at the same bed locations as soil temperature (plus the center of the bed at 15 cm). The effect of irrigation method at each bed location was tested for differences following four irrigation events in July. The greatest variation in soil water content occurred for SDI in both the I_{50} (Fig. 8) and I_{100} (Fig. 9) irrigation rates, ranging from 0.058 $m^3\ m^{-3}$ at I_{50}, 5 cm, dry side (Fig. 9a) to 0.351 $m^3\ m^{-3}$ at I_{100}, 15 cm, wet side, although MESA and LESA contents were nearly identical at this bed location (Fig. 9c). Water contents for LEPA (and to a lesser extent SDI) generally increased with proximity to the wetted furrow; however, dry side LEPA and SDI water contents were greater than those in the center of the bed at the 10- and 15-cm depths for the I_{100} rate. When soil water contents were averaged for the entire bed, water contents for MESA and LEPA were significantly greater than those for LESA and SDI at the I_{50} rate; but water contents for MESA and LESA were significantly greater than those for LEPA and SDI at the I_{100} rate (Fig. 10). These results were likely related to the method of water application, but could have also been related differences in root water uptake as influenced by soil temperatures. The interaction between wetting patterns, root water uptake, and soil temperatures will be investigated further after TDR waveforms are reinterpreted for the entire season.

On August 11 (DOY 223, 86 days after planting), first and second position squares were slightly greater in number for LEPA and SDI compared with MESA and LESA in both the I_{50} and I_{100} irrigation rates (Fig. 11). For the I_{100} rate, differences in CSHU between MESA and LESA (Fig. 7) did not appear to influence square formation (Fig. 11). It is presently uncertain to what extent the crop will mature because significant rainfall (200 mm) and cool temperatures have persisted during the latter part of August, in stark contrast to the previous eleven months, which were characterized by extreme drought and above average temperatures.

Conclusions

Application of irrigation by SDI resulted in greater soil temperatures than those for all other methods. Soil temperatures associated with LEPA irrigation were less than those for other methods on the irrigated (wet) side of the bed, but similar to or greater than those for MESA or LESA on the non-irrigated (dry) side of the bed. Irrigation using LESA resulted in cooler soil temperatures than all other methods for the I_{100} rate, but was similar to temperatures for MESA at the I_{50} rate. In July, at the I_{50} rate, MESA and LEPA resulted in greater bed-averaged soil water contents than did LESA and SDI, whereas at the I_{100} rate, MESA and LESA resulted in greater soil water contents than did LEPA and SDI. Soil water variability within a bed was greater for SDI than for other methods. Future analyses will include soil water dynamics between wetting events to quantify water uptake and relationships with soil temperatures; and soil water contents early in the season will be analyzed to quantify the effect of irrigation method and irrigation rate on crop emergence.

Acknowledgements

This research was partially supported by the Ogallala Aquifer Project initiative (Sustaining Rural Economies Through New Water Management Technologies) and USDA-ARS National Program 201 (Water Quality and Management). Drs. Kathy Yeater and Sara Duke, Statisticians for the USDA-ARS Southern Plains Area assisted with the statistical design and analyses. Chad Ford and Luke Britten, student workers, installed, operated, maintained, and processed data of the thermocouple and TDR system, with additional assistance provided by Dr. Troy Peters, agricultural engineer, and Jennifer Childress, Virginia Chadick, Nathan Clements, Bryan Clements, Justin Molitor, Chad Haley, Kelli Bird, and Julie Ledbetter, student workers. Don McRoberts, Ed Hutcherson, Brice Ruthardt, and Jim Cresap, biological technicians, operated and maintained the irrigation system and were responsible for field operations.

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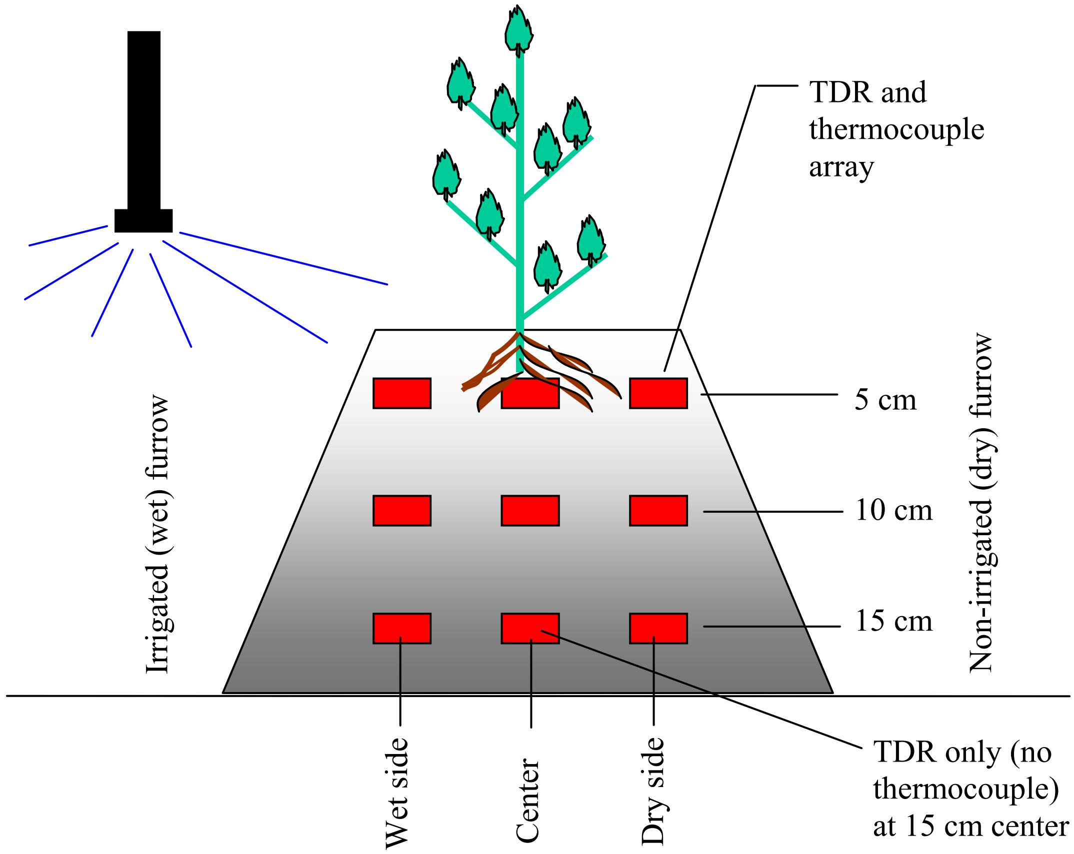


Figure 1. Installation of nine time-domain reflectometry (TDR) probes and eight thermocouples in a raised bed planted in cotton.

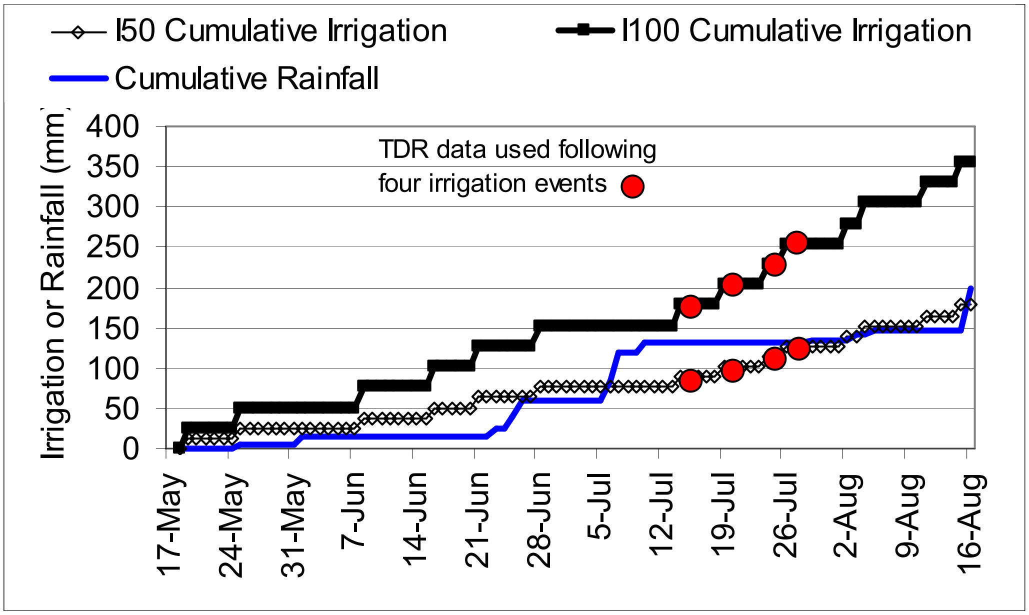


Figure 2. Cumulative irrigation and rainfall through August 16, 2006, and dates of soil water measurement (using TDR) following four irrigation events.

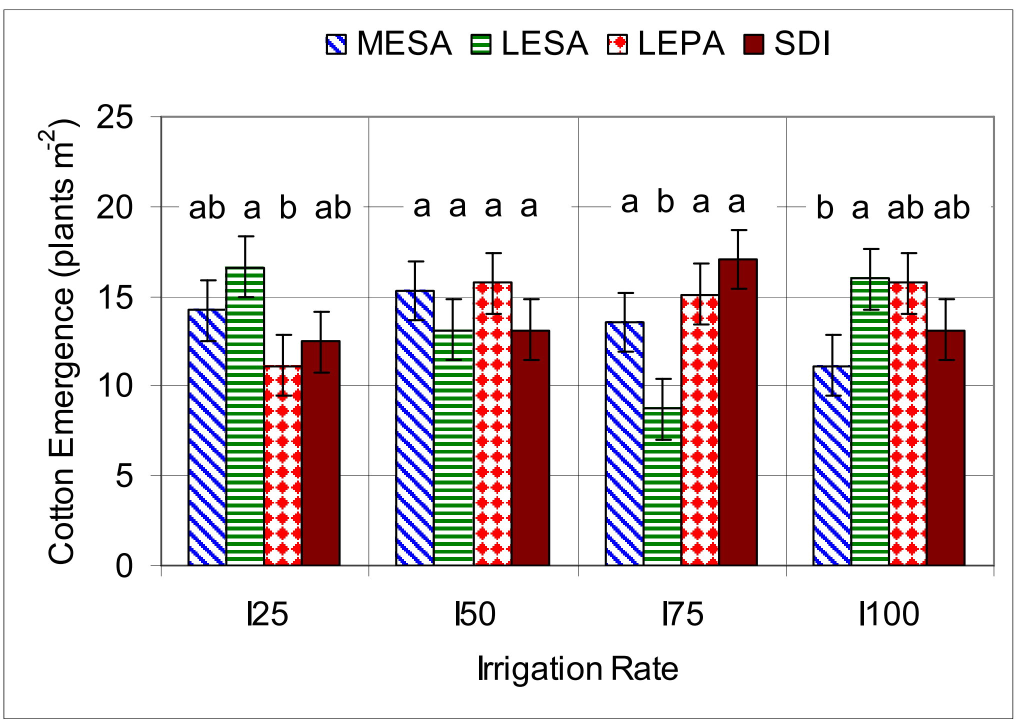
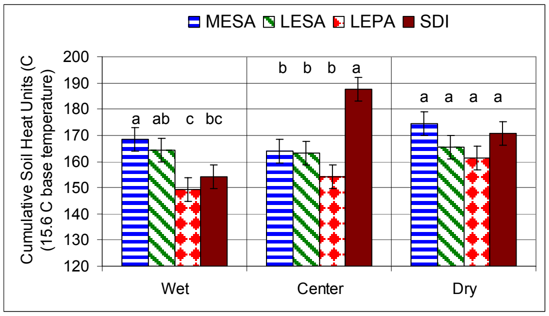
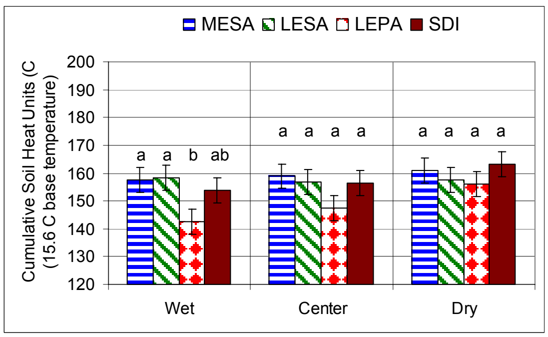


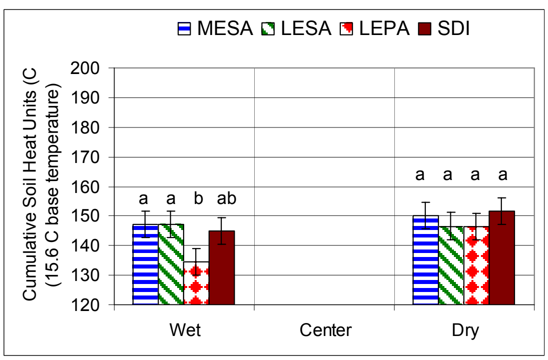
Figure 3. Cotton emergence by June 2, 2006 (DOY 153; 16 days after planting). Columns with the same letter within an irrigation rate are not significantly different ($\alpha \leq 0.05$).



a) 5 cm depth

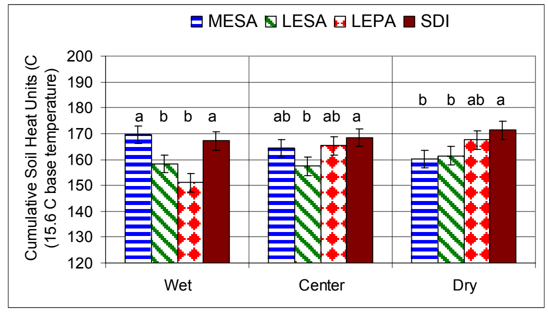


b) 10 cm depth



c) 15 cm depth

Figure 4. Soil heat units through June 2, 2006 (DOY 153; 16 days after planting) for the I_{50} irrigation rate. Columns with the same letter within a bed position (wet, center, or dry) are not significantly different ($\alpha \leq 0.05$).



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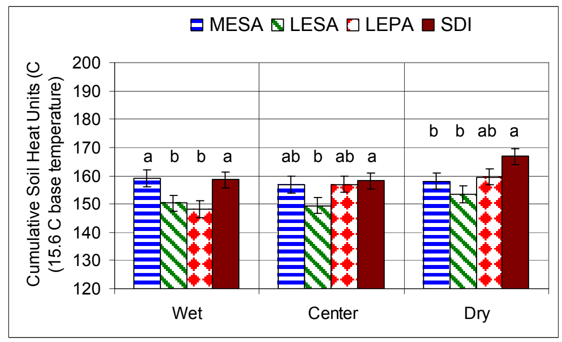

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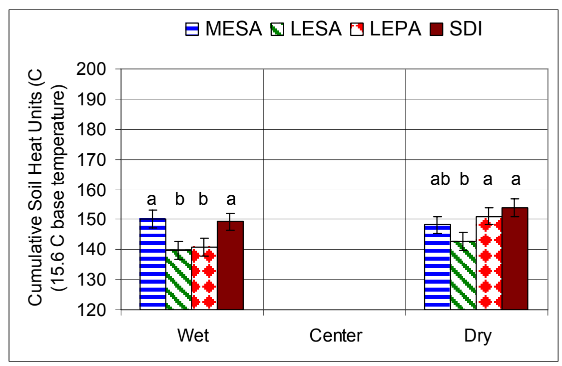
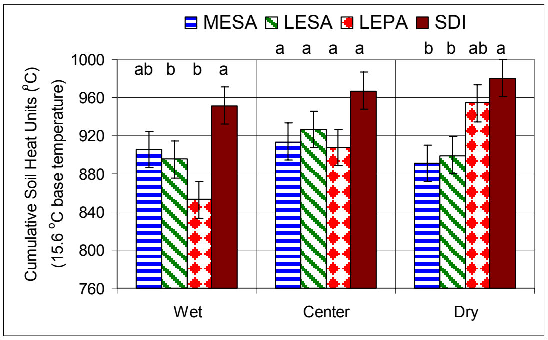


c) 15 cm depth

Figure 5. Soil heat units through June 2, 2006 (DOY 153; 16 days after planting) for the I_{100} irrigation rate. Columns with the same letter within a bed position (wet, center, or dry) are not significantly different ($\alpha \leq 0.05$).



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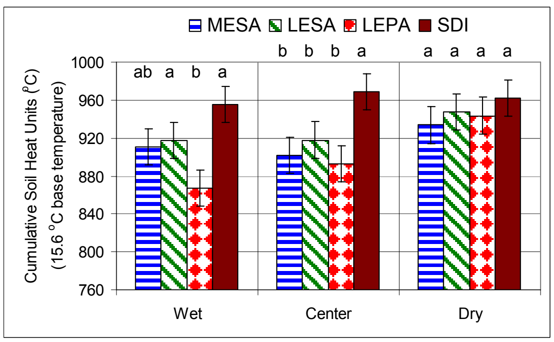
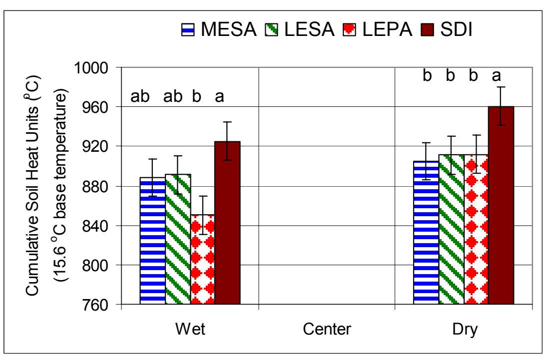
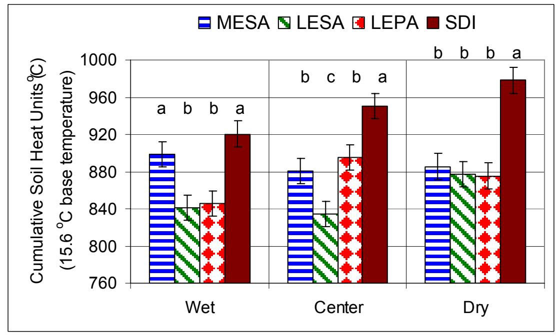


b) 10 cm depth

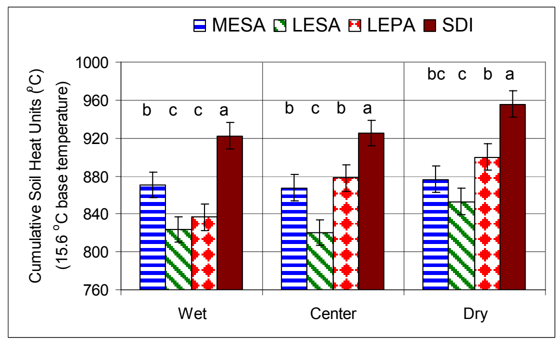


c) 15 cm depth

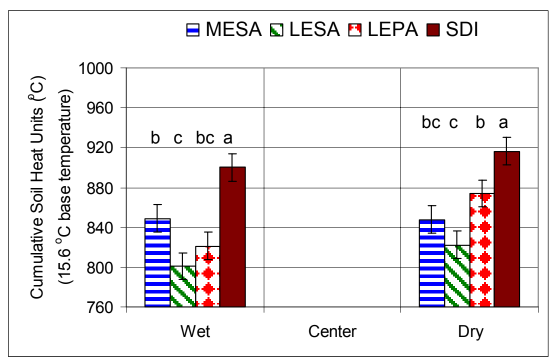
Figure 6. Soil heat units through August 20, 2006 (DOY 232; 95 days after planting) for the I_{50} irrigation rate. Columns with the same letter within a bed position (wet, center, or dry) are not significantly different ($\alpha \leq 0.05$).



a) 5 cm depth

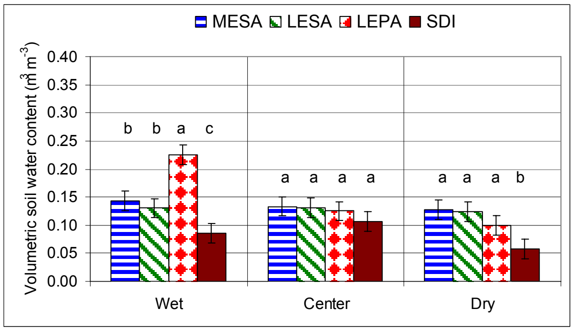


b) 10 cm depth



c) 15 cm depth

Figure 7. Soil heat units through August 20, 2006 (DOY 232; 95 days after planting) for the I_{100} irrigation rate. Columns with the same letter within a bed position (wet, center, or dry) are not significantly different ($\alpha \leq 0.05$).



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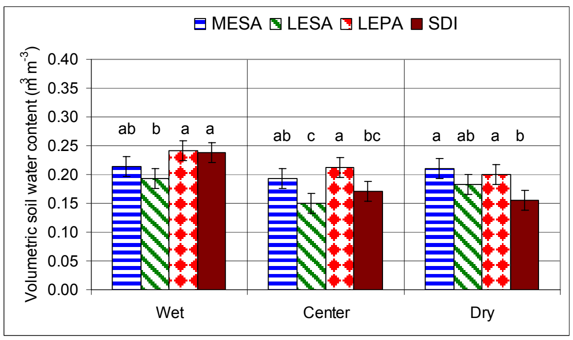
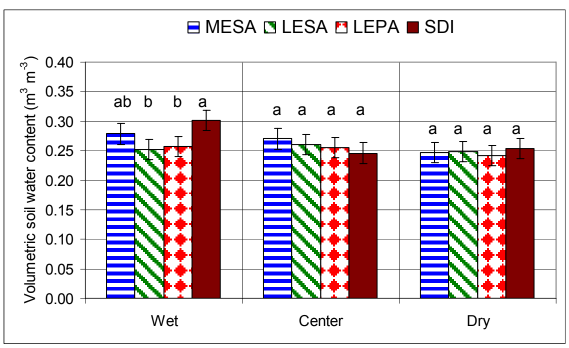
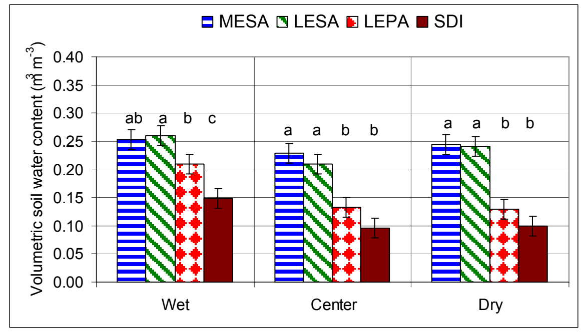


b) 10 cm depth

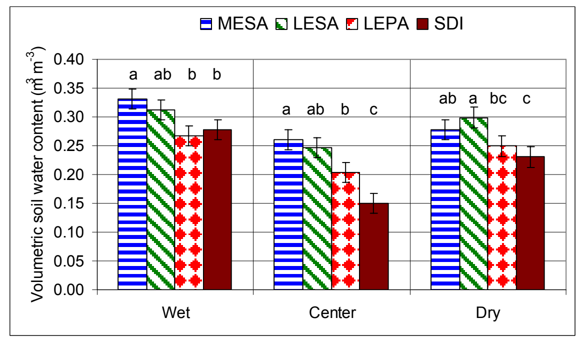


c) 15 cm depth

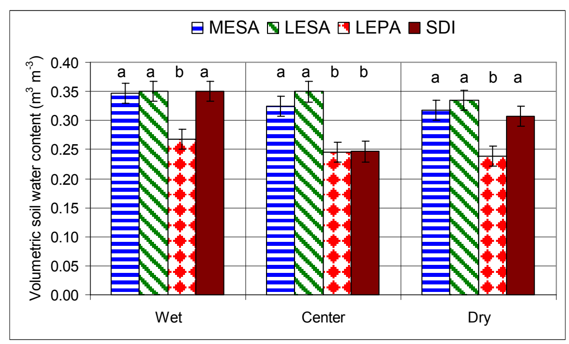
Figure 8. Volumetric water content (using TDR) after four irrigation events in July 2006 for the I_{50} irrigation rate. Columns with the same letter within a bed position (wet, center, or dry) are not significantly different ($\alpha \leq 0.05$).



a) 5 cm depth



b) 10 cm depth



c) 15 cm depth

Figure 9. Volumetric water content (using TDR) after four irrigation events in July 2006 for the I_{100} irrigation rate. Columns with the same letter within a bed position (wet, center, or dry) are not significantly different ($\alpha \leq 0.05$).

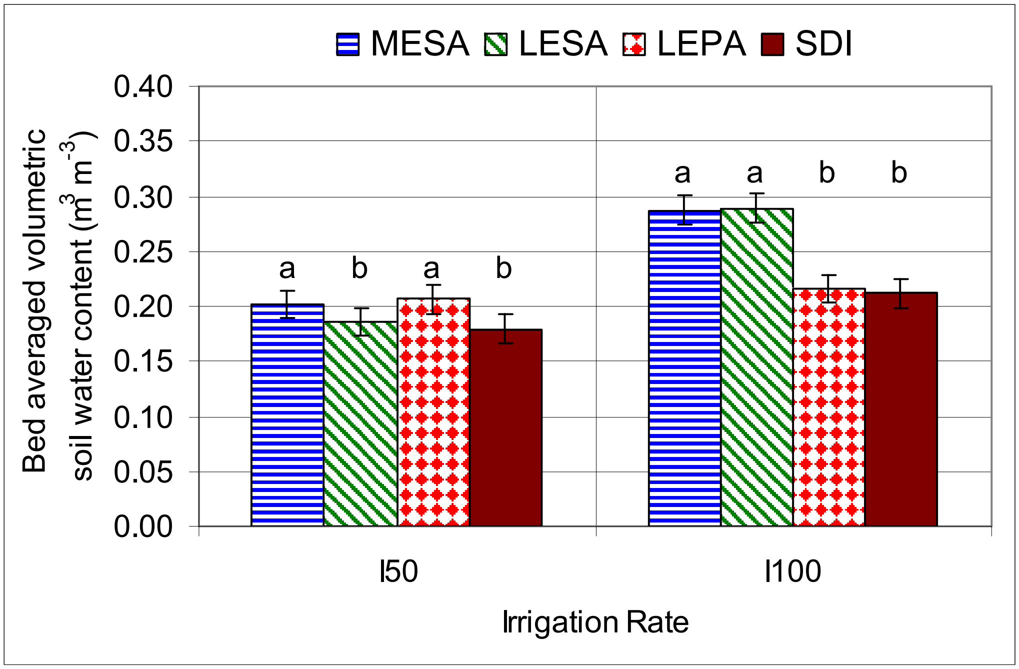


Figure 10. Volumetric water content (using TDR) after four irrigation events in July 2006 averaged for the entire bed.

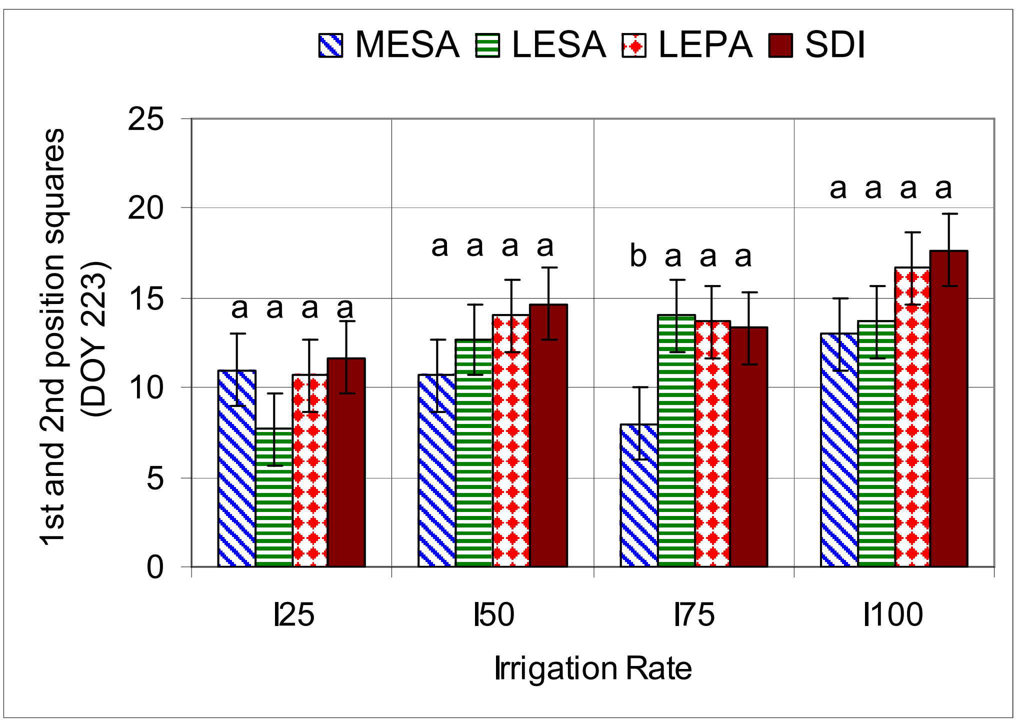


Figure 11. First and second position squares for each irrigation rate and method on August 11, 2006 (DOY 223, 86 days after planting).

Shock Chlorination of Irrigation Wells to Reduce Iron-Related Bacteria and Emitter Clogging

Michael Clubb [1] and Jos. C. Henggeler[2]

ABSTRACT

A test was undertaken to evaluate what effect super chlorinating wells might have in reducing emitter clogging. Two similar two-inch wells with iron concentrations around 10 ppm were used in the test. One well was shock treated with a concentration of 5,000 ppm chlorine and the other was not. Drip systems were installed at each well using three types of drip tape. The chlorinated well had no drop in flow rates, whereas the untreated well had 50% and 73% less flow then the original flow after 18 days.

INTRODUCTION

Iron in ground water used for irrigation can cause emitter, sprinkler and, even, well screen clogging. While the iron is still in solution (the ferrous state [Fe^{+2}]), the water poses little clogging potential. Once pumped out of the ground and exposed to increased oxygen levels, two changes can occur. The soluble Fe^{+2} iron can reduce to ferric iron (Fe^{+3}) which is insoluble and causes the characteristic reddish cast to water high in iron. Also, part of the iron can join with other elements and precipitate out of solution. The precipitated matter is heavier then water and will settle to the bottom of a container.

The iron present in the water can be expressed as:

$$\text{Total iron} = Fe^{+2} + Fe^{+3} + \text{precipitated iron compounds} \qquad \text{(Eq. 1)}$$

Typical water tests will only measure Fe^{+2} and total <u>ionic</u> iron (e.g., $Fe^{+2} + Fe^{+3}$). The ferric iron (Fe^{+3}) can then be calculated by subtracting out the Fe^{+2} value from the total ionic iron content. Since the precipitated iron is out of solution it is not measured in a water test. This precipitation action is the reason that total ionic iron levels of a water sample can decrease over time.

Clogging occurs in two ways. The minor way is that the precipitated iron and soluble ferrous iron can lead to clogging. However, the more serious way is that iron related bacteria (IRB) can complex with iron to form bacterial slime growths that lead to clogging. The IRB are microbial organisms that use iron in water as a host during their life cycle. These bacteria are more of a nuisance than they are a threat to human and animal health, like *e coli* is. Clusters of them can increase the brownish red or green

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color of water. The source of the IRB is often the water well, where high levels of iron (the fourth most abundant mineral on earth) allow it to breed. Water pumped from contaminated wells will re-infect water systems with IRB, where new colonies can begin to grow and multiply. Thus even when the irrigation system downstream of the well is treated with chlorine or other disinfectants, new colonies of IRB will be re-introduced from the well once pumping starts again if IRB in the well is not controlled, and the clogging potential continue. IRB can thrive on iron levels as small as Fe^{+2} = 0.2 ppm.

Two modes of treatment are often advised for drip systems that have water high in iron. The first mode, a biological one, is to use some sort of disinfectant to kill iron-related bacteria. If bacteria are eliminated then the clogging potential is greatly reduced since colloid iron does not pose a severe threat to clogging. The second mode of action, a chemical one, involves reducing all the Fe^{+2} to Fe^{+3} which can then be filtered out; without the iron the IRB can not thrive. One of the difficulties for irrigation managers is that the solution of choice for both modes of problems involves chlorine, which seems to blur the focus on whether chlorine is meant to be a disinfectant or a reducing agent. What is essential in the disinfectant mode is concentration and, to a lesser degree, contact time. What is important in the iron reduction mode is mixing time and filtration. Many filters in drip systems are placed just a few feet downstream of the chlorine injectors. Since piping is often sized to provide a velocity of 7 feet per second then in situations where a filter is only 5 feet away from the injector, a mixing time of only 0.7 second is available.

Canada and Australia have areas with ground water that has major iron problems that affect the life of water wells. Shock chlorination of wells with high IRB levels is a recommended practice (Williams, 2003). Shock chlorination treatments will decrease the number of iron related and other bacteria in a water well, but probably does not affect the iron content, which they live on, in the water. However, in one study in Canada iron levels did appear to be reduced as seen in figure 1 (Anonymous, 1999).

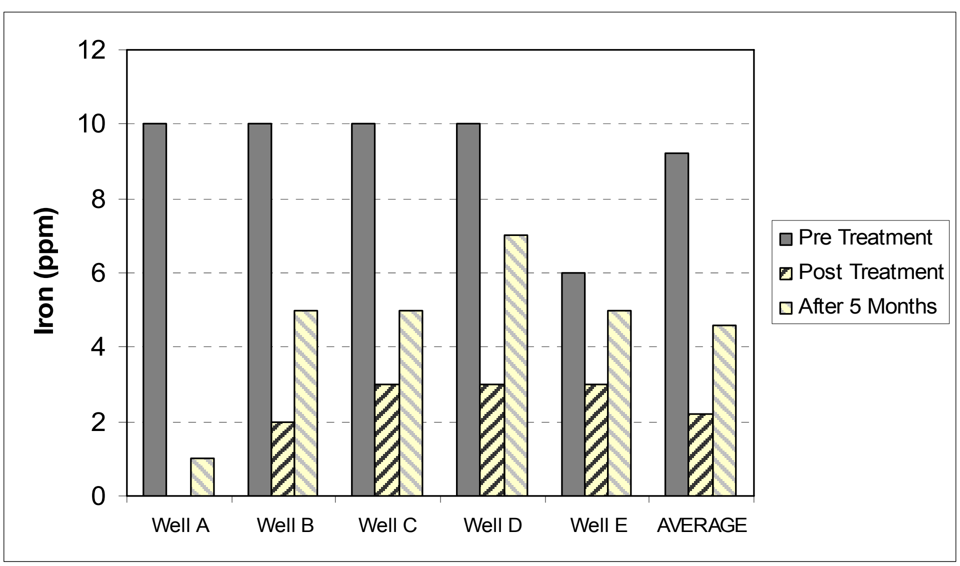

Fig. 1- Iron content of five different wells before, directly after and 5 months post chlorination.

Gilbert and Ford (1986) report water with total iron concentrations > 1.5 ppm is considered to have a severe clogging hazard. The iron content of underground water in Missouri, like many other states in the Midwest and mid-South, is generally high. A survey of 272 irrigation wells in southeast Missouri (SEMO) in 1987 showed the average iron content was 2.5 ppm, with Butler County wells averaging 4.5 ppm (Tracy and Hefner, 1993). Figure 2 is a map of SEMO showing the iron water content found in the wells. There is much variation in iron content within this area. About 13% of the farmers described the content of iron in their irrigation wells as "low", 71% as "medium", and 16% as "high" when asked to describe the iron level in an irrigation survey (Henggeler, 2003).

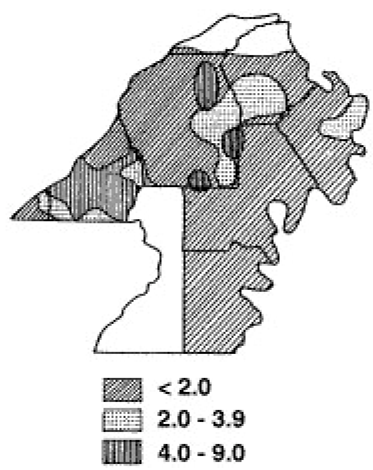

Fig. 2- Iron content in irrigation wells in southeast Missouri (after Tracy and Hefner, 1993).

The high level of iron in SEMO water wells causes problems for local watermelon and vegetable growers using drip irrigation. These users employ light-weight tape that is meant to be used just a single year and have minimal filtration and chlorine injecting capacity. In many years, especially in drier ones, the tapes clog before the season is over. One producer started a program of injecting chlorinated water into his small two-inch wells. He reported that the tapes afterward appeared to resist clogging for a longer period of time. The University of Missouri developed a well chlorination strategy based on this procedure.

MATERIALS and METHODS

An experiment was undertaken to measure the effectiveness of shock treating water wells with chlorine to reduce iron bacteria and clogging in drip irrigation systems. Two-inch wells cased in PVC pipe and originally jetted in to a depth of about 90 feet were used in the tested. The iron levels of both wells were high in iron with values around 10 ppm. One well was treated with a shock chlorination treatment, while the other was not treated and served as a check. Both wells were located on the University of Missouri Delta Center's Lee Farm approximately 150 feet from each other. Wells such as these can yield 100 GPM. Particulars concerning the two wells are shown in table 1.

Table 1. Year installed, current depth, standing water level and chlorination mix for wells in the test.

Name	Year Installed	Current Depth (feet)	Standing Water Level (feet)	Treatment	Chlorination Procedure	
					Water Added (gals)	Chlorine Added (oz)
L-8	1998	59.1	10.3	Treated	2.0	118
L-7	2003	44.0	10.8	Check	---	---

Initial water quality readings were taken that included iron (total & ferrous), oxidation reduction potential (ORP), chlorine (total & free), and pH. In addition, samples were tested for iron-reducing bacteria using BART testers.

Well L-8 was shock chlorinated on April 6, 2006 and again on August 28, 2006 in a procedure developed by Henggeler (2006). The procedure involves injecting a chlorine solution into the well casing under pressure. The concentration of chlorine in the pumped-in solution is such that the water standing in the well will be brought up to a concentration of 5,000 ppm chlorine. This concentration is higher then most recommendations, but was done on the suggestion of Dr. D.R. Cullimore a world renowned expert in the area of IRB (Cullimore, 2006). A 25-gallon sprayer equipped with a 12-volt pump was used to inject the chlorine solution into the well.

This solution is allowed to remain in the well for at least 24 hours before it is pumped out. At the end of August a drip irrigation system was installed at both well sites (Fig. 3). The system included a 12-volt, submersible pump, pressure gauges, an 8-psi pressure regulator, and a 5/8ths-inch water meter. Three types of drip tape were used and there were four laterals of 25 feet for each type. A cutoff valve was located at the head of each lateral line so that flow volumes could be isolated for the test. The particulars of the drip tapes are shown in table 2. No filtration or chemical injection during pumping was used in the test to purposefully accelerate clogging.

Table 2. Parameters of the two drip tapes used in the study.

Manufacturer	Tape Type	Nominal emitter flow (GPH)	x	k	Emitter Spacing (inches)	Total Amount of Tape (feet)	Number of Emitters
Netafim	Typhoon	0.18	0.48	0.059	12	75	75
Netafim	Typhoon	0.58	0.48	0.184	18	75	50

Flow rates were tested on a periodic basis for both systems. Flow was isolated to just the laterals of the individual tapes during the test. Flow rate was measured and pressure was recorded during the test. The flow rates were compared their original flows to determine the rate of clogging. The flow-head curves provided by the pump manufacturer overrated the capacity of the pumps, thus the seating pressure of the 8-psi regulators was not always met. Since operating conditions varied between test periods due to this and the level of charge on the battery at the time of the test, flows were adjusted for different operating pressures by using the *x* and *k* flow rate variables provided by the manufacturer. One of the tape types was constructed with fold-over seams used in the emitter design. These tapes allowed leakage around their connectors, so the results from them were not used in the test results.

Water samples were collected prior to the test and at weekly intervals after the test began. A sample was collected from the manifold which provided a water sample fresh from the well and another at the distill end of the tapes which would represent water that remains stagnant in the tape.

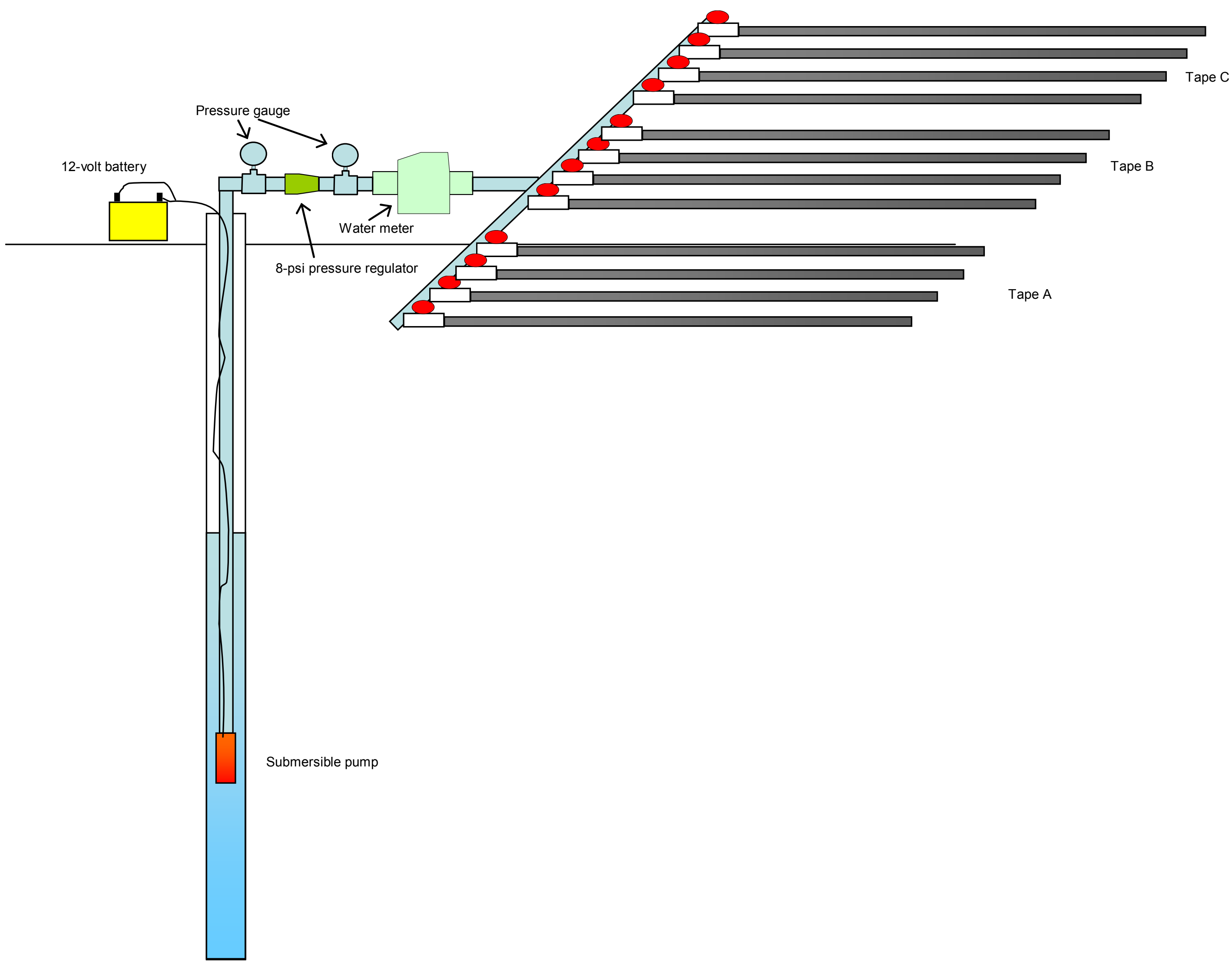

Fig. 3- A schematic of the drip system used in the test.

RESULTS

The untreated drip lines began to clog before a week had past. Eighteen days after the first irrigation water was pumped, the untreated 0.58 GPH and 0.18 GPH tapes were 73% and 50% of original flow, respectively. The treated drip lines were both at 101% of original flow. Figure 4 shows the flowrates as percentage of original flow over the course of the study. Figure 5 shows averages of both tape types for the treated and untreated treatments.

The higher flow rate (and assumed larger orifice size) 0.58 GPH tape had much less clogging then the tape with the smaller orifice sizes.

The ORP values had a reasonable correlation to ferrous iron (Fe^{+2}) values. Since ORP measures oxidation potential it would be a good "back door" method to ascertain chlorine levels. The beauty of ORP measurements are they are near instantaneous. Chlorine and iron readings require introduction of a reagent and a set reaction time. Therefore, they are somewhat impractical to use in evaluating mixing time effects. Figure 6 shows ORP values versus ferrous iron values from water samples taken from both wells.

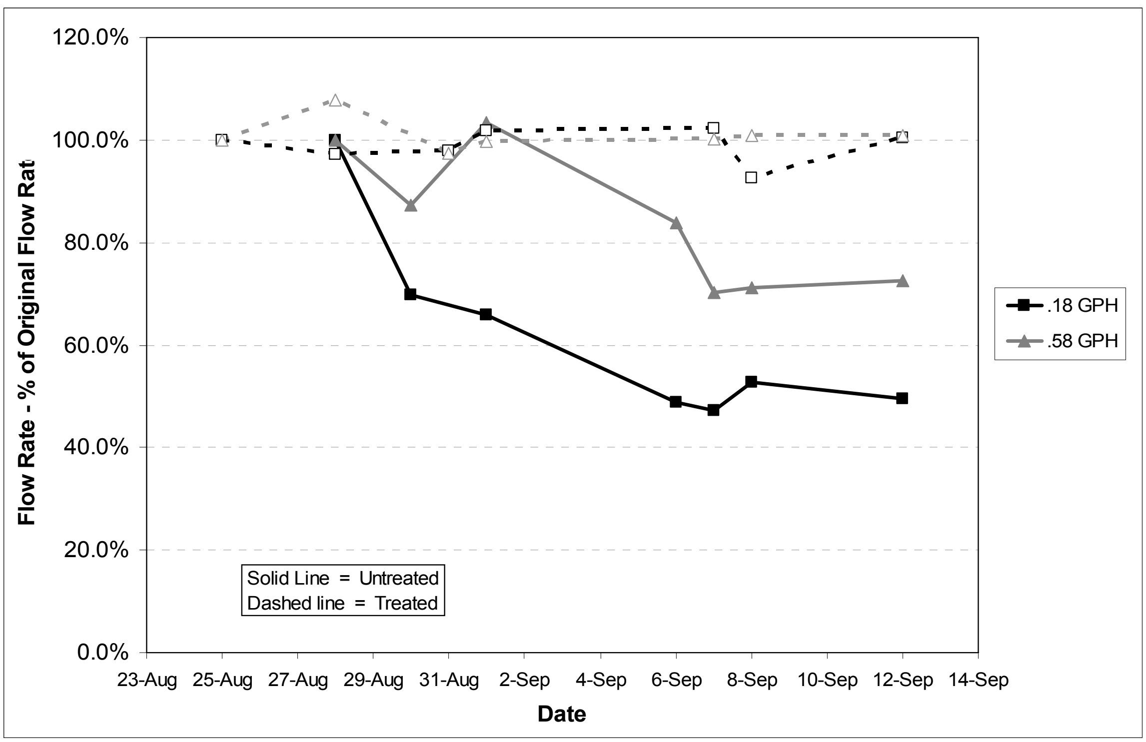

Fig. 4- Flow rates as percentage of original flow for both treated and untreated 0.18 GPH and 0.58 GPH tapes.

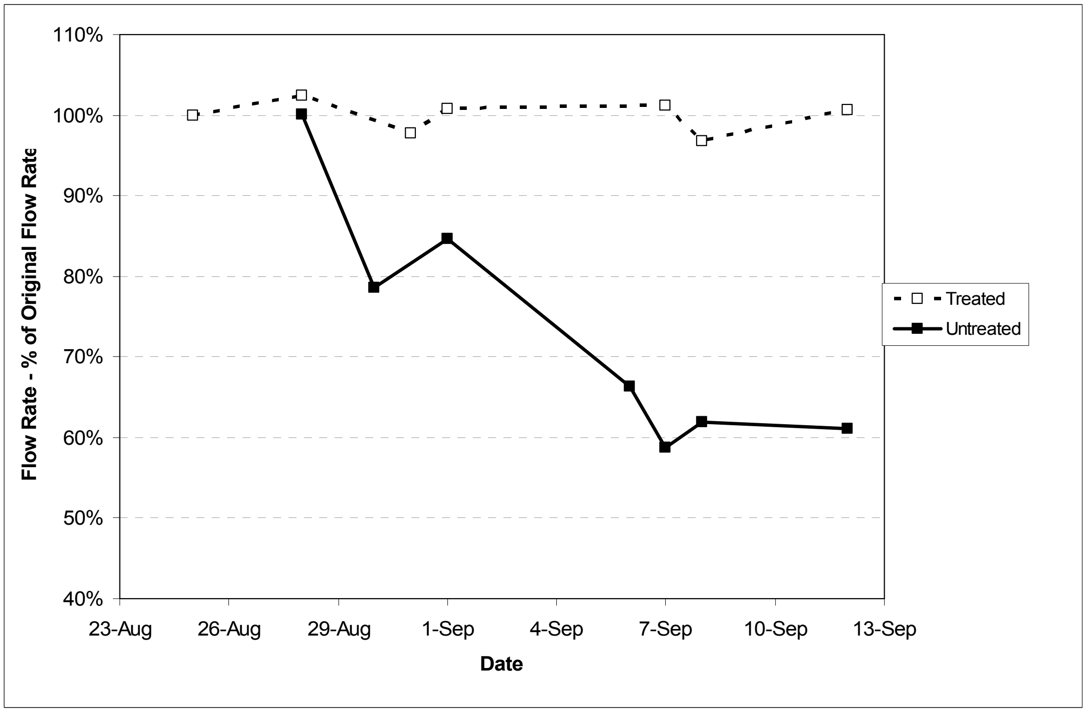

Fig. 5- The average flow rates as percentage of original flow for both tape types for the treated and untreated treatments.

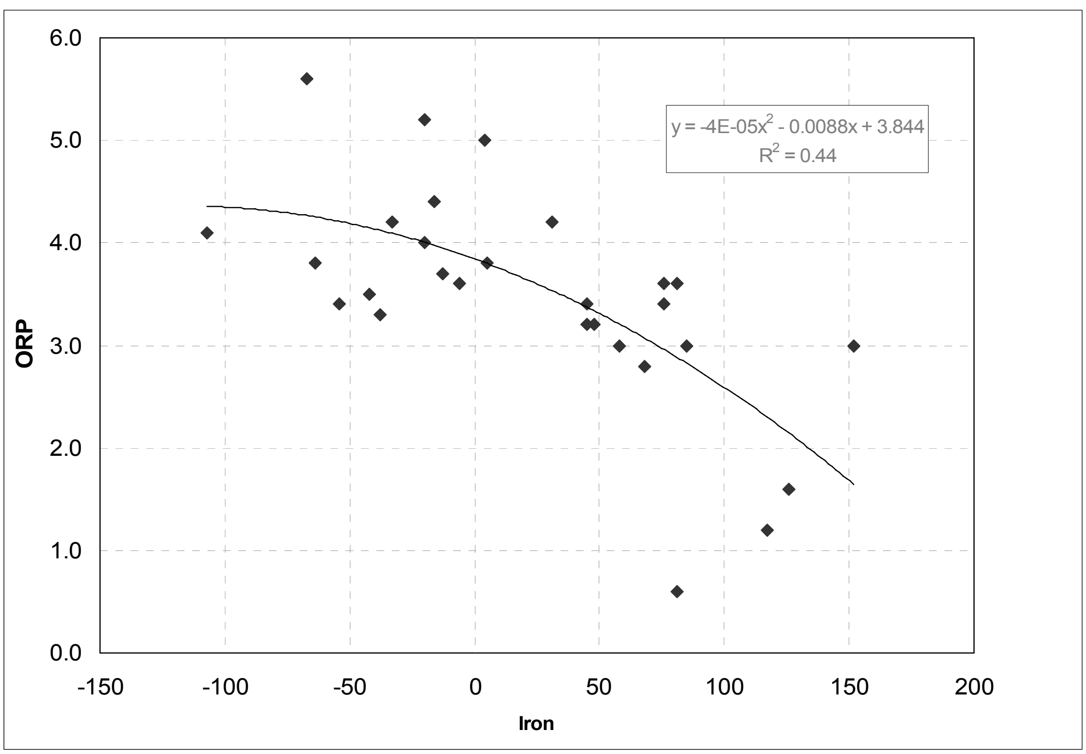

Fig. 6- ORP values versus ferrous iron values from water samples of the two wells.

CONCLUSIONS

- Super chlorination of water wells helps reducing emitter clogging in wells with high iron levels.
- Emitters with larger orifice sizes are less prone to clogging from iron related bacteria.
- Measurement of ORP may be a good tool in drip system management.

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Evaluation of a Low–Cost, Low-Tech Micro-Irrigation System Designed for Small Plots

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Water-use efficiency (WUE) is of utmost importance to many small-scale farmers and gardeners living on arid lands throughout the world. Some rely on small, low-output wells or unreliable surface sources to provide water for irrigating food crops for sustenance or for supplementing income. This is common even in the southwest U.S. where, on many Indian reservations, water must be transported from community wells or ponds to the irrigation site in containers. In other rural or urban settings, the volume of water available for irrigating agricultural fields and small vegetable plots may become limited by water restrictions or use-limits imposed during droughts or other water-short situations. In any case, it's important to maximize WUE (crop yield/water used).

The area of land that can be irrigated from a given volume of water can be significantly increased by converting from traditional surface irrigation to drip irrigation. Drip or trickle irrigation involves frequent application of small amounts of water directly to the base of plants. Water is applied under low pressure and only a small area around each plant is wetted. If managed properly, water is saved because it is not applied to the soil area in-between plants as in flood or sprinkler irrigation and soil water evaporation is decreased. Since large areas of ground remain dry, weeds are less problematic than when the entire soil surface is wetted.

Due to the costs and complexity of conventional state-of-the-art micro-irrigation systems, however, small-scale farmers have been reluctant to convert from familiar flood and sprinkler irrigation to drip irrigation. One purpose of this experiment was to evaluate the potential for using a simple, low-cost drip irrigation system that might receive wider acceptance by these farmers. The system, while originally developed in India (and promoted by International Development Enterprises for use in developing, resource-poor countries) could potentially be used in many situations where water conservation is of concern.

Regardless of the irrigation system used, WUE cannot be maximized without proper system management. This includes appropriate system maintenance and irrigation scheduling based on estimated crop water requirements. Other purposes of this experiment were to evaluate yield/water relationships (water production functions) for selected vegetable crops irrigated with the drip system and to formulate recommendations for scheduling irrigations on these crops.

Objectives

Evaluate the practicality of use and water conservation potential of a simple, low-cost drip irrigation system.

Identify water production functions of various vegetable crops when drip irrigated.

Materials and Methods

A randomized complete block design (Figure 1 and Figure 2) consisting of three replications (blocks) of three different drip-irrigation treatments (zones) was used to evaluate the yield/water relations of chile peppers, tomatoes, and sweet corn in 2005 and 2006 in northwestern New Mexico. The study was conducted on a very fine sandy loam soil at a site having an elevation of 1710 m (5600 ft) above mean sea level, and an annual average precipitation of 208 mm (8.2 in). Irrigations were applied every two to three days at volumes required to replace 50%, 75%, and 100% of Penman-Monteith (tall) reference ET (ETrs) in 2005 and 65%, 85%, and 105% of ETrs in 2006.

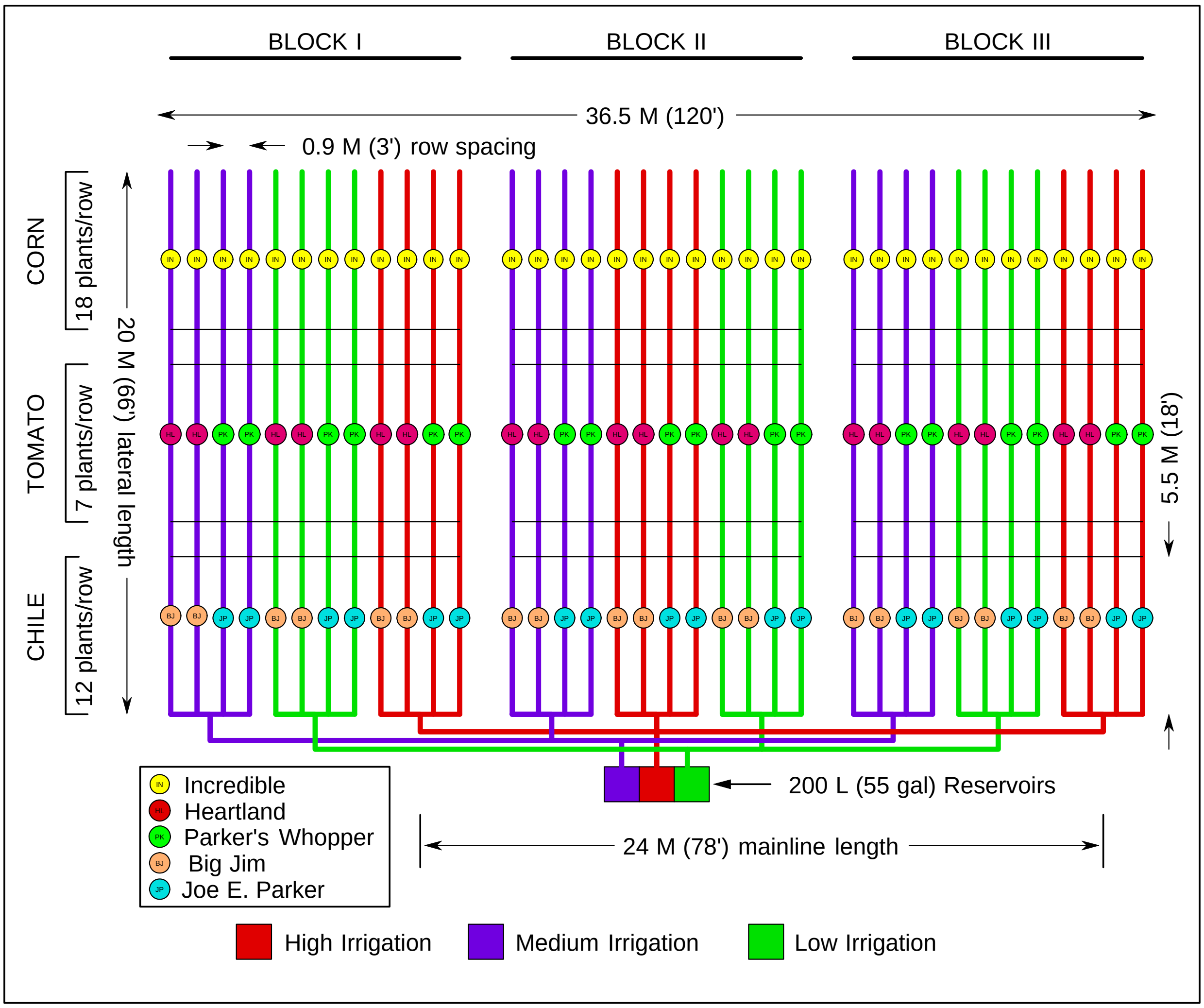


Figure 1. Diagram of the low-cost, low-tech drip garden (randomized complete block) used to evaluate yield/water relations of vegetable crops in 2005.

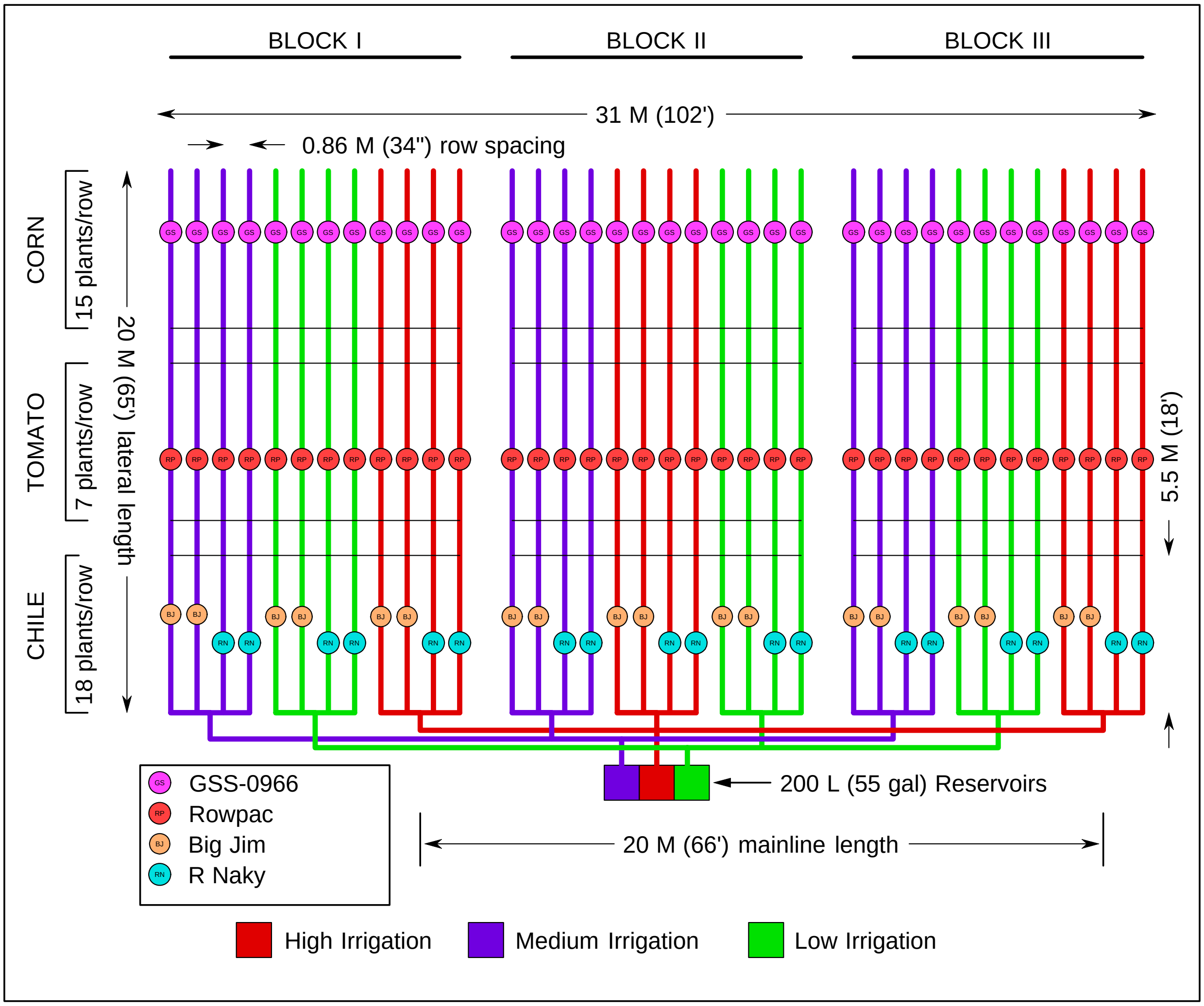


Figure 2. Diagram of the low-cost, low-tech drip garden (randomized complete block) used to evaluate yield/water relations of vegetable crops in 2006.

Major System Components

<u>Water reservoirs</u>: Three plastic, 208 L (55 gallon) drums, laid on their sides and elevated to a height of about 6 feet above the soil surface of the garden, were used to store and supply water to the three drip zones. A hinged access door, about 300 mm (12 in) by 400 mm (16 in), was cut into the topside of each drum to provide easy access for filling the drums with water and/or fertilizer when needed (Figure 3).

<u>Water distribution systems including filters and microtubule emitters</u>: In 2005, water was delivered from the reservoirs to the laterals of each zone through a 25 mm (1 in) black polyethylene (poly) pipe mainline and a 24 m (78 ft) long, 13 mm (½ in) poly pipe sub-main (Figure 4). Twelve, 20 m (66 ft) long drip-tape laterals spaced 0.9 m (3 ft) apart (Figure 4) delivered water to 250 mm (10 in) long microtubule emitters placed at each plant (Figure 5.) within each zone.

The distribution system in 2006 was similar to that of 2005 except each mainline was 20 m (66 ft) long (instead of 24 m) and the diameter of all mains and submains was 19 mm (3/4 in). Additionally, the microtubule emitters were cut in half to 125 mm (5 in) long (rather than 250 mm). In both years, an inline screen filter was installed on all mainlines.

A summary of system specifications and cropping information is presented in Table 1.

Figure 3. Elevated reservoirs (left) and access doors (right.)

Figure 4. Mains and submains (left) and laterals (right).

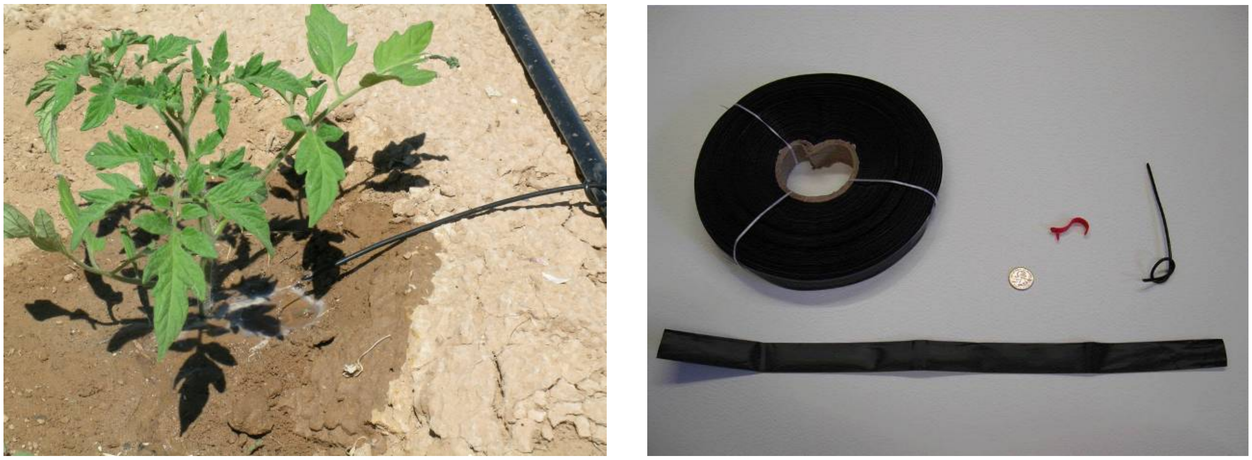


Figure 5. Microtubule emitter watering tomato plant (left), drip tape roll and short section, hole punch, and microtubule emitter (right).

Table 1. Specifications of each block (3 blocks total) in the randomized complete block design used to evaluate drip irrigation treatment effects on three vegetable crops in 2005 and 2006.

Component	2005			2006		
Lateral size	200 μm (8-mil) thickness, 15 mm (0.59") ID					
Laterals per block	12			12		
Lateral spacing, cm (in)	91 (36)			86 (34)		
Lateral length w/borders, M (ft)	20 (65)			20 (66)		
Microtube emitters per lateral	37			40		
Microtube emitter length, cm (in)	25 (9.8)			12.5 (4.9)		
Total emitters per block	444			480		
Flow rate/emitter, ml min^{-1} (gph)	43 (0.68), 28 (0.45)†			35 (0.55)		
Flow rate per block, l min^{-1} (gpm)	19.1 (5.0), 12.4 (3.3)			16.8 (4.4)		
	Chile	**Tomato**	**Corn**	**Chile**	**Tomato**	**Corn**
Plant (emitter) spacing, cm (in)	46 (18)	76 (30)	30 (12)	30 (12)	61 (24)	30 (12)
Plants per lateral	12	7	18	18	7	15
Planting Date	9-11 June	12-13 June	17 June	23-24 May	23-24 May	1 June
Transplants (T) or Seed (S)	T	T	S	T	T	S
Planting method	Hand	Hand	Hand	Machine	Machine	Hand

†Flow rates measured before and after installation of timers, respectively.

Planting and Fertilizer Information

The plot area was prepared for planting (disked, fertilized, rototilled, leveled, and pre-irrigated) in May of both years. In 2005, pre-plant fertilizer (11-52-0) was incorporated into the soil on 20 May at a rate of 49 kg N ha^{-1} and 233 kg P_2O_5 ha^{-1} (44 lbs. N and 208 lbs. P_2O_5/acre). The area was pre-irrigated with approximately 50 mm (2 in) of sprinkler-applied water on 25 May. On 5 June (prior to planting) the garden area was sprayed with glyphosate (3% solution) to kill small weed seedlings that had emerged.

In 2006, the plot was established in a different area previously planted to turfgrass, Pre-plant fertilizer (11-52-0) was incorporated on 11 May at a rate of 25 kg N ha-1 and 116 kg P_2O_5 ha-1 (22 lbs N and 208 lbs P_2O_5/acre). Sprinklers were used to apply a 20 mm (0.75 in) deep irrigation on 19 May prior to planting and a 3 mm (0.50 in) irrigation on 24 May after planting but prior to set-up of the drip system.

In both years, chile pepper and tomato seedlings from 25 mm (1-inch) pots (six-packs) were transplanted into rows at spacings shown in Table 1. In 2005, plants were set into holes that were pre-wetted with about 350 ml (12 oz) of a water-fertilizer solution (500 ml dry all purpose fertilizer [Table 3] to 4 gallons of water) by hand. In 2006, a mechanical, three-point hitch transplanter was used and a similar fertilizer volume was applied with each transplant through the transplanter.

Drip-tape laterals were laid out in rows next to the plants and emitters were installed (pointing downstream) into the water-filled laterals at each plant location after planting in both years. Sweet corn seeds were planted by hand about 1 week after the transplants in both years and then microtubule emitters were installed into the drip line next to each seed. The total plot area was about 720 m^2 (7750 ft^2) in 2005 and about 620 m^2 (6670 ft^2) in 2006 (Figure 1 and Figure 2). In 2006, row spacing was slightly narrower and borders between blocks were eliminated.

Maintenance Fertilization

In addition to the pre-plant fertilizer, the garden was fertilized through the drip system (fertigation) six times during the 2005 season by adding liquid nitrogen and a micronutrient solution to the reservoirs during irrigation (Table 2). Soluble fertilizers (Table 3) were dissolved in 11-19 L (3-5 gals) water before being added to reservoirs. A similar fertilization program was followed in 2006.

Table 2. Dates and amounts of drip fertigation per block in 2005.

Date	Product*	Total Product† g (oz)	Rate per Plant† g (oz)
24 June	$CaNO_3$ (15.5% N)	285 (10)	0.64 (0.0225)
	Peter's	285 (10)	0.64 (0.0225)
1 July	20-0-0	285 (10)	0.64 (0.0225)
	Peter's	285 (10)	0.64 (0.0225)
12 July	UAN (32% N)	480 (16)	1.08 (0.0360)
	Peter's	285 (10)	0.64 (0.0225)
22 July	UAN (32% N)	700 (23)	1.58 (0.0527)
	Peter's	425 (15)	0.96 (0.0338)
29 July	UAN (32% N)	400 (14)	0.95 (0.0315)
	Peter's	285 (10)	0.64 (0.0225)
12 August	UAN (32% N)	700 (23)	1.58 (0.0527)
	Ace	340 (12)	0.77 (0.0270)

†Value represents ml (liquid ounces) for UAN.

Table 3. Nutrient analyses of dry plant foods used in fertigation of vegetables in the low-tech drip garden during 2005.

Peter's Professional (20-20-20)	Ace All-Purpose (15-30-15)

Nutrient	%	Nutrient	%
N (2% NO_3-N, 18% Urea N)	20.0	N (5.8% Amm. N, 9.2% Urea N)	15.0
P_2O_5	20.0	P_2O_5	30.0
K_2O	20.0	K_2O	15.0
Mg	0.5	B	0.02
B	0.02	Cu	0.07
Cu	0.05	Fe	0.10
Fe	0.10	Mn	0.05
Mn	0.05	Mo	0.0005
Mo	0.0005	Zn	0.06
Zn	0.05		

Other cultural information

Weeds were controlled by hand-hoeing or pulling during both seasons and no pesticides were used. All crops were harvested by hand as they matured.

Irrigation

In 2005, due to very slow establishment attributed to disease (curly top virus), the entire plot area was drip-irrigated uniformly at near 100% of ETrs up through 24 July (6 weeks after planting) at a frequency of three irrigations per week. Irrigation treatments (volumes sufficient to replace 50%, 75%, and 100% of ETrs) commenced on July 27 and continued through the end of September (Table 4). In 2006, varying drip treatments (volumes to replace 65%, 85%, and 105% of ETrs) were started on 15 June (Table 5) and continued to the end of season (not yet established). An average value of plant canopy area for all three crops was used to adjust irrigation volumes during the growing season.

The equation used to calculate water volumes for the irrigation treatments was:

$$I = ETrs \times TF \times 0.62 \times CA \quad \text{[Eq. 1]}$$

Where:

- I = irrigation in gallons
- ETrs = Penman-Monteith Reference ET tall (inches)
- TF = treatment factor (0.50, 0.75, or 1.00 in 2005 and 0.65, 0.85, or 1.05 in 2006)
- 0.62 = gallons of water to cover 1 square foot to a depth of 1 inch
- CA = plant canopy area (square feet)

Daily weather parameters from a New Mexico Climate Center (NMCC) weather station (Campbell Scientific) located within 100 m (328 ft) were used to calculate ETrs (http://weather.nmsu.edu).

In 2005, plant canopy area (CA) increased from 230 cm^2 (0.25 ft^2) per plant after planting to a maximum of 0.21m^2 (2.25 ft^2) per plant on 27 July. In 2006, plant canopy area increased from 190 cm^2 (0.2 ft^2) after planting to 0.24 m^2 (2.6 ft^2) on 21 July and afterwards.

The water volume applied to each treatment was controlled by timing the irrigations. In 2005, random measurements of emitter flow rates during the season indicated 43 ml min^{-1} (0.68 gph) from June 19 through about mid-August. Subsequent measurements indicated a decrease in flow rate to 28 ml min^{-1} (0.45 gph) per emitter and run times were adjusted accordingly. Total flow rate per block (444 plants) then ranged from about 1145 L hr^{-1} (5 gpm) during the first half of the season, to 745 L hr^{-1} (3.3 gpm) during the last half of the season. The decreased flow rate per emitter as the season progressed appeared to be caused either by algae or other precipitates in the emitters or possibly by mainline flow restriction after installation of timers. As of this writing, the timer theory has yet to be tested.

In 2006, flow rate per emitter averaged 35 ml min^{-1} (0.55 gph) from June through 21 August and then increased to 49 ml min^{-1} (0.78 gph) when the laterals were shortened after corn harvest (see further discussion below). Total average flow rate per block then was 1008 L hr^{-1} (4.44 gpm) prior to 21 August (480 emitters) and 882 L hr^{-1} (3.88 gpm) after that (300 emitters).

Results and discussion

Irrigations and System Evaluation

The garden was irrigated 45 times between 19 June and 4 October in 2005 and 33 times between 31 May and 28 August in 2006. The total volumes of irrigation water applied to each plant in the high, medium, and low irrigation treatments were 162, 135, and 113 L (42.8, 35.6, and 29.9 gallons), respectively in 2005 and 140, 117, and 95 L (37, 31, and 25 gallons), respectively, up to 29 August in 2006. An additional 99 mm and 74 mm (3.9 and 2.9 in) of precipitation fell on the plots during the 2005 and 2006 seasons, respectively. Sweet corn was harvested before 7 September in 2005 and before 17 August in 2006 so water applied after those dates did not contribute to corn yield. Additionally, since fruit production has not yet ceased in the tomatoes and chile peppers as of this writing, the totals shown in Table 5 for 2006 are sub-totals only.

In 2005, total ETrs from planting (13 June) to the final harvest of tomatoes in October was 965 mm or 38 in (Table 4). In 2006, ETrs from planting 24 May to August 28 totaled 807 mm or 32 in (Table 5).

Table 4. Calculated reference ET (ETrs) and average water volumes applied to each plant during the 2005 season at three irrigation treatments with the low-tech, low-cost drip irrigation system†.

			Irrigation Treatment Level					
	ETrs	ETrs	High (100% ETrs)		Med. (75% ETrs)		Low (50% ETrs)	
Date	mm	in	Liter	Gallon	Liter	Gallon	Liter	Gallon
19-Jun	-	-	0.39	0.10	0.39	0.10	0.39	0.10
19-Jun	55.6	2.19	1.35	0.36	1.35	0.36	1.35	0.36
21-Jun	20.3	0.80	3.69	0.97	3.69	0.97	3.69	0.97
24-Jun	25.4	1.00	3.69	0.97	3.69	0.97	3.69	0.97
26-Jun	16.5	0.65	3.20	0.84	3.20	0.84	3.20	0.84
27-Jun	10.4	0.41	1.23	0.32	1.23	0.32	1.23	0.32
28-Jun	10.9	0.43	2.46	0.65	2.46	0.65	2.46	0.65
30-Jun	17.0	0.67	2.87	0.76	2.87	0.76	2.87	0.76
1-Jul	8.9	0.35	1.85	0.49	1.85	0.49	1.85	0.49
3-Jul	20.3	0.80	2.87	0.76	2.87	0.76	2.87	0.76
6-Jul	30.0	1.18	5.33	1.41	5.33	1.41	5.33	1.41

8-Jul	21.6	0.85	3.08	0.81	3.08	0.81	3.08	0.81
10-Jul	20.6	0.81	3.69	0.97	3.69	0.97	3.69	0.97
12-Jul	19.8	0.78	4.72	1.25	4.72	1.25	4.72	1.25
14-Jul	21.8	0.86	2.67	0.70	2.67	0.70	2.67	0.70
15-Jul	11.9	0.47	1.23	0.32	1.23	0.32	1.23	0.32
16-Jul	10.2	0.40	0.81	0.21	0.81	0.21	0.81	0.21
17-Jul	11.2	0.44	0.81	0.21	0.81	0.21	0.81	0.21
18-Jul	9.9	0.39	3.24	0.86	3.24	0.86	3.24	0.86
20-Jul	22.4	0.88	3.24	0.86	3.24	0.86	3.24	0.86
22-Jul	25.4	1.00	3.24	0.86	3.24	0.86	3.24	0.86
24-Jul	20.1	0.79	0.81	0.21	0.81	0.21	0.81	0.21
27-Jul	25.4	1.00	5.37	1.42	3.70	0.98	2.05	0.54
29-Jul	18.8	0.74	2.48	0.66	1.86	0.49	1.27	0.34
31-Jul	22.9	0.90	2.03	0.54	1.62	0.43	1.22	0.32
1-Aug	9.1	0.36	2.59	0.68	1.84	0.49	1.08	0.29
3-Aug	18.8	0.74	2.70	0.71	2.03	0.54	1.35	0.36
5-Aug	16.3	0.64	2.43	0.64	1.76	0.46	1.08	0.29
10-Aug	33.8	1.33	3.92	1.03	2.70	0.71	2.84	0.75
12-Aug	12.4	0.49	1.89	0.50	1.89	0.50	0.81	0.21
15-Aug	19.8	0.78	2.97	0.78	2.21	0.58	1.49	0.39
19-Aug	29.2	1.15	3.16	0.83	2.38	0.63	2.54	0.67
22-Aug	21.8	0.86	5.08	1.34	3.81	1.01	2.54	0.67
24-Aug	15.2	0.60	3.24	0.86	2.43	0.64	1.62	0.43
26-Aug	15.0	0.59	3.67	0.97	2.84	0.75	2.13	0.56
29-Aug	24.9	0.98	5.27	1.39	3.94	1.04	2.62	0.69
31-Aug	17.8	0.70	4.48	1.18	3.16	0.83	1.84	0.49
2-Sep‡	18.3	0.72	4.86	1.28	3.51	0.93	2.16	0.57
7-Sep	35.8	1.41	4.05	1.07	5.89	1.56	7.97	2.10
13-Sep	45.7	1.80	12.29	3.25	6.62	1.75	4.05	1.07
16-Sep	24.9	0.98	4.73	1.25	3.51	0.93	2.30	0.61
19-Sep	23.1	0.91	6.13	1.62	4.08	1.08	2.86	0.76
22-Sep	19.1	0.75	5.13	1.36	3.78	1.00	2.43	0.64
26-Sep	33.0	1.30	7.67	2.03	5.94	1.57	4.05	1.07
3-Oct	42.9	1.69	7.02	1.85	7.02	1.85	4.59	1.21
4-Oct	10.7	0.42	2.43	0.64	0.00	0.00	0.00	0.00
Totals	**965**	**38.0**	**162**	**42.8**	**135**	**35.6**	**113**	**29.9**

†Water volumes do not include 98 mm (3.9 in) of precipitation.

‡Sweet corn was harvested between 9/2 and 9/7.

Table 5. Calculated reference ET (ETrs) and average water volumes applied to each plant during the 2006 season at three irrigation treatments with the low-tech, low-cost drip irrigation system†‡.

			Irrigation Treatment Level					
	ETrs		High (105% ETrs)		Med. (85% ETrs)		Low (65% ETrs)	
Date	**mm**	**in**	**Liter**	**Gallon**	**Liter**	**Gallon**	**Liter**	**Gallon**
31-May	67.8	2.67	3.84	1.01	3.84	1.01	3.84	1.01
2-Jun	19.8	0.78	3.84	1.01	3.84	1.01	3.84	1.01

5-Jun	29.2	1.15	1.92	0.51	1.92	0.51	1.92	0.51
7-Jun	22.4	0.88	3.84	1.01	3.84	1.01	3.84	1.01
12-Jun	40.9	1.61	4.80	1.27	4.80	1.27	4.80	1.27
15-Jun	35.8	1.41	0.80	0.21	0.64	0.17	0.48	0.13
18-Jun	28.7	1.13	2.34	0.62	1.92	0.51	1.44	0.38
20-Jun	20.6	0.81	1.60	0.42	1.28	0.34	0.96	0.25
22-Jun	17.5	0.69	2.46	0.65	2.02	0.53	1.54	0.41
25-Jun	31.5	1.24	1.54	0.41	1.25	0.33	0.96	0.25
27-Jun	18.8	0.74	3.62	0.96	3.30	0.87	2.46	0.65
30-Jun	26.7	1.05	3.94	1.04	3.14	0.83	2.50	0.66
1-Jul	10.2	0.4	3.84	1.01	2.88	0.76	2.24	0.59
5-Jul	33.5	1.32	2.69	0.71	2.30	0.61	1.79	0.47
12-Jul	41.4	1.63	3.20	0.85	2.56	0.68	1.92	0.51
14-Jul	17.8	0.7	3.04	0.80	2.72	0.72	1.92	0.51
17-Jul	30.5	1.2	3.84	1.01	2.88	0.76	1.92	0.51
19-Jul	18.8	0.74	5.76	1.52	4.48	1.18	3.68	0.97
21-Jul	17.0	0.67	4.80	1.27	4.00	1.06	3.20	0.85
24-Jul	25.7	1.01	6.78	1.79	5.92	1.56	4.48	1.18
26-Jul	16.8	0.66	5.28	1.39	3.84	1.01	2.88	0.76
28-Jul	14.2	0.56	4.80	1.27	3.94	1.04	3.04	0.80
31-Jul	22.9	0.9	4.80	1.27	3.84	1.01	2.88	0.76
2-Aug	14.2	0.56	5.28	1.39	4.32	1.14	3.36	0.89
3-Aug	8.6	0.34	4.16	1.10	2.72	0.72	1.60	0.42
8-Aug	31.5	1.24	2.40	0.63	2.08	0.55	1.44	0.38
10-Aug	13.2	0.52	5.76	1.52	5.12	1.35	4.16	1.10
14-Aug	30.7	1.21	8.32	2.20	6.82	1.80	5.38	1.42
16-Aug§	12.7	0.5	3.78	1.00	3.20	0.85	2.66	0.70
18-Aug	15.7	0.62	3.97	1.05	3.20	0.85	2.46	0.65
21-Aug	23.6	0.93	7.25	1.92	5.88	1.55	4.41	1.17
24-Aug	19.1	0.75	8.48	2.24	6.52	1.72	4.41	1.17
28-Aug	29.2	1.15	8.58	2.27	7.84	2.07	4.66	1.23
Totals	**807**	**31.8**	**141**	**37.3**	**119**	**31.4**	**93**	**24.6**

†Data up to 28 August 2006. Tomato and chile pepper season not yet complete.
‡Water volumes do not include 75 mm (2.9 in) of precipitation.
§Sweet corn harvest – 17 August 2006.

System Evaluation

With careful management and close supervision, the irrigation system performed satisfactorily under the conditions of this study. After starting each irrigation sequence, the system was inspected for leaks, lateral kinking, emitter clogging, etc. While emitter clogging was of primary concern, it was usually not a significant problem except after rain storms when the emitter outlets would become clogged from pointing down into mud puddles. Most other times, less than 5% of the emitters became clogged. These emitters were removed, blown out and reinstalled, or replaced. It appeared that some clogging could be prevented by flushing the laterals as they filled. This was done by pulling off a short sleeve of drip line that was slipped over the folded lateral end (serving as an end cap) and allowing water to free-flow for a few seconds. Also, when installing the emitters, the opening was pointed downstream inside the lateral.

Since, in our situation, the irrigation water was relatively clean and free of sediments, filter clogging was usually not a problem during this study. Because our filter housings were transparent, however, algal growth occasionally occurred in the filters, especially after N fertigations. In these cases, the housing was removed and the filter screen flushed. The addition of about 120 ml (0.5 cup) of household bleach was added to the filled reservoirs occasionally to prevent algal build-up.

Drip tape kinking, primarily due to expansion and contraction with temperature changes, occurred but was a minor nuisance. To minimize the effects of these changes, and to avoid irrigating through hot drip tape, all irrigations were applied in early morning. The drip line was cool and contracted at this time so kinking was minor. To insure unrestricted water flow, the laterals were pulled taught from the ends to straiten and eliminate kinks at the beginning of each irrigation. Landscape staples or U-shaped wires were used to hold the laterals in place when empty.

Leakage was nominal with the system when first installed and remained minimal throughout the study period. Occasionally however, gophers chewed holes into drip laterals that were in close proximity to their burrow entrances. Traps were used to control these occasional rodents and affected drip lines were repaired with couplers.

As with all irrigation systems, water distribution uniformity (DU) is a primary concern when evaluating the efficiency of drip irrigation systems. During this study, an estimate of DU was obtained by measuring the output (flow rates) from several system emitters using a small glass beaker (which was slipped carefully under the emitter), a watch with a second hand (to keep track of the outflow duration), and a graduated cylinder (to precisely measured the emitter-output water during that duration). Usually, measurements were taken from the 1st, 18th, 26th, and 40th (last) emitter along several selected laterals within each block of the plot layout. In 2006, mean single-emitter flow rate averaged 35.6 ml min^{-1} from 27 June to 14 August and did not differ significantly between three sampling dates (Table 6). The coefficient of variation (*cv*) increased (from 0.116 to 0.166) and the low-quarter DU decreased (from 0.85 to 0.79) however, (Table 6) indicating an increase in flow variability between emitters with time. All laterals were cut shorter by 6 m (20 ft) on 21 August (after the sweet corn was harvested) eliminating 15 emitters from the ends of each lateral. Mean flow rate of the remaining emitters increased to 49.4 ml min^{-1} (from 35.3 ml min-1 on 14 August), cv decreased to 0.135 (from 0.166 on 14 August), and DU increased to 0.84 (from 0.79 on 14 August). Total block flow rate decreased to 889 L hr^{-1} or 3.92 gpm (from 1017 L hr^{-1} or 4.48 gpm).

Table 6. Average measured flow rate, coefficient of variation (*cv*), and low-quarter distribution uniformity (DU_{lq}) from emitters on four dates in 2006.

Date	Number of Samples	Mean Flow Rate (ml min-1)	*cv*†	DU_{lq}‡
27 June	40	36.4	0.116	0.85
21 July	26	35.1	0.158	0.82
14 August	40	35.3	0.166	0.79
29 August	26	49.4§	0.135	0.84

†Mean divided by standard deviation

‡Distribution uniformity (low quarter) = avg. measured output of lowest ¼ of emitters divided by the avg. output of all emitters
§ Laterals were shortened from 20 m (65 ft) to 14 m (45 ft) after corn harvest.

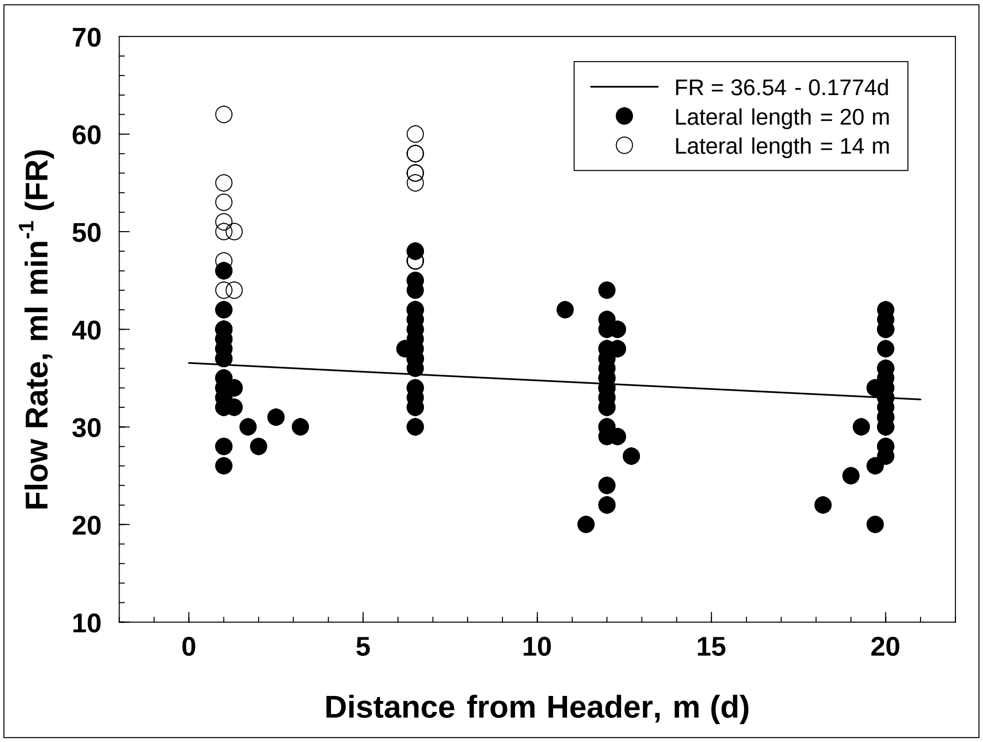


Figure 6. Measured flow rates of emitters located different distances down various laterals from the sub-main header during 2006 prior to, and after shortening each lateral by 6 m (15 emitters).

Note: The linear function applies only to the measurements taken before shortening the lateral. No significant trend was noted in measurements after shortening the lateral.

Prior to shortening the laterals in 2006, there was a trend of decreasing emitter flow-rate with increasing distance of the emitter away from the sub-main header (Figure 6). The regression function indicates a linear decrease in flow rate from 36.4 ml min^{-1} at the 1st emitter (1 m from the header) to 33.0 ml min^{-1} at the last emitter (20 m from the header).

Crop Production

Since the low-tech drip system evaluated in this study is designed for use on small plots (generally less than 0.5 ha or 1 acre), crop yields and components of yields are expressed in units per 100 m^2 (or 1000 ft^2). These terms may be more meaningful to the small-scale farmer than per ha (or per acre) units.

Sweet Corn

In 2005, there was no significant difference between sweet corn yields or components of yield at the different irrigation treatments (Table 7). The number of ears per plant, ears per unit area, weight per ear, and total yield, however, were all greater at the highest irrigation level (106 L per plant or 100% ETrs) than at the medium (75% ETrs) and low (50% ETrs) irrigation levels (95 and 83 L per plant, respectively). The number of marketable ears produced per 100 m^2 averaged 606 (563 per 1000 ft^2) and total yield of unhusked ears averaged 208 kg 100 m^{2-1} or 427 lbs per 1000 ft^2 (Table 7).

Table 7. Yield and yield components of sweet corn (cv. Incredible) at three, drip-irrigated water application levels in 2005†.

Component of Yield and Yield	Irrigation Level, L/plant (gal/plant)‡			
	106 (28)	95 (25)	83 (22)	Mean
Plants per 100 m^2 (plants/1000 ft^2)	302 (281)	316 (293)	344 (320)	321 (298)
Ears per plant	2.2	1.8	1.7	1.9
Ears per 100 m^2 (ears/1000 ft^2)	658 (611)	581 (540)	578 (537)	606 (563)
Weight per husked ear, g (oz)	266 (9.4)	249 (8.8)	252 (8.9)	255 (9.0)
Yield with husk, kg 100 m^{2-1} (lbs/1000 ft^2)	226 (464)	204 (418)	195 (399)	208 (427)
Yield w/o husk, kg 100 m^{2-1} (lbs/1000 ft^2)	172 (354)	146 (298)	148 (303)	155 (317)

†ANOVA indicated no significant difference between treatments for any factor.
‡Irrigation between planting (17 June) and harvest (8 Sept.). Does not include 60 mm (2.37 in.) of precipitation

In 2006, sweet corn yield and the number of husked ears per plant and per unit area were significantly lower at the lowest level of irrigation (88 L per plant or 65% ETrs) than at the medium (111 L or 85% ETrs) and high (133 L or 105% ETrs) irrigation levels (Table 8).

Table 8. Yield and yield components of sweet corn (cv. GSS-0966) at three, drip-irrigated water application levels in 2006†.

Component of Yield and Yield	Irrigation Level, L/plant (gal/plant)‡			
	133 (35)	111 (29)	88 (23)	Mean
Plants per 100 M^2 (plants/1000 ft^2)	367 (340) ab	356 (330) b	369 (342) a	364 (338)
Ears per plant	2.0 a	1.9 a	1.5 b	1.8
Ears per 100 M^2 (ears/1000 ft^2)	743 (690) a	665 (618) a	561 (521) b	656 (610)
Weight per husked ear, g (oz)	199 (7.0)	196 (6.9)	184 (6.5)	193 (6.8)
Yield with husk, kg 100 M^{2-1} (lbs/1000 ft^2)	203 (416) a	177 (363) a	141 (289) b	174 (356)
Yield w/o husk, kg 100 M^{2-1} (lbs/1000 ft^2)	148 (303) a	131 (268) ab	104 (213) b	128 (262)

†Means in a row followed by the same letter within a row are not significantly different at the 5% level of confidence based on Tukey's HSD means comparison.
‡Irrigation between planting (1 June) and harvest (17 Aug.). Does not include 73 mm (2.89 in.) of precipitation.

While ear weight is important for marketability, sweet corn is usually sold by number of ears. When ear number data from both years are combined, a highly significant linear relationship was found between the number of marketable ears produced per unit area and the volume of water applied per plant (Figure 7).

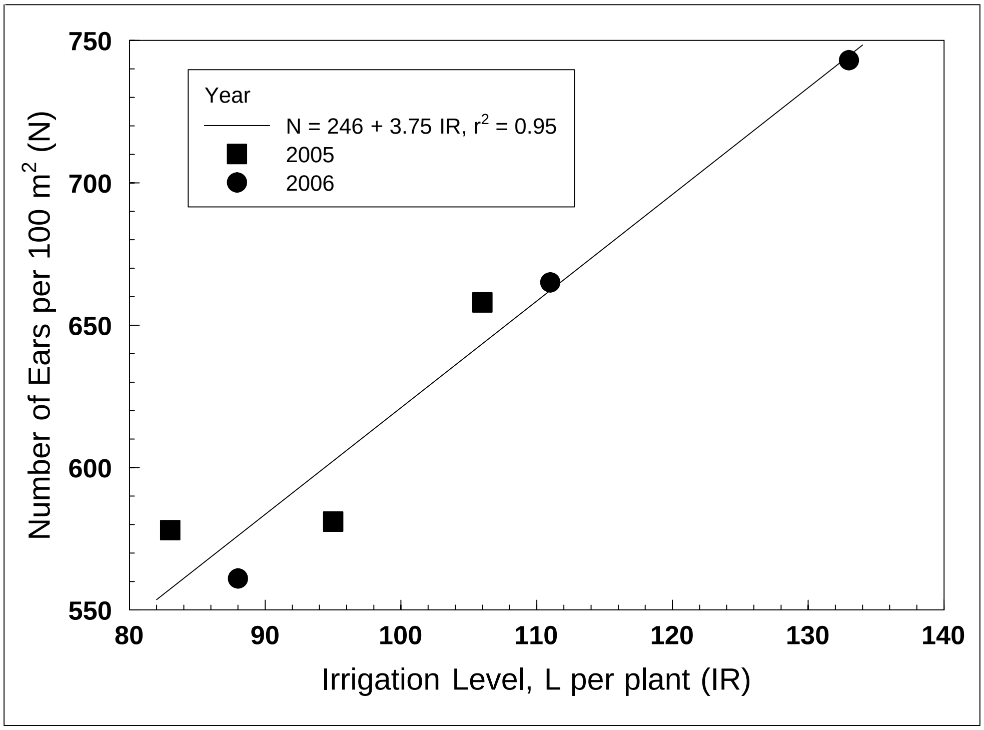


Figure 7. Marketable number of sweet corn ears produced per 100 m2 as related to the volume of water applied per plant with the drip system in 2005 and 2006.

Tomato

In 2005, a suspected case of curly top virus killed about 60% of the tomato plants so data for that year are not presented in this report.

In 2006, no significant difference was found among irrigation treatments between marketable yields, fruit weights per plant, weights per fruit, and numbers of fruit per plant (Table 9). Marketable yield (up to 29 August) averaged 491 kg 100 M^{2-1} (Table 9). While this yield is about half of that achieved for the same cultivar when grown under full sprinkler irrigation in previous studies at this site, the 2006 tomato season is still in progress.

Table 9. Yield and yield components of tomato (cv. Rowpac) at three drip-irrigation levels in 2006[†‡].

Component	Irrigation Level, L/plant (gals/plant)[§]			
	141 (37)	**119 (31)**	**93 (25)**	**Mean**
Marketable Yield, kg 100 M^{2-1} (lbs/1000 ft^2)	512 (1050)	478 (980)	484 (992)	**491 (1007)**
Fruit Weight per Plant, kg (lbs)	2.70 (6.0)	2.65 (5.8)	2.64 (5.8)	**0.62 (1.37)**
Weight per Fruit, g (oz)	143 (5.0)	140 (4.9)	127 (4.5)	**137 (4.8)**
No of Mkt. Fruit per plant	19.1	18.8	20.9	**19.6**

[†]Anova indicated no significant difference between treatments for any factor.
[‡]Cumulative data up to 29 August 2006. Tomato season still in progress.
[§]Irrigation between planting (24 May) and 29 August. Does not include 75 mm (2.9 in) of precipitation.

Chile Peppers

In 2005, marketable yields of Big Jim peppers were significantly greater at the highest irrigation level (163 L per plant) than at the lowest (114 L per plant), 363 kg m^{2-1} vs. 208 kg m^{2-1}, respectively (Table 10). There was also a decreasing trend in chile weight per plant and number of marketable fruit per plant with decreased irrigation in this cultivar and the Joe E. Parker cultivar in 2005. There were no significant differences between pepper yields or components of yields among irrigation treatments in the Big Jim and R. Naky cultivars in 2006 (Table 11) but the harvest season is not yet completed.

Table 10. Yield and yield components of two chile pepper varieties at three, drip-irrigation levels in 2005[†].

Component	**Big Jim**				**Joe E. Parker**			
	Irrigation Level, L/plant (gals/plant)[‡]				**Irrigation Level, L/plant (gals/plant)[‡]**			
	163 (43)	**136 (36)**	**114 (30)**	**Mean**	**163 (43)**	**136 (36)**	**114 (30)**	**Mean**
Market Yield, kg 100 M^{2-1} (lbs/1000 ft^2)	363 (744) a	246 (537) ab	208 (427) b	**278 (569)**	354 (725)	269 (551)	246 (505)	**287 (588)**
Chile Weight per Plant, kg (lbs)	1.68 (3.7)	1.27 (2.8)	1.00 (2.2)	**1.32 (2.9)**	1.72 (3.8)	1.41 (3.1)	1.22 (2.7)	**1.45 (3.2)**
Weight per Green Fruit, g (oz)	54 (1.9)	48 (1.7)	48 (1.7)	**51 (1.8)**	51 (1.8)	51 (1.8)	48 (1.7)	**51 (1.8)**
No of Mkt. Fruit per plant	33	27	22	**27**	34	29	26	**30**

[†]Means followed by the same letter within a row within a variety are not significantly different at the 5% level of confidence based on Tukey's HSD means comparison. The absence of letters indicates no significant difference between treatments for that factor.
[‡]Irrigation between planting (13 June) and final harvest (21 October). Does not include 89 mm (3.5 in) of precipitation.
[§]Assuming 100% plant survival.

Table 11. Yield and yield components of two chile pepper varieties at three, drip-irrigation levels in 2006[†‡].

Component	**Big Jim**				**R. Naky**			
	Irrigation Level, L/plant (gals/plant)[§]				**Irrigation Level, L/plant (gals/plant)[§]**			
	141 (37)	**119 (31)**	**93 (25)**	**Mean**	**141 (37)**	**119 (31)**	**93 (25)**	**Mean**
Market Yield, kg 100 M2-1 (lbs/1000 ft2)	232 (476)	231 (474)	233 (478)	**232 (476)**	268 (549)	243 (498)	259 (531)	**257 (527)**
Chile Weight per Plant, kg (lbs)	0.62 (1.36)	0.61 (1.34)	0.62 (1.37)	**0.62 (1.37)**	0.71 (1.57)	0.65 (1.44)	0.69 (1.52)	**0.68 (1.50)**
Weight per Green Fruit, g (oz)	61 (2.2)	64 (2.3)	66 (2.3)	**64 (2.3)**	50 (1.8)	52 (1.8)	55 (1.9)	**52 (1.8)**
No of Mkt. Fruit per plant	10.1	9.6	9.6	**9.8**	14.4	12.8	12.7	**13.3**

[†]Anova indicated no significant difference between treatments for any factor.
[‡]Cumulative data up to 29 August 2006. Chile pepper season still in progress.
[§]Irrigation between planting (24 May) and 29 August. Does not include 75 mm (2.9 in) of precipitation.

Summary

This study has shown that a simple, low-cost drip irrigation system can be effectively used to irrigate small vegetable plots. Sweet corn, tomato, and chile pepper production was acceptable as compared to those from similar sprinkler-irrigated trials conducted at this study site. Sweet corn yields increased with increasing irrigation indicating that, for maximum production, irrigations should be scheduled at 100% (or more) of ETrs. Water-use efficiencies (yield per water applied) were about 2 times greater in drip irrigated chile peppers than in those grown under sprinkler irrigation in previous years at this site.

There are limitations on the number of plants that can be reasonably irrigated from a reservoir that must be filled with buckets by hand. During this study, for example, flow rates to irrigate more than 400 plants were in excess of 15 L (4 gal) per minute. At this rate, a 200 L (55 gal) reservoir (effective capacity of 170 L or 45 gals laid on side) would empty in less than 15 minutes and would have to be filled about 4 times a day during peak plant water-use periods (1.5 L or 0.4 gal per plant per day). We used pressurized irrigation lines controlled by float valves to keep our reservoirs full but this may be beyond the means of small, resource poor farmers.

The information collected during this study provides some guidelines that might be used when planning a small drip-irrigated plot.

Drip Irrigation for Third World Kitchen Gardens

By Richard D. and William A. Chapin of Chapin Living Waters

Abstract: After drip irrigation for greenhouses was introduced in 1960, it spread rapidly to commercial field crops. In the nineteen seventies Richard Chapin introduced Bucket Kit drip irrigation. This concept has grown so that Chapin Living Waters Foundation is now partnering with more than 2,000 organizations in over 150 countries where millions are threatened with starvation. Bucket Kits make it possible for the poorest of the poor to grow vegetables when there is no rain. If a lady can get 10 gallons of water daily, she can grow enough vegetables in her kitchen garden for a small family. A 5-gallon bucket, mounted one meter above the soil, provides sufficient pressure. Container loads of bulk materials are sent to third world countries to be assembled into individual Bucket Kits. CLWF has held Workshops and Seminars in many countries to train trainers to teach others to use Bucket Kits.

Drought conditions worldwide result in millions of people going to bed hungry every night. Food becomes scarce and expensive when there is no rain, and poor people have no money to pay for food. Starvation then death is too often the result (Fig.1). Children and the elderly are most vulnerable. Women who have most of the kitchen gardens cannot grow vegetables without water.

Charitable and Governmental organizations have spent billions in sending Relief Food to help starving people in third world countries (Fig. 2). Not only does the food have to be purchased, but also there is an additional cost in getting it to the other side of the world (Fig. 3). Then the next drought creates the need all over again.

Can Drip Irrigation be Adapted for the World's Poor People?

When Drip Irrigation for greenhouse flowerpots (Fig.4) was introduced in 1960, it saved growers labor, water, and fertilizer. It also helped prevent disease and gave better control of the crop. Growers across the country soon began to install drip irrigation on their greenhouse benches.

With all of these advantages it seemed that drip irrigation would also be ideal for field grown row crops. In 1964, Mr. Norman Smith (Fig.5), County Agent on Long Island, used drip irrigation combined with plastic mulch for a crop of cantaloupes. Mr. Smith's great success with this field led to Mr. Bernarr J. Hall (Fig.6), San Diego County Farm Advisor, to run tests comparing drip irrigation with furrow irrigation on tomatoes. His published Paper showed a 26.8% increase for the drip irrigated rows.

With these success stories, drip irrigation soon spread to tomato (Fig.7), strawberry (Fig.8), and pepper (Fig.9), crops in California, Mexico, and southern Florida. Sugar cane and pineapple (Fig.10), growers in Hawaii were soon convinced that drip irrigation would save production costs and give them better control of their crops.

Early third world trials

In 1974, Catholic Relief (Fig.11), of Senegal asked for help to be able to grow vegetables during their dry season. A 50-gallon drum was mounted about 6 feet above the soil and connected to rows of drip line. The drum was filled with water as needed and produced a good crop of vegetables. However, this system would be far too expensive for families who have very little income.

Simple and Inexpensive Bucket Kit

Later in the 1970's, a simple and inexpensive Bucket Kit system (Fig.12) was developed. It was found that a 5 gallon bucket mounted one meter above the soil would provide enough pressure to drip irrigate 2 rows 50 feet (15 meters) long, or 4 rows 25 feet (7.5 meters) long or 6 rows 16.5 feet (5 meters) long, depending on the shape of the garden. The bucket needs to be filled once in the morning and once in the afternoon. When it is first set up, the bucket should be filled 2 or 3 times to make wet spots at each outlet. Then a plant is transplanted into each wet spot. In this way, every drop of water goes directly to a plant with no waste of water.

Often the water used for Bucket Kits is rather dirty. To overcome this a 3 stage-filtering system is used:

1. A heavy cloth is tied over the top of the Bucket, and the water is poured through the cloth.
2. The water goes through a screen filter as it leaves the bucket.
3. There is an internal filter segment extending the full length of the drip tape. All the water has to pass through this filter before it reaches an outlet. This filter segment has 10,000 tiny openings for each 100 feet of drip tape.

NOTE- The drip tape is always placed on the ground with the outlets up. This allows any foreign particles to fall to the bottom of the tape so they can be flushed out the end of the Tape.
If there is a hot dry wind and the crop is well developed, it might be necessary occasionally to fill the bucket a third time daily. The object is to grow a good crop with as little water use as possible. This is especially important when water is carried for a considerable distance.

Training in use of Bucket Kits

Experience has shown that it is much better to demonstrate the set up and use of Bucket Kits when they are distributed, rather than just giving the ladies a package for her to

Fig. 1 Drought Conditions

Fig. 2 Truck of Relief Food

Fig. 3 Distribution

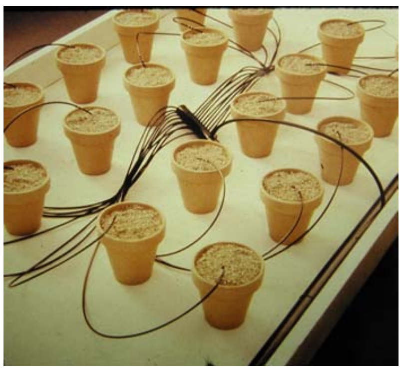


Fig. 4 Drip for Flower Pots

Fig. 5 Norman Smith

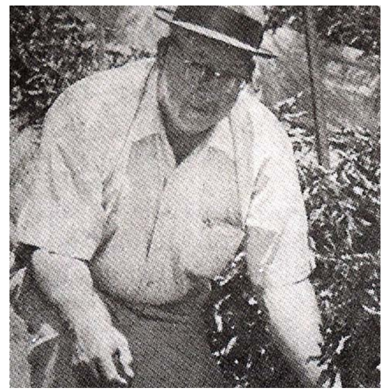


Fig. 6 Bernarr J. Hall

Fig. 7 Tomato Field

Fig. 8 Strawberries

Fig. 9 Peppers

Fig. 10 Pineapples in Hawaii

Fig. 11 Catholic Relief

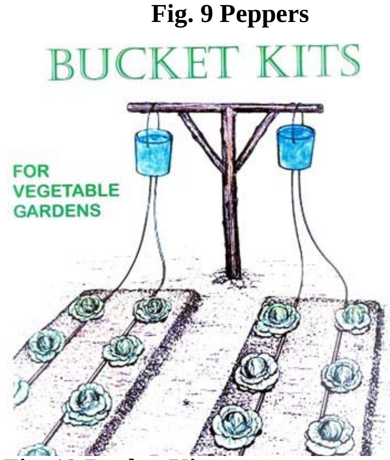


Fig. 12 Bucket Kits

Fig. 13 Seminar

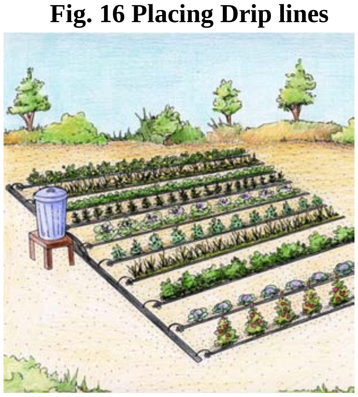
Fig. 14 Classroom

Fig. 15 Preparing Soil

Fig. 16 Placing Drip lines

Fig. 17 Filling Bucket

Fig. 18 Transplanting



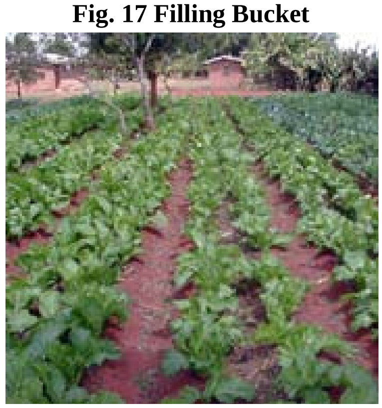


Fig. 19 Super Bucket Kit

Fig. 20 1/4 Acre Kit

Fig. 21 Test Garden

Fig. 22 3 Bucket Kits

Fig. 23 Large Field

Fig. 24 Bucket Kits

figure out. Also, it is better to charge at least a nominal fee for the kits rather than donating them outright because the recipients will take better care of them.

Often 2 day workshops or several day Seminars (Fig.13) are held to train trainers in third world counties. The organizations, which distribute the Bucket Kits, often want 10 to 30 of their key people to attend these Seminars. Usually the mornings are in a classroom setting (Fig.14) with the afternoons spent in hands-on work preparing the soil, (Fig.15), making the stand for the bucket, placing and connecting the drip lines, (Fig.16), filling the bucket, (Fig.17), and transplanting into each wet spot, (Fig.18).

Larger size Kits requested

Schools, orphanages, and community gardens have requested larger Drip Irrigation Kits. One request was for a Super Bucket Kit, (Fig.19), which could irrigate 10 rows 10 meters long. This Kit uses a 35 gallon plastic garbage container mounted one meter above the soil, and is filled once daily.

If water under pressure is available, the ¼ Acre Kit (Fig.20) can be used. This kit irrigates a total of 2,000 feet of row.

Feeding 86,000 Orphans daily!

An organization in Malawi has used 10,000 Bucket Kits. Later, they built a food factory and at the latest report, they were providing a nutritious Vita meal to 86,000 orphans daily.

Charitable Organizations Need Effective Use of Donor Funds

A heavy 15 mil Drip Tape is used to give long life. 2006 is the 11th year that the same Bucket Kit has been used in our test garden (Fig.21). In 2005, this same Bucket Kit produced nearly 700 lbs of tomatoes. Bulk Bucket Kits can be delivered to most countries for $8.00-$10.00 each in container lots. If they are only used for 5 years, this brings the cost to about $2.00 per year.

What organization can purchase hundreds of pounds of vegetables and deliver them to the other side of the world for $2.00? (Fig. 22-24).

No One Company or Organization Can Supply the Whole World!

Chapin Living Waters is pleased to know that similar kits are being produced by manufacturers in several countries. It is our hope to encourage many more manufacturers and organizations to take up the call of starving people and get this type of simple drip irrigation into their hands!

Presented at The Irrigation Association
The 27th Annual International Show
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Water Quest: Saving Water by the Yard

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The Water Quest program was developed by Jordan Valley Water Conservancy District (JVWCD) in 2003 to demonstrate principles of water-wise landscaping throughout the community. Based on reality television, the program follows a family's quest to save water on their landscape. Each year a different family, with the help of professionals, retrofits their all-turf front yard to water-wise landscaping. Landscape water use is metered and compared with water use records from previous years to show water savings. There is no monetary cost to the family. The purpose of the program is to:

- Raise awareness about the need for residents to adopt water-wise landscaping practices.
- Demonstrate the aesthetic and practical benefits of water-wise landscaping.
- Provide a convenient location where residents can go to get ideas for a water-wise landscape.
- Reduce outdoor water consumption, thus lowering per capita water use and helping JVWCD achieve its conservation goal.

JVWCD Background Information

Jordan Valley Water Conservancy District provides wholesale water deliveries to nineteen member agencies in Salt Lake County including: Granger-Hunter Improvement District, West Jordan City, Midvale City, Draper City, Taylorsville-Bennion Improvement District, Water Pro Inc., Kearns Improvement District, White City Water Improvement District, Riverton City, Magna Water Company, Bluffdale City, and the City of South Jordan. There is also a retail service area consisting of 8,500 connections in the unincorporated areas of Salt Lake County. Major facilities of Jordan Valley Water Conservancy District include two water treatment plants, 28 wells, 14 booster pump stations, and 170 million gallons of storage capacity.

Water Conservation Challenges in Utah

With an average annual rainfall of 13 inches and periodic droughts, Utah is the second driest state in the nation. Rapid population growth has increased the demand for an already scarce water resource. As a result, the State has adopted a water conservation goal to reduce per capita water use 25% by the year 2050, using the year 2000 as the base year. Since 60-65% of all culinary water in Utah is used outdoors, it makes sense to focus on landscapes. Keeping on track with the conservation goal will ensure an adequate supply of water for coming years and delay the development of costly new sources of water.

JVWCD Conservation Programs

The Conservation Garden Park, a 2.5 acre water-wise garden, at Jordan Valley Water was built in 2000-2001 to provide a central location in the Salt Lake Valley where the public can go to see firsthand what a finished water-wise landscape looks like and to get ideas for their own yards. Water use is monitored, charted and displayed in several different themed areas of the Garden. In addition, plants are labeled and listed so people can look for them at the nursery. With plans to eventually expand to ten acres, this garden promises to be the most exciting conservation destination in the state.

In addition to the Conservation Garden Park, other conservation programs include:

- **Support of the statewide media campaign:** “Slow the Flow, Save H2O”.
- **Model landscape ordinances:** Available for cities to adopt.
- **Ultra low flush toilet replacement program:** 2002 and 2003 in retail service area.
- **Residential and commercial water audits:** Water Check Program operated by Utah State University Extension Services.
- **Water-wise landscaping classes:** Fourteen classes in 2006 taught by JVWCD conservation staff and other local experts.
- **Large-water-user workshops:** One day classes geared for water managers.
- **Water-wise landscape awards:** Provides recognition for residences and businesses who invest in water-wise landscapes.
- **Member Agency Assistance Program:** Grant money available to member agencies for conservation projects in their own retail service areas.
- **Water Quest: Saving Water by the Yard**

WATER QUEST

A total of four yards have been relandscaped so far in Salt Lake County. The 2003 home is in Sandy City, the 2004 home is in the City of West Jordan, and two homes were done in 2005; one in Kearns and the other in West Valley City. Although the landscape designs differ, they all follow the principles of water-wise landscaping. All the projects include some turf, which is watered by pop-up spray heads. All the shrubs beds are watered by drip irrigation. Irrigation controllers range from typical operator-based timers to more technical “smart” controllers that irrigate based on evapotranspiration (ET) or soil moisture sensors.

Meter information is recorded monthly from all four sites to track water savings. This program has shown that significant water savings can be achieved through proper landscaping and irrigation.

Selection Criteria

Water Quest homes were chosen by a selection process involving JVWCD staff, the participating member agency and the media consultant hired to administer the program. Once the member agency was determined, neighborhoods within the service area were scouted for ease of access and overall appearance. Applications in the form of flyers were distributed in selected neighborhoods. As applications were received by JVWCD, they were screened to narrow the participant pool. The top three were interviewed and one family was selected as the participant. This process involved the following criteria:

- Review of the application to evaluate responses.
- Size of the yard.
- Overall look of the yard (majority bluegrass).
- How well it is currently cared for.
- The interview of the family.
- Existing irrigation system.
- Access to billing information for the past three years for comparison.
- Marketability of the home for media relations and promotion of program.
- Location and easy access from a major road.
- Overall willingness to work with JVWCD, the media consultant, and the participating member agency.

An agreement, detailing the responsibilities of each party involved, was signed by both the participant and the District. Specifically outlined in the agreement was the purpose and nature of the program, design specifications, construction specifications, and participant requirements.

Sandy City 2003

The first home of the Water Quest Program was located in Sandy City within the JVWCD retail service area. A home with a "traditional" Utah landscape emerged from the selection process. The front yard was a typical Utah landscape consisting predominantly of Kentucky Bluegrass with a small planter area next to the house. Water usage information was easily accessible from billing records since the house was located in the JVWCD retail service area. The family was interviewed and demonstrated that they were willing and eager to participate.

Based on the design, construction on the front yard landscape renovation began in May 2003 after a significant leak was repaired in the service line between the water meter and the house. Much of the labor and materials for this project were donated. Specific design elements included a much smaller turf area consisting of turf-type dwarf tall fescue watered by a sprinkler system, a cobble-rock dry river bed, a variety of water-wise plants watered by a drip system, an elaborate hardscape area made of pavers and retaining wall blocks, an arbor structure with a porch swing, and an irrigation system controlling both sprinklers and drip automatically based on soil moisture sensors in the landscape.

In response to press releases issued at various stages of the project, a number of media events accompanied both the construction and completion of the Sandy Water Quest Project. This media interest was likely due, in some part, to a hightened public awareness of water conservation because of the ongoing drought. Most of the major television networks covered the project, usually by doing a remote weather broadcast from the site.

With the completion of the project in June 2003, water usage was tracked using three different water meters: the main meter and two sub-meters, one for front yard irrigation and the other for back yard irrigation. The back yard was untouched by the scope of the project and remained predominantly Kentucky Bluegrass. However, the back yard was now controlled independently from the front using a weather-based controller, while the front yard irrigation was controlled with a completely separate system using soil moisture sensors.

Water usage information is recorded monthly from both sub-meters and from the main meter, then charted based on overall usage from the main meter. As indicated on the water usage chart (Figure 1), there was a short adjustment period in 2003 immediately following completion, when water use increased slightly. The leak in the service line is also evident on the 2003 line chart shown in figure one. Overall usage, however, has remained lower than the prior three year average since completion of the project.

During the remainder of the growing season of the first year, which was June through October of 2003, there was nineteen percent water savings compared to the prior three year average (Figure 2). In April through October of 2004 there was forty-nine percent savings, and in 2005, there was fifty-six percent savings. There was a change in the ownership of the home in the fall of 2005, but savings continued into 2006 with a savings of forty-eight percent from April through July.

City of West Jordan 2004

A similar home was chosen in 2004 in West Jordan using the same selection process. Again, the front yard and parking strip was all Kentucky Bluegrass turf. An existing mature Green Ash tree in the front yard was incorporated into the new design. The back yard was left unchanged and consists of Kentucky Bluegrass turf, planters next to the house and an in-ground swimming pool. Water billing records for the prior three year period were accessible through the City of West Jordan.

The new design of the front yard landscape once again incorporated all the principles of water-wise landscaping. Existing turf was removed and replaced with a smaller but functional area of dwarf tall fescue. A wide pathway made of pavers connected the driveway with the front door of the house. Large curving planters consisting of a variety of water-wise plants were created everywhere else and covered with a layer of bark mulch. The new irrigation system consisted of fixed spray pop-up heads for the new turf and drip emitters for all the planter areas. The controller was also replaced, but not with a weather-based product as in the previous year's project. This controller was a standard operator-based controller. Sub-meters were installed as part of the landscape contract, one to monitor front yard usage, and one to monitor back yard usage. No changes were made in the back yard landscaping.

As with the previous year, the media was an important part of the 2004 Water Quest project. A television event was held to kickoff the project with the beginning of the turf removal. Another television event was held at the end of construction and a third media event was held shortly after that to showcase a water audit of the turf area. There were also a few smaller broadcasts and articles on the project throughout the summer.

In addition to these events, a block party sponsored by JVWCD, was held at this home two years later, in July 2006, for the purpose of reaquainting family and friends of the homeowners with the Water Quest project. Four hundred flyers were distributed through the neighborhood to advertise the evening event. Participants enjoyed food, drinks, prize giveaways, and of course, water-wise landscape information. The block party event was reported in the local newspaper.

Water consumption has been monitored and reported by reading the three water meters monthly from April through October (Figure 3). The relandscape was completed in June 2004, so reporting began in July 2004. Monthly readings are compared to the prior three year average. Beginning in July 2004, water consumption fell drastically for the rest of the year. In 2005 there was a typical bell shaped usage curve, but it was well below the prior average. In the spring of 2006, the pool in the back yard was drained for some repairs, then refilled. As a result, the overall usage was above normal in May, but landscape water usage was similar to the previous year.

Year one (2004) for the West Jordan home saw twenty-six percent water savings from July through October (Figure 4). Year two (2005) saw thirty-three percent savings from April through October, and year three (2006) saw fifteen percent savings from April through July despite the filling of the pool.

West Valley City and Kearns Community 2005

Two homes were relandscaped as part of the Water Quest program for 2005. The selection process was essentially the same: both homes were owned by families willing to participate in the program, had lawns consisting of Kentucky Bluegrass, and had accessible water records. However, some challenges came up in 2005 that had not been experienced before. One of these was the weather. Winter hung on a little longer than normal and resulted in a couple wet months in May and June. It was hoped to have both projects completed by early June, but the wet weather was a contributing factor in pushing the completion of each landscape back a few weeks. Another factor was a contractor change that became necessary during the construction of the landscapes. This required the last minute hiring of a different landscape contractor and concrete sub-contractor during their busiest time of year when they were already behind schedule because of the rain! As a result, both of these projects sat unfinished for several weeks. Days went by with very little activity, which caused some concern from the homeowners and JVWCD staff. Finally, it all came together and both landscapes turned out very well.

The West Valley City home is located in an older part of town on a street lined with mature honey locust trees. There was some talk of removing these trees from the parking strip because of the damage they cause to the sidewalk, curb and street, but in the end, the trees stayed because of the value they add to the neighborhood. In the case of this project, many of the plants were chosen for shade tolerance due to the shady conditions provided by the large trees. The new design called for a stamped concrete walkway to the front door, a smaller turf area (fescue) across the middle of the yard, concrete curbing, plants consisting of groundcover, perennials, shrubs and trees, bark mulch in the beds, and a brick paver sitting area with an ornamental metal planting container. Irrigation consisted of fixed spray pop-up heads for the grass and a drip system for the plants. The old controller was replaced with a new weather based unit that receives a paging signal from a local weather station and allows the system to irrigate based on current weather conditions. Some minor changes were made to the large, all turf back yard to improve sprinkler efficiency, but it remained as turf.

The Kearns home was relandsaped simultaneously with the West Valley home. The design, however, was completely different. It consisted of a stamped concrete walkway with a different stamp pattern and color, connecting the front door to the back yard gate. The turf was donated fescue sod in a curvy pattern near the front and center of the yard. Plants were more heat tolerant due to the increased sun exposure of this location. The main difference though, was the use of ¾” -1” colored rock mulch rather than bark mulch. The all turf back yard was untouched during the project. The irrigation system was installed exactly the same as the West Valley home with the same products, including the weather-based control unit.

Media events were usually combined for both projects. The kick-off event was held at the West Valley home with both families in attendance, and the final event was held at the Kearns home, again with both families in attendance to discuss their appreciation of the project with the media. There were also some remote broadcasts done from the Kearns home. A block party was also held at the West Valley home in July 2006. It was organized along with the block party at the West Jordan home, but they were on different dates.

Water tracking began at both homes in July 2005. Water consumption is monitored the same as all the other homes using monthly meter readings from three meters: front yard, back yard, and main meter. At the Kearns home, water usage increased during the first month to slightly above the prior three year average, then gradually declined below the average (Figure 5). This was likely due to an initial establishment period during the heat of the summer. In the spring of 2006, usage was again above the prior three year average. The high consumption was isolated to the back yard and attributed to an incorrect setting on the sprinkler controller. After the problem was corrected, usage dropped below the average throughout the remainder of the summer.

At the West Valley home, water consumption was well below the prior three year average for the remainder of the first season, but rose sharply in the spring of 2006 for no apparent reason (Figure 7). It was later discovered that a wire had come loose on the control unit, rendering the irrigation system unworkable, and the homeowner had been turning the stations on manually for a number of weeks. The wire was reattached and usage went down.

Challenges with the Water Quest Program

As a water conservation program, Water Quest has presented some challenges. In 2005, the main problem was the coordination of too many entities. First there was JVWCD sponsoring the projects. An outside consultant was hired by JVWCD to help manage the projects. The consultant then hired a landscape architect and a landscape contractor who was recommended by the architect. The situation became messy when the contractor didn't work out and had to be replaced by another landscape contractor and a new sub-contractor for the concrete. Add to that the coordination of donations from several companies and the recognition they desired, not to mention the family receiving the free landscape and their personal preferences for their yard. In addition to all that was the involvement of the member agencies of JVWCD who helped choose the participants. The challenge was treating all these people fairly while still achieving the purpose of the program.

Another challenge is finding publicity for the Water Quest projects given that they are located at private residences. The desire is to reach as large an audience as possible with the message of water conservation to make the project more cost effective and useful to the public. However, extra planning and sensitivity is required because the project is at a private residence rather than a public place. It is necessary to respect the privacy of the participating family.

The participating family could also be a challenge with the program. What if they were not as cooperative as initially thought? Also, they could move shortly after the completion of the landscape. Fortunately, all the families who have participated in the Water Quest Program have been easy to work with. The family in Sandy did move two years later, but the new family has been interested and cooperative as well.

The quality of the irrigation design and installation is critical. Since the purpose of the program is water conservation, the landscape must be more than just aesthetically pleasing, it must actually reduce water consumption. A poor design or installation would doom the project right from the start. Even with a good landscape design and proper irrigation system installation, constant monitoring is required through the summer months.

Cost effectiveness of the Water Quest Program is difficult to quantify. Water savings at each project is quantifiable, but the real goal is water savings in the whole community. It is difficult to estimate how many people see the project and even more difficult to know how many people incorporate the ideas in their own landscapes.

Known Benefits of the Water Quest Program

Despite the challenges, there are many positive aspects of the Water Quest Program. It has shown quantifiable water savings. Based on these four homes, people can expect a water savings of approximately twenty-five percent just by relandscaping their front yard provided they manage the irrigation properly. Another benefit of the program is that it brings mini "demonstration gardens" to these communities. JVWCD has a large demonstration garden that shows the principles of water-wise landscaping, but each of these Water Quest homes teach the same concepts on a smaller scale in different parts of the valley. Once the landscape is complete, it only gets more beautiful with age as the plants bloom more, fill in and mature. Maintenance is the responsibility of the homeowner, so the program is relatively easy to manage once the landscape is complete. It really only requires occasional communication with the homeowner and monthly monitoring of water usage through the summer months. In addition, the program does help conserve water by increasing public awareness, and by providing water-wise landscaping ideas and information. As a water provider sponsoring the program, there are also public relations benefits by helping families in the community and being able to refer to the program when people call in with questions about how to reduce outdoor water use.

Conclusion

From a review of the water consumption at all four homes, we see that water use in general, has declined after the completion of the new landscapes. Obviously, installing plant material (including turf) that requires less water, can result in water savings. However, the amount of water saved ultimately depends on how well the irrigation is managed. "Smart" controllers can make the process easier by eliminating the need to constantly make manual adjustments to the watering schedule, but that does not mean they can be ignored either (as shown by the problems encountered in spring 2006 at the Kearns and West Valley homes). Furthermore, a vigilant homeowner can achieve the same water savings with a standard operator-based controller (as demonstrated by the West Jordan home). An increased awareness of water consumption among family members may also contribute to water savings with these projects. Nevertheless, the end result with all four Water Quest homes has been substantial water savings.

Figure 1:

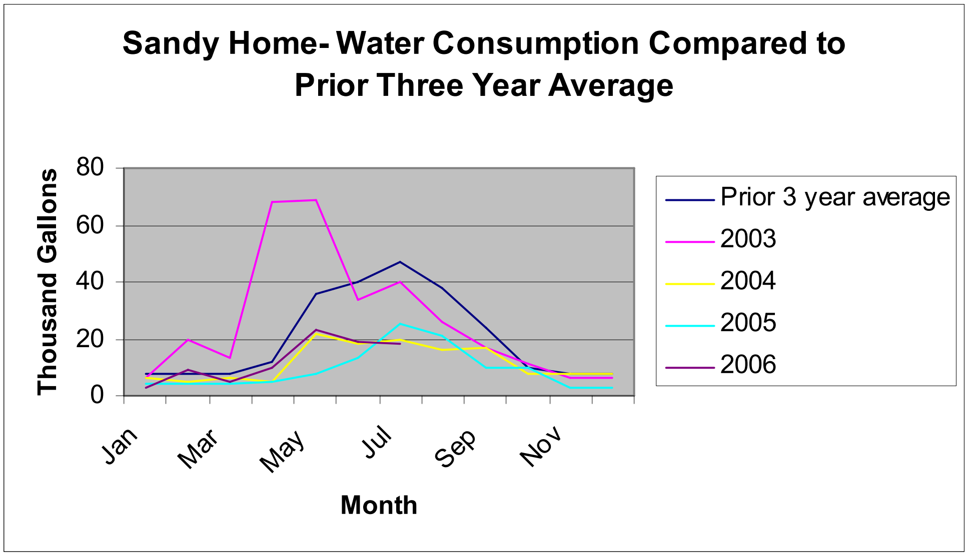


Figure 2:

Sandy Home - Water Use Report Chart

Consumption in thousand gallons

Sandy	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total April -Oct.	Total June-Oct.
Before Relandscaping (average 2000-2002)	8	8	8	12	36	40	47	38	24	10	8	8	**207**	**159**
Year One (2003)*	6	20	13	68	69	34	40	26	17	11	6	6	**265**	**128**
Water Saved (gallons) Year One	2	-12	-5	-56	-33	6	7	12	7	-1	2	2	**-58**	**31**
Percent Savings- Year One	**25%**	**-150%**	**-63%**	**-467%**	**-92%**	**15%**	**15%**	**32%**	**29%**	**-10%**	**25%**	**25%**	**-28%**	**19%**
Year Two (2004) **	6	5	6	5	22	18	20	16	17	8	8	8	**106**	
Water Saved (gallons) Year Two	2	3	2	7	14	22	27	22	7	2	0	0	**101**	
Percent Savings- Year Two	**25%**	**38%**	**25%**	**58%**	**39%**	**55%**	**57%**	**58%**	**29%**	**20%**	**0%**	**0%**	**49%**	
Year Three (2005) **	4	4	4	5	8	13	25	21	10	10	3	3	**92**	
Water Saved (gallons) Year Three	4	4	4	7	28	27	22	17	14	0	5	5	**115**	
Percent Savings- Year Three	**50%**	**50%**	**50%**	**58%**	**78%**	**68%**	**47%**	**45%**	**58%**	**0%**	**63%**	**63%**	**56%**	
Year Four (2006)	3	9	5	10	23	19	18							
Water Saved (gallons) Year Four	5	-1	3	2	13	21	29							
Percent Savings- Year Four	**63%**	**-13%**	**38%**	**17%**	**36%**	**53%**	**62%**							

*New Landscape was installed in June. Water savings in gallons and percent savings are from this point.
** Water savings in subsequent years are compared to previous average (2000-2002).

Owner change in September 2005

Figure 3:

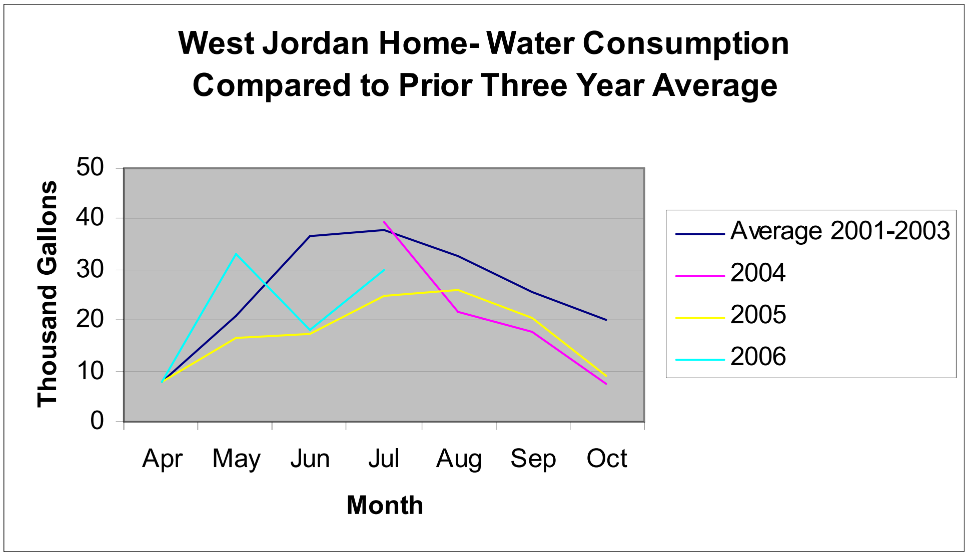


Figure 4:

West Jordan Home - Water Use Report Chart

Consumption in thousand gallons

West Jordan	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total April - Oct.	Total July -Oct.
Before Relandscaping (average 2001-2003)				8	21	37	38	33	26	20			**182**	**116**
Year One (2004)*							39	22	18	7			**86**	**86**
Water Saved (gallons) Year One							-2	11	8	13			**30**	**30**
Percent Savings- Year One							-5%	34%	30%	63%			**53%**	**26%**
Year Two (2005) **				8	16	17	25	26	20	9			**122**	
Water Saved (gallons) Year Two				0	5	19	13	7	5	11			**60**	
Percent Savings- Year Two				1%	22%	53%	34%	20%	20%	55%			**33%**	
Year Three (2006)***				8	33	18	30							
Water Saved (gallons) Year Three				0	-12	19	8							
Percent Savings- Year Three				0%	-57%	52%	22%							

*New Landscape was installed in June. Water savings in gallons and percent savings are from this point.
** Water savings in subsequent years are compared to previous average (2000-2002).
*** In May 2006 the pool was filled after some repairs. Landscape water usage in May was actually very low at slightly over 5,000 gallons.

Figure 5:

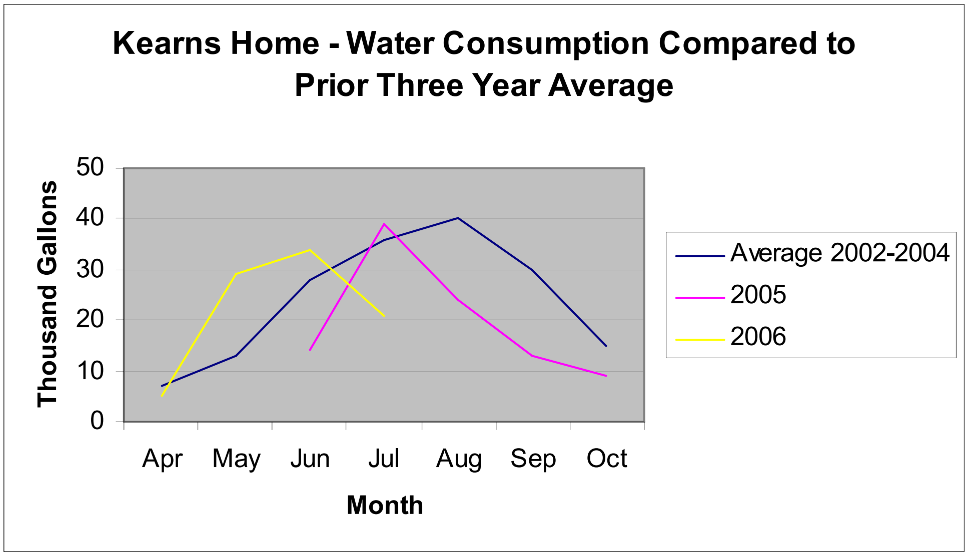


Figure 6:

Kearns Home - Water Use Report Chart

Consumption in thousand gallons

Arroyo	Apr	May	Jun	Jul	Aug	Sep	Oct	Total summer water use July -Oct.	Total summer water use April -Oct.
Before Relandscaping (average 2002-2004)	7	13	28	36	40	30	15	**121**	**169**
Year One (2005)*			14	39	24	13	9	**85**	**99**
Water Saved (gallons) Year One**			14	-3	16	17	6	**36**	**49**
Percent Savings- Year One			49%	-9%	40%	57%	39%	**30%**	**41%**
Year Two (2006)	5	29	34	21					
Water Saved (gallons) Year Two	2	-16	-6	15					
Percent Savings- Year Two	32%	-123%	-23%	42%					

* The landscape was installed in June, first month of official tracking was in July.

**Water saved above is shown in billing units (1=1000 gallons)

Figure 7:

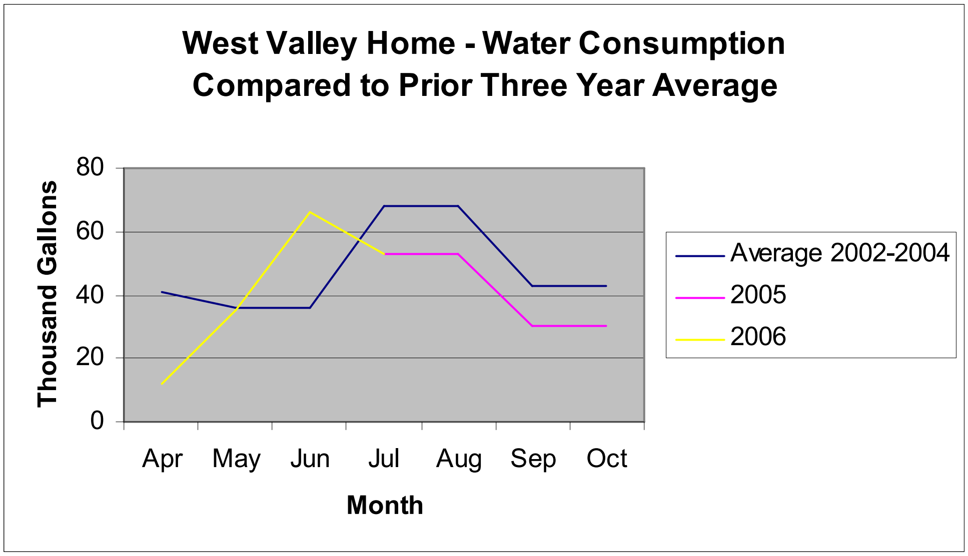


Figure 8:

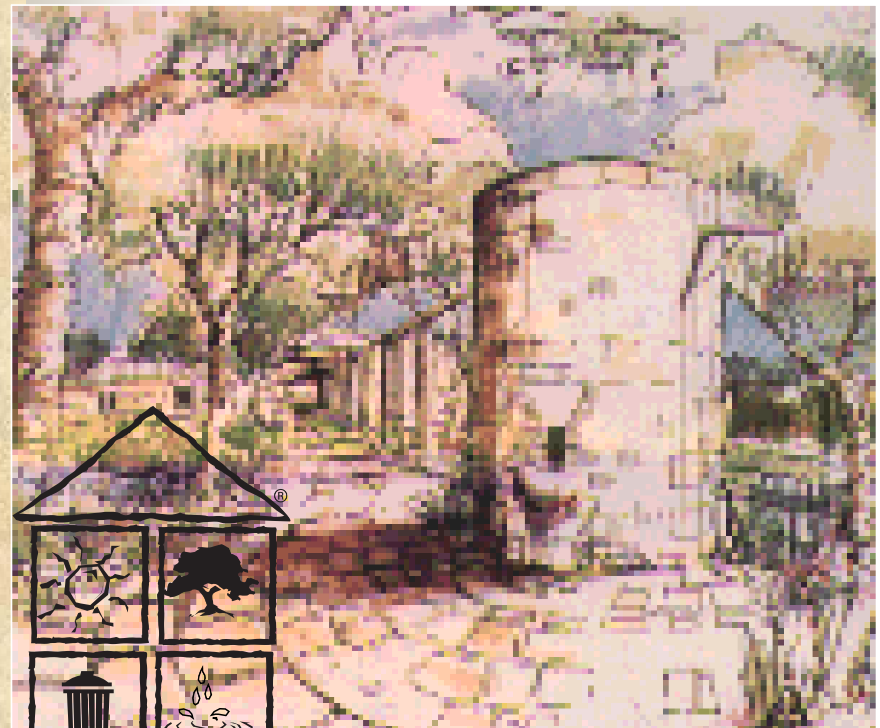
West Valley Home - Water Use Report Chart

Consumption in thousand gallons

Mason	Apr	May	Jun	Jul	Aug	Sep	Oct	Year One Water use July -Oct.	Water use April -Oct.
Before Relandscaping (average 2002-2004)	41	36	36	68	68	43	43	**221**	**334**
Year One (2005)*				53	53	30	30	**165**	
Water Saved (gallons) Year One				15	15	13	13	**56**	
Percent Savings- Year One				**22%**	**22%**	**31%**	**31%**	**25%**	
Year Two (2006)	12	35	66	53					
Water Saved (gallons) Year Two	29	1	-30	15					
Percent Savings- Year Two	**71%**	**3%**	**-83%**	**23%**					

*The landscape was installed in May and June. Water usage was tracked starting in July and compared to the prior three year average from that point.

Rainwater Harvesting for Landscape Irrigation



AUSTIN ENERGY
GREEN BUILDING
PROGRAM

Dick Peterson

Environmental Program Coordinator

Austin Energy

Green Building Program

www.austinenergy.com

Rainwater Through The Ages

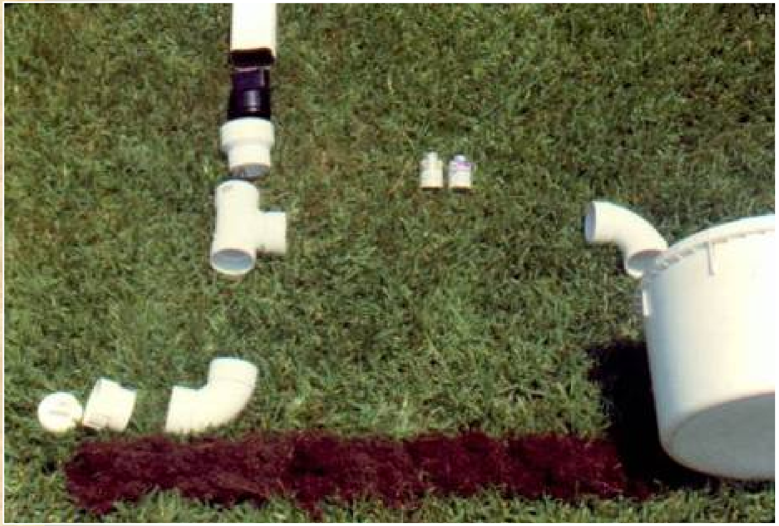
- Rainwater harvesting practiced for over 4,000 years in desert of southern Israel
- Ancient Roman had cisterns and aqueducts
- Early 1900's farms and ranches had cisterns
- Current resurgence of rainwater collection Lady Bird Johnson Wildflower Center
  - Currently 72,000 gallon capacity
  - have plans for another 25,000 gallons
- Many Caribbean nations mandate rainwater harvesting

Why Collect Rainwater?

- Rainwater pH is almost neutral
- Plants love it
- Rainwater does not have dissolved minerals from the soil
- Or chemicals from water treatment plants
- Harvesting reduces erosion
- Reduces water bill – you do not use as much expensive potable water on your landscape

Components

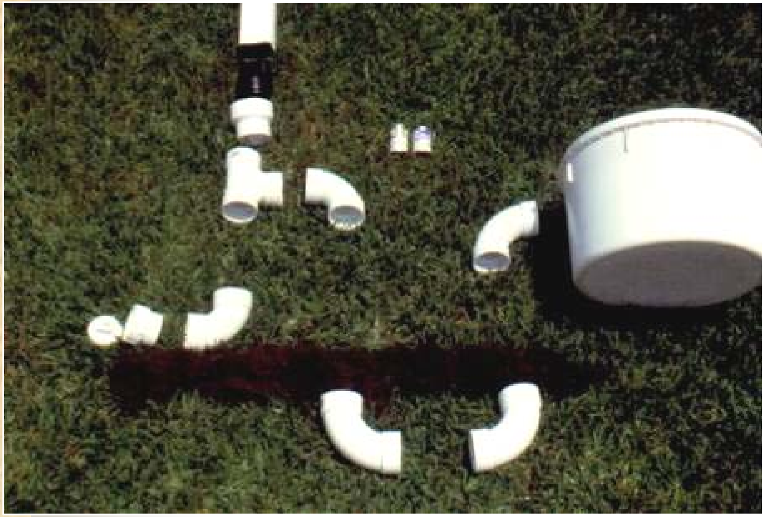
- First Flush "Poor Man's Roof Washer"



- PVC pipe with fittings running to the ground with a screw on cap at the bottom for clean out
- First 8-10 gallons collects debris from roof and gutters -- diverted by first flush before tank inlet

Components

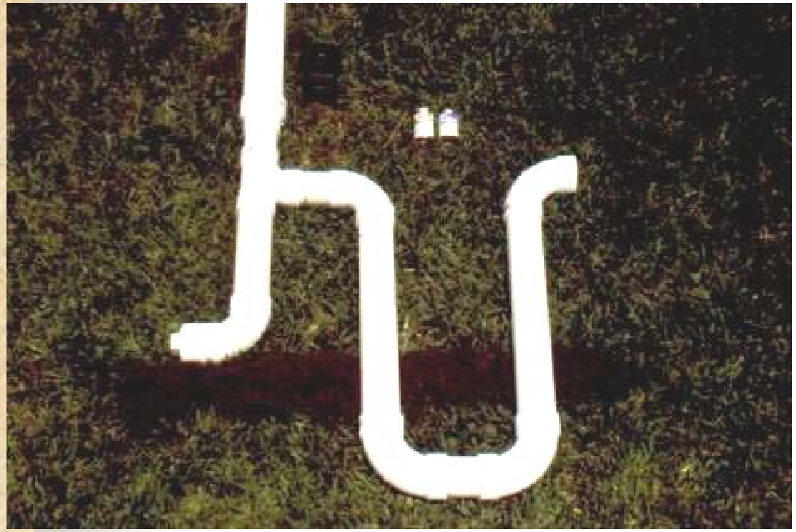
- First Flush “Poor Man’s Roof Washer”



- PVC pipe with fittings running to the ground with a screw on cap at the bottom for clean out
- First 8-10 gallons collects debris from roof and gutters -- diverted by first flush before tank inlet

Components

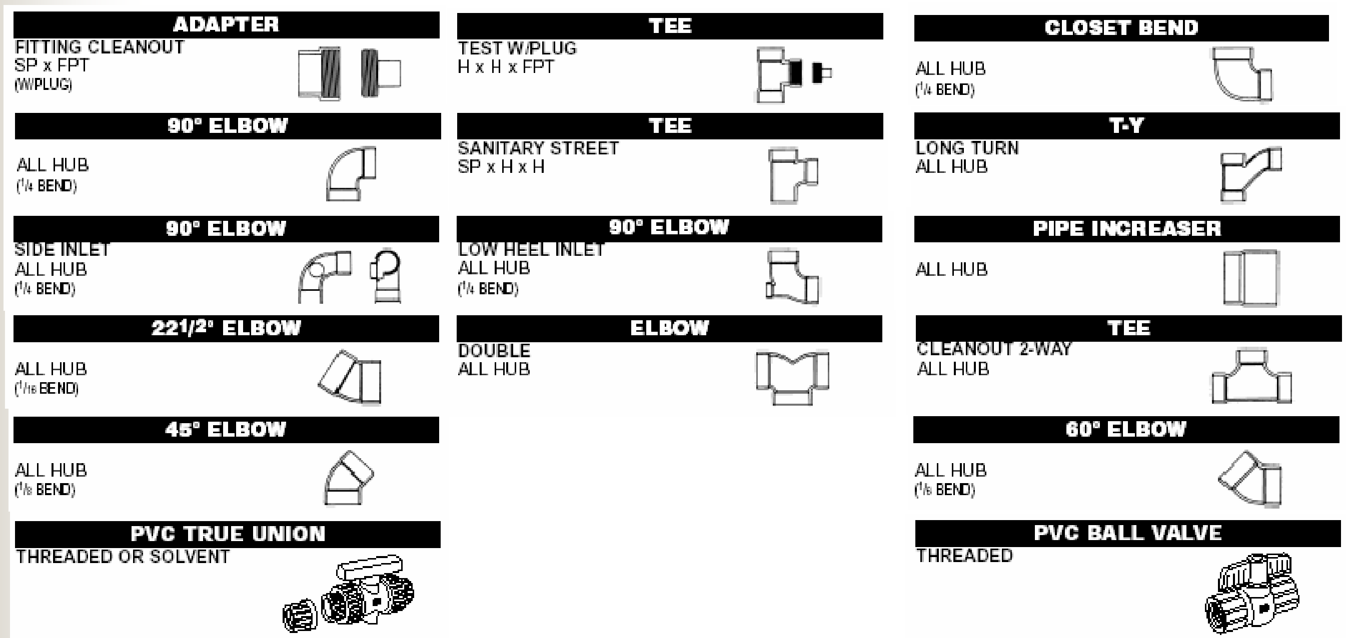
- First Flush "Poor Man's Roof Washer"



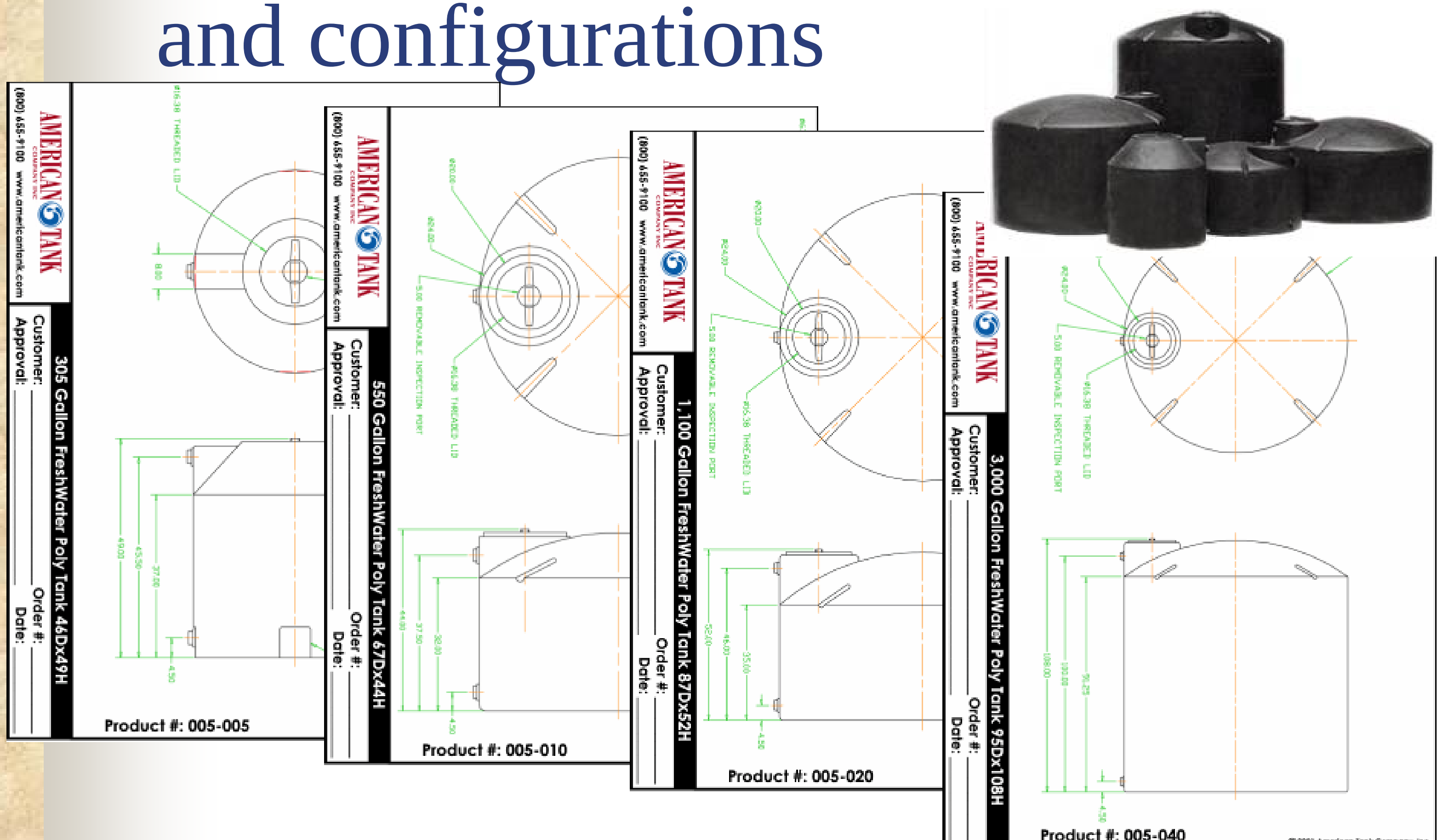
  - PVC pipe with fittings running to the ground with a screw on cap at the bottom for clean out
  - First 8-10 gallons collects debris from roof and gutters -- diverted by first flush before tank inlet

Components

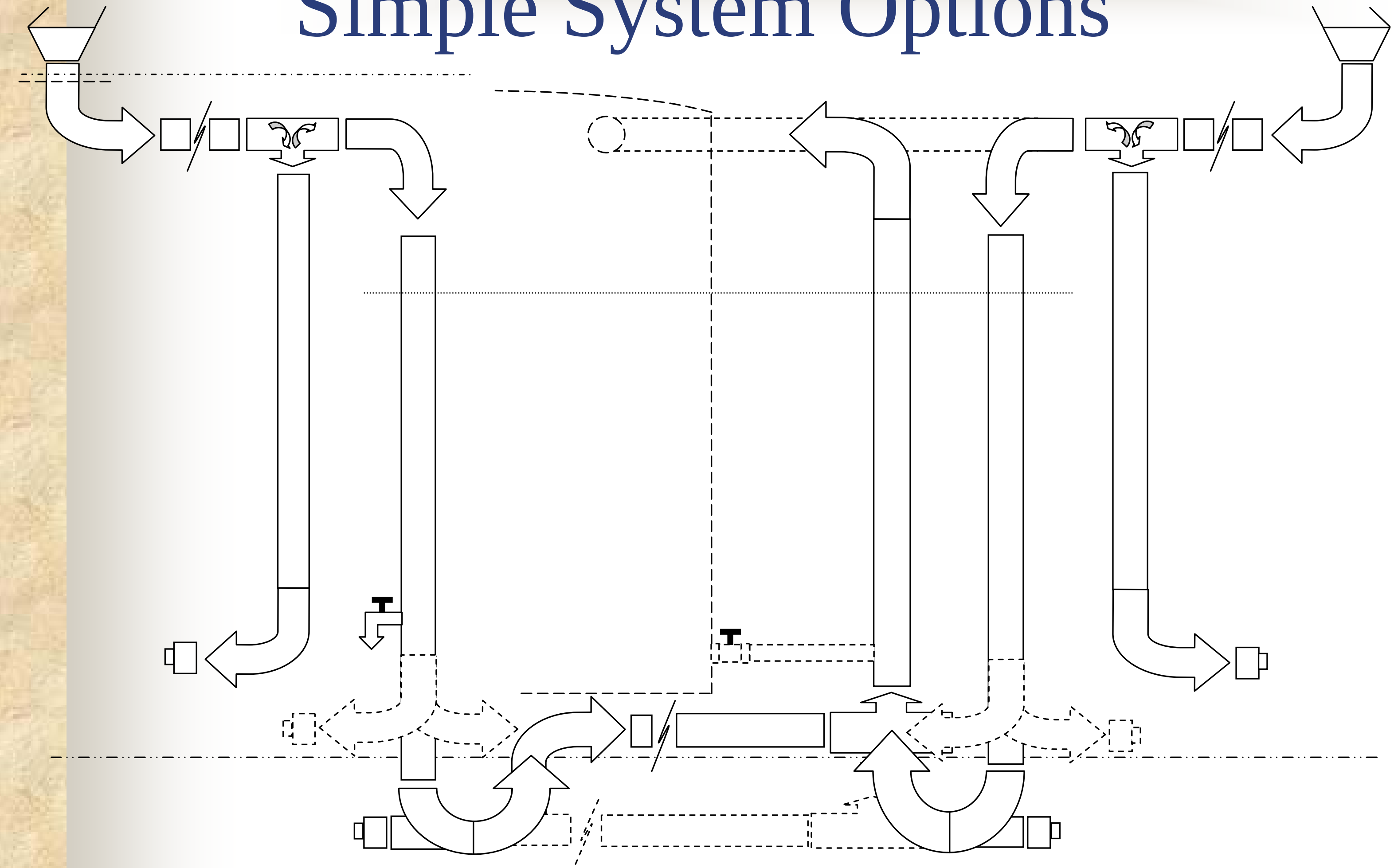
- PVC Drain-Waste-Vent Fittings



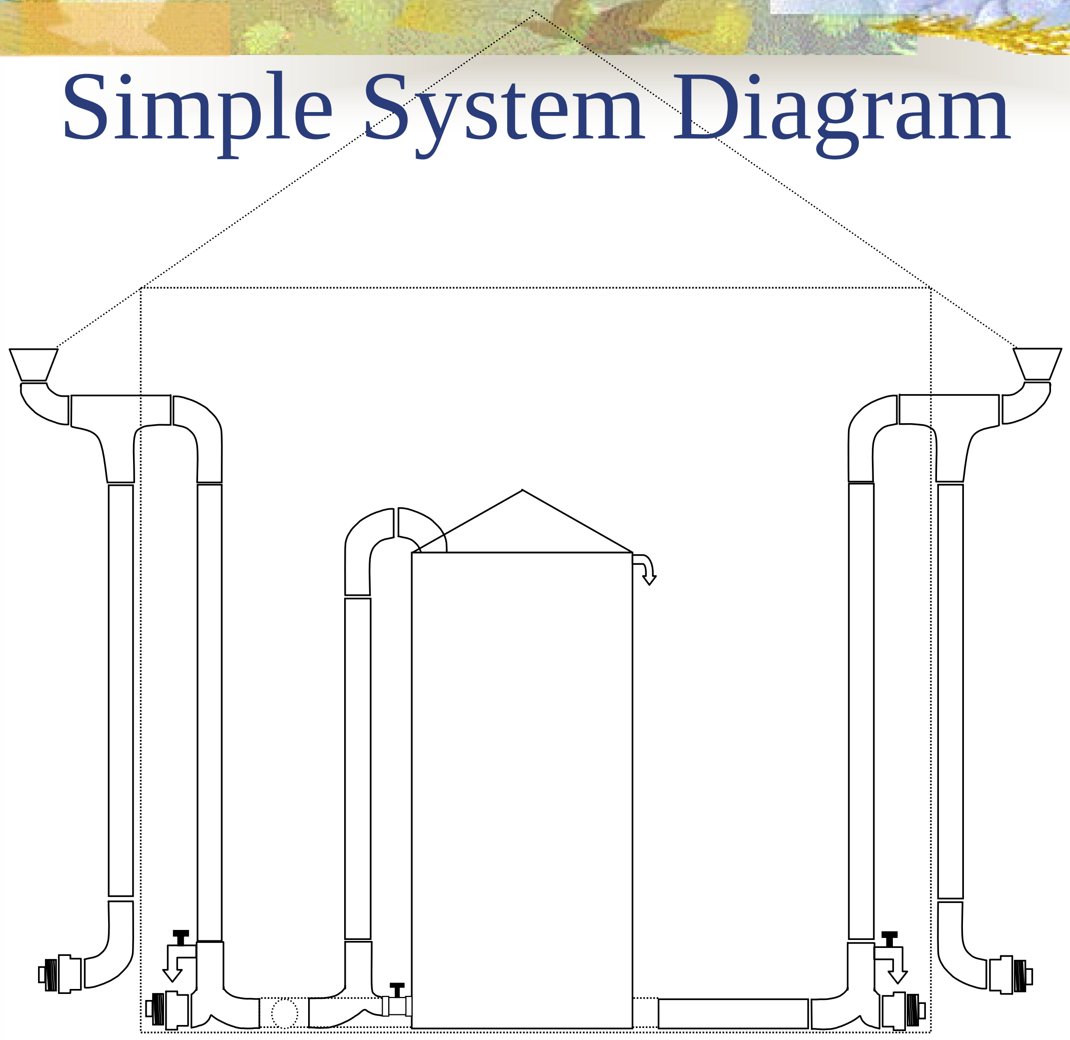
Tanks are available in many sizes and configurations



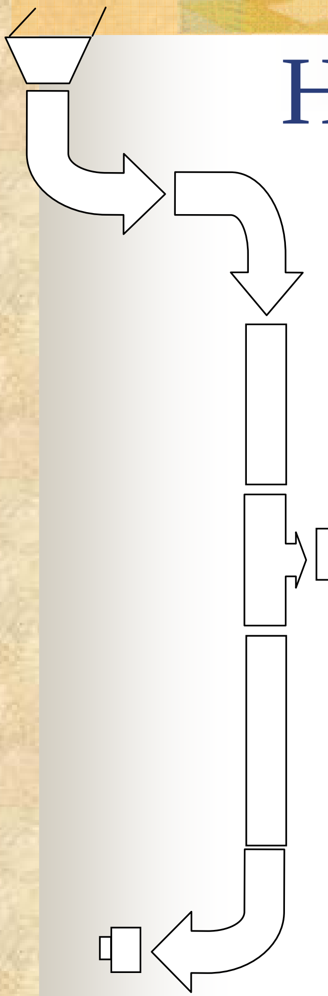
Simple System Options

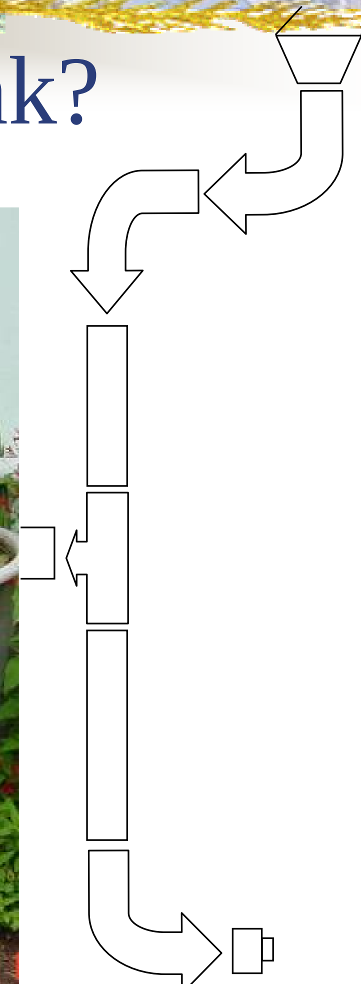


Simple System Diagram

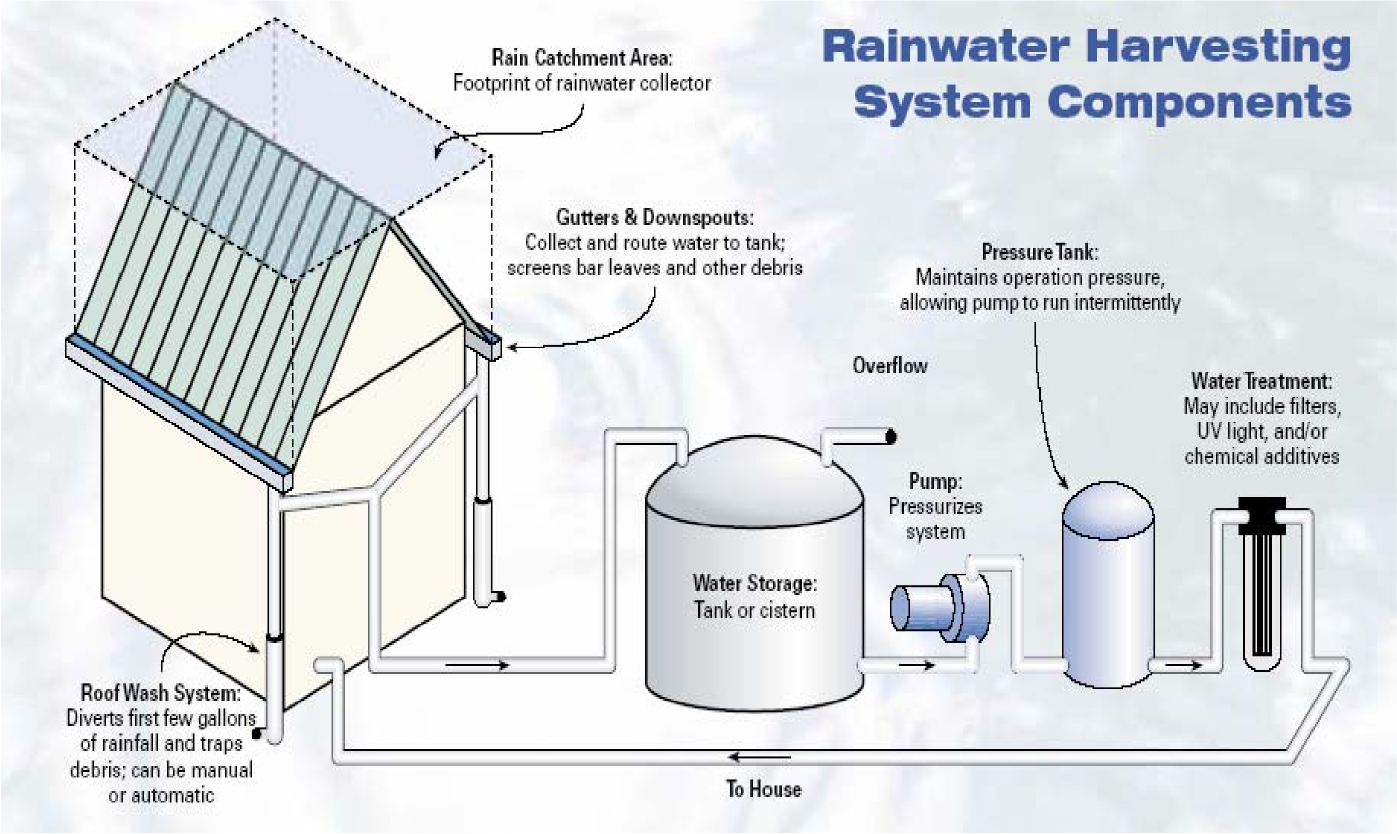


How about a pond tank?

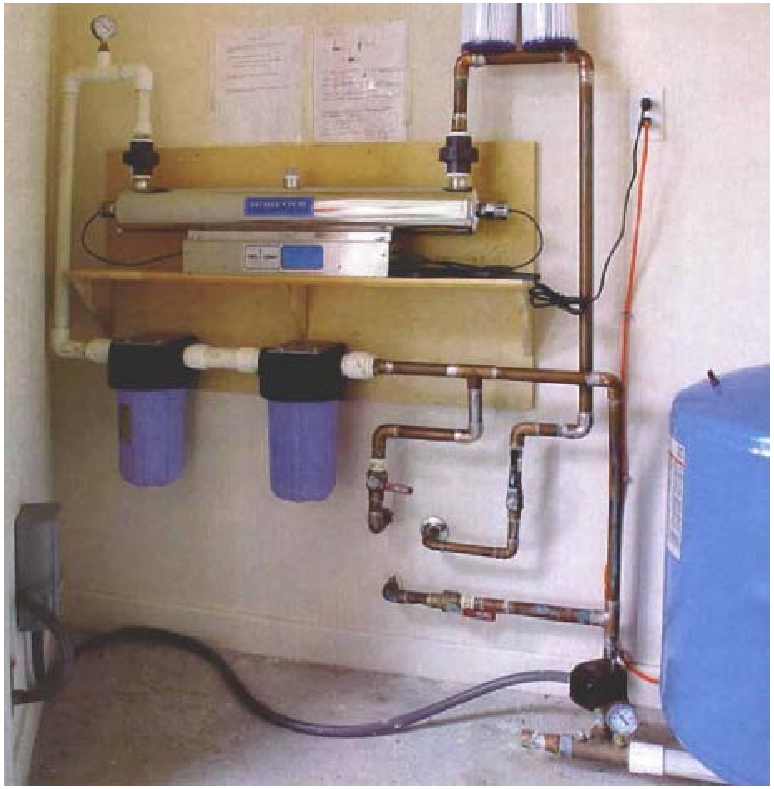




Drinking Water Systems



Drinking water systems require more equipment and maintenance

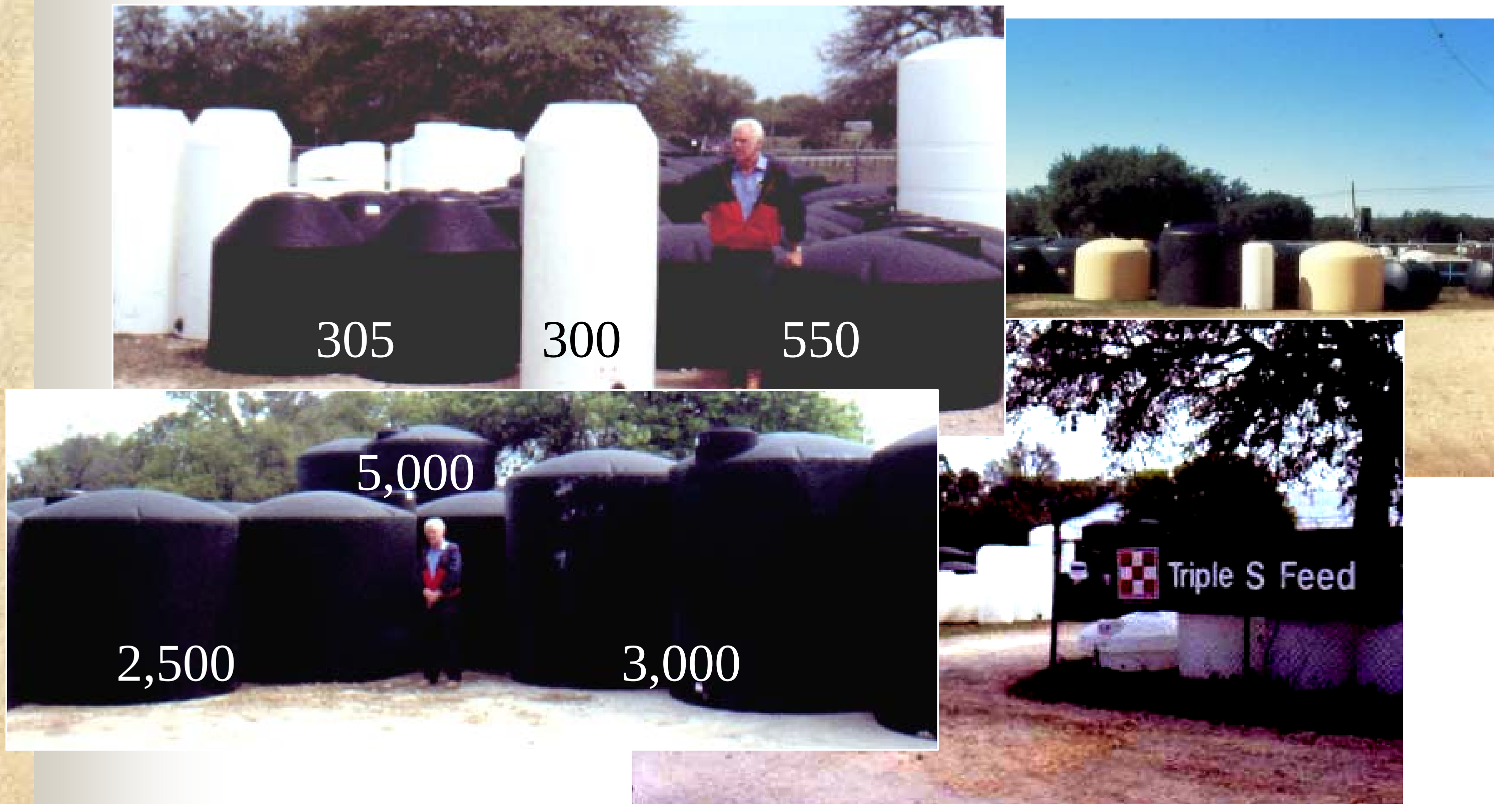


From “Rainwater-Collection Systems” by Peter Pfeiffer

Fine Homebuilding Magazine

Drinking water systems require more equipment and maintenance

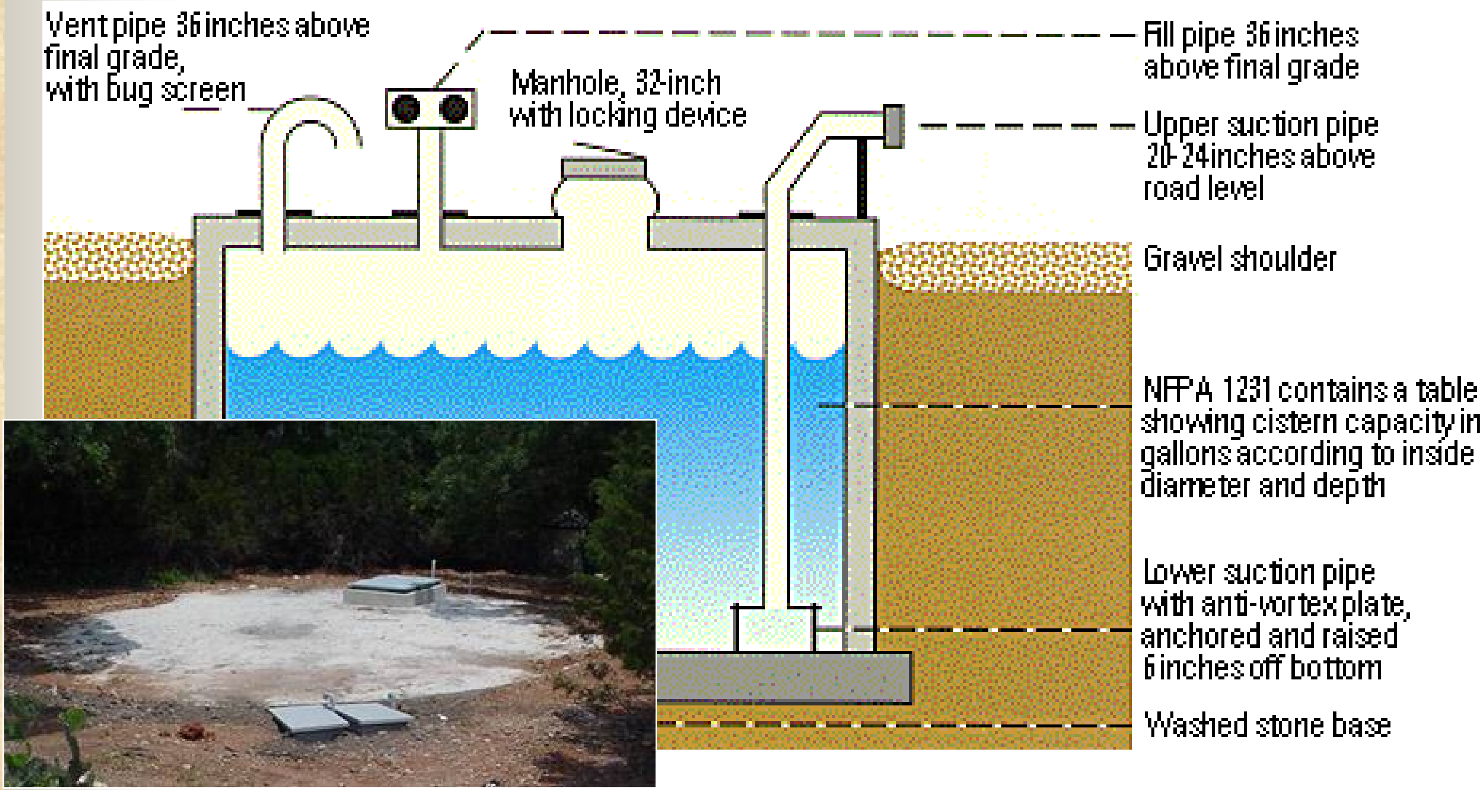
Good source of tanks are "feed and ranch" stores



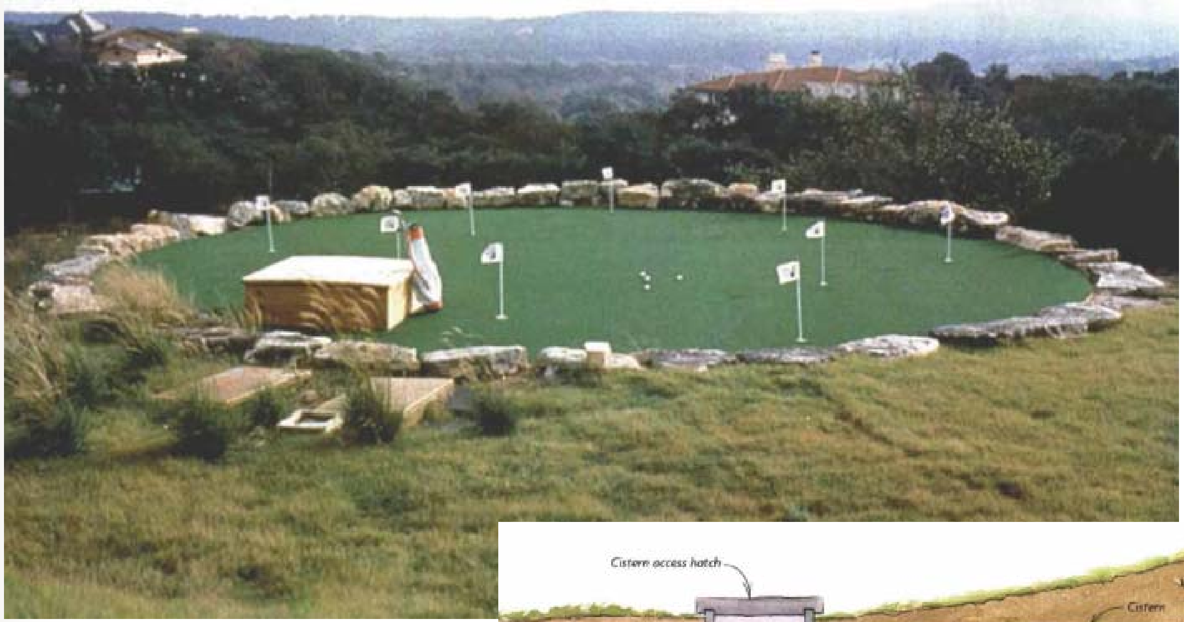
To reduce algae, tanks should be black, green, covered, or painted

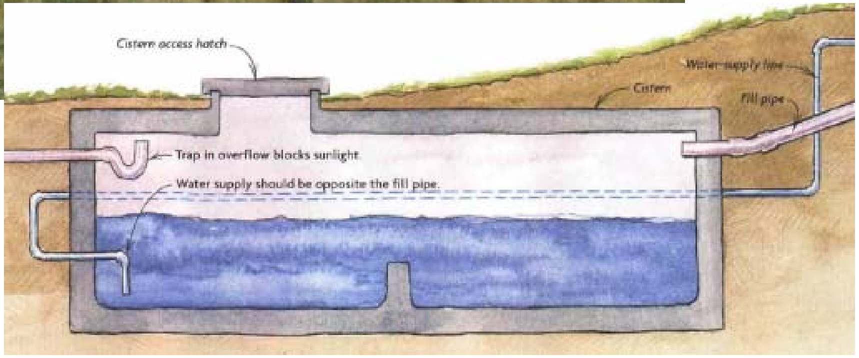
A 10’ x 10’ garden shed can collect 60 gallons in just a 1” rain

Typical Underground Cistern



37,500 gallon Ferro-cement tank





From “Rainwater-Collection Systems”
by Peter Pfeiffer

Fine Homebuilding Magazine

Wooden Tanks

How much will rainwater harvesting cost?

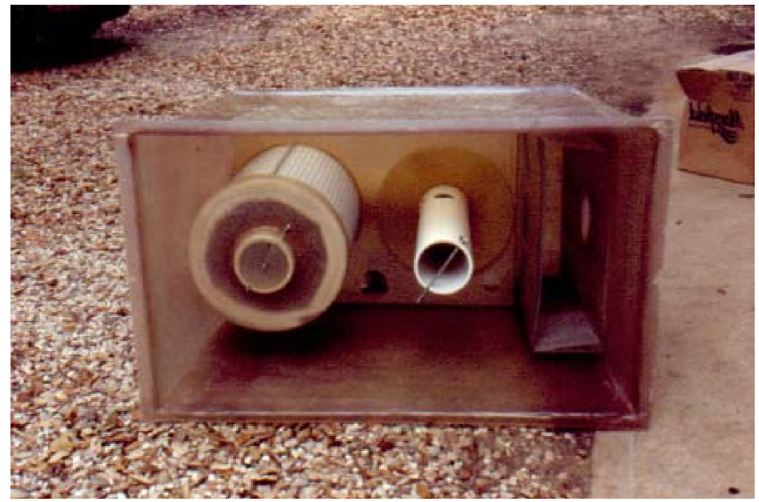
- It really does vary...
  - Do you already have gutters?
  - If not, what type will you install?
  - Type and size of tank
  - Will you use a pump?
  - Pad construction

Components

- **Roof Type**
  - Any roof will do
    - Metal is the ideal roof - smooth and non-absorbent
    - Composite, wood shingles, asbestos…all absorb water and will break down over time
- **Gutters**
  - 30 cents per foot for plastic up to $15 per foot for copper
- **Screens**
  - Screens are not necessary unless your house has a lot of tree cover

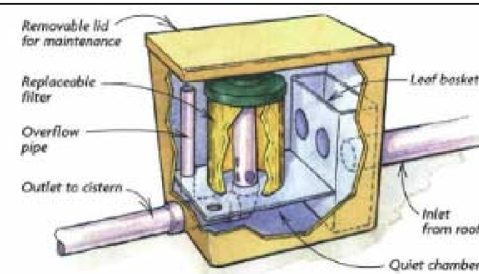
Components

Roof Washer



Roof washers clean the water, not the roof

The first water to fall on the roof cleans away dirt and debris accumulated since the last rain. Commercially available roof washers such as the one shown here funnel the water first through a leaf basket that collects the heaviest debris. The first 35 gal. of water, which is the dirtiest, fills the quiet chamber, where it drains away slowly. Cleaner water then passes through a replaceable filter element.



From “Rainwater-Collection Systems”
by Peter Pfeiffer

Fine Homebuilding Magazine

Components

- **Roof Washer**
  - $300-600
  - container with 30 micron filter
  - water must pass through filter before filling tank
  - If not cleaned regularly
    - breeding ground for bacteria
    - will keep water from entering tank
  - not necessary for non-potable systems

Components

- **Barrels**
  - Purchased or recycled barrel
  - Should be painted to keep out sunlight and prevent algae growth

Components

- **Polypropylene Tanks**
  - $.35 to $1.00 per gallon
  - Most common
  - Easy to install
  - Should be black, green or painted

Components

- **Concrete or Ferro-cement tanks**
  - $.35 to $1.00 per gallon
  - Durable
  - Can be buried

Components

- **Metal Tanks**
  - 40-60 cents per gallon
  - Short life span – rust, except with special liners

Components

- **Wooden Tanks**
  - $2.00+ per gallon
  - Ideal for remote locations, pack in the pieces
  - Can be dissembled and moved
  - Available up to 2,000,000 gallons!

Components

- **Stone Tanks**
  - Very expensive
  - Difficult to maintain

Components

- Pumps
  - $200-600
  - install pump as close to tank as possible
  - protect from freezing
  - in-tank float switch
  - in general 3/4 quarter horsepower is sufficient
  - It will allow you to pump water 400 feet

Maintenance

- With a first flush system you will want to clean out the PVC after every rainfall
- If you have screens, clean them after a rain when there has not been any rainfall for a period of time
- Most people who have installed their systems over the past 5 years, have not had to clean the tank of debris

Bt-Biological Mosquito Control

Whisky is for drinkin'…

Water is for fightin' over!

Mark Twain

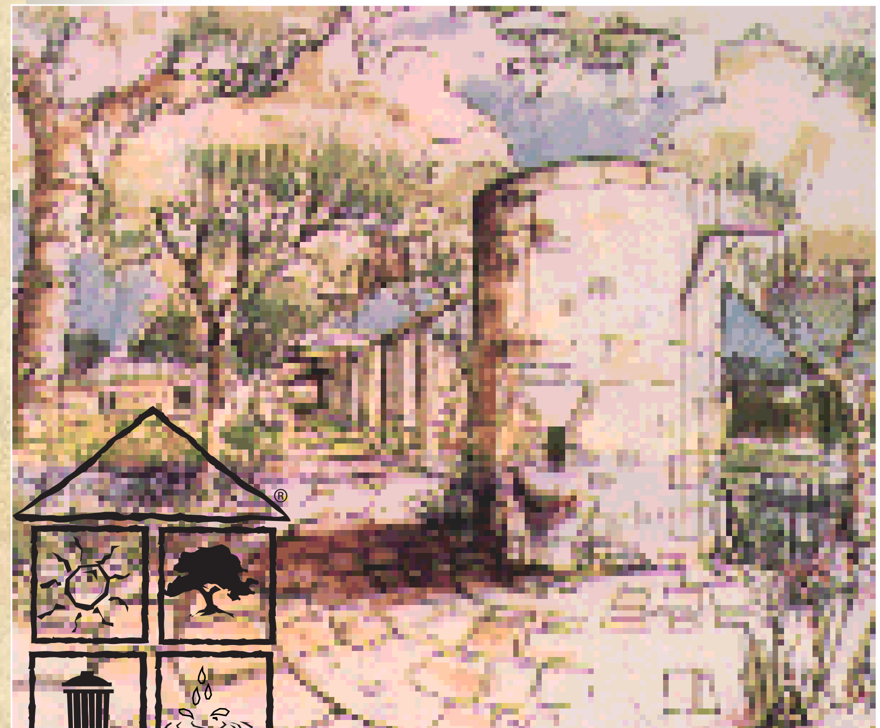
Water is a precious resource…

Use it wisely…

Harvest rainwater!

Austin History Center, St. Edward's cadet straddling Lake Austin

Rainwater Harvesting for Landscape Irrigation



AUSTIN ENERGY
GREEN BUILDING
PROGRAM

Dick Peterson

Environmental Program Coordinator

Austin Energy

Green Building Program

www.austinenergy.com

U.S. EPA WaterSense www.epa.gov/watersense

WaterSense: Every Drop Counts

Stephanie Tanner
Senior Engineer
U.S. Environmental Protection Agency

The Value of Water Efficiency

Approximately 75 percent of the Earth's surface is covered with water, but less than 1 percent of that is available for human use. In the United States, our growing population is putting stress on our available water supplies, and water resource protection has become a national priority. There are many markets in the United States that already face water shortages, and the number of markets facing this issue is projected to grow in the future. A Government Accountability Office survey of water managers across the country showed that 36 states anticipate local, regional or statewide water shortages by 2013, even under non-drought conditions. In addition to water shortages, water supply infrastructure is also a growing concern. In 2002, an EPA report identified a $224 billion gap in planned infrastructure investment as compared to needs. Water efficiency is one key way that local communities can help manage their infrastructure needs.

Using water more efficiently helps preserve water supplies for future generations, saves money, and reduces stress on water systems and the environment. Governments, utilities, manufacturers, businesses, communities, and individual consumers across the country can help protect our limited water resources by promoting the purchase of water-efficient products and adopting water-efficient practices.

WaterSense, a U.S. Environmental Protection Agency (EPA) voluntary partnership program, seeks to promote water efficiency and enhance the market for water-efficient products and services. The vision of WaterSense is to create an ethic of water efficiency by helping Americans make decisions about water and the environment. On a fundamental level, the goal of WaterSense is to decrease indoor and outdoor non-agricultural water use by making these products and services the clear and preferred choice. In addition to helping consumers identify water-efficient products and services, the program ensures product performance and encourages innovation in manufacturing.

How the Program Works

WaterSense is building the national brand for water efficiency, a symbol that represents the importance of protecting water resources in the United States. Products that are independently tested to meet EPA specifications will be able to bear the WaterSense label, currently under development. This label will help consumers identify products and services that use less water than their less efficient counterparts. Generally speaking, WaterSense labeled products will be about 20 percent more water-efficient than the average product in the same category. To ensure product performance, testing protocols are included to determine whether products perform their intended function as well as, or better than, their counterparts.

Program Partners

WaterSense also provides technical information and recognizes leadership in water efficiency through formal partnership agreements with program partners. Manufacturers committed to water efficiency and product innovation can differentiate their products from others in the marketplace, build consumer demand, and gain national recognition for their high-efficiency, high performance products by using the WaterSense label. Utilities will help promote the WaterSense Program through public awareness campaigns to attain local water conservation goals. Retailers and distributors will stock and promote certified water-efficient products.

Other program partners will include local, state, and federal governments; service providers; businesses; contractors; and trade associations committed to conserving water. EPA will work continuously to build brand awareness across a wide range of industrial, commercial, and consumer sectors through extensive outreach and education initiatives.

Indoor Water Use

Americans use significant quantities of water inside their homes. The average family of four uses 400 gallons of water every day, and, on average, approximately 70 percent of that water is used indoors.

The bathroom is the largest consumer of indoor water. The toilet alone can use 26 percent of household water. Almost every activity or daily routine that happens in the home bathroom uses a large quantity of water. For example:

- Older toilets use between 3.5 and 7 gallons of water per flush. However, new high-efficiency toilets require 75 to 80 percent less water.
- A leaky toilet can waste about 200 gallons of water every day.
- A bathroom faucet generally runs at 2 gallons of water per minute. By turning off the tap while brushing your teeth and shaving, a person can save more than 500 gallons of water per month.

Plumbing fixtures

WaterSense is currently in the process of developing specifications for labeling high-efficiency toilets (HETs) and residential faucet accessories. Toilets that bear the WaterSense label will use less than 1.3 gallons per flush and undergo independent performance testing. Specifications for HETs are expected to be final within the year. Shortly following will be specifications for residential faucets.

Landscape Irrigation

Commercial and residential outdoor water use in the United States accounts for more than seven billion gallons of water each day, mainly for landscape irrigation (Vickers 2001). As much as half of that is wasted due to evaporation, wind, or improper irrigation design, installation, maintenance, and scheduling (The Saving Water Partnership 2003). An efficient irrigation system requires not only water-efficient products, but also proper design, installation, and maintenance. To address these issues and improve water efficiency in the landscape, WaterSense is labeling both the professional service side and the product side of landscape irrigation.

Certification Programs

Currently, Watersense is in the process of labeling certification programs for irrigation professionals that advance the principles and applications of water-efficient irrigation. Programs that earn the WaterSense label must meet several criteria to ensure rigorous testing and certification processes that accurately assess professional knowledge in designing, installing and maintaining, or auditing water-efficient irrigation systems. To qualify for labeling, certification programs must include an experiential requirement, have a renewal requirement, evaluate proficiency through examinations, and be subject to independent oversight. Specifications are expected to be released in the fall of 2006.

The initial categories available for WaterSense labeling are:

- *Irrigation Auditor*: Applies to programs that certify irrigation professionals who assess the proper functioning of existing irrigation systems, perform water audits, and recommend watering schedules;
- *Irrigation Installation and Maintenance Professional*: Applies to programs that certify irrigation professionals who install new irrigation systems and/or repair and maintain existing irrigation systems; and
- *Irrigation Designer*: Applies to programs that certify irrigation professionals who develop the design of new irrigation systems and/or modifications to existing irrigation systems.

Products

WaterSense is also conducting research on multiple water-efficient irrigation technologies. The first product categories for labeling will be weather-based irrigation control technology and soil moisture sensors.

Weather-based irrigation control technology uses local weather and landscape conditions to tailor irrigation schedules to actual conditions on the site or historical weather data. Instead of irrigating according to a pre-set schedule, advanced irrigation controllers allow irrigation to more closely match the water requirements of plants.

Soil moisture sensors increase the water efficiency of irrigation systems by allowing them to operate only when irrigation is actually needed. Soil moisture sensors are placed beneath the soil surface at a specified depth to measure the amount of moisture in the soil. When the moisture level drops below a predetermined level, the controller is allowed to operate, watering your plants. Soil moisture sensors can be programmed for individual needs and can be fitted to most electronic automatic controllers.

These new control technologies offer significant potential to improve irrigation practices in homes, businesses, parks, and schools across the United States.

Water Use in New Homes

While water managers are aware of the benefits of water efficiency programs, they need more information on water use patterns in new homes to help develop these programs.

For example,

- Do new homes use more or less water than existing homes?
- If there is a difference between new home and existing home water use, is it because of inherent differences in the efficiencies with which water is used, or simply because the new homes are different in size or the number of residents?
- Is it possible to use advanced technologies in new homes in order to reduce water demand?

To answer these questions and provide an empirical basis for understanding water use in the 14 million new homes that will likely be built nationally in the next 10 years, the EPA has funded a grant project that will collect data from several large water utilities across the United States. Water Efficiency Benchmarking for New Single Family Homes is a nine-city research study funded by EPA to establish baseline indoor and outdoor water use patterns for new homes by collecting empirical data from billing records, surveys, and indirect measurements.

The project will also demonstrate how the use of advanced technologies can reduce new home water use compared to homes with traditional water-using equipment. The study will investigate relationships between household indoor water use and key variables such as number of residents, size of home, and types of fixtures and appliances present. Outdoor water use will be quantified from total annual use, rates of application, local plant water requirements, lot size, landscape design, and type of irrigation system controller.

The study will look at “standard” new homes and “high-efficiency” new homes built to enhance water conservation. This will assist with establishment of targets for builders who wish to provide buyers with increased water efficiency options, develop specific performance criteria, and create a special designation to help consumers identify them. The study results can also enhance the efforts of states and water utilities to establish performance criteria for water use in new homes.

EPA awarded a $350,000 grant to the Salt Lake City Water Department to coordinate the multi-city study. Each of nine study water utilities will contribute $20,000, for a total project budget of $530,000. EPA anticipates the study being completed in December 2008.

Next Steps

WaterSense will continue to promote water efficiency throughout the country, aiming to change how Americans think about water. Specifications will continue to be developed for new products and services, followed by consumer education and outreach aiming to change the nation’s water ethic. In addition to the program’s focus on irrigation in the landscape, WaterSense also plans to focus on other aspects of residential landscaping, such as water-efficient landscape design, water-efficient plant palettes, and landscape professional certification programs.

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Water Industry/Irrigation Cooperation during Drought

Karen Guz, Conservation Director, San Antonio Water System, 2800 Hwy 281 North, San Antonio, TX 78212 and Donna Fossum, Planner II, San Antonio Water System, 2800 U.S. Hwy. 281 North, San Antonio, TX 78212.

When drought occurs the conservation focus shifts from finding consistent ways to save water to managing a short-term supply shortage. Unfortunately the shortage of supply is usually concurrent with an increase in demand. Irrigators are often concerned that coping with supply shortages will be the death of their business due to watering restrictions.

History in San Antonio has shown the opposite to be true. By working proactively on drought management issues, irrigation professionals can assist with supply management, increase their business revenue and be viewed as a positive resource in the community. Being a landscape/irrigation contractor in a position to help customers cope with drought is a major marketing feature in a drought prone region. This talk will focus on how even water waste tracking, following necessary watering time/day restrictions and other drought processes can benefit high quality irrigators.

Watersaver Contractor Program - - A Win-Win for Industry and Public-Owned Utilities

Mark Peterson, M.P.A., B.S., Project Coordinator, San Antonio Water System, 1001 E. Market Street, San Antonio, TX 78298 and Donna Fossum, Planner II, San Antonio Water System, 2800 U.S. Hwy. 281 North, San Antonio, TX 78212.

The Watersaver Landscape Contractor program is designed to develop a cadre of industry professionals, both Landscape and Irrigation professionals, that have a good working knowledge of complying with the City of San Antonio's conservation ordinance and exhibit the cutting edge of landscape water conservation. The program incorporates not only maintenance, repair, and design of irrigation systems but also covers appropriate management, plant materials and landscape design retrofits to achieve a notable landscape. The focus is to also assist the commercial, industrial and institutional customers with a selection of recognized Watersaver Landscape contractors and to provide landscape/irrigation contractors with opportunities to become trained in water conservation practices

Irrigation of Native Plants vs. Popular Landscape Plants: A Head-to-Head Comparison

Background

In 2003 the City of Santa Monica examined its outreach efforts toward the encouragement of landscaping which features climate-appropriate, water-efficient plant materials. It was found that, although the City had a very popular demonstration garden prominently located at City Hall, very few City property owners were actually installing such landscapes on there own property.
After some research it was concluded that were two main obstacles:
~ The inability of residential property owners to see the demonstration garden at a large, public building as representing something that could be done on their property.

~ The inertia within the landscaping community to continue recommending and planting the plants that they were already familiar with rather than the native plants which had become, for practical purposes, "exotic" in their natural territory.

The Idea

To overcome these obstacles the City conceived the idea of a *comparison garden* composed of two adjacent, residential front yards typical of the City's primarily residential character.

One front yard would feature California-native plants, a water-efficient drip irrigation system, a weather-sensitive irrigation controller, permeable paving, mulch and a system for capturing storm water runoff for groundwater recharge.

The other front yard would represent the typical front yard garden found in Southern California. It would feature the style of garden that has traditionally been planted in Santa Monica in modern times: Exotic plants from Northern Europe and the Eastern United States, a standard, user-controlled sprinkler irrigation system and no provision for runoff mitigation.

Costs, labor hours, plant growth, water consumption, greenwaste production and other environmental factors would be tracked and compared for both gardens.

Installation

We found an ideal site for the *comparison garden* in a group of bungalow houses, acquired some years back by Santa Monica College, and used by the college for offices. Two houses, side-by-side at 1718 and 1724 Pearl Street, were offered by the college for our project. The front yards of these two houses became the project area. Each yard is approximately 1900 square feet.

A professional landscape designer was hired to design both gardens and an IA Certified Irrigation Designer on the City staff designed the irrigation systems. LiveArt Plantscapes, a Los Angeles landscape contractor, was awarded the installation contract.

The installation in both yards called for the complete demolition of the existing landscape, export of the waste for recycling, application of soil amendments appropriate for the plant material, irrigation system installation, purchase of plants and planting. Construction was completed in March 2004. Construction cost for these activities was $16,700 for the native garden portion (NG) and $12,400 for the traditional garden (TG). The overall project was named *garden\garden*.

Additional work in the NG (not included in the above costs) included demolition and replacement of an existing access ramp, installation of permeable paving and installation of a rainwater recovery system.

Soil

Soil tests of both gardens revealed that the soil type was sandy loam (moderate permeability), poor in organic matter and highly compacted from decades of turf. The tests also indicated high alkalinity and high levels of heavy metals including zinc and copper. Preparation of the soil before planting included aeration with pumice, tilling to a depth of approximately 15 inches throughout all planting areas, and addition of non-deactivated sludge composted organic matter. Turf areas in the TG were tilled with pumice and organic matter to a depth of 6 to 8 inches.

Plant Selection

Plant lists for both gardens and material sources for other components are listed in Appendix 1.

Native Garden

For the NG only California natives were selected. It was felt that a key factor in keeping the native plants in scale with the small size of an urban front yard was the use of cultivars which do not become too big as they mature.

Traditional Garden

This garden includes a selection of plants that are commonly planted in Santa Monica and other areas of Southern California. Although this is the type of landscaping traditionally planted in Southern California, they are almost all exotics and not naturally equipped to thrive in Santa Monica's coastal Mediterranean climate.

Planting

Native Garden

The ideal time to plant California native plants is in late fall so they utilize the winter rainfall to grow healthy roots and leaves that will help them survive summer heat and drought. With irrigation backup, they can be planted through winter and spring. A key factor in planting is adequate plant spacing to accommodate mature plant growth and provide a natural appearance. Mulch is used in the NG to retain moisture in the soil, reduce weed growth and provide cover for the irrigation tubing.

Traditional Garden

Bedding areas are designed to provide a formal and full appearance within a relatively short time. Sod provides instant green. The optimum time to install these plants is the Spring. In their native regions, spring and summer rains help them grow in order to survive the fall and winter when they naturally become dormant. Although it would help keep weeds down, mulch was not applied as it is not normally used in this type of garden in Santa Monica.

Irrigation System

Native Garden

The system includes drip and microspray. There are three drip zones; one each for shallow, medium and deep-rooted plants. Subsurface PVC pipe brings water from each valve to Riser Units in appropriate parts of the garden where it connects to 18mm poly tubing with inline emitters. The microspray zone operates on pop-up spray heads in two groups of native grasses. An early-model WeatherTRAK weather-based irrigation controller (WBIC) controls the system.

<u>Traditional Garden</u>
Pop-up sprayheads are used throughout with standard "head-to-head coverage." There are six zones; three for turf and three for shrubs. Anti-syphon valves are used for both shrub and turf zones. An Irritrol Rain Dial controller was installed

Urban Runoff Control
Hazardous and toxic substances like fertilizers, pesticides, automotive fluids, pet wastes and trash are washed into the storm drain system and into Santa Monica Bay by rain, and dry weather flow from hosing paved areas and excessive irrigation. This liquid waste, called urban runoff, is the single largest source of water pollution in the Bay.

<u>Native Garden</u>
The drip irrigation system in this garden completely eliminates irrigation runoff. A dry creek bed in the garden and permeable pavement such as the decomposed granite in the parkway and the open-grid surfaces on the access ramp and driveway, allow water to return to the groundwater supply instead of running off the property. Rain gutters channel roof runoff into a decorative ceramic urn and then through a subsurface drainpipe under the dry creek bed into an infiltration pit located near the center of the garden.

<u>Traditional Garden</u>
Roof runoff flows mostly onto the landscape. Rainfall on the paved driveway and access ramp will flow to the street. The sprayhead irrigation system applies water at approximately three times the rate that the soil can accept it. Although multiple start times on the controller can mitigate this somewhat, runoff is inevitable. Runoff also occurs when the heads, placed at the edge of the planting area, adjacent to hardscape, become misaligned.

Maintenance Plan

<u>Native Garden</u>
After a one-year establishment period, maintenance in this garden was planned to consist of annual or semi-annual hand-pruning on selective plants

beginning after twelve months plus monthly checks of the irrigation system and trash removal. Additional mulch is to be added as necessary.

Traditional Garden

In this climate these plants require regular care with lots of water, fertilizers and pest management. Turf areas are mowed and edged weekly. Shrubs require monthly application of soil additives to acidify the soil. Annual plants will be replaced two to three times a year. Occasional treatments are required for diseases and insect attack.

The First Year (2004-05)

After expiration of the installing contractor's 90-day maintenance period, a landscape maintenance company was hired to maintain both landscapes. For the first year, both gardens were visited weekly. The company was asked to keep separate records of material cost, labor hours and greenwaste production for each garden and report that data monthly. Each garden is separately metered and water consumption, initially recorded at two-month intervals, was recorded monthly beginning in Nov 04. See http://www.smepd.org/gardengarden for details.

Irrigation

The WeatherTRAK WBIC installed in the NG did not have automatic settings appropriate for newly installed gardens. So the controller was set for "User with ET" with a program created by the landscape and irrigation designers. After three months the controller was reset to "Full Automatic."

Initially the Rain Dial controller in the TG was set to water every third day to establish the plants. After six weeks the controller was reset to a program based on a schedule generated at www.bewaterwise.com a consumer-oriented, zip code-based irrigation scheduler provided by the Metropolitan Water District of Southern California. It was decided to adjust the watering schedule every three months.

During the second month it was observed that the installation contractor had misplaced four out of the eight pop-up microsprays watering the two Carex beds in the parkway of the NG. Because Carex creates a tufted, uneven surface that does not show uneven watering the way turfgrass does, it was decided to delay relocation of the heads to see if the plant material could develop a root system that compensated for the poor irrigation distribution in this zone.

The controller program in the NG was fine-tuned once during the year for root depth. Unusually heavy rain during the winter of the first year resulted in the TG controller being shut off for a total of two weeks in a three-month period. The NG controller was not shut off for rain. The percent adjust feature was not used on either controller.

Comparative water consumption for the two gardens in Year 1 can be seen at http://www.smepd.org/gardengarden .

Plants

The plantings in both gardens faired well during the establishment period. During the first year four plants were lost in the NG and six in the TG. The NG losses were due to plants adjacent to the sidewalk being trampled and to theft. TG losses were due to foreground plants blocking irrigation from plants further back. Annual color in the TG was replaced once. Costs for plant replacement are shown at http://www.smepd.org/gardengarden .

Labor and Greenwaste

During the first year, both gardens were maintained weekly. Labor hours and greenwaste production are shown at http://www.smepd.org/gardengarden .

Chemicals and Fertilizer

In conformance with Santa Monica City policy, no chemical herbicides or insecticides were used on either garden. Blood meal was occasionally applied in the TG.

The Second Year (2005-06)

At the beginning of the second year the steering committee met and considered several possible alterations to the garden. It was decided to make no changes and simply gather one more year of data with the gardens fully established. Each garden continued to be separately metered and water consumption recorded monthly. See http://www.smepd.org/gardengarden for details.

Irrigation

The WeatherTRAK WBIC installed in the NG continued in *Full Automatic* mode and the TG controller was adjusted quarterly as before. Neither controller was shut off for rain. The percent adjust feature was not used on either controller. Comparative water consumption for the two gardens in Year 2 can be seen at http://www.smepd.org/gardengarden .

Plants

The plantings in the NG garden grew well during the year with some loss of Heucheras due to wind and trampling from nearby sidewalk traffic. One Ceanothus Dark Star was lost to an insect infestation. Companula and Rhododendron plants in the TG continued to suffer from irrigation distribution problems with one Rhododendron lost. Parkway turf in the TG continued to suffer from foot traffic near the entrance to the building. Annual color in the TG was replaced once. Costs for plant replacement are shown at http://www.smepd.org/gardengarden .

Labor and Greenwaste

During the second year, both gardens continued to be maintained weekly. Labor hours and greenwaste production are shown at http://www.smepd.org/gardengarden .

Chemicals and Fertilizer

In conformance with Santa Monica City policy, no chemical herbicides or insecticides were used on either garden. Blood meal was occasionally applied in the TG.

The Third Year (2006-07)

At the beginning of the third year the steering committee once again met and considered several possible changes in the garden. It was decided to make three changes:

1. Reduce the monthly maintenance at the NG to quarterly.
2. Install a WBIC at the TG.
3. Install Run Time hour meters on one valve in each garden.

It was also decided to look into the possibility of recording the carbon output of the two gardens.

Irrigation

A Toro Intellisense WBIC was installed in the TG in June 2006. It was initially set to *Full Automatic* mode. With the coming of unusually hot, humid weather in July the turf zones began to show severe stress. The Toro hotline was called and a technician suggested several programming adjustments which were followed.

Because both gardens would now have WeatherTrak WBICs which do not have any historical tracking ability, hour-meters were installed on one shrub zone in each garden. The idea being to have some record of actual total run time for a give month. Due to technical difficulties, these devices were not installed until Mid July. See http://www.smepd.org/gardengarden for data collected thus far.

As of this writing (Aug 06) no adjustments have been made to the NG controller and neither controller has been shut off for rain. The percent adjust feature has not been used on either controller. Each garden continued to be separately metered and water consumption recorded monthly. See http://www.smepd.org/gardengarden for details.

Plants

The plantings in the NG garden grew very well during the year with loss of one Dudleya due to unknown causes. One Arctostaphylos and two Iris's due to trampling. There were problems with the parkway turf in the TG related to weather and the change in the irrigation controller (see above). Some portions of the turf recovered and others did not. The steering committee decided to leave the turf as-is rather than overseeding or patching with sod.

A significant renovation was done in the TG including replacement of annual color and Companula groundcover. Costs for plant replacement in Year 3 are shown at http://www.smepd.org/gardengarden .

Labor and Greenwaste

Maintenance of the NG was reduced to quarterly visits at the beginning of the second year. The TG continues to be maintained weekly. Labor hours and greenwaste production are shown at http://www.smepd.org/gardengarden .

Chemicals and Fertilizer

In conformance with Santa Monica City policy, no chemical herbicides or insecticides were used on either garden. Organic fertilizer, blood meal and soil conditioner were occasionally applied in the TG.

Measuring Net Carbon Output

As of this writing (August 2006), research into methods of measuring the carbon emissions of the two gardens is being conducted with the aim of measuring the output of the plants and well as the people and machines that maintain them. See http://www.smepd.org/gardengarden for data collected thus far.

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NOTE: This document was written in August 2006. *garden\garden* is an ongoing project. For the latest information and more comprehensive data, visit us on line at http://www.smepd.org/gardengarden Or write to garden\garden, City of Santa Monica Environmental Programs Division, 200 Santa Monica Pier, Suite K, Santa Monica California 90401

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Appendix 1

Native Garden Plant List

1. Arctostaphylos densiflora 'Howard McMinn'
A moderate size, four to five foot mounding shrub with shiny, green leaves and delicate white to pinkish, urn-shaped flowers and exceptionally attractive smooth, reddish bark.

2. Arctostaphylos uva-ursi 'Point Reyes'
Prostrate groundcover, 18 inches to two feet high with tightly spaced dark green leaves and pinkish flowers.

3. Carex praegracilis
A meadow sedge with six to eight inch high, bright green, tufted leaves. This sedge spreads by root running.

4. Carex tumulicola
A sedge with shiny, dark green leaves forming an eighteen inch mound.

5. Ceanothus 'Concha'
A moderate size, four to five foot mounding shrub with medium sized, dark green leaves and spring blooming cobalt blue flowers.

6. Ceanothus 'Dark Star'
A moderate size, four to five foot rigidly mounding shrub with small, tight, dark green leaves and spring blooming dark, violet blue flowers.

7. Ceanothus 'Snowball'
A five to six foot tall, upright shrub with large, bright green leaves and spring blooming white flowers.

8. Deschampsia caespitosa ‘Northern Lights’
A cultivated variety of California native grass with bright golden variegations along six to eight inch long, clumping leaf blades.

9. Dudleya hassei
A native succulent with clustered, silver and purple tinged, pointed, rounded leaves and tall, thin flower stalk.

10. Dudleya lanceolata
A coastal succulent with dark green, fleshy leaves and yellow or red flowers on long stems.

11. Dudleya pulverulenta
A twelve to fifteen inch wide, coastal succulent rosette of gray, glaucous leaves and a thick flower stalk.

12. Encelia californica
A three foot high shrub with dark green leaves and spring blooming, yellow daisy flowers. Winter deciduous.

13. Epilobium californicum
A perennial with gray-green leaves and bright orange to yellow, fall blooming tubular flowers. Hummingbirds love this plant.

14. Heuchera ‘Wendy’
A hybrid variety of Heuchera with tall clusters of peachy-pink flowers. All Heucheras are very attractive to hummingbirds.

15. Heuchera maxima
A Channel Islands native perennial with clumping, heart-shaped dark green leaves and tall clusters of small whitish to pinkish flowers from spring into summer.

16. Iris ‘Pacific Coast Hybrids’
A hybrid of California native iris with dark, evergreen, clumping strap leaves and assorted colors of flowers which bloom in spring.

17. Juncus effusus var. Pacificus ‘Quartz Creek’
A Pacific Coast Rush with three to four foot tall, dark green leaves.

18. Juncus patens ‘Elk Blue’
A hybrid variety of Gray Rush. This is a two foot high clump with a distinct bluish tint to the green foliage.

19. Lyonothamnus floribundus asplenifolius
A Channel Islands native twenty to thirty foot tall evergreen tree with scallop-edged leaves and unusual red-brown, shredding bark.

20. Muhlenbergia rigens
A native grass, four feet tall with bright green, clumping leaf blades and six foot tall yellow-purplish flower spikes in the fall.

21. Nasella pulchra
A needle grass with four inch long, silky, golden bristle flower heads which blow gracefully above two foot high, bright green leaf blades. Summer dormant.

22. Penstemon centranthifolius
A coastal native, three foot tall perennial with gray-green, long-shaped leaves and tall spikes of spring/summer blooming, bright red tubular flowers. Penstemon

flowers are a particular favorite of hummingbirds.

23. Penstemon heterophyllus ‘Bluespray’
A hybrid variety of the California native; two foot tall perennial with glossy, bluish-green irregular shaped leaves and spikes of reddish purple to deep blue flowers in spring.

24. Penstemon spectabilis
A four foot tall perennial of grayish-green, stem hugging leaves and rose to purplish flowers which bloom in spring and summer.

25. Philadelphus lewisii
A five foot tall, fountain shaped shrub with dark green leaves and white blooming flowers in spring. Winter deciduous.

26. Rhamnus californica ‘Mound San Bruno’
A hybrid variety of native Coffeeberry is a six foot tall mound of broad, flat, dark green leaves. Flowers are fairly insignificant in summer but large, red berries are a special treat for local bird populations in the fall.

27. Ribes sanguineum glutinosum 'Tranquillon Ridge'
A hybrid variety of native Currant. Ten foot tall, shrub with maple-like, dark green leaves and drooping, deep pink flower clusters in spring and summer. Winter deciduous.

28. Salvia apiana
A four foot tall shrub with extremely aromatic, silvery-gray leaves and spring blooming lavender-tinged white flowers. This sage has been historically used by California Native Americans for sweat lodge ceremonies.

29. Salvia clevelandii 'Whirly Blue'
A hybrid variety of Blue Sage it is a three foot, compact shrub with gray-green, fragrant leaves and dark blue flowers. All California native sages are a bountiful food source for bees and hummingbirds.

30. Salvia clevelandii 'Winifred Gilman'
A hybrid variety of native Blue Sage is a three foot arching shrub of gray-green, toothed, very aromatic foliage and dark violet-blue whorls of flowers in summer.

31. Salvia leucophylla 'Frankensense'
A hybrid variety of native prostrate Gray Sage, it has gray leaves and pinkish-purple flowers in spring.

32. Salvia spathacea
An eighteen inch high, mat-forming perennial of large, fuzzy, dark green leaves and eight to twelve inch spikes of purplish-blue flowers in spring. More shade tolerant than other sages. Extremely attractive to hummingbirds.

33. Sisyrinchium bellum and Californicum
A California native, one foot high, grassy perennial with bluish green leaves and either purplish-blue or yellow flowers on tall stems.
Naturalizes – Freely colonizes itself through seed.

34. Sphaeralcea 'La Luna'
A white flowering cultivar of native perennial Mallow with gray-green, scalloped, fuzzy leaves and a classic apple blossom shaped white flower.

Native Garden Materials List

Item	Type / Model	Brand / Source	Address
Planting			
Trees / Shrubs / Groundcover	California Native*	Theodore Payne Foundation	www.theodorepayne.org
		FK Nursery, Inc.	Trade only
Mulch	Xerimulch	Kellogg Supply	www.kelloggarden.com
Dry Creek			
Boulders	Malibu	Bourget Brothers	www.bourgetbros.com
Gravel	Del Rio aggregate	Bourget Brothers	www.bourgetbros.com
Decomposed Granite		Bourget Brothers	www.bourgetbros.com
Accessway			
Paving	GravelPave2	Invisible Structures	www.invisiblestructures.com
Bridge	ChoiceDek II	Advanced Environmental Recycling Technologies, Inc.	www.choicedek.com
Rain Catchment			
Infiltration Pit	D-Raintank	Atlantis Water Management	www.atlantiscorp.com.au
Rain chain	Copper Rain Chain	Susan Herbert Imports	503/248-0886
Furniture			
Concrete bowl	Garden Maker	San Marcos Growers	www.smgrowers.com
Pottery planters and urns		World of Pottery	626/961-4768
Plastic lumber for sign post	Trex	Trex Company	www.trex.com
Plastic lumber for sign placard	Codemo	Priema Plastics	www.codemo.com
Irrigation Equipment			
Controller	WeatherTrak	Hydropoint Data Systems	www.hydropoint.com

Master Pressure Regulator	Model 600	Wilkins	www.zurn.com
Filter	T-007C-XXX-E	API	www.agproducts.com
Valves	PGV-101A	Hunter Industries	www.hunterindustries.com
Zone Pressure Regulator	PRV075	Bermad	www.bermad.com
Microspray Heads / Nozzles	1806 / O-Jet	Rain Bird / Olson Industries	www.rainbird.com www.olsonirrigation.com
Drip Tubing	SFPC-BR-7212-01	Agrifim	www.agrifim.com
Drip Tubing Connectors	Easy Fit	Rain Bird	www.rainbird.com

* California-friendly garden resources

Rancho Santa Ana Botanic Garden	www.rsabg.org
Theodore Payne Foundation	www.theodorepayne.org
Tree of Life Nursery	www.treeoflifenursery.com
California Native Plant Society	www.cnps.org

Additional resources

City of Santa Monica	www.smped.org/landscape	
Metropolitan Water District	www.bewaterwise.com	Virtual garden tours

Traditional Garden Plant List

1. Acer palmatum 'Atropurpureum'
A native of Japan and Korea, small scale tree to 20 feet with purplish-bronze to bronze leaves. Insignificant flower, winged seed capsule. Winter deciduous.

2. Alstromeria hybrid
Evergreen varieties of 18 to 24 inch high perennials with light green leaves and lily-like flowers of many colors.

3. Asplenium bulbiferum
A native fern from the rainforest regions of Australia and New Zealand with finely cut, light green fronds to four feet long.

4. Astilbe x arendsii
Short lived perennial with finely cut, bright green leaves and long-stemmed plumes of small pink, white or red flowers. Winter dormant.

5. Azalea ‘Fielders White’
A Southern Indica Hybrid which is more sun-tolerant than the original Belgian Indica Hybrids of the east coast regions.
‘Fielders White’ has white flowers.

6. Azalea ‘Formosa’
A Southern Indica Hybrid which is more sun-tolerant than the original Belgian Indica Hybrids of the east coast regions. ‘Formosa’ has rose- colored flowers.

7. Begonia ‘semperflorens’
Six to eight inch high fibrous flowering bedding plants with very soft leaf, stem and flower in colors ranging from deep maroon to white. Bedding Begonias are treated as annual (seasonal) plants, which are replaced two to three times a year.

8. Campanula poscharskyana
A spreading, eight inch high perennial ground cover with deep green leaves and star shaped lilac-blue, lavender or white flowers in spring and summer. Spreads by root runners to cover soil.

9. Eucalyptus globulus (existing)

10. Fuchsia x hybrida
An evergreen hybrid variety of soft-woody, two foot high, loose shaped shrub with dark green leaves and pinkish- violet bell shaped flowers.

11. Gardenia augusta ‘August Beauty’
A hybrid variety of a native shrub from China and Japan, growing to five feet high with shiny green leaves and highly fragrant white flowers in summer.

12. Hemerocallis (hybrids)
An evergreen, tuberous, clustering, perennial with 18 inch high green strap leaves and various colored lily-like flowers on tall stems.

13. Hydrangea macrophylla 'Nikko Blue'
A hybrid variety of the native shrub from Japan, it grows to six feet high with large toothed green leaves and large white to lavender blue flower clusters which bloom in the summer and fall. Winter deciduous.

14. Impatiens (Bedding)
Annual plant, six to 15 inches high with soft, fibrous green leaves and stems and various colors of flower during summer. Plant typically looks very poor in winter.

15. Marathon #1 Turf

16. Rhododendron
A hybrid variety of a six foot high shrub with large, thick, dark green leaves and large clusters of white to rose-red flower clusters throughout spring and summer.

17. Rosa 'Angel Face'
A lavender flowering Floribunda variety.

18. Rosa 'Iceberg'
An evergreen white flowering Floribunda variety.

19. Rosa 'Queen Elizabeth'
A pink-blend Grandiflora variety.

20. Syringa vulgaris 'Lavender Lady' (Lilac)
An Eastern Europe native, ten to 15 feet tall shrub with roundish green leaves and vertical clusters of pinkish to lavender, highly fragrant flowers in spring. Winter deciduous.

Traditional Garden Materials List

Item	Type / Model	Brand / Source	Address
Planting			
Trees / Shrubs / Bedding plants	Traditional / Seasonal	FK Nursery, Inc.	For sale to trade only. See your landscape professional for details.
Sod	Marathon I	Southland Sod	www.sod.com
Furniture			

Plastic lumber for sign post	Trex	Trex Company	www.trex.com
Plastic lumber for sign placard	Codemo	Priema Plastics	www.codemo.com
Irrigation Equipment			
Controller	Rain Dial	Irritrol	www.irritrolsystems.com
Pressure Regulator	Model 600	Wilkins	www.zurn.com
Valves	ASV-075	Hunter Industries	www.hunterindustries.com
Sprayheads	1804	Rain Bird	www.rainbird.com

Utilizing Multiple Water Sources for Landscape Irrigation

Eddie Wilcut, Conservation Planner, San Antonio Water System, 2800 U.S. Hwy 281 North, San Antonio, TX 78212 and Bruce Rathburn, Backflow Prevention Supervisor, San Antonio Water System, 2800 U.S. Hwy 281 North, San Antonio, TX 78212.

The utilization of multiple sources of water for landscape irrigation is a practice that should be highly encouraged and incentivized wherever possible.

Alternative water sources such as greywater, recycled water, rainwater, cooling tower blowdown, and air-conditioning condensate can, in many cases, provide for all the supplemental needs of a given landscape. However, issues surrounding the use of such sources must be fully understood by the end user before adopting a reuse program.

This paper takes a look at issues surrounding the collection, treatment, distribution, and application of alternative sources of water as they relate to landscape, health and safety, and the Uniform Plumbing Code.

Evaluation of Sensor Based Residential Irrigation Water Application

Melissa B. Haley[1], Michael D. Dukes[2], Grady L. Miller[3]

Paper presented at the 27th Annual International Irrigation Show
San Antonio, TX
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Abstract
An irrigation study to determine the effects of sensor based irrigation controllers on residential irrigation water use is described in this paper. This project is comprised of 64 homes in Pinellas County, Florida, with automatic in-ground residential irrigation systems. Homes for this study were categorized into three groups of water users based on historic water use; low (20-36 mm/month), medium (40-87 mm/month), and high (92-214 mm/month). Experimental treatments to be evaluated include an automatic time based irrigation controller, set and operated by the cooperator, the integration of a soil moisture sensor, a rain sensor, and a rain sensor along with educational material given to the cooperator. Our hypothesis is that the use of soil moisture sensors, rain sensors, and educational materials will reduce residential irrigation water application.

Introduction

Nearly all new homes in Florida are constructed with in-ground automatic irrigation systems. Studies have shown that residential lawn and landscape irrigation can account for more than 64% of the total water use for a single family home (Haley et al., 2006). Furthermore, recent research in Florida has indicated that homeowners are over irrigating, by irrigating more the plant water needs based on local evapotranspiration rate and precipitation (Haley et al., 2006). Irrigation water use conservation efforts are necessary due to the rise in the state's population. The South West Florida Water Management District (SWFWMD), which is one of five Florida water management districts, accounts for a quarter of the State's overall population, with more than four million inhabitants. Between 1990 and 2000, the population within the District grew by over 640,000 residents, approximately 19%, and is projected to increase another 1.8 million by 2025. The 2000 population for Pinellas County, the study area, was 921,482 and is forecasted to be 1,078,600 by 2025, an increase of 17%.

Within the SWFWMD, public water use accounts for 42% if the total freshwater use, the second largest water use sector after agriculture. Although there has been considerable population growth, the water use amount has remained fairly constant from 1993-2002. This is a result of an 11% decrease in per capita water use, from 533 to 476 L/d. However, when the per capita water use is normalized for drought or excessively wet seasons; the total public water use shows an

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upward trend. It is expected that as population growth continues, public water use will become the dominant water use sector. According to the SWFWMD 2005 District Management Plan, the projected water demand for the public supply is expected to increase to 845 million L/d (SWFWMD, 2005). More than 80% if this water withdrawn from groundwater sources, most of which comes from the Floridan aquifer, which has increasingly been regarded as a limited resource. Within the SWFWMD, the exclusive source of natural replenishment to the Floridan aquifer is from precipitation.

Although within the Water Management District, twice weekly landscape irrigation is permitted, Pinellas County has more stringent water use regulations. In accordance with Pinellas County Code 82-2, irrigation within Pinellas County is only authorized for one day a week (PCU, 2006a). Watering is prohibited between the hours of 8:00 am and 6:00 pm. The current rate for potable water from Pinellas County Utilities is \$3.60, and will increase to \$4.04 as of October 1, 2006 for 3780 L (PCU, 2006b). According to the Florida Water Rates Evaluation of Single-Family Homes, completed in 2005, the main concern of homeowners with respect to increased costs is outdoor use (Whitcomb, 2005).

In a study on residential irrigation efficiency with the St. Johns River Water Management District (SJRWMD), on average, 64% of the water in individual homes went to irrigation. In the summer months this percentage increased as high as 88%. The study also showed that setting irrigation controllers with respect to historical turfgrass seasonal water needs resulted in a 30% reduction of irrigation water applied (Haley et al., 2006). During this study it was observed that the homeowners did not have a clear understanding of when and how much to irrigate. With the combination of substantial microirrigated landscape planting areas, and irrigation based on historical evapotranspiration rates, the fraction of water use for irrigation purposes was decreased on average by 50% (Haley et al., 2006).

Sensor based technology can result in irrigation water savings. Typically, a soil moisture sensor is buried in an irrigated area, and an adjustable threshold controller is mounted near the irrigation system time clock. This sensor can result in the bypass of scheduled irrigation events based on soil moisture content. Soil moisture sensors have been shown to reduce irrigation water use under rainy conditions up to 70%, with no decline in turf quality (Cardenas-Lailhacar et al., 2005). Rain sensors are the most common type of senor used in conjunction with automatic irrigation systems. They should be installed in an area unobstructed from rainfall and after a rain event the sensor causes the system to bypass to prevent unnecessary irrigation similar to soil moisture sensors. All irrigation systems in Florida installed since 1991 are required to have a functioning rain sensor (Florida Statutes, Chapter 373.62). However, this statute is not typically enforced (Whitcomb, 2005). According to University of Florida research, systems which incorporate rain sensors used 31% less water than systems without a functioning rain shut-off device (Cardenas-Lailhacar et al., 2005).

The objectives of this study are to assess the effect of soil moisture sensor control, rain sensors, and educational materials for irrigation scheduling on residential irrigation water use in Southwest Florida.

Materials and Methods

The homes included in this research project are all located in the City of Palm Harbor in Pinellas County which is part of the Pinellas-Anclotte River Basin within the South West Florida Water Management District. The target number of cooperators is 64. Currently, 58 residential cooperators with automatic in-ground irrigation systems have been recruited. The county was divided into quadrants, based on weather station proximity, denoting a location number for each home (Figure 1).

- **(L1)** Northwest quadrant
- **(L2)** Southwest quadrant
- **(L3)** Southeast quadrant
- **(L4)** Northeast quadrant

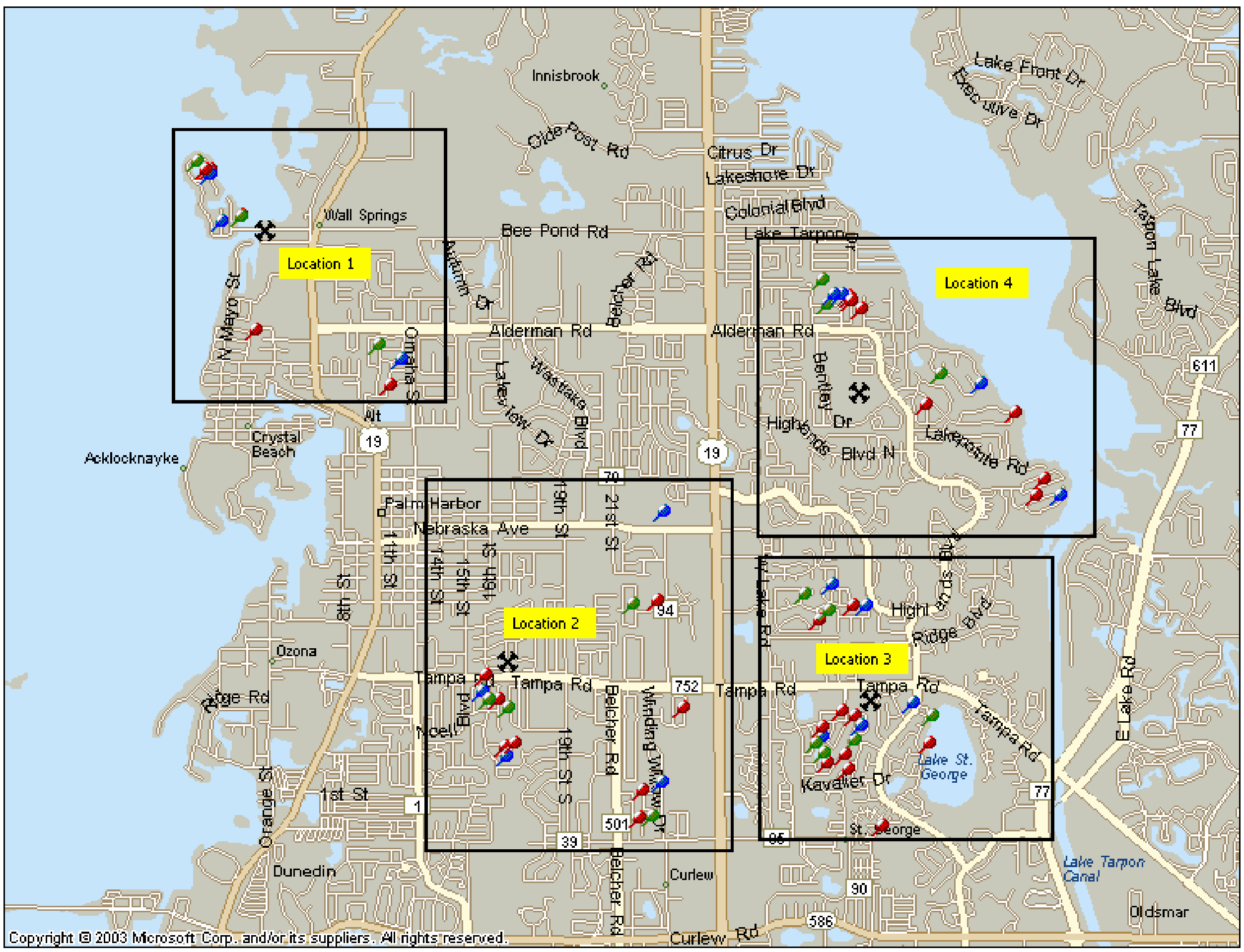


Figure 1. Map of the City of Palm Harbor in Pinellas County Florida, with homes denoted by pins and weather station locations marked by an "x".

Pinellas County has a humid subtropical climate, with frost and freezing temperatures occurring at least once annually. The average annual rainfall within the SWFWMD is 1350 mm, with 60-65% occurring between in the summer months when evapotranspiration rates are highest. The groundwater supply in southwest Florida comes from the Floridan aquifer. This aquifer is primarily dependant on the rainfall which occurs in the district as the sole source of natural replenishment (SWFWMD, 2005).

To measure the climactic parameters and precipitation, a weather station (Figure 2) was installed in each of the four locations (Figure 1). The stations were centered within a 2 km radius of the homes. The station sites were county owned and managed properties, with flat-grassed areas and minimal canopy coverage of at least 61 m distance if possible. Date, time, relative humidity and temperature (model HMP45C, Vaisala, Inc., Woburn, MA), solar radiation (model LI200X, Li-Cor, Inc., Lincoln, NE), wind speed and direction (model WAS425, Vaisala, Inc., Sunnyvale, CA) and, precipitation (model TE525WS, Texas Electronics, Inc., Dallas, TX), are recorded in 15 minute intervals via a CR10X data logger (Campbell Scientific, Inc., Logan UT). To determine whether over irrigation has occurred, the amount of irrigation water use will be compared to crop evapotranspiration (ET_c) which is calculated as the product of reference evapotranspiration (ET_o) and a crop coefficient (K_c). Effective rainfall will also be considered. ET_o will be determined by ASCE-EWRI standardized Penman-Monteith equation (ASCE-EWRI, 2004).

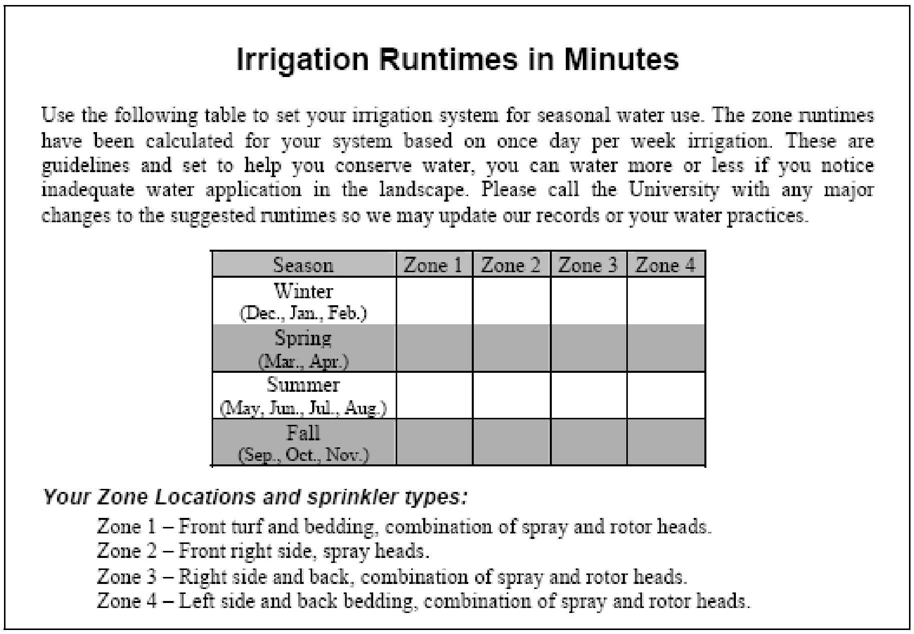
Figure 2. One of the weather stations located in Pinellas County.

Household water consumption, both total and water used for irrigation purposes only will be recorded by weekly flow meter readings. All of the homes included in this study obtain water from Pinellas County Utilities. The utility water meter will be used to determine the total (indoor plus outdoor) amount of water consumed by the household. A flow meter was also installed in the irrigation mainline to determine the volume of irrigation water used. Positive displacement flow meters were purchased due to their accuracy and convenience (Baum et al., 2003), and installed by a local contractor on each of the cooperating residential homes. The meters were installed with no obstruction within approximately ten diameters of the inlet and outlet of the meter when possible. This was to ensure minimal turbulence in flow through the meter to maintain accuracy.

Treatments
The homes were divided into four experimental treatments. The treatment classifications refer to the additional educational materials or sensor based technology incorporated into the systems.

- **(T1)** Treatment one: Current irrigation system with soil moisture sensor set at 10% volumetric soil water content (approximately field capacity)
- **(T2)** Treatment two: Current irrigation system with rain sensor
- **(T3)** Treatment three: Current irrigation system with no additional sensor
- **(T4)** Treatment four: Current irrigation system with rain sensor and educational materials

The educational materials will include brochures of outdoor water saving tips developed by the SWFWMD and a customized irrigation run time card (Figure 3).



Irrigation Runtimes in Minutes

Use the following table to set your irrigation system for seasonal water use. The zone runtimes have been calculated for your system based on once day per week irrigation. These are guidelines and set to help you conserve water, you can water more or less if you notice inadequate water application in the landscape. Please call the University with any major changes to the suggested runtimes so we may update our records or your water practices.

Season	Zone 1	Zone 2	Zone 3	Zone 4
Winter (Dec., Jan., Feb.)				
Spring (Mar., Apr.)				
Summer (May, Jun., Jul., Aug.)				
Fall (Sep., Oct., Nov.)				

Your Zone Locations and sprinkler types:

Zone 1 – Front turf and bedding, combination of spray and rotor heads.
Zone 2 – Front right side, spray heads.
Zone 3 – Right side and back, combination of spray and rotor heads.
Zone 4 – Left side and back bedding, combination of spray and rotor heads.

Figure 3. Front of sample irrigation scheduling card.

Each home in the treatment will receive a run time card that is based on the home's specific system design and zone layout. The card will be laminated and can be affixed to the controller box.

Background Analysis
Residential water use data, consisting of both indoor and outdoor use, were analyzed based on two year historic data for each home. Bimonthly data, from April, 2003 to October, 2005, was provided by Pinellas County Utilities. To estimate the bimonthly irrigation water use, the indoor water use was subtracted from the total water use, by assuming that indoor water use was the minimum bimonthly consumption over the two year period if less than 15,000 L. This value was determined as the average indoor water use across all homes. The irrigation water use in volume was then divided by 85% of the non-structural land area to determine the irrigation application per given time period. In a previous study conducted with SJRWMD, on average the irrigated area was 85% of the non-structural area (Haley et al., 2006). The non-structural land area for each home was calculated from county parcel records and it was assumed that all of this area was

irrigated. Once the bimonthly irrigation water use was estimated, each home was then categorized into an irrigation tendency classification. These classifications were based on quartiles where the low quartile was "low", two next quartiles (2 and 3) were "medium" and the upper quartile was classified as "high" irrigation users. Homes from each of these water use tendencies were approximately evenly distributed across the four treatments. From the provided data, 26% of the homes were low irrigation water users and had an average irrigation water application of 30 mm per month of water for outdoor use. Medium water users accounted for 48% of the homes and consumed an average of 62 mm of water for outdoor use monthly. The high water users had an average of 134 mm of water per month for outdoor use and comprised the upper 26% of the sample.

Table 1. Historical water use statistics.

	Est. Outdoor Water Use (mm/30d)		
Group	**Average**	**Min.**	**Max.**
Low	30	20	36
Medium	62	40	87
High	134	92	214

Compared to a study in the Central Florida ridge, the water usage for the data analyzed here was slightly less. The average outdoor water use for the homes in the SJRWMD study ranged from 80-140 mm/month (Haley et al., 2006) compared to 30-134 mm/month.

Irrigation Evaluations

System evaluations were conducted for each home included in the study. The evaluation is a means of quantifying the irrigation system performance. Irrigation cycle water consumption is computed by recording the actual flow rate for each zone multiplied by the zone run time. During this evaluation any required maintenance resulting from broken heads and leaks is noted. Any maintenance that would compromise the uniformity test was fixed before the testing began.

An estimation of system distribution uniformity (DU_{lq}) was calculated by performing a catch-can test following the Mobile Irrigation Lab Handbook guidelines for Florida (Micker, 1996). DU_{lq} can be calculated with the following equation (Merriam and Keller, 1978):

$$DU_{lq} = \frac{\overline{D}_{lq}}{\overline{D}_{tot}} \qquad [1]$$

where, $\overline{D}_{lq}$ is the lowest quarter of the average of a group of catch-can measurements and $\overline{D}_{tot}$ is the total average of a group of catch-can measurements.

Uniformity of water distribution measures the relative application depth over a given area. This concept can assign a numeric value to quantify how well a system is performing. The term uniformity refers to the measure of the spatial differences between applied waters over an irrigated area. The average DU_{lq} of the sampling of the 53 homes tested to date in this study is 0.61, ranging from 0.29 to 0.85. Compared to the Irrigation Association distribution uniformity quality ratings for an irrigation system (IA, 2005), 58% the homes in this study can be classified as "good" or better (Figure 4). Although nearly a quarter of the homes are lower than "fair", the landscape quality is generally acceptable in most cases. Less than acceptable irrigation system DU_{lq} ratings do not necessarily result in poor landscape quality in Florida (Baum et al., 2005).

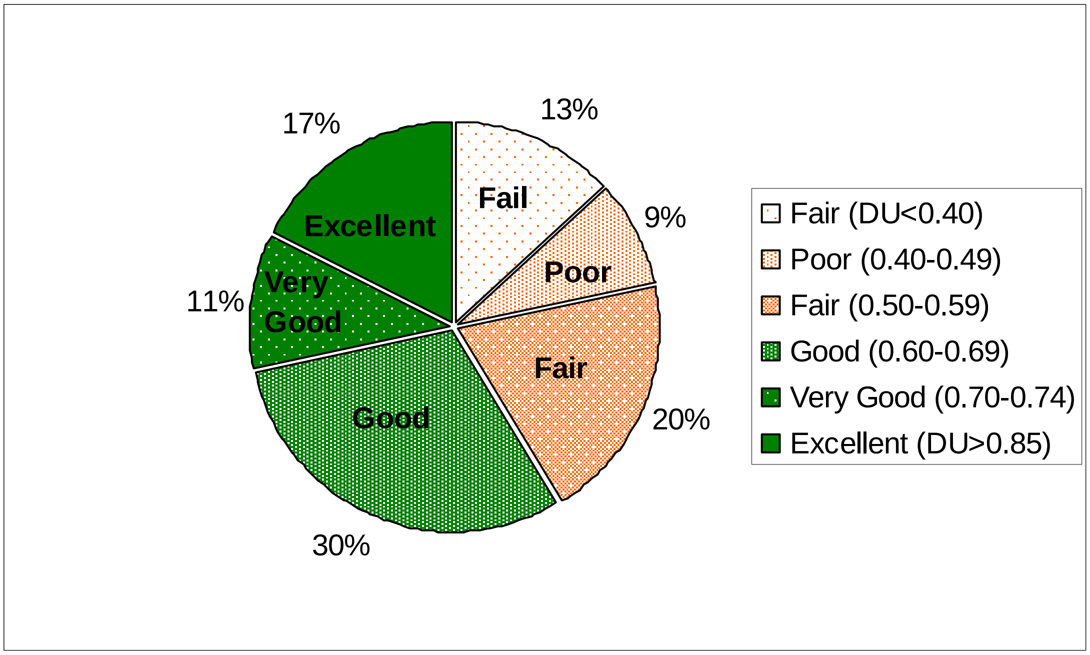


Figure 4. Irrigation system quality ratings related to low quarter distribution uniformity (IA, 2005).

Initially every home was given a visual inspection and assigned a numeric value based on landscape level (Figure 5). The landscape level is based on the percentage turfgrass versus bedded areas.

- **(LL1)** Turfgrass comprises a greater area then bedded landscape area
- **(LL2)** Turfgrass and bedded areas comprise equal parts of the landscape
- **(LL3)** Turfgrass comprises a lesser area then bedded landscape area

(A) 


(B)

(C)
Figure 5. Landscape level examples, from top to bottom (A) LL1, (B) LL2, (C) LL3.

Turf quality ratings can quantify the overall appearance of the turfgrass area and as a measure of functional use and aesthetics (Figure 6). Initial turf quality ratings were taken for each home during the irrigation evaluations, as a baseline standard of comparison for each home. The assessment of turfgrass is a subjective process following the National Turfgrass Evaluation Procedures (NTEP) (Shearman and Morris, 1998). This assessment is based on visual estimates such as color, stand density, leaf texture, uniformity, disease, pests, weeds, thatch accumulation, drought stress, traffic, and quality. The rating scale is from 1-9, with 1 being lowest and 9 being highest possible. A rating of 5 is considered minimally acceptable. Turf quality will be rated at each house seasonally throughout the duration of the study.

(A) (B)

Figure 6. Turf quality examples, (A) high, (B) poor.

Weather Data Quality Control

To determine the actual amount of irrigation needed, evapotranspiration is calculated from the weather parameters logged from sensors at each weather station. Since the calculated ET_o relies on the collected data quality, weather data integrity and quality assurance must be assessed (ASCE-EWRI, 2004). In addition to data assessment, routine maintenance must be performed to ensure the proper functionality of the weather station. Technical maintenance includes the evaluation, repair and replacement of equipment, while non-technical site maintenance includes removal of debris from tipping bucket, cleaning solar panel, bird prevention, mowing, etc.

Common methods for quality assessments are done by comparing incoming parameters against relevant physical extremes, employing statistical techniques to find extreme or anomalous values, and comparing neighboring stations. Quality control for the weather data collected in this study, evaluated three primary weather parameters: solar radiation, temperature, and wind speed.

Solar radiation is measured by a pyranometer (model LI200X, Li-Cor, Inc., Lincoln, NE). To check the operation and calibration of the pyranometer, the daily average readings for solar radiation (R_s) can be plotted against computed clear sky conditions (R_{so}) (Figure 7). All R_s values should fall below the R_{so} curve. Cloud free days are indicated by R_s values near the R_{so} curve. When R_s is below the R_{so} curve cloudy or hazy days are indicated. These plots can also show shifts in the time stamp associated with the data set.

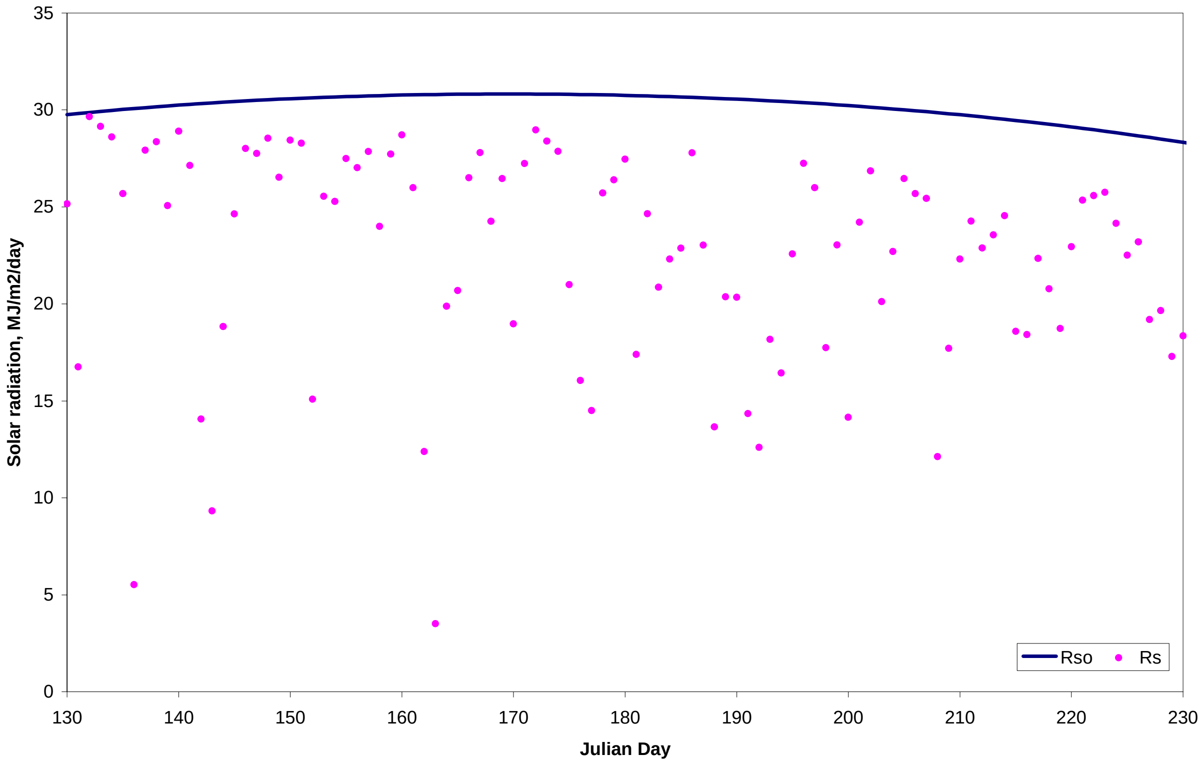


Figure 7. Daily measured R_s and calculated R_{so} recorded from Loc1, Palm Harbor, FL during 2006.

Relative humidity (RH) and air temperature (measured by model HMP45C, Vaisala, Inc., Woburn, MA) screening identifies reasonable and unreasonable values. To determine if data is questionable or erroneous, local conditions must be known. Sensor calibration is needed if RH maximum values are in excess of 100% (±5%) or if minimum values are frequently less than 30% (Figure 8). During a continuous precipitation event, dew event, or during evening hours following an intense precipitation event, the RH values should be within 90-100%.

Since the dew point temperature (T_{dew}) is calculated from RH, errors in the reported RH values will also be observed in the plotted T_{dew}. In this study area, which is classified as a humid region, it is common for the calculated T_{dew} to approach the measured T_{min} (Figure 9). Exceptions to this result from a change in air mass due to a frontal passage, or during days with high winds and/or cloudless nights.

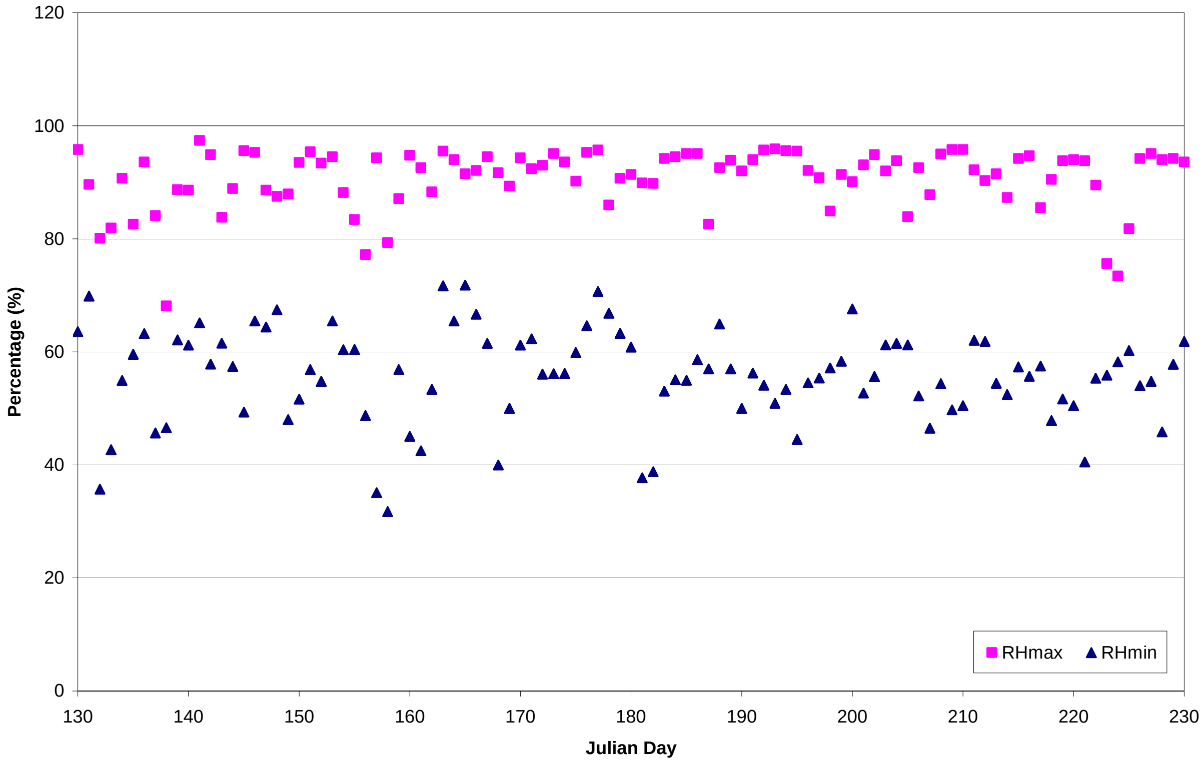


Figure 8. Daily maximum and minimum relative humidity recorded from Loc1, Palm Harbor, FL during 2006.

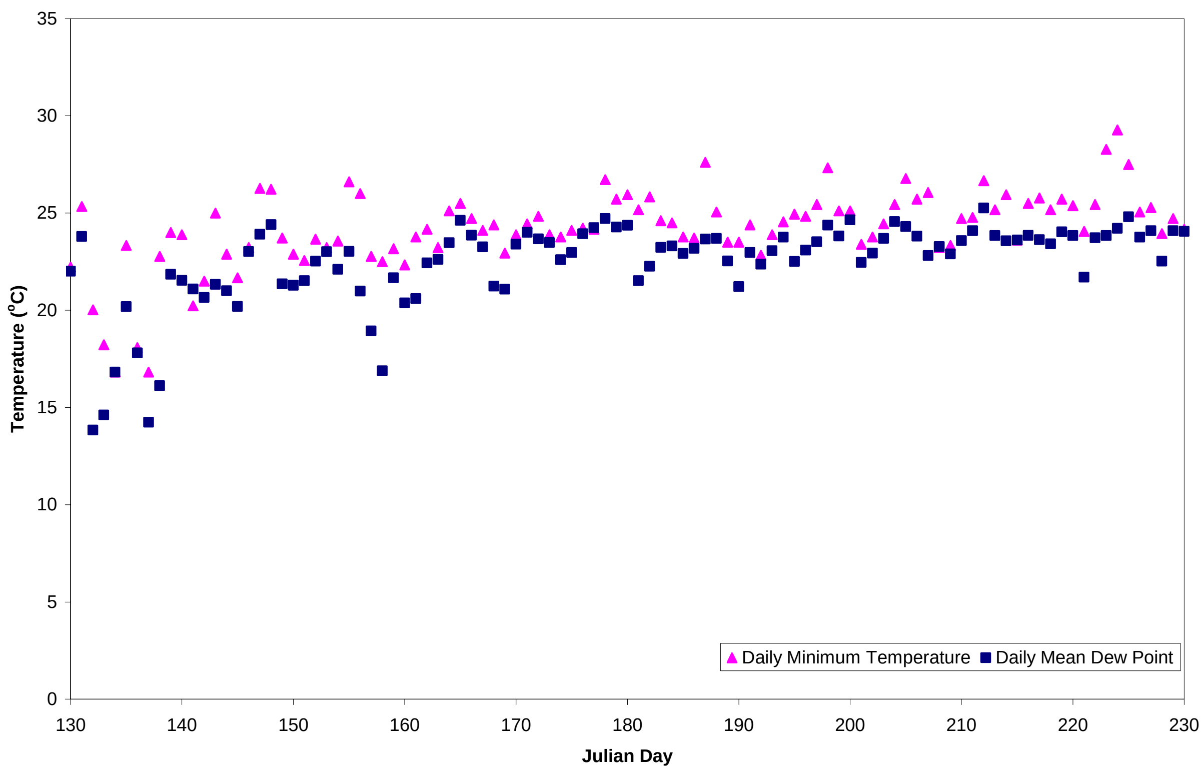


Figure 9. Measured daily minimum air temperature and mean daily dewpoint temperature recorded from Loc1, Palm Harbor, FL during 2006.

Wind speed and direction is measured with an ultrasonic anemometer (model WAS425, Vaisala, Inc., Sunnyvale, CA). The gust factor is calculated as the ratio of maximum wind speed to mean daily wind speed. This ratio serves as an index for assessing wind speed accuracy. When plotting the gust factor over time, if the gust factor has exceptionally increased values, there may be a malfunction with the sensor. In this case, it is possible for the anemometer to malfunction for only a given period of time and then return to functioning normally. During hurricane season, the gust factor will result in high values during the storm event. The figure below depicts a normal functioning anemometer.

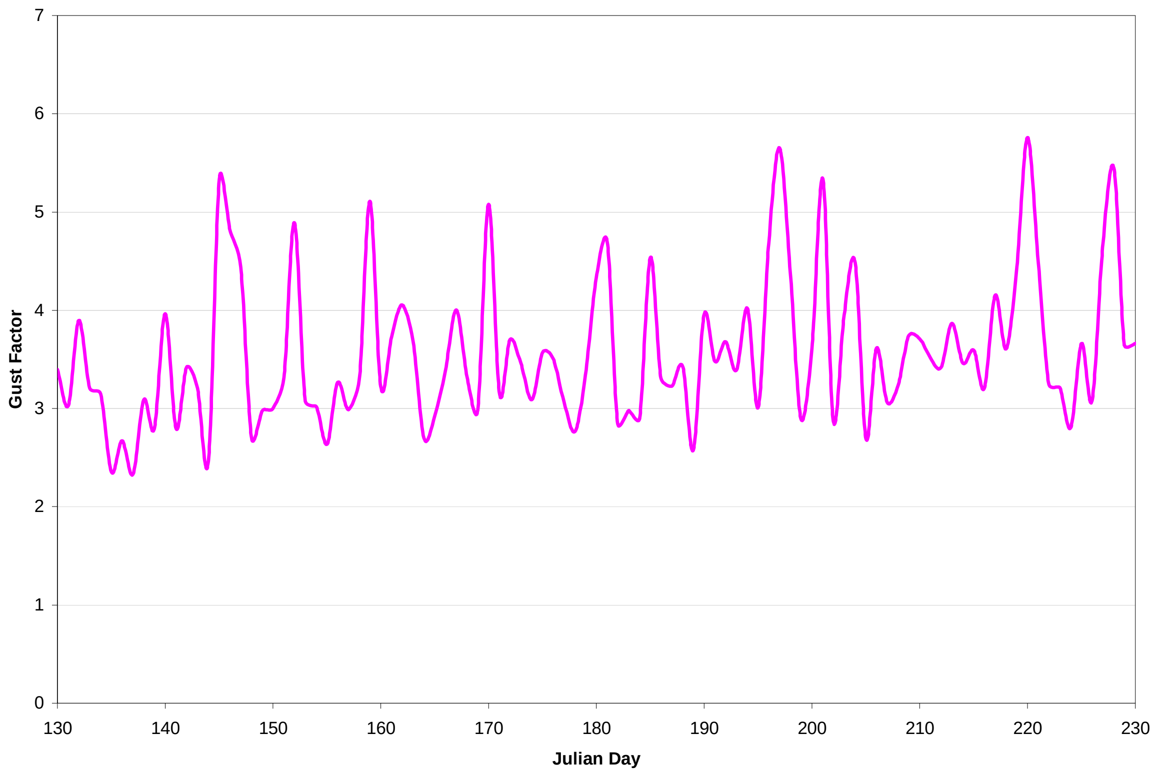


Figure 10. Ratio of maximum wind speed to mean daily wind speed recorded from Loc 1, Palm Harbor, FL during 2006.

As previously outlined, weather stations have been installed within each of the four described location areas. For weather data quality assurance, the calculated ET_o at each station is compared (Figure 11). Station comparison provides a means to ensure sensor accuracy and offers an alternative data source in the event of missing records. Due to local variations in rainfall, different precipitation amounts for each location must be considered when calculating effective rainfall (Figure 11). At the time of this paper submission, weather data was only being collected at three of the four stations.

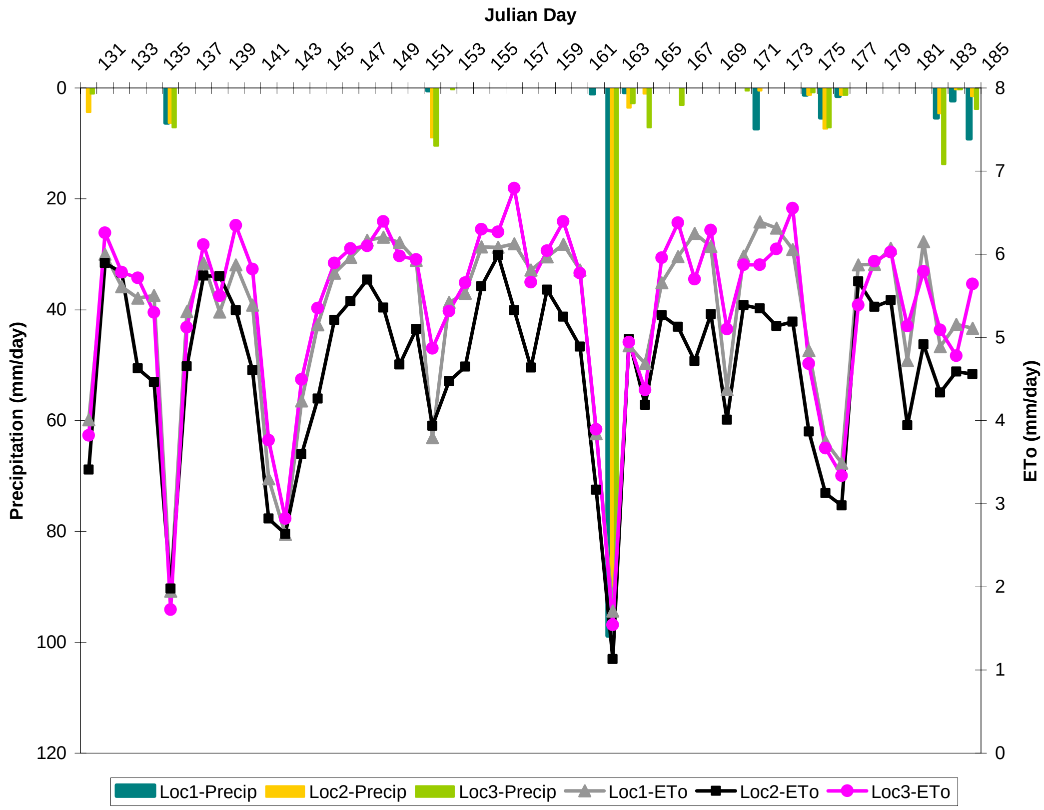


Figure 11. Calculated ET_o and recorded precipitation from Loc 1, Loc 2, and Loc 3, Palm Harbor, FL during 2006.

Initial Water Use Data

Actual water use data collection began in the summer of 2006, initial results can be found in Table 2. Both total household water use and irrigation water use are recorded in gallons on a weekly basis. These data are collected by the Pinellas County Utilities Alternative Water Sources division. The individual households irrigated area is used to convert gallons of irrigation water used to depth (mm) of irrigation water applied. With both the total household water use and irrigation water use recorded from separate meters, it is possible to determine the percentage of water used for irrigation purposes. However, upon initial data collection, it was discovered that many of the city utility meters were in poor condition and required attention to result in proper data collection. Because of the replacement of multiple meters in week 3, the gallon use recorded values were inconsistent and therefore the ratio of irrigation water use to total household consumption is not reported in this paper.

The irrigation water use application depths (Table 2) are compared based on treatment type, with homes within each location serving as treatment replications. Initial findings show the sensor based treatments (T1 includes a soil moisture sensor; T2 rain sensor; T4 having both a rain sensor and educational scheduling materials) to be using less water than the solely time controlled treatment (T3). T3 applied 283 mm of irrigation water in this first month of data collection. As expected, the T1 homes, with the buried soil moisture sensor have the lowest weekly use and have to lowest irrigation application amount in the first month, 12 mm. The two treatments with rain sensors, T2 and T4, have similar weekly amounts, with the month total being slightly lower for T4.

Table 2. Recorded irrigation water use depth per week and monthly total depth applied.

	Actual Irrigation Water Use (mm)			
	T1 $_{avg}$	**T2** $_{avg}$	**T3** $_{avg}$	**T4** $_{avg}$
Week 1	2	9	37	12
Week 2	4	10	126	12
Week 3	4	13	44	28
Week 4	2	12	74	14
Std. Dev.	4	11	40	13
CV	1.28	1.00	0.57	0.78
Month Sum	12	43	283	66

Compared to historical trends in irrigation water use based on a user profile for the sample population (Table 1), the irrigation amounts are within the expected normal values. From these classifications, the minimum monthly irrigation water consumption amount for a "low" user was 20 mm. From this initial actual water use data, T1 falls below the low range, as would be expected. T2 and T4 fall within the lower spectrum of the water use for homes in the "medium" classification. The monthly total for T3 (283 mm) is greater than the maximum for the "high" classification (218 mm).

Future plans

Weekly irrigation water use and continuous weather data continue to be collected. When a sufficient duration of data has been collected, appropriate statistical analyses will be performed on the treatment divisions to quantify differences between water use considering sensor type and the distribution of educational materials. The weather data is downloaded monthly from the weather stations. Additionally, turf quality analysis will continue to be monitored on a seasonal basis. It is expected with the incorporation of soil moisture sensors, rain sensors, and educational materials, to help home owners implement their irrigation schedule; irrigation water application will be reduced.

Acknowledgements
The authors thank the Pinellas-Anclote Basin Board of the South West Florida Water Management District, the Florida Nursery Growers and Landscape Association, the Florida Turfgrass Association, and the Florida Agricultural Experiment Station for funding support. In addition, the authors appreciate the assistance of Bernardo Cardenas, Larry Miller, Danny Burch, Wayne Williams, Mary Shedd, and Stacia Davis.

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Appendix

Table A1. Uniformity test results from irrigation evaluations.

House No.	DU_{lq}	DU_{lq} Rating	House No.	DU_{lq}	DU_{lq} Rating
2860	0.29	fail	486	0.66	good
3620	0.32	fail	252	0.66	good
105	0.33	fail	1694	0.67	good
3013	0.34	fail	4926	0.67	good
325	0.36	fail	4849	0.68	good
3022	0.38	fail	2936	0.68	good
1521	0.44	poor	2196	0.68	good
513	0.44	poor	2980	0.68	good
1543	0.46	poor	128	0.7	very good
217	0.49	poor	101	0.72	very good
633	0.5	fair	3001	0.72	very good
515	0.5	fair	351	0.73	very good
3528	0.51	fair	131	0.73	very good
3037	0.52	fair	2302	0.76	excellent
3135	0.53	fair	2790	0.76	excellent
3906	0.57	fair	148	0.76	excellent
3994	0.57	fair	4881	0.8	excellent
2207	0.58	fair	2954	0.8	excellent
3835	0.59	fair	4958	0.82	excellent
3061	0.6	good	2829	0.83	excellent
2879	0.62	good	3925	0.85	excellent
3040	0.63	good	Min	0.29	
3925	0.64	good	Max	0.85	
2852	0.65	good	Mean	0.61	
3701	0.65	good	Std Dev	0.15	

Table A2. Initial data collection for homes with one month of complete data as on 7/14/2006, water use data presented in mm/wk of irrigation application.

TMT	Rep	Week 1	Week 2	Week 3	Week 4
T1	R1	5	11	0	0
	R2	0	4	7	0
	R3	2	2	0	0
	R4	0	0	9	9
Weekly Average		2	4	4	2
T2	R1	11	21	27	22
	R2	0	0	29	24
	R3	0	0	0	0
	R4	24	20	19	12
	R5	0	0	0	0
	R6	23	23	31	10
	R7	0	0	0	0
	R8	13	18	14	14
	R9	6	5	0	22
Weekly Average		9	10	13	12
T3	R1	42	79	61	76
	R2	14	13	27	27
	R3	36	25	40	40
	R4	0	542	33	410
	R5	94	95	50	31
	R7	77	32	53	21
	R8	29	30	56	3
	R9	0	189	35	3
Weekly Average		37	126	44	76
T4	R1	16	16	23	26
	R2	0	0	0	10
	R3	7	14	39	19
	R4	13	10	32	0
	R5	22	19	47	16
Weekly Average		12	12	28	14

Start-up of a Secondary Water Supply Company and First Phase Design of a Regional System

by

Stephen W. Smith

and

Amy L. Johnson

Abstract. Highland Ditch Company formed the Highland Secondary Water Company (HSWC) as the entity that will provide pressurized untreated water to new multi-use developments within their historical agricultural water service area for new landscape irrigation needs. This case study describes the process from the start-up of the HSWC through the final design of the first phase of their regional pressurized irrigation transmission system.

The Highland Ditch Company participated in the Dual Water Systems Study (which reviewed opportunities for mutual irrigation ditch companies to promote their water delivery service to growing urbanizing areas along the Colorado Front Range by delivering pressurized raw water for landscape irrigation) conducted by Colorado State University and funded by the Colorado Water Conservancy Board.

Aqua Engineering completed a Feasibility Study for the Highland Ditch Company to evaluate the options of providing raw water to new developments. A business plan was developed to evaluate company operations and to determine the water rate structure. The Preliminary Design was developed to serve four initial developments and to be oversized for future developments within a 3-square-mile area.

Meetings and negotiations took place between HSWC and local potable water purveyors. A drought study was conducted to help set forth operational decisions necessary to help preserve the secondary water for both agricultural and urbanized users in future possible droughts. Standards and specifications were produced. Legal agreements were drafted between parties.

The first phase transmission system is currently under design and includes a check structure, ditch lining, pump station, pipeline, and SCADA system.

Introduction

The Highland Secondary Water Company (HSWC) was formed by the Highland Ditch Company as the entity that would provide pressurized untreated water to new multi-use developments within their historical service area (agricultural water delivery) for landscape irrigation needs.

Aqua Engineering has assisted the Highland Ditch Company and the HSWC from before the inception of HSWC. This case study will describe our work with both companies including the process from the concept idea to the start-up of the HSWC and the final design of the first phase of their regional pressurized irrigation transmission system.

Background

The Highland Ditch Company holds direct flow and storage water rights, which are historically used for irrigation water for agriculture. The company's headworks and diversion, and the start of the canal system known as Highland Ditch, are located within the Town of Lyons on the St. Vrain Creek in Northern Colorado. The total service area of approximately 35,000 acres is located between the Little Thompson River on the north and Saint Vrain Creek on the south. The irrigated area served by Highland Ditch and several other incorporated lateral companies is generally surrounded by the communities of Longmont, Johnstown, Milliken, and Platteville.

The Highland Ditch Company participated in the Dual Water Systems Study conducted by Colorado State University and funded by the Colorado Water Conservancy Board. This study involved looking at the opportunities available for traditional mutual irrigation ditch companies to promote their water delivery service to the growing urbanizing areas along the Front Range of Colorado by delivering pressurized raw water for landscape irrigation. After participating in this study (which can be located on the web at http://waterlab.colostate.edu/DualStudy/finished_dualstudy.pdf), the Highland Ditch Company chose to pursue investigating their opportunities by conducting a feasibility study specific to their company and service area.

Feasibility Study

Aqua Engineering was retained to complete a Feasibility Study for the Highland Ditch Company to evaluate the options of providing raw water to new developments. The study included a broad look at the entire historical service area, estimates of development impact, and conceptual infrastructure design. The study was cost-shared by the Colorado Water Conservancy Board. The Feasibility Study was completed in November 2004.

The primary purpose of the Feasibility Study was to examine the opportunity to provide pressurized secondary water to housing developments, parks, streetscapes, and golf courses that are envisioned to be built. Pressurization in and of itself results in a fully modernized canal, even to the extent that the canal may eventually become obsolete and essentially replaced at some point by pressure piping. Urbanization at the current level is expected to occur rapidly over the next 10 to 15 years. Although the potential for urbanization within the Highland Ditch service area is high, it is likely that traditional agricultural will remain a part of the system for some time.

A secondary supply or dual system is basically a utility. Potable water is provided for largely indoor culinary uses and a secondary or "dual system" is provided for primarily outdoor landscape irrigation. A sound engineered approach to secondary water management includes a detailed design of the infrastructure piping and the irrigation system, and due consideration to long-term system operation and management. The provision of secondary supply may also afford significant opportunities for the ditch company to modernize its 100-year-old plus canal infrastructure. Modernization may include structural or operational improvements, or a combination of these, the benefits of which can complement the ditch company's provision of secondary supply for urbanization. This is expected to materially benefit the larger community, in terms of the water conserved in agricultural uses.

Pressurized secondary water is envisioned to be, not only a key canal modernization strategy, but a mechanism for actually sustaining an agricultural economy and setting (i.e. desirable open space areas) under Highland Ditch. The study took the approach of fast forwarding to a complete secondary supply build-out scenario. Consideration was given to the whole system service area and a forecast of the mix of landscape treatments and changing irrigated areas associated with new housing. Several phases have been suggested based on the known development areas and logical boundaries based on system hydraulics. This work was compiled through various elements of work with the Highland Ditch Company, including several site visits and discussions with the Board of Directors (BOD). This study reported on the important elements of a pressurized secondary system for Highland Ditch including:

- A conceptual layout of the secondary supply infrastructure.
- Probable costs of infrastructure design and construction.
- Development and construction approaches.
- Optional funding sources.
- Financial payback, including a forecast of revenues and expenses over the first ten years.

This report provided answers to questions posed by the BOD in sufficient detail to allow the continuance of discussions and hopefully, the ultimate and satisfactory implementation of a pressurized secondary supply system. Secondary supply provides an opportunity for Highland Ditch shareholders, for the potable water purveyors, and ultimately the homeowners under the Highland Ditch service area, to be the long term beneficiaries of secondary water for landscape irrigation.

The conceptualized pressurized pipe system will serve an area of approximately 14,583 acres. The irrigated area is a fraction of the total service area to be irrigated with landscape irrigation systems. These areas include parks, open spaces, rights-of-way, golf courses, streetscapes, commercial lots, schools and public spaces, multi-family housing areas, and individual residential lots. For the water requirement elements of the study, it was assumed that the actual irrigated area was 30% of the service area, or about 4,375 acres. Experience has shown that irrigated area can range from 20% to 40% of a development site, which is a function of the type of construction and local development and landscape requirements. Considering a mixed land use development, the assumption of 30% of the total area irrigated was assumed to be reasonable for this study.

The seasonal irrigation requirement for turf is approximately 28 inches in the project area. The total required flow rate to irrigate 4,375 acres within a 12-hour watering window is approximately 59,820 GPM during peak season (typically in July).

Conceptual design of a transmission system was developed and included preliminary calculations for water storage, pump stations, and pipeline networks. For this feasibility study, the BOD envisioned two major phases based on the known and anticipated development plans in the area. The first Phase, Phase I, was anticipated to be a 3-mile radius circle, centering on Highway 66 and I-25. Phase II is anticipated to be about a 3-mile radius area on the northern end of the service area, just south of Johnstown and Milliken. Additionally, smaller phases would cover the outlying areas to the west (Phase III) and to the east (Phase IV). Phase I includes 1,400 acres or irrigated area, Phase II includes 1,250 acres of irrigated area, Phase III includes 1,300 acres of irrigated area, and Phase IV includes 450 acres of irrigated area.

Two storage reservoirs and two pump stations are proposed to service the landscape demands throughout the area. Currently, the Highland No. 3 Reservoir, which is located near the southwest corner of Highway 66 and I-25, is envisioned as the first reservoir on the system for

Phase I. This reservoir is fully owned by the Highland Ditch Company. Utilizing the existing reservoir is a logical component to this system because it is at the heart of the development in Phase I, is owned by the Company, and has established storage rights. This "transmission network" was conceptualized in order to understand, on a preliminary level, how much pipe is needed, where pipe is to be installed, and what the size and cost might be. A hydraulic model was developed to determine the optimum pipe sizing based on the developed pipe routing and existing and proposed reservoir locations. Both pump stations contribute to the total flow rate for the pressurized irrigation system. It is assumed that both proposed pump stations operate simultaneously. Each station will include some redundancy to allow for maintenance of the pumps and motors without disrupting the service flow rate.

The Phase I pump station was proposed to be located at Highland No. 3 Reservoir. Output from the hydraulic model requires approximately 32,000 GPM at a discharge pressure of approximately 116 PSI. The total required horsepower is anticipated to be approximately 3,200 HP. Eight pumps, each with 400 HP motors, are proposed for this pump station. Four skids, each capable of 8,000 GPM, would be required to meet the total demand of the secondary supply system at build-out level.

The Phase II pump station will be located at the proposed new reservoir near the head of the Erkenbeck Lateral. Output from the hydraulic model requires approximately 28,500 GPM at a discharge pressure of approximately 106 PSI. The total required horsepower is anticipated to be approximately 2,600 HP. Seven pumps, each with 400 HP motors, are proposed for this pump station. Four skids would be required to meet the total demand of the secondary supply system at build-out level from this station with three skids capable of delivering 8,000 GPM and a single skid capable of approximately 4,500 GPM.

The Opinion of Probable Construction Cost was developed for the build-out scenario of a pressurized secondary supply system in the Highland Ditch service area. The grand total Opinion of Probable Construction Cost for Phase I was found to be approximately $12 million (including 10% contingency and 10% engineering fees). The grand total Opinion of Probable Construction Cost for Phase II was found to be approximately $12.4 million (including 10% contingency and 10% engineering fees). Including two other future phases that would mainly involve piping systems, the grand total estimated cost of the proposed secondary supply system for the identified area was found to be approximately $32.4 million.

Based on the findings of the Feasibility Study and the development pressures in the vicinity of the proposed Phase I secondary supply system, the Highland Ditch Company proceeded to further the evaluation of this system. A White Paper was written to summarize the Feasibility Study and to provide this information to interested participants for support of the next level of Preliminary Design.

Preliminary Design

Three developer participants and the local school district were included in the initial Preliminary Design. This became the first phase of the overall plan. The Preliminary Design was developed to serve these initial four sites and to be oversized for future developments within a 3-square-mile area. The results of this Preliminary Design were furnished to the participants in a memorandum in March 2005.

Phase 1 of the HSWC is shown in Figure 1. This area was modified from the Feasibility Study based on the participant input and further estimation of the immediate growth areas. Phase 1 is approximately three miles by three miles bounded by I-25 on the east, Colorado State Highway 66 on the north, and roughly Colorado State Highway 119 on the south. Phase 1 was broken down into Phase 1A and Phase 1B. Phase 1A includes the developments that have been working with HSWC during the Preliminary Design process and have committed to the advancement of this project to date.

The peak season daily water requirement was calculated for the anticipated build-out in Phase 1 and each development in Phase 1A. The total anticipated irrigated acreage in Phase 1 is approximately 1,530 acres. This area was calculated based on the known irrigated acreage presented by the Phase 1A developments, and an assumption that 40% of the total land area of each development would be irrigated. The known and assumed irrigated area in Phase 1A is approximately 345 acres based on preliminary information provided by each development company.

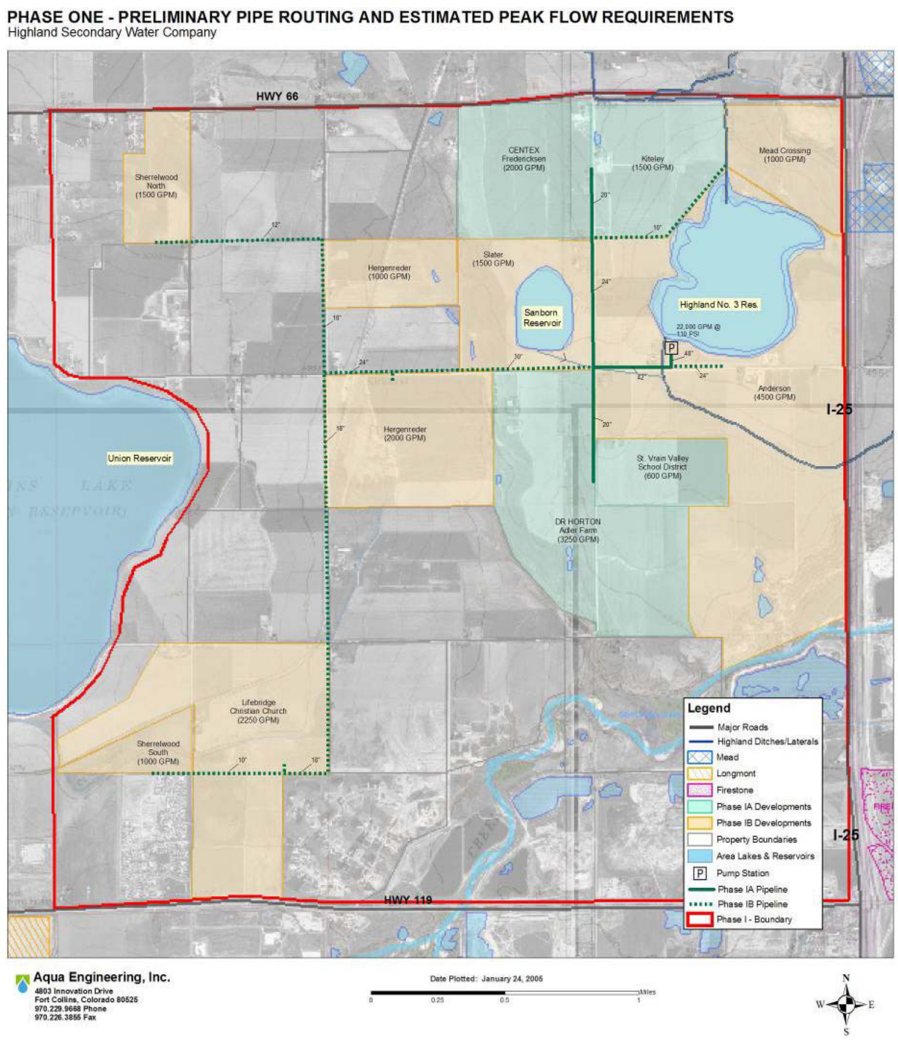

Figure 1. Phase 1 boundary refined during Preliminary Design

The water use requirements were calculated for the Phase 1 build-out and for the Phase 1A needs. The recommended pump size for Phase 1 is 22,000 GPM which correlates to two different calculation methods used: the estimated peak season flow rate for a total irrigated area of approximately 1,500 acres and the estimated sum of the peak season flow rate for each of the proposed or assumed developments of Phase 1, based on total irrigated area for a 12-hour watering window. The Phase 1A estimated flow rate was determined to be 7,350 GPM.

The pump station will include multiple pumps to provide a range of required flow rates, from incidental watering needs to the peak day demand. The pump station will consist of multiple pump skids that include vertical turbine pumps capable of supplying the required peak season flow rate at the set pressure. The main pumps will be controlled by variable frequency drives (VFD) to provide constant pressure to the system.

The Phase I pump station will have a build-out flow rate of approximately 22,000 GPM at a discharge pressure of approximately 110 PSI. The proposed station includes four pump skids each rated for 5,500 GPM. Each of the skids would include 4 vertical turbine pumps at 150 HP. The initial pump skids will also include smaller pumps to maintain system pressure and meet the low flow demands. The total required horsepower is anticipated to be approximately 2,340 HP. For Phase 1A, two skids will be required for a total flow rate of 11,000 GPM (7,350 GPM required). As additional demands are required, the additional two pump skids will be added to the pump system.

An intake structure is planned to be located in the storage reservoir (Highland No. 3 Reservoir, owned by the Highland Ditch Company) and will help prevent large debris from entering the pump system. The intake screen will be connected to a concrete wet well located below the pump system and building.

A hydraulic model was developed to determine the optimum pipe sizing based on the developed pipe routing and pump station location. Anticipated flow demands in the system were assigned to nodes on the pipe network. The pipe material used for transmission system includes C900 and C905 pressurized PVC pipe. This pipe material is typically used for municipal waterlines and is rated for installation in roadways. The transmission piping will end at the entrance to each development. A master meter will be installed as part of the HSWC system. Downstream of the master meter, the secondary supply distribution system will be installed for the development.

The Opinion of Probable Construction Costs was developed for the Phase 1 build-out scenario as well as the Phase 1A initial system. Acquisition of easements has not been included in the cost estimates because easements will be required from each developer to route the pipe to their development. The estimated construction cost (including contingencies and engineering fees) for Phase 1 was found to be approximately $7.9 million. The Phase 1A estimated construction cost was found to be approximately $3.6 million because of the minimal, initial pipe network and only installing the first two pump skids. Proportional costs were calculated to determine how much each developer and the school district would be required to contribute in order for the project to proceed. The proportional cost was based solely on the anticipated flow rate (GPM) compared to the combined flow rate of Phase 1A.

During the Preliminary Design, preliminary Rules and Regulations were drafted to establish how the end users and the HSWC would work together. These will be completed in the final design phase. Additionally, HSWC Standards and Specifications were produced for the development’s distribution systems that would connect to the main transmission system. These standards outline the requirements for the distribution system within each development, in order for HSWC to accept the system after installation. Considerations such as pipe material, burial depth, and location are outlined in the standards.

The outcome of the Preliminary Design and the positive responses of the participants was evidence that HSWC should proceed and the next step was for the newly formed company to develop a Business Plan.

Business Plan

The Highland Secondary Water Company (HSWC) was formed by the Highland Ditch Company BOD in January 2005 for the purpose of providing secondary water for landscape irrigation to residential developments within the historical service area of the ditch company.

After the HSWC was formed, a business plan was developed to evaluate the operations of the company and to help determine the water rate structure. Development of the business plan involved input from a former manager of a similar company in Utah. The intent of this business plan was to help HSWC further refine their approach for operating the company. The business plan was complete enough for the company to begin operation, and should be updated on a continual basis to monitor current and future operation. Four basic financial forms were developed as part of this business plan:

- Buildout
- Income Statement
- Cash Flow Analysis
- Break Even Analysis

The members of what is now the Highland Secondary Water Company, with the assistance of legal counsel, filed with the Secretary of State of Colorado to do business as a Limited Liability Company (LLC). Current Highland Ditch Company owners of record will be provided with four shares of the Highland Secondary Water Company shares for each share of Highland Ditch. So, in other words there will be a 4:1 issuance of stock in HSWC on the basis of Highland Ditch shares. Figure 2 illustrates this process.

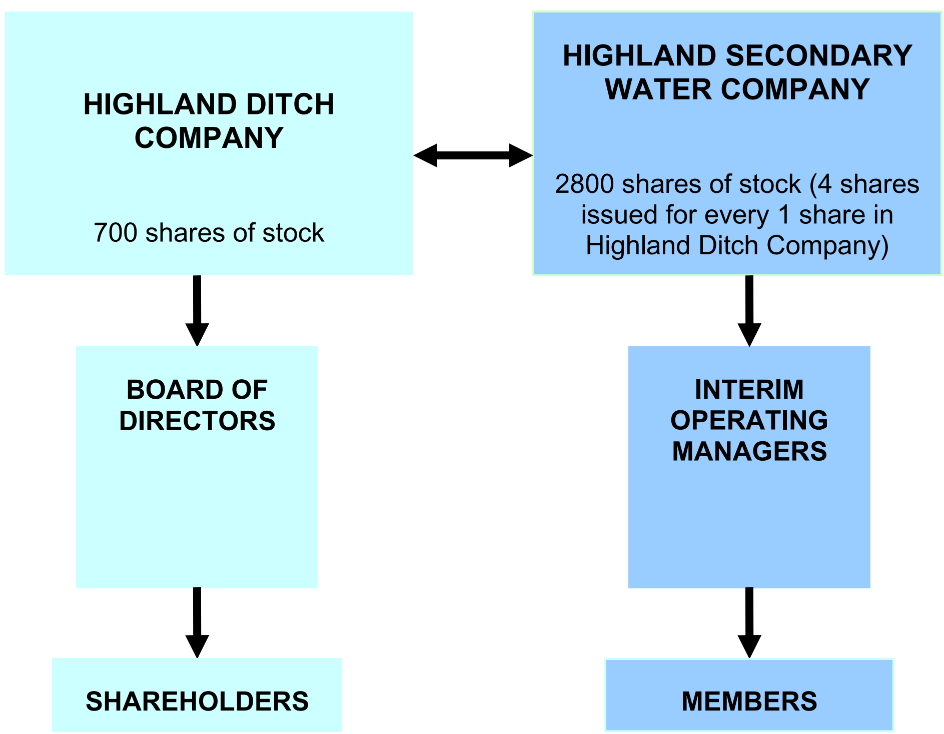

Figure 2. Flowchart for issuance of HSWC stock.

Stock in the new company is not tied to land or the Highland Ditch Company shares, and can be sold on the open market like other stocks. Specifics regarding voting, annual meetings, and company membership and management are yet to be determined for the HSWC.

For the current financial model, it is assumed that HSWC's average water bill will be approximately 80% of a comparable bill from the local potable water purveyor, Longs Peak Water District. The basis for this assumption is that:

- Secondary water supply customers will benefit financially in the form of lower water rates for non-potable water.
- The water rate structure will adequately cover the operation and maintenance costs of the HSWC, even during times when water use on landscapes significantly decreases, such as during extremely wet years and during drought conditions

The water rate structure developed for the financial model assumes a monthly base rate and consumption rate per 1,000 gallons of water consumed for both residences and open space. To insure an adequate cash flow throughout the year, the base rate was assumed to be charged to customers 12 months of the year. The consumption rate is only to be charged during the irrigation season when water is consumed. This approach allows for more adequate cash flow to the HSWC and more evenly distributes the cost of non-potable water to customers.

In the financial model, a base rate of $20 per month was selected for residential use (1-inch tap) and $45 per month was selected for open space use (2-inch tap) because these amounts will adequately cover the fixed costs of operating and maintaining the system, even in years when little to no water is consumed such as during a drought. In the financial model, the consumption rate for both residential and open space uses was selected to be $1.75 per 1,000 gallons of water consumed. Longs Peak consumption rate for potable water is $2.73 per 1,000 gallons. For a typical residential lot, the HSWC water rate structure would amount to an annual fee that is equal to 80% of the fee that would be charged under Longs Peak Water District. This assumes that a typical lot is approximately 10,000 square feet of gross area with approximately 3,500 square feet of irrigated bluegrass – for an average annual consumption of 61,000 gallons. Rates to be charged to homeowners will generate the funds to operate and maintain the system. A projected or pro forma Income Statement was developed and shows in detail the expected revenues and expenses of the company. The Income Statement shows that after the start up transitional years, revenues will be generated to offset expenses and leave a good profit. However, during the start up year, the company will incur expenses to run the system while the revenue will begin to come in gradually. This provides a challenge which will require careful planning on the part of the HSWC managers.

For the first two years, a breakeven analysis is provided, which shows how many houses must be built and serviced for financial breakeven. It is probable that additional costs will be incurred which are not now known, which will decrease the profit projected. Having a large indicated return gives plenty of leeway for additional expenditures. Regarding monthly Cash Flow in the first year, it should be noted that some adjustments may be necessary to balance expenses against income.

The results show that for the given assumptions, operation of the HSWC is feasible in the short-term and almost certainly highly profitable thereafter.

Legal Agreements and Negotiations

For the first Phase of the HSWC regional transmission pump system, three primary agreements have been executed or are in process: Franchise Agreement with the Town of Mead (the first developed was annexed in to the Town), Agreement with the Longs Peak Water District, and Service Agreement with the developer.

Meetings and negotiations took place between the HSWC and potable water purveyors in the area. To mutually benefit all parties, the potable water purveyors were contacted to help establish reduced water rate turnover requirements from the developers when a secondary water supply system was implemented. Actual ownership of the raw water shares was also a critical component to the systems. The pending agreement with Longs Peak Water District is based on the amount of water that will be turned over for secondary supply systems servicing individual residential lots, or other lots where a potable water tap would usually provide irrigation water. For parks and open spaces, HSWC will own the water rights.

The Franchise Agreement with the Town was required by the Town in order for the HSWC distribution system (paid for and installed by the developer, then turned over to HSWC after completion) to be located in the streets of the development. The agreement requires that HSWC provide the Town with a certain annual percentage of their income from operating this system. This payment is anticipated to be used for repairs of the Town street in the event that the HSWC system causes problems that HSWC does not repair.

The agreement between HSWC and the developer sets the stage for the relationship between the two entities, outlines the service commitment that HSWC is providing, and establishes the details of how the systems work. An example of some of the information contained in this agreement is the intended operation dates of the pressurized secondary supply system: "May 15th through September 30th, unless HSWC, in the reasonable exercise of its discretion modifies the season of use as a result of unusual climatic conditions." The initial water rates are also outlined in this agreement.

Drought Study

A drought study was conducted to help set forth the operational decisions that would be necessary to help preserve the secondary water for both agricultural and urbanized end users in future possible droughts. The drought study presented a conceptual drought response plan for the Highland Secondary Water Company. A drought response plan includes indicators and associated responses that can be used in future drought years to more effectively manage water use under the secondary supply system. A drought plan defines what various drought indicators (such as reservoir levels) should trigger what drought response mechanisms (such as mandatory landscape watering restrictions). The drought study was developed to provide a road map that the HSWC can use in future drought years to insure effective and equitable management of their water resource. Specifically, the plan discussed:

- An analysis of historical Saint Vrain basin droughts and Highland Ditch Company diversions during key drought years.
- A forecast and analysis of landscape water requirements at urbanization build-out for Phase 1A development.
- Determination of conceptual drought indicators and measurements.
- Development of conceptual drought response mechanisms.

The drought plan concluded that:

- Drought indicators for both river water and reservoir water should be considered to help determine future drought conditions.

- A review of historical stream flows and diversion records for the Saint Vrain Creek and the Highland Ditch indicate four levels of drought conditions (1976, 1955, 1966, and 2002 – in order of increasing drought severity).
- A hypothetical evaluation of HSWC Phase 1A developments indicates that drought response mechanisms should more specifically target late season water demands, which are on average large compared to historical storage water availability.
- Landscape plantings other than bluegrass may help to reduce the critical late season demand.
- Drought response mechanisms should be further evaluated relative to drought indicators to determine what mechanisms most effectively reduce demand.

Final Design – Transmission System

The first phase transmission system is currently under design after being modified to meet the needs of one initial development and the school district. The first developer committed to funding the final design and the capital cost of the transmission system. Many components in the system are being designed for future needs (intake system, building, and electrical service) and many components are being sized only for the initial users (first pump skid, pipelines). Construction of the transmission system is expected in the winter of 2006 for service in the spring of 2007

The final design includes improvements to the existing reservoir outlet ditch, an intake and wet well structure; the Phase 1A prefabricated pump skid, oversized building and floor slab, and pipe system. The intake system, pump system, and building concepts were revisited and several new ideas were incorporated into the final design. These changes will allow the Phase 1A system to be installed and provide water to the initial participants. As future participants join the system, modifications to the infrastructure and expansion will be required.

The pipes have been sized to serve the initial two participants and another development (as requested by the first developer, the second development has been included based on their discussions that they will join the system but they didn't have the capital to be involved in the design and construction of the transmission system presently). As future participants join the system, pipe sizes or looping requirements will have to be increased in order to add capacity to the infrastructure. System expansion, as well as system changes, will be the requirement of future secondary supply system participants. The following significant changes allowed a reduction in the Opinion of Probable Construction Cost to less than $2 million for Phase 1A.

A system concept change was made regarding the intake system and pump station placement. Rather than constructing an intake assembly in Highland Reservoir #3 and raising the finished grade of the property on the southwest corner of the reservoir to bring the pump station to the necessary elevation, an alternative approach was agreed upon. The existing 36-inch outlet pipe from the reservoir appears to have available capacity that can be used to take water from the reservoir for Phase 1A. The new intake system and pump station will be installed on the existing outlet ditch. Eventually, the intake pipe from the reservoir will need to be enlarged for future phases. By proceeding with this option, work around and through the existing dam will not be a factor in this phase of the project, reducing costs and eliminating reviews by the State Engineer's Office.

Rather than construct the building for the build-out size (approximately 25 ft by 75 ft), a 25 ft x 30 ft steel building will be designed to house the first pump skid. As the system grows, the steel building can be expanded.

The pipe sizes from the pump station to each participant's property have been reduced. From the pump station, a 24-inch C905 PVC pipe is proposed west to WCR7. This pipe is designed to carry 4,550 GPM (1,900 GPM to the first development, 1,900 GPM to the future second development, and 750 GPM to the school site). From the intersection of WCR 7 and WCR 28, a 10-inch C900 PVC pipe is proposed to the school site and a 20-inch C905 PVC pipe is proposed north to the development properties.

The pump station will be designed as pre-fabricated, skid-mounted stations including the main pumps, pressure maintenance pumps, variable frequency drives, piping, valves, and electrical controls. Automatic filtration will also be included on the skid, downstream of the pumps. This filter will prevent debris from entering the irrigation systems and help avoid clogging sprinklers or valves. The pump station will be composed of several pump "skids" in order to meet the required total flow rate being pumped and to allow for incremental phasing as the system grows. The Phase 1A pump skid was reduced to only provide water at a rate of 4,550 GPM for the first three participants. This is smaller than the original proposed single skid sizes of 5,500 GPM. Therefore, future skids may be larger than 5,500 GPM to still meet the build-out demand with a total of four pump skids. A SCADA (Supervisory Control and Data Acquisition) system has been included to provide remote monitoring and control as desired by HSWC.

Conclusion

The Highland Ditch Company formed the Highland Secondary Water Company as the entity that will own, operate, and maintain a new regional secondary water supply transmission and distribution system. The secondary water system will provide pressurized irrigation water (non-treated) for landscape irrigation purposes to multi-use developments and a local school site.

This paper described the work that has been completed from the beginning Feasibility Study concept designs through the final design (currently in process). Engineering designs and studies and legal agreements are all covered as part of the process that were required for this project.

Acknowledgements

The authors would like to acknowledge the Highland Ditch Company Board of Directors and the Highland Secondary Water Company Mangers for their ownership of this project and their foresight in planning a regional secondary water system that will benefit their current and future water users.

Rain Water Irrigation in Toronto

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Bay Blorview Children's Centre is being torn down. New building right from the ground up to the 11 rooftop gardens is coming. An eloborate reclaimed water irrigation system has been designed. All the water will come from rain collected onsite and stored in a 80,000 gallon cistern.

Rooftop gardens will utilize low volume drip tubes controlled by soil moisture sensors. ET data for automatic scheduling will be supplied from a ET station. Trees, watered individually with micro bubblers while strip planter will utilize dripline, mulched to achieve a high retention level resulting in a highly efficent irrigation system.

The irrigation mainline will be connected to the city water supply only to be utilized if the cistern runs dry. The cistern has been sized to be able to supply water up to 90 days before running out.

If their was such a long dryspell, the building automation system would receive a low level signal. This would signal the cisterns pumps to be turned off. The city water supply would be opened when the next watering cycle occured. A check valve at the cistern would prevent the city water supply from filling the cistern with city water.

Water Utilities: Influencing the Smart Controller Market

Scott Sommerfeld
East Bay Municipal Utility District, Oakland, California

Since the mid nineteen-nineties, water agencies have tracked the development of a new generation of smart irrigation controllers that have the potential to save time, water and money by automatically adjusting the amount of water applied to the landscape according to changes in the weather. Landscape irrigation is the single largest end use of water in California's urban sector. One third of all urban water (residential, commercial, industrial and institutional) is dedicated to landscape irrigation and over half of residential water is applied to landscapes. Thirty-six states anticipate that even under average conditions, they will experience freshwater shortages in the next ten years. Capital and environmental costs of building additional storage are dramatically higher today than in the past. Today water conservation is the most inexpensive and responsible way to extend water supply needed for new customers. In California it is estimated that 1,000 to 2,000 million gallons per day (MGD) of water demand will be supplied through conservation measures over the next twenty years. Manufacturers claim that weather-based irrigation controllers (WBICs) can save twenty to forty percent of the water currently being applied by traditional controllers. Water agencies hope this new generation of smart irrigation controllers will help achieve a portion of the savings needed to meet the future water demand.

East Bay Municipal Utility District (EBMUD), located in Oakland, California, received a $1.6 million California Department of Water Resources (DWR) grant to provide financial incentives for 2,600 WBIC retrofits in pre-qualified residential, commercial, industrial and institutional landscapes by October 2008. EBMUD is lead agency and one of six northern California partner agencies participating in this three-year program. Controller installations began in September 2005 in the service areas of EBMUD, Alameda County Water District, Contra Costa Water District, City of Davis, Santa Clara Valley Water District, and Sonoma County Water Agency. At the same time, Metropolitan Water District of Southern California (MWD) received a similar $1.7 million grant as lead agency for 18 southern California water agencies with plans to install 5,500 WBICs. To date, these two California programs represent the largest effort to distribute and evaluate emerging WBIC technology. The DWR grants include funds for a consultant to analyze product performance, customer satisfaction and the effectiveness of the States 24 water agency distribution and marketing programs in a final report. Although the primary purpose of the DWR grants is the ambitious goal of saving fifty-thousand acre feet of water over an assumed 10 year useful life of the combined total of 8,100 controllers, these two programs also seek to accelerate market transformation of this emerging smart controller technology.

Will WBICs be an effective water conservation tool?

Pilot studies conducted in California, Colorado, Utah and elsewhere show that if WBICs are installed and programmed properly, water savings are achieved. However, questions remain, as to whether WBICs will actually save water outside of professionally controlled pilot studies and whether WBIC programs will produce the savings manufacturers claim and water agencies hope for. Unlike many indoor water conservation measures such as the installation of ultra-low-flow-toilets (ULFTs), outdoor water conservation measures are much more difficult to implement. Indoor savings are virtually guaranteed when a piece of hardware using more water is replaced with a piece of more efficient hardware that does as good a job (or better) with less water.

Traditional irrigation timers are just clocks that turn the irrigation on and off according to a pre-set schedule regardless of whether or not the landscape actually needs to be watered. As a result, plants are often watered too frequently and for too long. Before WBICs were introduced to the marketplace, outdoor water savings relied on the customer actively adjusting the irrigation timer as the seasons changed or in response to unseasonably high or low temperatures. To achieve outdoor savings, some water agencies provided educational consultations to teach customers how to properly program and adjust their irrigation controllers. Water savings from educational consultations vary widely based on the skills of water agency staff in communicating recommendations and how well customers understand and implement them. Traditionally, outdoor water savings have been more difficult to achieve than indoor savings because it is harder to change a person's behavior than to change a piece of hardware.

Achieving outdoor water savings is made even more difficult by the fact that it is not just controller management that accounts for water savings. Poor quality in the irrigation design, installation and routine maintenance can reduce water savings potential significantly. The sprinklers in older and poorly designed irrigation systems often overspray pavement. Less commonly observed, but just as wasteful, is the unintentional over-spray from one planting area into an adjacent planting area resulting in areas being watered twice. Uneven sprinkler spacing and zones that have different types of sprinklers installed on the same circuit create wet and dry areas. The circuit must run long enough to keep the driest area green, even if it is only a small area, resulting in wasteful over-watering in the rest of the zone. Although traditional timers can be programmed to minimize run off, they seldom are programmed correctly and water is commonly seen running down the curb and into the storm drain even in newly completed projects. In spite of the complicated nature of landscape irrigation and all the limitations that rightfully should be considered when developing an incentive program, this author believes there is enough evidence to support manufacturer's claim that WBICs can be an effective water conservation tool.

WBICs could be the single most cost effective outdoor water savings recommendation

The fact that WBICs may be able to simplify water management and minimize or eliminate over-watering and run off issues inherent with traditional irrigation controllers are key reasons why water agencies are interested in promoting this technology. Smart controllers are designed to apply the right amount of water at the right time and in a manner that reduces wasteful run off that can carry harmful lawn and garden chemicals into nearby waterways. Although, it is unlikely that the water savings on sites with poor design, improper installation and deferred maintenance will be as great as the water savings on well designed sites, some savings are still possible because WBICs automatically make program adjustments much more frequently and accurately than traditional controllers. In addition, WBICs are easy to program, convenient to use and save time since they don't have to be manually reprogrammed every time the weather changes. Retrofitting a traditional controller with a WBIC, and properly programming it, could be the single most cost effective outdoor water savings measure a water agency can recommend. The reason for this is that good irrigation management can save water even on a poorly designed system and the cost of upgrading the controller is usually far less expensive than upgrading a poorly designed system. Irrigation upgrades require specialized knowledge that few contractors currently possess and often involve digging up portions of the landscape. None the less, irrigation upgrade programs that provide education or additional financial incentives to correct system deficiencies will enhance water savings and compliment WBIC incentive programs. To assure that an adequate workforce with knowledge of water conservation practices is available to customers, water agencies should encourage the development of certification programs. Certification programs are necessary to promote and enhance WBIC programs, raise irrigation industry standards and to increase the pool of contractors with the specialized knowledge necessary to upgrade irrigation system efficiencies.

A not well known but very significant side benefit of smart technology is that WBICs not only have the potential to save water and protect the environment; they also have the potential to save energy. Seven to eight percent of California's energy use is consumed moving water from the northern third of the state where most water is collected and stored to the southern two thirds of the state where the majority of people live. If consumer end uses are included such as heating water and agricultural pumping, nineteen percent of California's electrical and thirty-nine percent of the States natural gas energy loads are related to water and could be reduced through more efficient irrigation. Since installing WBICs can reduce energy demand by using less water to irrigate the landscape, water agencies should explore the possibility of funding WBIC programs with grants provided by power companies. More importantly, if the public can see the energy connection with water savings it could be a helpful supporting influencer in their decision to adopt this smart technology.

Influencing the smart controller market

At the Irrigation Association International meeting in 2002, ten water agencies (including EBMUD) engaged irrigation manufacturers in a discussion with the purpose of influencing manufacturers to build more water conserving products that would reduce irrigation waste. The manufacturers thought they were already building products that saved water and that the real issue was that water agencies were not doing enough to educate the public in how to use existing technology. At the time there were only a few start-up companies producing WBICs for the commercial and residential markets. Established manufacturers seemed to view emerging WBIC technology with skepticism.

The formation of the Smart Water Application Technology (SWAT) committee was an outcome of this initial and several subsequent meetings. Although the purpose was to promote all water saving technology, the initial focus was clearly on WBICs and their moisture sensor counterparts. The committee quickly established two sub-committees, the first to produce test protocols to measure the water saving claims of WBIC manufacturers and the second to promote market transformation of WBICs and other water saving technology.

Test protocols were important because the last thing water agencies needed was a repeat of the debacle that occurred with the introduction of ultra low flow toilets (ULFTs). Some early models did not perform well and to this day some people believe ULFTs do not perform as well as higher water using models. The Center of Irrigation Technology (CIT), under the direction of the SWAT committee, created protocols for testing both climate based controllers and soil moisture sensors. Many believe that independent testing of these products will enhance consumer confidence. The mission of the SWAT market transformation sub-committee was to create demand for water saving technology so manufacturers would compete in the marketplace to produce high quality water conservation products. The committee produced generic marketing materials that can be customized by any water agency wanting to implement WBIC programs in their service areas. EBMUD was one of the first agencies to modify these materials for its targeted direct mail marketing program to 30,000 residential and commercial customers using more that 750 gallons per day for irrigation. The centerpiece of the suite of marketing materials is the brochure which is reproduced in Figures 1. and 2.

Making customers aware of WBIC technology and benefits

EBMUD contracted with the same marketing firm that produced the SWAT marketing materials to explore alternative ways of reaching and communicating with target residential and commercial customers. This effort was specific to EBMUDs individual program but the information was shared with the other five northern California partners. Key to getting EBMUD customers to participate in a WBIC program is convincing them that they can save a specific amount of money on their water bill by using a WBIC and how long their payback period would be. In addition, it was important to assure the customer that the WBIC would allow their landscape to remain healthy and flourish and to view customers as responsible people wanting to do the right thing rather than people negligent of wasting limited water resources. Probably the biggest challenge is that most customers are not even aware of WBIC technology, WBIC water saving potential and other WBIC benefits. The research indicated that public agency programs lend credibility to products and will likely improve acceptance. EBMUD expects their marketing plan and materials will be useful tools to help introduce WBICs to customers who know very little about them and to inform them about the benefits. Another interesting finding was that both residential and commercial customers relied on landscape professionals to advise them if a WBIC was a worthwhile investment. EBMUDs market research report with specific recommendations for messaging and product positioning is available for review by contacting ssommerf@ebmud.com.

Six northern California WBIC programs compared

Providing a financial incentive for customers to replace their traditional controller with a new smart controller is the most direct way water agencies can influence the smart controller market. Table 1 on the next page compares six different northern California incentive programs. All northern California programs target high water using customers which was necessary to make the programs cost effective and to meet the water saving goals of the DWR grant. Some agencies qualify customers based on consumption while others use minimum square feet of irrigated area. One agency only targets customers that previously used their large landscape upgrade program. A few agencies limited the choice of eligible manufacturers by using a competitive bid process for the manufacturer selection and other programs allow any manufacturer to participate.

Table 1. Comparison of six northern California WBIC programs:

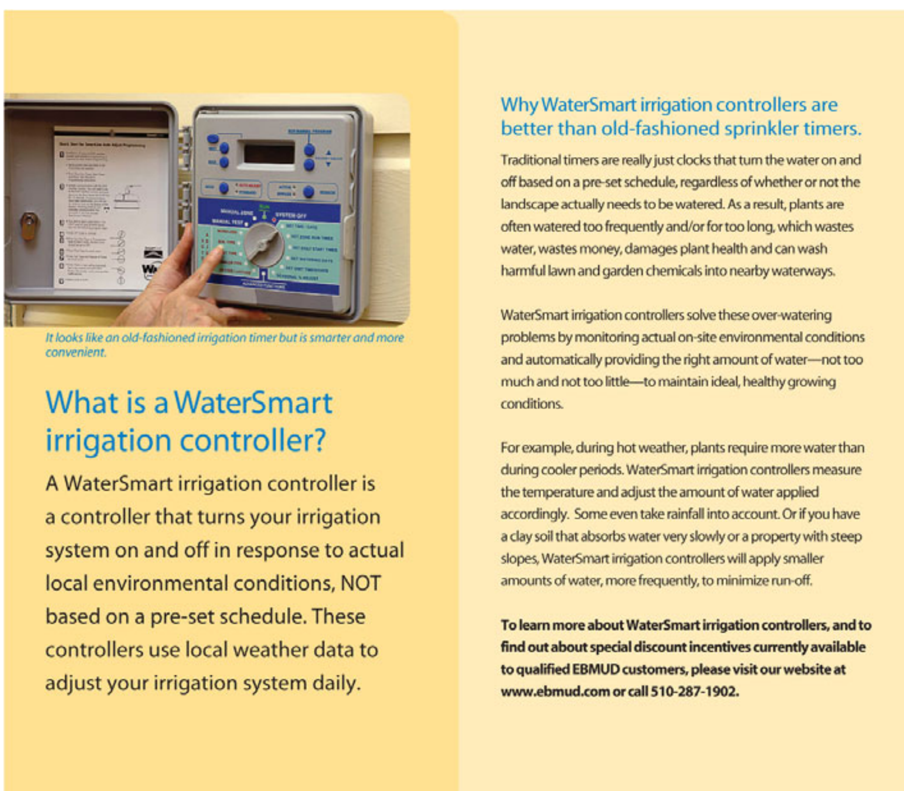
Agency	Incentive Type	Eligible Technology	Incentive Amount	Installation Method
East Bay Municipal Utility District (EBMUD)	Targeted voucher for both residential and commercial customers using more than 750 gallons per day for irrigation.	All technology that posts SWAT performance reports on web site.	50% of controller cost up to a maximum voucher amount based on gallons per day of irrigation use, three tiers: Max voucher/irrigation use (gpd) 1: $300/750 to 2,999 2: $600/3,000 to 5,999 3: $1,200/> 6,000	Self install or referral to manufacturer's certified professional. Customer pays for installation
Alameda County Water District	Targeted rebate for residential sites with at least 1500 square feet and for commercial sites with at least 40,000 square feet of irrigated landscape that includes at least 25% turf	All technology, no restrictions	Residential: full cost of controller up to $475 per controller Commercial: full cost of controller up to $1220 per controller	Direct install. Agency pays for installation by installer contracted by agency
City of Davis	Targeted rebate for residential customers with use greater than 25 % of average per square foot of lot size and commercial rebate to schools	Hunter and Weathermatic only	$169 per residential controller Commercial rebate to schools to be determined	Self install, customer pays for installation
Contra Costa Water District	Targeted rebate for both commercial and residential	All technology, no restrictions	Based on number of active stations up to 100% of controller cost: Residential: $25 / station with 4 station minimum Commercial $40 / station	Self install, customer pays for installation
Santa Clara Valley Water District	Targeted installation program for both residential and commercial	Aqua Conserve and Hydropoint only	50% of controller cost up to a maximum	Direct install, agency pays for installation by installer contracted by agency.
Sonoma County Water Agency	Targeted rebate for both residential and commercial	All technology that posts SWAT performance reports on web site	Residential: 50% of controller cost up to $300 plus 100% of 5 years of pre-paid signaling fee up to $150. Commercial: 12 to 24 stations 50% up to $700 and >25 stations 50% up to $1,100, no commercial rebate for service fees	Self install, customer pays for installation

Note:

The cost of financial incentive programs varies depending upon the program design. Incentives can be set to match expected utility cost savings and avoided costs of providing new supply.

Figure 1. Brochure (Outside)

Figure 2. Brochure (Inside)



Two agencies allow any manufacturer whose products have been tested by SWAT. The incentive amount varied widely among the six partner agencies. Some agencies offer the controller and the installation for free while others require the customer to make a co-payment. To make the incentive cost effective some agencies link the maximum amount of the rebate to how much water the customer is currently using for irrigation. One agency calculates the rebate based on the number of active controller stations to provide a larger rebate for larger sites with more stations. Other agencies simply base the rebate on whether the program participant is a residential or commercial customer.

The relative success of various installation methods will be interesting to look at in the final evaluation report. Installation method may significantly impact the percent of potential water savings achieved by the WBICs. Some believe that the setup and programming is so complicated that only professionals can effectively install the controllers and have therefore chosen a direct install style program. Others believe that professional installation will not boost the savings enough to justify the higher cost of direct installation and have therefore chosen a self install style program or offer the customer a choice of professional installation but at their expense.

Eighteen Southern California programs are not compared in this paper due to space limitations but a full report is available from the California Urban Water Conservation Council (CUWCC) at www.cuwcc.org. In addition to providing further variations of targeted rebate programs, southern California tried one unique distribution method, an exchange program where customers were invited to bring in their old controller and were given a free WBIC along with on-the-spot training on how to install their new smart controller.

Labeling programs support WBIC market transformation
Water agencies, including EBMUD, helped persuade the Environmental Protection Agency (EPA) to introduce a labeling program for water efficient products similar to the energy sector's EnergyStar. Water efficient products, that meet specific water conservation standards, will soon receive a WaterSense label and designation. The water conservation standards will become more restrictive over time to promote further efficiency improvements. WaterSense will increase customer awareness and use of water conservation products and encourage the free market to produce increasingly more efficient water conserving products.

Pending legislation supports WBIC market transformation
In California, legislation (AB 1881) has passed the legislature and is awaiting the Governor's signature. AB 1881 will amend the 13 year old California Model Water Efficient Landscape Ordinance (AB 325). If the Governor signs the bill, it will require performance standards and labeling requirements for irrigation equipment including smart controllers. The bill will require the energy commission to adopt those requirements for irrigation controllers and moisture sensors by 2010 and would prohibit the sale or installation of an irrigation controller or moisture for the landscape use unless the controller or sensor meets those adopted requirements by 2012.

Lessons Learned

One drawback of the California programs is that each agency developed their own program rather than collectively developing a regional program. This shortcoming required extra time and expense for each agency to develop their respective programs and delayed program launch. A regional approach was considered prior to the initial grant proposal (November 2002) but was abandoned because agencies had unequal resources available to commit to a WBIC program and there wasn't enough experience in water smart technology to confidently develop a regional program that fit all agencies needs and concerns. The development of separate programs is now presently an opportunity to compare the different approaches and learn which are most effective.

Not all early WBIC programs have been successful in reducing water use. Early indications are that getting the WBIC programmed correctly still presents a challenge for many users and may be the reason potential water savings are sometimes not realized. Most traditional controllers sold in the last five years have good water conservation features built in, but they still require the end user to enter the number of minutes and how often to run each station and this is a very complex task to get it right. One of the most innovative features incorporated into most (but not all) WBICs is a scheduling program that asks a series of questions about each irrigation zone or station. For example "is the plant type lawn, shrubs…"? "Is the irrigation type spray, rotary, drip…"? and so on. The WBIC then calculates the minutes for you. WBICs that offer scheduling programs are using tangible information customers can identify (some controllers even provide pictures) rather than an abstract concept such how many minutes to enter. This appears to be a very good idea that will significantly improve the ability of customers to program the WBIC accurately and minimize over watering. It will be interesting to see how the water savings compare between WBICs that incorporate a scheduling program and those that do not.

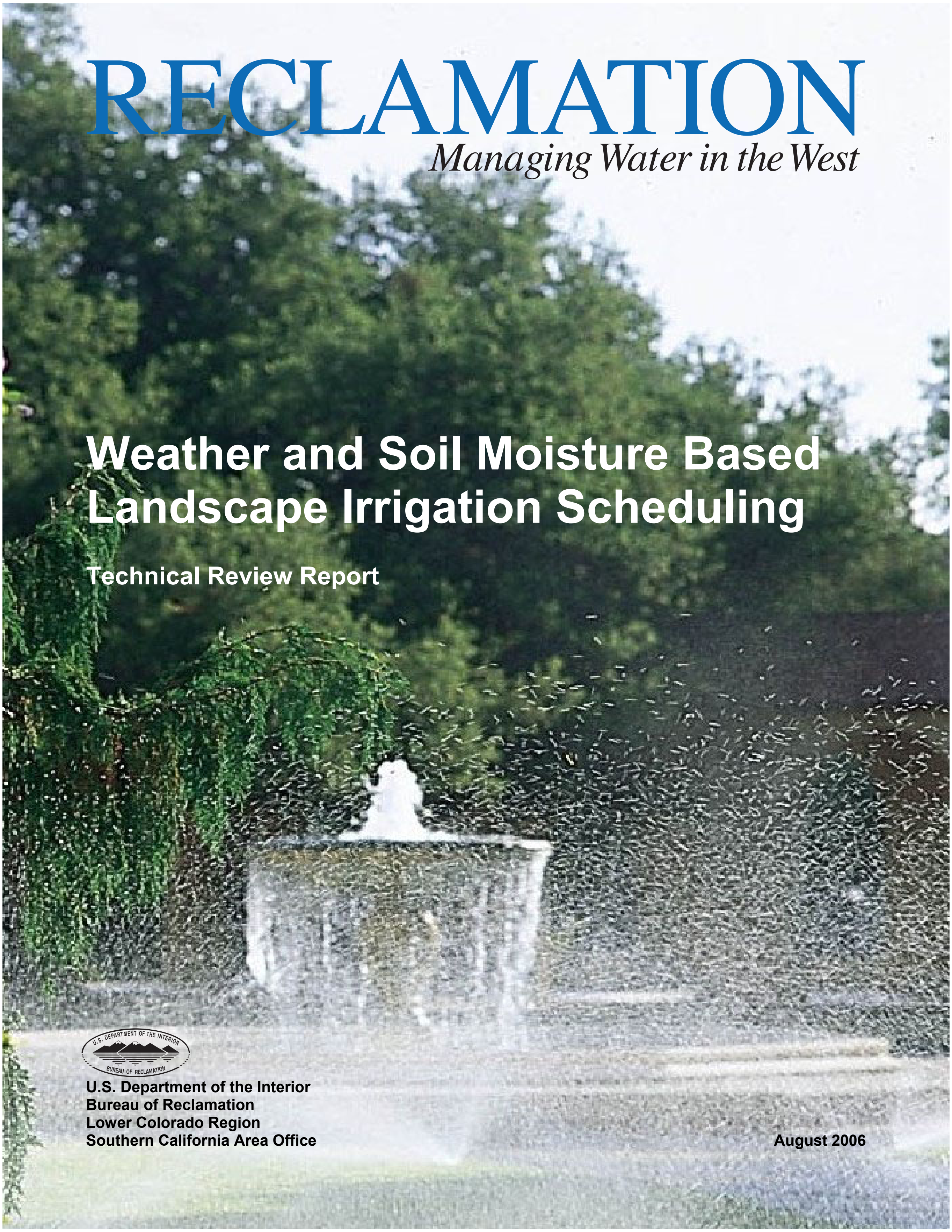
The proper programming of the WBIC is such a critical step in achieving water savings it may be worthwhile to include a site visit to validate the initial WBIC set-up in the program design. Once set up and programmed properly, however, WBICs are designed to automatically adjust the water applied every day and this should prove to be a huge breakthrough for dependable outdoor water savings.

Water agencies that have the ability to monitor on-going consumption may want to include this function in WBIC programs. If current consumption is compared to a baseline consumption established before the WBIC was installed and found not to meet water saving expectations, the agency can intervene with a phone call or site visit to assist the customer in getting back on track. If the water agency has the resources to measure the irrigated area of participating customers, it may be useful to calculate a water budget and compare the budget to how many inches of water are actually applied to a site. This comparison can be used to evaluate what percentage of potential water savings a WBIC is achieving.

One useful feature that WBICs currently do not have is the ability to show how many inches of water are actually applied to each landscape zone for a given period of time (day, week, month, year). We know that most shrubs require about half the amount water as turf to stay healthy. Knowing how many gallons of water are applied to a zone requires a calculation to evaluate if the gallons applied are an appropriate amount. If an "inches applied" feature was added to the WBIC , the water manager could immediately compare a zone of turf to a zone of shrubs. If about half the number of inches was being applied to the shrub zone as to the lawn zone and both zones were healthy the manager could assume the irrigation schedule was about right. If, on the other hand the number of inches being applied to both the turf and shrub zones was about equal the manager could potentially fine tune the turf or shrub zone up or down to water more appropriately and potentially water more efficiently.

Conclusion

Water agency market transformation efforts have already been fruitful. Four years ago only a few startup companies existed. Today there are more than twenty companies producing water smart technology including every major irrigation manufacturer who only four years ago were skeptical of the technology. The two California programs are not only helping the market transformation process but will provide valuable information to shape future programs. An impact analysis of California's two smart Irrigation controller programs will present results on a statewide, regional, and local level. The evaluation will include a statistical analysis of water savings, a comparison of program distribution and marketing methods, an assessment of product performance and customer satisfaction and a cost-benefit analysis from both the customer and utility perspectives. This evaluation is scheduled to be completed in October of 2008 which allows enough time for at least one full year of post-installation data to be collected and analyzed. The report will be available at www.cuwcc.org.



RECLAMATION

Managing Water in the West

Weather and Soil Moisture Based Landscape Irrigation Scheduling

Technical Review Report

U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Region
Southern California Area Office

August 2006

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Weather and Soil Moisture Based Landscape Irrigation Scheduling

Technical Review Report

prepared by

Southern California Area Office
Temecula, California

and

Technical Service Center
Water Resources Planning and Operations Support Group
Denver, Colorado

U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Region
Southern California Area Office

August 2006

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Representatives of the reviewed product manufacturers provided product information and reviews of their respective product discussion sections of the report. The preparers of this report very much appreciate each of these individuals' input. It is acknowledged the report's level of detail could not have been achieved without the significant assistance provided by the controller manufacturers' representatives. These individuals are identified in the product summary tables located at the end of the report.

Disclaimer

A significant portion of the information presented in this document was provided by the product manufacturers' representatives. Some of this information was verified by third parties as appropriate and as possible given the scope of the project. Every effort was made to accurately incorporate the information provided and to avoid errors and oversights, but it is recognized some may exist. The Bureau of Reclamation plans to update this report periodically and any identified deficiencies will be corrected at that time. Errors, omissions and new product information should be reported to Mark Spears at 303-445-2514 or mspears@do.usbr.gov or to Reclamation's Southern California Area Office at 951-695-5310.

Introduction

Water agencies implementing water use efficiency programs have long struggled to achieve quantifiable and reliable water savings. Historically, programs targeting landscape savings have focused on education pertaining to irrigation system maintenance, irrigation scheduling and climate appropriate plantings. Although these efforts have garnered savings, much potential exists for further landscape irrigation efficiency improvements.

In the late 1990's, the Irvine Ranch Water District, Municipal Water District of Orange County and Metropolitan Water District of Southern California learned of an emerging irrigation management technology using weather based irrigation controllers. This technology removes the need to make regular scheduling adjustments because the "smart" controller or signal receiver adjusts the schedule automatically as weather changes. A water savings evaluation of this technology was implemented which is known as the "Residential Weather-Based Irrigation Scheduling – The Irvine ET Controller Study". This evaluation identified an average single-family home savings rate of 37 gallons per day (irwd.com, 2001). Alas, a new opportunity for quantifiable and reliable residential landscape water savings had materialized.

In an effort to address non-point source pollution, a second weather based controller study was performed to evaluate the linkage between improved residential irrigation management and reduced dry-weather runoff. The "Residential Runoff Reduction (R3) Study" found comparable water savings of 42 gallons per day per day per single-family home (irwd.com, 2004). Savings at non-residential sites were 545 gallons per day. The R3 study also quantified a reduction in runoff ranging from 64 to 71 percent. With this change in runoff volume, concentrations of pollutants did not change therefore reducing pollution by a like amount.

Although soil moisture sensors have been used in agricultural and research applications for many years, this technology has only recently been applied successfully in the landscape irrigation field. Initial attempts to use soil moisture sensors to control landscape irrigation were unsuccessful due to the state of the technology, maintenance requirements and cost. Within the past ten years, soil moisture sensor technology has advanced significantly with accurate and maintenance free systems being offered by several companies at competitive prices. Recent study findings indicate water savings resulting from soil moisture based smart systems are similar to those discussed above for weather based systems (Allen, 1997; Cardenas-Lailhacar et al., 2005; DeOreo et al.; Mecham).

Water agencies throughout the country recognize smart irrigation control as an emerging tool to achieve landscape water savings and reduce non-point source pollution. When the first study began, the study team was aware of only a few smart controller technologies. Today, over 20 smart irrigation control manufacturers exist and others are quickly emerging into the marketplace.

In 2003, the Municipal Water District of Orange County approached the Bureau of Reclamation, Southern California Area Office and requested an objective evaluation of weather based residential irrigation controller technologies available to consumers. An evaluation was performed to document the overall status of weather based residential technologies and provide general descriptions of these products. The purpose of the evaluation was to allow water agencies to quickly gain knowledge about the technologies for use in their residential incentive programs.

The results of the evaluation were published in Reclamation's May 2004 Technical Review Report "Weather Based Technologies for Residential Irrigation Scheduling." Since 2004, Reclamation has monitored the status of the products reviewed in the original report, and incorporated information on commercial products by these 7 companies in this report. Reclamation has also researched residential and commercial weather based irrigation control products by 12 additional companies for this report. In addition, soil moisture sensor control systems by 7 companies were researched. In total, this report documents the research of smart irrigation control products by 26 companies that were available as of June 2006.

The decision to include commercial and soil moisture sensor products at this time was based on interest expressed by numerous water entities with landscape water conservation incentive programs.

Smart Irrigation Technology Overview

Smart irrigation control systems typically include either a stand alone controller or an add-on device which interfaces with a conventional clock-type controller. The weather or soil moisture based technologies incorporated into these devices allow them to function similar to a thermostat. Like a thermostat, the devices permit irrigation to occur when needed rather than on a preset schedule. Regardless of the specific method or technology, the concept is for the appropriate irrigation quantity to be applied at the appropriate time.

Most of these systems are available in a variety of sizes from small residential to large commercial applications. For the 2004 report, residential products were considered to be those with capacity less than 16-24 stations or zones. For this report, a device with more than a 12 station capacity is considered large residential or light commercial. In most cases, light commercial products possess the same features as the residential products, but have larger station capacity. Industrial type commercial products possess larger station capacity and offer additional features such as flow sensing, surge and lightning protection, multiple master valve circuits, concurrent station operation, and other features.

Industrial type commercial irrigation control products can be subdivided into two types: stand-alone controllers and computerized central control systems. The latter consist of multiple "satellite" controllers that are controlled through a centralized computer system. This allows for monitoring and control of multiple irrigation systems including flow rates, pressures, pumps, master valves, etc. from a single location. Typical central control system applications include golf courses, municipal park systems, highway corridors and other large landscape irrigation systems. Although review of central control systems is beyond the scope of this report, several systems are mentioned since they are offered by the companies reviewed for their stand-alone smart controllers. Also, some of the stand-alone controllers reviewed possess central control system type features.

In an effort to set an industry conservation standard the Irrigation Association® has organized the Smart Water Application Technologies™ (SWAT™) initiative. This initiative functions as a partnership with constituents from public entities and private companies from the landscape irrigation industry. The first products for which testing protocols have been developed are for weather based irrigation control products, and draft protocols for soil moisture based systems are currently under review.

The Center for Irrigation Technology at California State University – Fresno (CIT) is leading SWAT protocol development and began bench mark testing of weather based irrigation control devices for the Irrigation Association in 2005. The testing uses a virtual landscape that is subjected to a representative climate to evaluate the ability of a device to adequately and efficiently irrigate that landscape. Testing results are summarized in performance reports (performance summaries and technical reports) which are posted on the Irrigation Association's website (www.irrigation.org/default.aspx) as test results are released by manufacturers. The summaries include percentage scores in the categories of Irrigation Adequacy and Irrigation Excess. The technical reports include details associated with these scores and an Overall Irrigation Efficiency percentage score, which is comprised of Scheduling Efficiency and Application Efficiency components. At the time of this report, only 5 performance reports had been posted. Since the Irrigation Association does not disclose which products have been tested until a performance report is released, it is unknown how many of the products have been submitted. Whether or not a device has been submitted for testing and the status of the testing is discussed in this report only if this information was made available by the manufacturer.

Other than the inclusion of SWAT testing results, no attempt has been made to rate the products relative to each other. Certain comparison criteria are discussed, and it is left to the reader to research further and determine which products may suit various applications most appropriately.

Weather Based Irrigation Control System Principles

All of the weather based products reviewed operate on the principle of scheduling irrigation as a function of weather conditions. Most of the products use real time or historic weather data to schedule irrigation based on evapotranspiration (ET), which is a function of weather conditions and plant type. ET is the quantity of moisture that is both transpired by the plant and evaporated from the soil and plant surfaces.

The American Society of Civil Engineering's (ASCE) standardized reference ET equation parameters are maximum and minimum air temperature, net solar radiation, average vapor pressure and average wind speed. Vapor pressure can be calculated from humidity, dry and wet bulb, or dew point data and solar radiation can be derived from pyranometer or sunshine recorder data. The standardized reference ET equation is widely recognized as the best empirical method for estimating ET (Allen et al., 2005). Other less accurate equations are also used which require only temperature and solar radiation parameters, and solar radiation is sometimes estimated as an average value based on historic data for a given site latitude. The problem with using estimated solar radiation values is the significant variability due to cloud cover is neglected, and solar radiation is the single most important parameter in ET calculation using the ASCE standardized equation. Some of the products evaluated use these empirical ET equations in their scheduling algorithms. It is significant to consider which equation is used with regard to ET estimation accuracy, or what parameters are measured if the equation used is not referenced.

Each of the weather based irrigation scheduling systems evaluated utilize micro-processing devices which calculate or adjust irrigation schedules based on one or more of the following parameter sets: weather conditions (temperature, rainfall, humidity, wind and solar radiation), plant types (low versus high water use and root depth), and site conditions (latitude, soils, ground slope and shade). Some of the systems are fully automatic, and others are semi-automatic. The semi-automatic systems typically require the user to enter a base daily irrigation schedule, and then the controller or signal receiver determines the frequency (which days) irrigations occur. Some of the semi-automatic systems provide guidelines for establishing the base schedule and others do not.

A significant factor in comparing the products that use real time weather data is the quality of the data used. The cost to install and maintain a complete weather station onsite in order to collect the data necessary to use the standardized reference ET equation is prohibitive in most cases. Two techniques are used to collect current weather data as alternatives to onsite weather stations. Specifically, irrigation demand is calculated either using on-site measurements (typically a limited set), or using a full set of weather station data from a remote site. There are trade-offs associated with both methods.

If only a limited set of data are used to calculate ET with onsite sensors, the accuracy of the calculated ET may be poorer than ET calculated with a full set of weather station data. Conversely, if the weather station data are not representative of the irrigator's site, the calculated ET value and or rainfall sensing or measurement may not be accurate.

Certain of the products reviewed use on-site temperature measurements combined with historic monthly ET or solar radiation data in the daily ET calculation. The historic data used are a function of the site location. An obvious consideration with this technique is the accuracy of the historic data relative to a specific site. In one case only five sets of data are available for the entire U.S.

Several of the products reviewed calculate ET using a full set of remotely collected data from local weather stations or a network of weather sensors. The weather station data are collected from public and or private weather stations. The weather station and sensor network data are processed by a centralized computer server, and transmitted to the irrigation sites. There are ongoing service provider costs associated with the operation of the weather stations, sensor networks, computers, and information transmission systems associated with these products. These costs are either absorbed by water entities or are paid by the users.

In some cases, compelling data were submitted by the manufacturers showing accurate ET calculation and or significant water savings associated with their product as discussed under the product descriptions. In addition to the SWAT testing discussed above, a science-based evaluation of 4 of the weather based products reviewed was conducted by the University of California Cooperative Extension in 2003 and the results are reported by Pittenger et al. (2004). Given the general lack of data, it is difficult to draw conclusions about the overall performance of one product or technique versus another.

Weather Based Control Product Features and Comparison Criteria

Significant weather based controller product components and features are discussed below. The discussion also identifies different methods used to achieve similar results by the various products, and associated advantages and disadvantages.

Installation

Although most of the manufacturers recommend professional installation and programming of their products, several indicate installation and programming can be done by a non-professional. Most of the individuals associated with residential product demonstration programs and pilot studies who were interviewed during this review expressed concerns about homeowner installation and programming. Some of the products have default values which can result in an irrigation schedule that is not optimal for a given site, and in some cases can lead to over-irrigation. The degree of difficulty to install any of the products can vary significantly depending on site-specific conditions. It appears that in most cases all of the commercial products should be professionally installed. It is difficult to determine what percentage of homeowners successfully install and program the various residential products. Installation and programming instructions are available for many of the products at their websites. All potential customers should review this information when shopping for a device regardless of whether they plan to do their own installation and programming.

Stand-Alone Controller Versus Add-on Device

The primary component of most of the products reviewed is an automatic irrigation controller that replaces an existing clock type controller. Alternatively, several of the products include a receiver or scheduler that is connected to an existing controller. In some cases, the lower cost of the add-on device is a significant attraction. Regardless of cost, the quality of an existing controller should be a factor when considering replacement. If the existing controller is a high quality unit with adequate features, an add-on receiver may be an attractive alternative. The level of automation is limited with some of these units relative to some of the replacement controller systems. Specifically, some devices only prescribe irrigation frequency or adjust preset run times and do not automatically calculate run times.

Irrigation Schedules and Run Time Calculation and Adjustment

Some of the products reviewed will automatically generate irrigation schedules and run times for various zones as a function of sprinkler application rate, plant and soil types, slope and sun/shade conditions, and distribution uniformity. The ability of the automatic controllers to accurately generate an efficient schedule is dependent on the controller, the user's knowledge of the landscape parameters and proper programming. Other devices require a base irrigation schedule with specific run times which are entered by the user. In which case, the user must manually calculate run times based on experience and or guidelines provided by the manufacturer. Some of these controllers adjust the preset run times based on weather conditions, and others only control the irrigation run frequency. The product descriptions identify the manufacturers that provide guidelines for determining appropriate run times for the devices that require a base schedule.

Regardless of automatic or manual run times, many of the products have a fine-tune feature which allows adjustment of station run times by a percentage factor or by minutes giving the user the ability to compensate for inadequate run times.

Application and Distribution Uniformity (or Efficiency) Rates

Some of the products reviewed allow the user to enter actual sprinkler application rates versus preprogrammed rates based on irrigation type (spray, rotor, drip, etc.), and to enter a distribution uniformity or efficiency factor. The distribution uniformity/efficiency factor (typically a percentage) describes the effectiveness of the sprinkler coverage, and is most common with automatic scheduling controllers. Irrigation Run and Soak Cycles
All of the stand-alone controllers reviewed provide for multiple cycle-and-soak times to limit runoff. Some calculate them automatically, and the others require manual programming. For most of the add-on controllers, this feature is dependant on the clock-controller they are connected to.

Rain Sensors and Gauges

Most of the products reviewed include a rain sensor or gauge with the system, or as an optional add-on accessory, and have a rain delay feature that is triggered by the sensor or gauge. Some of the products' rain delay only interrupts ongoing irrigation when significant rainfall is detected. Other systems adjust the irrigation schedule based on the amount of rainfall measured. Although no documentation was reviewed for this report on the measurement accuracy of different types of rain gauges, it is assumed the tipping bucket type is more accurate than hygroscopic type rain sensors (sensors that absorb rainfall). Some of the systems have the ability to initiate a rain delay or adjust the irrigation schedule based on rainfall measured at a nearby weather station. Other systems use an on-site rain sensor that has the advantage of measuring rainfall that actually occurs at the site. One of the systems uses rainfall estimates from National Oceanic and Atmospheric Administration (NOAA) Doppler radar stations. The accuracy of these estimates can vary significantly depending on several factors (Loffler-Mang et al., 1998).

Other Sensors

Some of the products reviewed include standard or optional solar radiation, wind, temperature and flow sensors. In addition to calculating irrigation demand using temperature data, some of the devices interrupt or delay irrigation when wind and or temperature conditions are adverse to irrigation. Alternatively, some of the systems delay irrigation based on wind and temperature conditions measured at a local weather station. Most of the commercial products include flow sensor input terminals. In addition to monitoring to detect for high and low flows indicative of irrigation system problems, some of the controllers factor flow conditions into automatic scheduling decisions.

Power Supply and Surge and Lightning Protection

With one exception, all of the stand-alone controllers include a power transformer that converts 110-120 volts of alternating current (VAC) to 24 VAC. The transformers are either hardwired inside the controller cabinet (internal), or plugged into a power outlet (external). The Alex-Tronix controller operates on a pulsed 9 volts of direct current (VDC) using battery power. The add-on scheduling devices operate on either 24 VAC, 9 VDC or 12 VDC and either receive power from the existing controller or from an external transformer. Most of the transformer devices include some type of current overload protection such as a fuse or breaker switch. Some controllers include lightning and or surge protection, or offer these as an optional feature. Surge and lightning protection limits damage to the controller's circuitry from transient voltage and current from the power source (surge) and from the valve circuits (lightning).

Station Circuit Rating, Wiring and Terminal Wire Sizes

The compatibility of the existing electrical circuits (wiring from the controller to the station valves) should be considered in the selection of a new irrigation controller. If the station wire terminals on the controller will not accept the existing wire, adapters must be used. Also, the circuit current capacity required for an existing system should be checked prior to installing a new unit. Reports from demonstration studies indicate installation problems associated with insufficient circuit capacity to operate some irrigation valves with high circuit resistance.

The traditional wiring system (circuitry) used for most controllers consists of a common and a dedicated wire from the controller to each valve and sensor. Some controllers utilize “2-wire” circuitry that consists of a single pair of wires connected to all of the valves and sensors in the system. These systems require the installation of a decoder device for each valve and sensor. Applications include large systems and linear systems (e.g., highway corridors) with large quantities of wiring required for traditional circuitry.

Clock Mode Operation

Most of the controllers reviewed will operate in a standard clock mode. Some of them can be programmed for clock mode operation by station. One of the controllers that receives a scheduling signal does not have clock mode capability. Therefore, if the signal subscription is cancelled the controller must be replaced.

Non-volatile Memory and Batteries

All of the products reviewed have non-volatile memory to protect their programming during power outages. Most of the products also include a backup battery for maintenance of the date and time during power failures, and those that do not provide this back-up protection by other means.

Warranties and Reliability

All of the products reviewed come with a warranty. Warranty periods are discussed separately in the review of each product. Although the warranty periods may or may not be indicative of the life expectancy of the products, in some cases there appears to be a correlation between the cost and overall quality of the product to the warranty period. It is assumed the cost of a product somewhat reflects the quality of the construction materials and electronic components. Hence the less expensive residential devices should not be expected to last as long and function as reliably as the more expensive residential and commercial products. Since most of the devices are relatively new products, it is difficult to speculate on how long they should last. Depending on site conditions and maintenance, the weather sensors and other outdoor components may be vulnerable to degradation due to exposure to the elements.

Weather Based Product Descriptions

The following product descriptions address operational characteristics and features, and include discussions of available information from demonstration and pilot studies relative to documented water savings and operation. Each of the manufacturers was provided with copies of the product descriptions for their input prior to being incorporated into this report.

AccuWater

AccuWater, Inc. was incorporated in October 2002 and is based in Austin, Texas. The company has developed a centralized, weather-based irrigation management system for residential and commercial property applications. The AccuWater system has been in development since mid-2000 and pilot testing was performed from October 2002 through July 2004. The company has been actively marketing their system within Texas since July 2004. Sales outside of Texas began in July 2005.

AccuWater™ is a network-centric irrigation control system that is based on the latest Internet hardware and software technologies. AccuWater controllers are designed to irrigation industry standards and connect directly to all 24 VAC valves, replacing any existing "clock." The AccuWater data center is located in Austin, Texas in a professionally managed Internet co-location facility. Communication and data transfer between the controllers and the data center is accomplished through an Internet connection. Currently supported configurations include: wireless (802.11b/g), wired (Cat5 Ethernet), GPRS (digital cellular) radio.

The AccuWater system schedules irrigation based on calculated soil moisture in each irrigation zone. Soil moisture is updated hourly for each zone taking into account local weather (rainfall and ET) and actual irrigation (as reported by the AccuWater controller). To ensure the accuracy and timeliness of the weather data, AccuWater utilizes a combination of attached weather sensors and publicly available weather sources (e.g. NOAA, CIMIS). A backup schedule, based on recent ET, allows the controller to irrigate for up to 21 days without network connectivity. This schedule can be modified through an ethernet computer connection to the controller.

One of the unique attributes of the AccuWater system is that it can share weather data between nearby units via the AccuWater data center. The AccuWater controllers send weather data to the data center, and the data center fills in missing data elements from nearby sites by searching a pre-defined hierarchy. The server then sends each controller a complete weather context for that location including temperature, humidity, barometric pressure, wind speed and rainfall. As a result, AccuWater controllers can receive current weather conditions and make decisions (adjust, delay or abandon) without the benefit of on-site weather sensors.

The model R116 AccuWater controller is an indoor unit with a 16-station capacity, including one station terminal that may run concurrently with all the other stations to control a master valve or pump start relay. The controller housing is constructed of injection-molded ABS plastic, and the transformer is external to the controller. The station circuit terminals will accept 14 gauge and smaller wire sizes and the station circuit current rating is 0.75 amperes. All AccuWater controllers include percent adjust, syringe cycle, distribution setting features and surge and lightning protection. The retail price for the R116 controller is $549. Up to three R116 controllers can be interconnected to create 32 or 48 station units.

AccuWater also sells commercial grade 16, 32 and 48 station models in ventilated outdoor steel enclosures priced at $1099, $1699 and $2499, respectively. The outdoor unit has an internal transformer with 2.0 ampere circuit capacity. The optional GPRS radio is priced at $495 and requires an Internet wireless plan from T-Mobile or Cingular.

Annual service fees start at $149 for 16 stations. Fees are based on the number of equipped stations at a "location" and the cost per station declines as the number of stations increases. A location is defined as a contiguous property under a single owner/operator.

AccuWater's circuitry is based on a 75 megahertz Java-based central processing unit. It has one megabyte of volatile storage and 4 megabytes of non-volatile memory, as well as a 10-year lithium ion battery just for the onboard clock. All configuration and operating data for AccuWater controllers are stored in the AccuWater data center. After a power or network interruption, the controller will synchronize itself with the data center. If a connection to the data center cannot be made, the controller will reload its operating program and configure data from non-volatile memory.

To ensure accurate rainfall data, AccuWater recommends the use of their wired, tipping bucket rainfall gauge ($150). The gauge is commercial grade and is constructed of UV-resistant, heavy-gauge, white nylon. AccuWater also offers temperature, humidity, barometric pressure, wind speed/direction and solar radiation sensors for direct connection to the controller. Additionally, AccuWater controllers can utilize real-time weather data from Campbell Scientific Turf Weather and WeatherHawk weather stations over an Internet connection. In the absence of a local weather station on the AccuWater network, the system will automatically utilize data from NOAA or CIMIS. Other state-wide weather networks are being integrated as required.

AccuWater provides a one-year limited warranty on their products. AccuWater products are currently available directly from the company or from AccuWater-certified irrigation contractors.

AccuWater reports that many homeowners are capable of installing and configuring the controller, but professional installation is recommended. The AccuWater website (www.AccuWater.com) provides a step-by-step guide to installing and configuring the product. Technical support is available by telephone at 512-331-9283 and through the company's website, and local technical service representatives are available for service calls.

Installation of the AccuWater system involves (1) installing the AccuWater controller in place of the existing controller; (2) installing weather instrument(s) and connecting to the new controller; (3) performing an initial site survey to determine flow and precipitation rates; and (4) configuring the stations and performing a test run of all stations.

Because of its Internet-centric design and web-based controls, the AccuWater system integrates easily into most home automation systems. As of this writing, the following companies have committed to integrating AccuWater into their whole-home automation solutions: Crestron, AMX, Control4, Vantage Controls and Convergent Living.

AccuWater controllers are configured and managed by the end user on the company's website.

Configuration information for each controller includes:
- Location (latitude, longitude and elevation)
- Environmental limits (temperature and wind speed)
- Watering window (including "no water" days)

Configuration information for each zone includes:
- Plant type
- Soil type and depth
- Precipitation rate
- Flow rate
- Distribution efficiency
- Sun and rain exposure

- Cycle-and-soak
- Soil moisture depletion limit
- Minimum and maximum irrigation limits

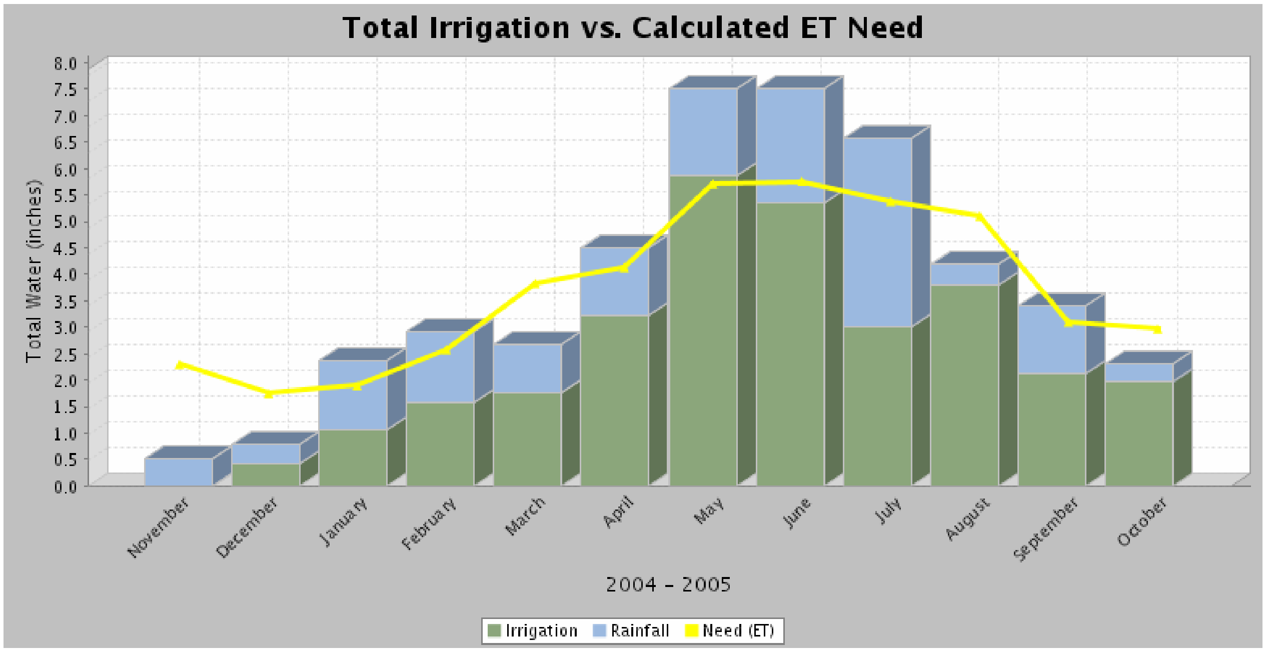
Controllers can be grouped into "locations" and any location can be delegated to another user (free accounts) or to one of AccuWater's landscape maintenance partners. This allows owners to maintain control and monitor water usage while simultaneously allowing authorized third parties to manage AccuWater systems remotely. AccuWater provides a free, cell phone remote control program. This program enables the end user (or their authorized delegate) to access and control his/her AccuWater controller from anywhere.

At 6:30 pm local time each day, the AccuWater data center calculates a one-time-use irrigation event for each irrigation zone based on calculated soil moisture and the National Weather Service (NOAA) local rain forecast. If the forecast includes a high probability of rain and soil moisture levels allow, irrigation may be deferred for 24 hours. Irrigation events are sent to and stored on the controller for execution during the watering window. If weather conditions are not appropriate for irrigation, the controller will wait for conditions to improve. If conditions do not improve before the watering window closes, no irrigation will occur. In the event data are not available, a 21-day back-up schedule is calculated based on recent ET.

As of November 2005, AccuWater has accumulated over 700 controller-months of operating data. AccuWater reports its analysis of these data suggest that average water savings are in the 30 percent range, with individual controllers yielding savings as high as 55 percent. The chart (Total Irrigation vs. Calculated ET Need) is taken directly from the AccuWater web site for a residential property in Austin, Texas. It shows the AccuWater prescribed irrigation quantity relative to reference ET as reported by Texas A&M University.

As of November 2005, AccuWater has accumulated over 700 controller-months of operating data. AccuWater reports its analysis of these data suggest that average water savings are in the 30 percent range, with individual controllers yielding savings as high as 55 percent. The chart on the next page (Total Irrigation vs. Calculated ET Need) is taken directly from the AccuWater web site for a residential property in Austin, Texas. It shows the AccuWater prescribed irrigation quantity relative to reference ET as reported by Texas A&M University.

This system's computer interface provides an easy and effective method for monitoring irrigation information and weather conditions. The AccuWater System should satisfy the more demanding and affluent portions of the residential weather based irrigation controller market.



Alex-Tronix

Alex-Tronix™ Controls is a division of GNA Industries, Inc. and is located in Fresno, California. This manufacturer of turf irrigation controllers was established in 1977 and specializes in battery operated controllers. The Alex-Tronix Smart Clock™ and Enercon Plus™ are the industries' only battery operated weather based residential and commercial controllers, respectively.

The Smart Clock and Enercon Plus controllers entered the market in 2005 after 3 years of research and development. They are lithium battery powered controllers which operate using the temperature budgeting based Set It, Don't Sweat It® Program. The program incorporates a weather parameter estimation model developed at the University of Oregon known as PRISM (**P**arameter-elevation **R**egressions on **I**ndependent **S**lopes **M**odel). Daily irrigation schedules are calculated by the controller as a function of site latitude (radiation), real time temperature, and maximum annual high temperature. An optional rain switch is available which stops and prevents irrigation when significant rainfall occurs.

The Set It, Don't Sweat It program is based on a temperature budget theory. Once a schedule is programmed into the controller for peak summer irrigation, daily schedules are calculated as a function of the actual temperature for the day relative to the maximum annual temperature. Alex-Tronix believes this simple and logical programming concept is easy for the user to understand, thus encouraging proper utilization.

The key to optimizing this system is proper programming of the peak summer irrigation schedule. Appropriate station run times and soak cycles must be determined and entered manually. Once peak summer run times are set; additional programming consists of entering the site zip code and connecting a temperature sensor. The rain delay feature can be triggered manually or automatically, with an optional rain sensor, for an adjustable irrigation delay of up to 99 days.

The Smart Clock controller is suitable for indoor or outdoor installation. It is powered by three 9-volt lithium batteries and is suited for residential applications with 6 stations plus a master valve terminal. Each station may be programmed for up to 4 cycles per day. This allows for the total station run times to be divided into multiple cycles in order to minimize run off. Specific days of the week or interval of days for irrigation may be programmed by the user.

The battery operation of the controller eliminates potential surge problems and burned out coils due to excessive voltage. The pulsed DC current eliminates capacitive problems associated with AC powered systems and galvanic copper wire deterioration caused by steady DC operation.

The standard Smart Clock is a locking powder coated 8.25” x 7.5” x 5.2” commercial grade metal enclosure. A stainless steel enclosure is available, and a pedestal for mounting either enclosure style is also available. The controller terminals will accept wire sizes up to 14 gauge. The station circuit capacity is 5 amperes. The controller includes a self-powered removable panel for programming at a convenient location. The controller’s high temperature rated liquid crystal display is 2.4” x 0.7” and is easy to read. The controller possesses a unique valve test function that allows cycling through each station for a programmed amount of time without the need to return to the controller.

The Enercon Plus includes all of the features as the Smart Clock and more, and provides more capacity with 4, 8, 12, 16, 20 and 24 station models. It comes standard with a stainless steel pedestal that the temperature sensor can be mounted to. The overall dimensions are 35.6” x 7.5” x 5.1”. This arrangement provides a large wiring area for ease of installation and service. Optional output board lightning protection is available for the Enercon Plus.

The Smart Clock and Enercon Plus controllers are recognized and sponsored by the U.S. Department of Energy for energy efficiency. Alex-Tronix controllers may be purchased through recognized turf and landscape irrigation distributors including Ewing, John Deere and Hughes. The current list price for the standard Smart Clock (temperature sensor included) is $995, and the stainless steel model is $1,215. The price for the controller pedestal is $795. The standard Enercon Plus price is $1,799 for a 4 station model and each additional 4-station model is $199 each. The optional rain sensor is $149 and lightning protection for the Enercon Plus is $460. A two-year warranty on the controllers and batteries (included) comes with purchase.

Installation and setup are reported to be easy, and it is reported that installation of the residential controller may be accomplished by most homeowners. The time required for an inexperienced user for installation and setup is reported to be 2 hours. An experienced professional should be able to install and setup the Smart Clock in one hour or less. Detailed step-by-step installation and setup instructions are included in the owner's manual which is available with the controller and at www.alex-tronix.com.

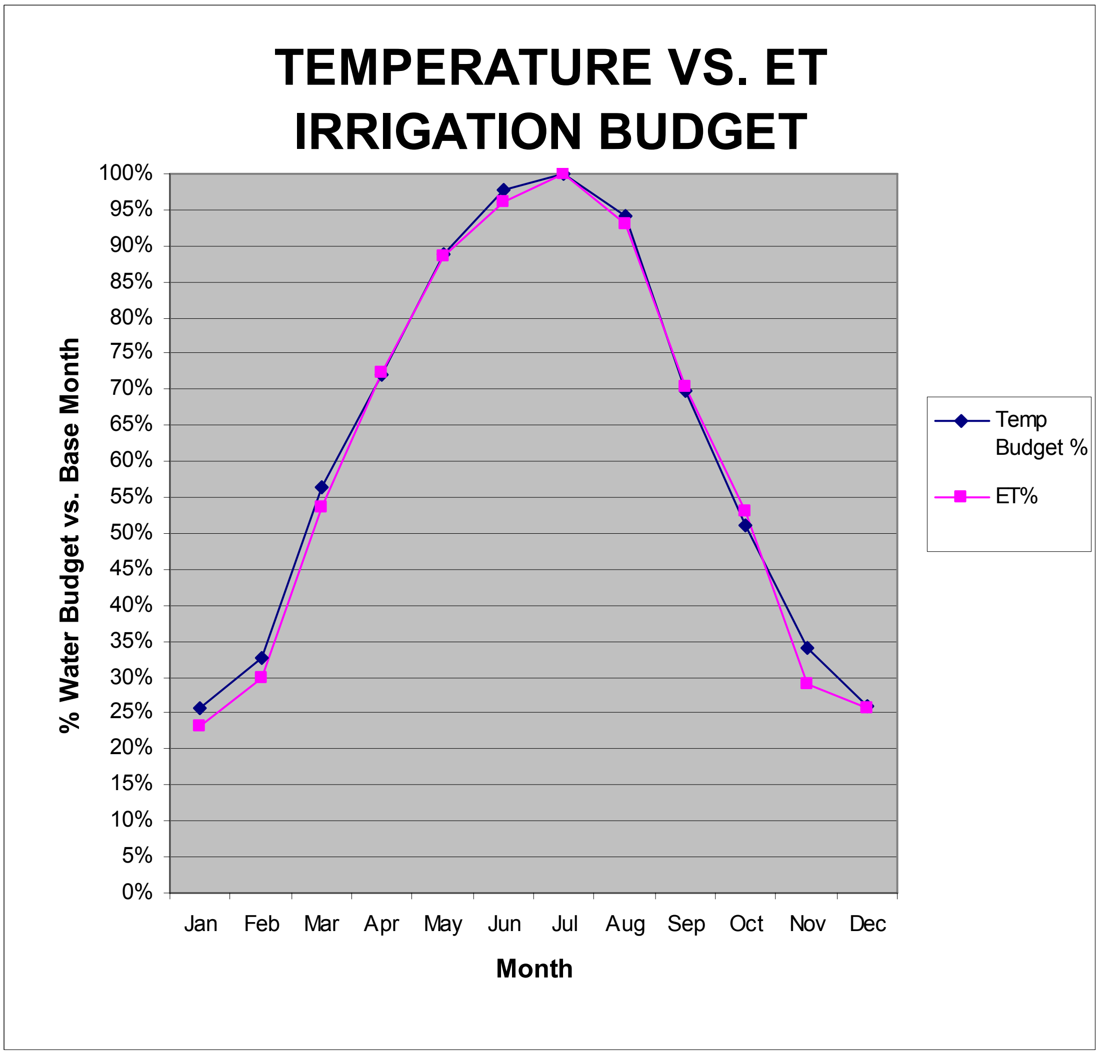
To program the Smart Clock, the site zip code is entered along with the peak summer irrigation schedule. A minimum irrigation temperature may be entered for cold regions to prevent irrigation during freezing weather. The schedule entered may be based on either days of the week or interval of days.

Alex-Tronix is also developing a controller add-on device that should enter the market in 2007. The Temperature Budgeting Module (TBM) will be attached to the outputs of any irrigation controller to make it weather based. It is self-powered, does not require any controller hardware or software changes, and there will be no monthly service fee. It can be mounted anywhere between the controller and valves and monitors the 24 VAC to the valves and automatically adjusts the station run times based upon a patent pending algorithm that is not ET based. The module programming consists of entering the local zip code. A minimum irrigation temperature can also be programmed into it, and it will accept an optional rain switch. Every day, the TBM computes a daily water budget and adjusts the irrigation accordingly. It will be suitable for use with residential or commercial controllers.

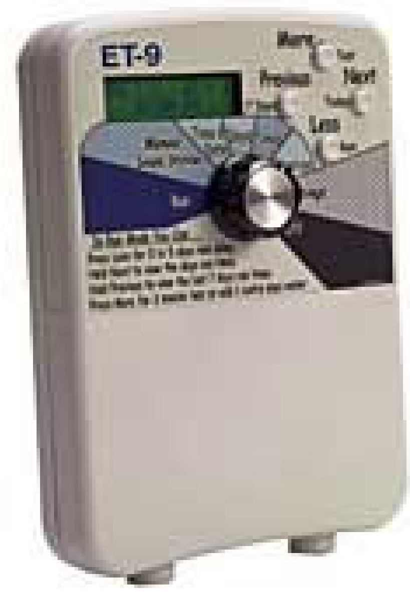
The Smart Clock and Enercon Plus controllers were submitted for SWAT testing in September 2005. Preliminary test results are available from Alex-Tronix and posting of the performance report is anticipated by the publishing of this report when SWAT test reference ET rain parameter requirements should be satisfied. No other independent testing or demonstration studies have been performed on the Smart Clock. The Smart Clock offers the unique characteristic of being installed anywhere regardless of power availability

Alex-Tronix performed a five year study comparing their Set It, Don't Sweat It temperature budget calculated irrigation demands at 25 locations to nearby CIMIS station reference ET. Results of the study are summarized in the graph below. The plot shows monthly percentage of peak temperature budget demand compared to the monthly percentage of peak CIMIS reference ET.

ALEX-TRONIX TEMPERATURE BUDGET COMPARISON TO CIMIS ET



Aqua Conserve



Aqua Conserve, Inc., located in Riverside, California has been in business since 1996. The company manufactures 5 residential ET controller models, a large variety of commercial ET controllers, and controller replacement panels and accessories. The Aqua Conserve® controller operation is based on adjusted historic ET data, with the adjustment made as a function of on-site temperature sensor readings. Combined rainfall/temperature sensors are included with some controller models and are available as add-on components for the other models which include only a temperature sensor.

Aqua Conserve's residential and commercial controllers have been on the market for approximately 8 years. Three indoor residential models are available, which accommodate 6, 9 or 14 stations, and the two outdoor residential models accommodate 8 or 12 stations. Aqua Conserve offers two types of commercial controllers, both of which come in wall mount and top entry models. The commercial controllers are outdoor units and will accommodate from 16 to 66 stations. Aqua Conserve's basic commercial models come in 16, 24 and 32 station models. The ULTIMO commercial controller series offer additional features and include 16, 26, 36, 46, 56 and 66 station models.

Aqua Conserve's ET controllers are preprogrammed with 16 individual historic ET curves, each representing geographic regions within the states of Arizona, California, Washington, Nevada, New Mexico, Utah, Colorado and Texas. The user enters one of the 16 regions into the controller. The controller then makes automatic seasonal changes to the run-times based on the historic ET curves, and daily changes based on the onsite temperature sensor. July run-times are entered into the controller for each station by the user. Aqua Conserve provides suggested run-times that are specific for plant types and for either spray or rotor sprinkler heads. Suggested run-times for drip systems are not provided. The suggested run-times are available at Aqua Conserve's web site (www.aquaconserve.com) for each of the 16 geographic regions mentioned above. Refinements to the suggested run-times to compensate for soil, slope and shade conditions are also provided. Further refinement of run-times can be made based on visual observations.

All products are available directly from Aqua Conserve by telephone and Internet order, and through a limited number of local distributors. Controller retail prices are summarized in the table below. The residential models come with combined rain/temperature sensors, which are available as on optional add-on for the commercial models. The additional cost for the wired rain/temperature sensor is

$75.90, and the solar powered wireless model is $129. The commercial models come with wired temperature sensors. There is no ongoing service cost associated with these controllers, and All Aqua Conserve products come with a limited 3-year warranty.

Retail Prices for Aqua Conserve Controllers

Controller Description	Model No.	2006 Price
6-Station Indoor Residential Wall Mount	ET-6	$240
9-Station Indoor Residential Wall Mount	ET-9	$256
14-Station Indoor Residential Wall Mount	ET-14	$358
8-Station Outdoor Residential Wall Mount	ET-8B	$434
12-Station Outdoor Residential Wall Mount	ET-12B	$529
16-Station Commercial Wall Mount	ET-16B	$804
24-Station Commercial Wall Mount	ET-24B	$931
32-Station Commercial Wall Mount	ET-32B	$1,047
16-Station Commercial Top Entry	ET-16SP-1	$2,191
24-Station Commercial Top Entry	ET-24SP-1	$2,919
32-Station Commercial Top Entry	ET-32SP-1	$3,404
16-Station ULTIMO Wall Mount	ET-16u	$1,339
26-Station ULTIMO Wall Mount	ET-26u	$1,763
36-Station ULTIMO Wall Mount	ET-36u	$2,186
46-Station ULTIMO Wall Mount	ET-46u	$2,610
56-Station ULTIMO Wall Mount	ET-56u	$3,033
66-Station ULTIMO Wall Mount	ET-66u	$3,457
16-Station ULTIMO Top Entry	ET-16uSP-1	$3,210
26-Station ULTIMO Top Entry	ET-26uSP-1	$3,694
36-Station ULTIMO Top Entry	ET-36uSP-1	$4,178
46-Station ULTIMO Top Entry	ET-46uSP-1	$4,662
56-Station ULTIMO Top Entry	ET-56uSP-1	$5,146
66-Station ULTIMO Top Entry	ET-66uSP-1	$5,630

The findings of a 2003 study by the University of California Cooperative Extension indicate installation and programming of a residential controller is relatively simple and that the controller performed well (Pittenger et al., 2004). Professional installation of commercial controllers is recommended. Aqua Conserve provides toll free telephone technical support and provides technical information on their web site. Aqua Conserve will participate in training contract installers upon request. Aqua Conserve reports that their support system meets or exceeds industry standards and the installation and programming instructions reviewed for this report are complete and easy to understand.

The various Aqua Conserve controllers provide 4 programs that allow the user to specify different watering days for different stations. 4 to 8 start times are available for each program to allow for refinement of total run-times into multiple cycles and soak times to compensate for soil and slope conditions to limit run off.

The maximum station run time is 99 to 240 minutes for the various models. The minimum irrigation frequency is once per week for low water plants. The controllers include 1 to 4 station circuits that may run concurrently with all the other stations to control a master valve or drip system. Other stations may not run concurrently.

The actual irrigation run-times for a given day are dependant on the programming described above and an automatic adjustment made by the controller, which is based on the measured on-site average temperature and historic ET data. The controllers have an accumulation feature that eliminates short cool period run-times. The short cool period run-times are accumulated until 50 percent of the July run time has been reached and then irrigation will occur.

Aqua Conserve commercial models come with a wired temperature sensor. Combined rain and temperature sensors are included with residential models and are an optional add-on with the commercial models. The combined sensors signal the controller once every 20 minutes, initiating the rain delay (shut-off) function when significant rainfall is detected. In the rain delay mode, the controller will not re-initiate irrigation for at least a 24-hour period after significant rainfall has ceased. Depending on the duration of the rain event, the rain delay can cause the controller to interrupt irrigation for up to 5 days. The user also has the capability to trigger the controller's rain delay feature manually.

All controllers have non-volatile memory and a 9-volt back-up battery. The back-up battery powers the controller clock in the event of a power outage for the residential and basic commercial units. The ULTIMO controllers include a storage capacitor that maintains the clock in the event of a power outage. All of the controllers can be programmed when powered only by the backup battery. The controller terminals accept 12 to 18 gauge wiring.

The residential indoor controllers provide 4 programs and 4 start times, and the outdoor models provide 4 programs and 4 start times. Both have one station circuit that may run concurrently with all the other stations to control a master valve or drip system. The indoor models are constructed of plastic and the outdoor controllers are housed in lockable stainless steel cabinets. The indoor models' dimensions are 8.3" x 6" x 2" and the outdoor models' dimensions are 9" x 8.8" x 3.3". The controller panel features dial type controls and a 2-line LCD display. The indoor controller models have a station circuit current capacity of 0.5 amperes, and the outdoor models' station circuit current capacity is 0.75 amperes. All residential controllers are powered through an external transformer (included with purchase).

All commercial controller models are housed in lockable stainless steel wall mount or top entry cabinets. The top entry units are designed for placement on a concrete foundation and are vandal resistant. The ULTIMO commercial controllers include all of the features of the basic models, plus station capacity expansion, additional master circuits, flow meter monitoring and other features.

The basic wall mount commercial models are powered through an external 24VAC transformer (included with purchase), and provide 4 programs and 4 start times. The basic top entry commercial models are powered through an internal transformer, and include 4 programs and 4 start times. The wall mount cabinet dimensions are 9.8” x 10.8” x 4.3”, and the top entry dimensions are 34.5" x 17.5" x 11.5". All of the basic commercial models’ panels feature dial type controls and a 2-line LCD display. The station circuit capacity for the basic commercial controllers is 0.75 amperes, and one station circuit may run concurrently with all the other stations to control a master valve or drip system.

All of the ULTIMO models are powered through an internal transformer, and provide 4 programs and 8 start times. The wall mount cabinet dimensions are 12" x 14.3" x 14.3", and the top entry dimensions are 34.5" x 17.5" x 11.5". The ULTIMO controllers provide for manual, semi-automatic and timed operations. The ULTIMO controllers can also detect leaks and excessive flows, and notify the operator or shut down the affected zone or master valve. A new plant/landscape establishment program allows added watering by station for a specified period to establish new landscaping, and then automatically reverts to the ET based schedule. Other ULTIMO features include 10-station expansion modules, water meter connections, large 4-line LED display, current and historic programming information access, ATM type push button programming, and start time stacking for all programs. The station circuit capacity for the ULTIMO controllers is 1.0 amperes, and they have four station circuits that may run concurrently with all the other stations to control a master valve or drip system.

Based on pilot studies conducted with Aqua Conserve controllers, significant water savings can be achieved for a relatively low initial cost and no ongoing costs. Reported outdoor water use savings for pilot studies with Aqua Conserve controllers, which were performed by the City of Denver, Colorado, Sonoma, California, and the Valley of the Moon Water District in Northern California were 21, 23 and 28 percent, respectively (Addink and Rodda, 2002). A preliminary SWAT test performance report is available at Aqua Conserve’s website.

Calsense

Calsense®, started in 1986, is a Carlsbad, California based company that manufactures water management systems for large commercial customers. Since its startup, the company has specialized exclusively in water management systems using weather-based irrigation, real-time flow monitoring, moisture sensors and a wide variety of communication technologies. Calsense markets its products to municipalities, school districts, universities, transportation departments, and other high volume landscape irrigators. Calsense provides free onsite training with its products, and emphasizes their commitment to customer service, support, and successful utilization of its products.

The Calsense ET2000e controller functions as either a stand-alone unit or as a field controller component for their water management central control system. The Calsense Command CENTER Software is the central component of the system. Although the ET2000e is a new product for 2006, its basic design is unchanged from its predecessor, the ET2000 and favorably improved from the ET1, originally introduced in 1993.

The ET2000e can automatically adjust daily irrigation schedules with onsite reference ET measurements from the optional Calsense ET Gauge, a Campbell Scientific Weather Station , or with historic average monthly ET. California Irrigation Management Information System (CIMIS) based monthly average values are preprogrammed into the controller, or the user can enter monthly values. Measurements from an optional tipping rain bucket are incorporated into the irrigation schedule calculation to account for effective precipitation. Irrigation can be interrupted in the event of rain, and high winds with the use of optional switch type sensors. A soil moisture sensor can be used with the ET2000e also and override the decision determined through on-site ET. (See Calsense discussion under Soil Moisture Sensor Products section.)

In the ET scheduling mode, the user programs the controller's run times based on field knowledge for the time of year and soil moisture content. This base schedule is adjusted daily as a function of weather conditions. Monthly ET adjustment percentage factors are fine tuned for each station depending on plant types, sun/shade conditions, and soil moisture content. Crop coefficients can be entered as well, for each month for seven different kinds of plant material. Cycle-and-soak times are manually programmed into the base schedule to minimize runoff.

The Calsense ET Gauge is an automated atmometer for estimating reference ET for turf (tall fescue). The covered ceramic evaporator at the top mimics solar energy absorption and vapor diffusion resistance of irrigated plants. A reservoir below the evaporator holds distilled water. The evaporator draws water from the reservoir at approximately the same rate that grass removes water from soil by ET. Water drawn from the reservoir passes through a calibrated measuring vial and corresponds to 0.01 inch of ET. Electronic circuitry components sense when the vial is empty. It is then immediately refilled and the 0.01 inch event is marked by a switch-closure type pulse which is transmitted to the controller. The controller uses a 28-day ET table to calculate runtimes based on station precipitation rates. The ET Gauge operates on 24 VAC supplied from the controller. An optional stainless steel vandal proof enclosure is available for the ET Gauge.

The ET2000e is available in 8, 12, 16, 24, 32, 40 and 48 station models. The controllers have two additional outputs for master valve and pump circuits. In addition, the controllers may be ordered with hardware and software for 4 additional 24 VAC outputs for the operation of lights, gates, water features, etc. at no additional cost. These outputs are controlled independently from the irrigation programs.

The controller has 7 regular programs and several syringe/propagation programs. A maximum number of start times or repeats per station is determined by station total minutes (programmed or ET calculated) and by a fixed set run time per cycle and a fixed set soak time between cycles. The cycle-and-soak times are set manually. The user selects 7, 14, 21 or 28-day watering schedules to accommodate watering requirements, and no-water days can be designated by program. Programs can operate simultaneously based on the system capacity of the mainline and flow management. The ET2000e is typically installed by a landscape contractor and then Calsense provides assistance programming assistance to the user following the landscape establishment period.

A Calsense Model FM flow meter can be connected to the controller to continuously monitor flow through the irrigation mainline and learn each station's flow rate automatically when irrigation occurs. This feature detects and alerts the user to mainline breaks, no flows, high flows (due to broken risers and pipe) for each individual station, and low flows due to pressure drops, malfunctioning valves, and or clogged heads.

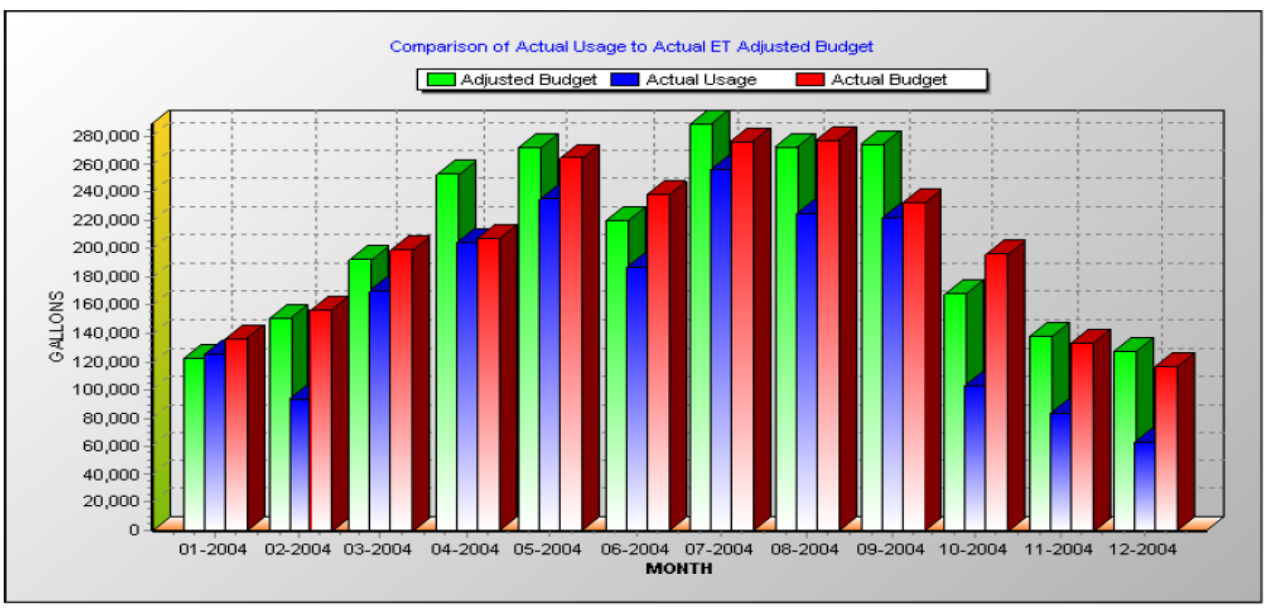
An optional remote control receiver board is integrated into the ET2000e allowing the user to activate valves and view operational details without going to the controller. The Calsense Remote SENSE remote control transceiver allows the user to view valve-on, area description, flow rate, electrical use and remaining time.

A water volume budget feature determines when monthly use, with projected usage, will exceed the programmed monthly budget and alerts the user before the month ends. This capability helps maintain water rates and keep staff accountable to a water management program. The table and graph below present data from an actual site that demonstrates the utilization of the water budget feature, and shows the correlation between historical and measured ET. The adjusted budget shown is the result of the automatic scheduling performed by the controller. The controller also possesses a laptop computer interface for field uploads and downloads so that detailed reports can be produced and potential expansion to a central system can be evaluated.

Date	# of Days	CONTROLLER HISTORICAL ET	*ACTUAL ET TABLE	ADJ %	**CONTROLLER BUDGET GALLONS	***ADJUSTED BUDGET GALLONS	****USAGE ACTUAL GALLONS	SAVINGS GALLONS	PERCENT SAVED
Jan-2004	31	2.17	1.96	-10 %	135,997	122,836	124,985	-2,149	**-2 %**
Feb-2004	29	2.61	2.51	-4 %	156,722	150,717	93,164	57,553	**38 %**
Mar-2004	31	3.41	3.30	-3 %	199,228	192,801	170,397	22,404	**12 %**
Apr-2004	30	3.30	4.03	22 %	206,679	252,399	203,713	48,686	**19 %**
May-2004	31	4.34	4.46	3 %	264,385	271,694	235,704	35,990	**13 %**
Jun-2004	30	3.90	3.59	-8 %	238,227	219,291	187,099	32,192	**15 %**
Jul-2004	31	4.65	4.86	5 %	276,207	288,681	255,869	32,812	**11 %**
Aug-2004	31	4.65	4.58	-2 %	276,606	272,442	224,724	47,718	**18 %**
Sep-2004	30	3.90	4.59	18 %	232,492	273,625	221,700	51,925	**19 %**
Oct-2004	31	3.41	2.91	-15 %	196,724	167,879	103,225	64,654	**39 %**
Nov-2004	30	2.10	2.17	3 %	133,555	138,007	84,064	53,943	**39 %**
Dec-2004	31	1.86	2.04	10 %	116,526	127,803	63,363	64,440	**50 %**
TOTAL	366	40.30	41.00	2 %	2,433,348	2,475,614	1,968,007	**507,607**	**21 %**

ET values and usages set to zero when budget is zero
*County and city settings for controller are San Diego and San Diego
** Controller Budget was Calculated at 100% of Controller Historical ET.
*** Adjusted budget uses actual ET to modify the controller budget.
**** Usage based on: Test usage, manual usage, scheduled usage, radio remote usage

Water Management **November 03, 2005 4:24:13 PM**
Jan/01/2004 - Dec/31/2004



Extensive current and historic irrigation information can be viewed at the display or downloaded from the controller. The controller monitors and keeps a record of all site water usage by month for up to 2 years. Scheduled irrigation usage is recorded on a station-by-station basis and on a total controller basis for the current month and the previous month. Unscheduled water usage (pressing the manual water or test key), and non-controller water usage (e.g. quick-couplers, manually bleeding valves, etc.) is recorded separately showing how the water is being applied.

The ET2000e is a weatherproof wall mount unit and the cabinet is powder coated rolled steel. The front panel includes an ergonomic key layout and a large16-line by 40-character LCD display (English or Spanish). The cabinet dimensions are 11.4” x 11.1” x 7.3”. The controller has non-volatile memory and the clock maintains time during power outages without the need for a backup battery. It is powered through an internal transformer. The controller accepts up to 14 gauge wire size, and the station current capacity is 1.5 amperes. Optional AC power line overload protection consists of a sealed unit suitable for outdoor installation and carries full UL approval. Optional transient (lightning and surge) protection is provided with the TP-1 board. The transient protection board can be purchased either with or without an outdoor cabinet. The ET2000e will detect, alert and identify open and shorted circuits in field wires and solenoids. The affected station is skipped until repaired.

Calsense products are available from many distributors located throughout the U.S. A list of these distributors is available from Calsense upon request (1-800-572-8608 or www.calsense.com). Current prices for all ET2000e models and certain accessories are summarized in the table on the next page. All Calsense products come with a 5-year warranty.

Although Calsense has not participated in any outside studies or demonstration projects, its track record speaks for itself. During Calsense’s 20 years of existence, they have developed a large data base on its products’ performance and customer success.

Calsense submitted data for this report prepared by their in-house research and development department showing average water savings of 22 and 33 percent for two typical installations. Calsense reports an overall average water savings rate of approximately 20-40 percent depending on past water usage and project history.

Although the controller models have evolved, the Calsense ET scheduling technology has been in place since 1992. Many of the Calsense systems installed since that time continue to function today. Several articles written by end users in Calsense’s niche market testifying to the successful operation of their Calsense systems were submitted for this report. A SWAT test performance report for the ET2000e was not available for this report.

Calsense Products Price Summary

Description	Model No.	Price
8-Station ET2000e Controller	ET2000e-8	$1,290
12-Station ET2000e Controller	ET2000e-12	$1,790
16-Station ET2000e Controller	ET2000e-16	$1,980
24-Station ET2000e Controller	ET2000e-24	$2,350
32-Station ET2000e Controller	ET2000e-32	$2,890
40-Station ET2000e Controller	ET2000e-40	$3,280
48-Station ET2000e Controller	ET2000e-48	$3,680
ET Gauge	ETG	$1,310
ET Gauge Controller Interface	-G	$435
Rain Gauge	RG-1	$575
Rain Gauge Controller Interface	-RG	$435
Wind Gauge	WG-1	$545
Wind Gauge Controller Interface	-WG	$435
Soil Moisture Sensor	1000-S	$199
1-inch Brass Flow Meter*	FM1B	$575
1.5-inch PVC Flow Meter*	FM1.5	$490
Transient Protection	TP-1	$265
Enclosure for TP-1	TPB	$199
AC Line Protection	TP-110	$165

* Other brass and PVC flow meter sizes are available up to 3-inches.

Calsense provides potential clients with a reference list of all past and current users so that they can learn of their personal and professional experiences. In some cases, Calsense loans controllers to potential clients to demonstrate its system. The ET2000e provides a complete water management system as a stand-alone field controller, which can easily be expanded into a central control system.

ECO Research

ECO Research LLC, located in Nampa, Idaho, began work on the weather based ECO 100™ Sprinkler Optimizer in January 2003. The first prototypes were tested during April to October of 2003. In 2004, production units were distributed for testing at additional locations. In 2005, the ECO 100 was introduced to the general market.

The ECO 100 works with any existing clock/timer controller to irrigate based on calculated ET. The device calculates ET from on-site temperature measurements and site location average solar radiation. No remote or historical data are used, and any industry standard rain sensor can be connected to the system to improve performance. The ECO 100's ET calculation algorithm is based on the Hargreaves equation for estimating ET. The device is connected to an existing controller and interrupts the controller from irrigating until calculated ET accumulates to the appropriate level.

Hourly temperature sensor readings are logged by the ECO 100, and solar radiation is calculated as a function of minimum and maximum temperatures and site latitude. Latitude is entered during system setup as one of 5 zones covering all of the U.S. These data are used to calculate daily ET, and daily ET is accumulated to determine when irrigation should occur. When rain is detected by an optional sensor, the system will stop or prevent watering and adjust ET accumulation. ET accumulation adjustment is based on the amount of time the rain sensor is tripped, and an adjustable delay switch setting. The delay switch is set by the user during setup to delay ET accumulation from 0 to 7 days when the rain sensor is tripped. If no rain sensor is installed, the user can also manually enter a rain delay and cause ET accumulation adjustment.

The ECO 100 Sprinkler Optimizer is an add-on product that can be used with any existing electrical clock/timer type controller. The intent of this design is to minimize product installation and setup costs. It also simplifies operation since the existing controller is not replaced and it is not necessary for the user to learn a totally new system.

Installation and setup are reported to be easy, and may be accomplished by most homeowners. The time required for an inexperienced homeowner for installation and setup is reported to be 2-3 hours. An experienced professional should be able to install and setup the ECO 100 in one hour or less. Detailed step-by-step installation and setup instructions are included in the owners manual which is available at the ECO Research website (www.ecoresearch.com). Additional setup time (1-2 hours) is required to measure station flow rates if sprinkler head flow rates are not known. This procedure is covered in the owner's manual.

The ECO 100 manages watering by controlling watering frequency. This is accomplished by controlling the electrical connection from the common valve circuit to the controller. The controller is typically set to water every day, but watering will only occur when the ECO 100 has determined that the ET accumulation (soil moisture deficit) is equal to the last amount watered. The controller will water the same amount every time, but the frequency of irrigation is controlled by the ECO 100. The user adjusts the individual station times on the controller during setup, as recommended in the installation manual.

The recommended station run times are based on the sprinkler head application rate and irrigation of either 0.5 or 0.75 inches per watering. The manual provides instructions for measuring application rates, and discusses division of total run times to reduce run off. The method discussed for dividing total run times requires the user to observe the irrigation time which induces runoff and adjust accordingly. Specific adjustments based on soil, slope and shade conditions are not included in the manual. Consideration of soak cycles is also discussed. The Wetter/Dryer control is used to make minor frequency adjustments. This allows the user to slightly increase or decrease irrigation frequency as conditions warrant.

The ECO 100 may be programmed to only control certain stations of the controller. This allows the user to have stations irrigate at high frequency for plant germination, or for long run times to accommodate drip irrigation. The clock controller can be set to skip a day of the week and irrigation will occur the following day, if needed. The unit has a low temperature shut off which prevents irrigation at temperatures below 38° F. Watering history is displayed on the ECO 100, showing irrigation activity for the past two weeks.

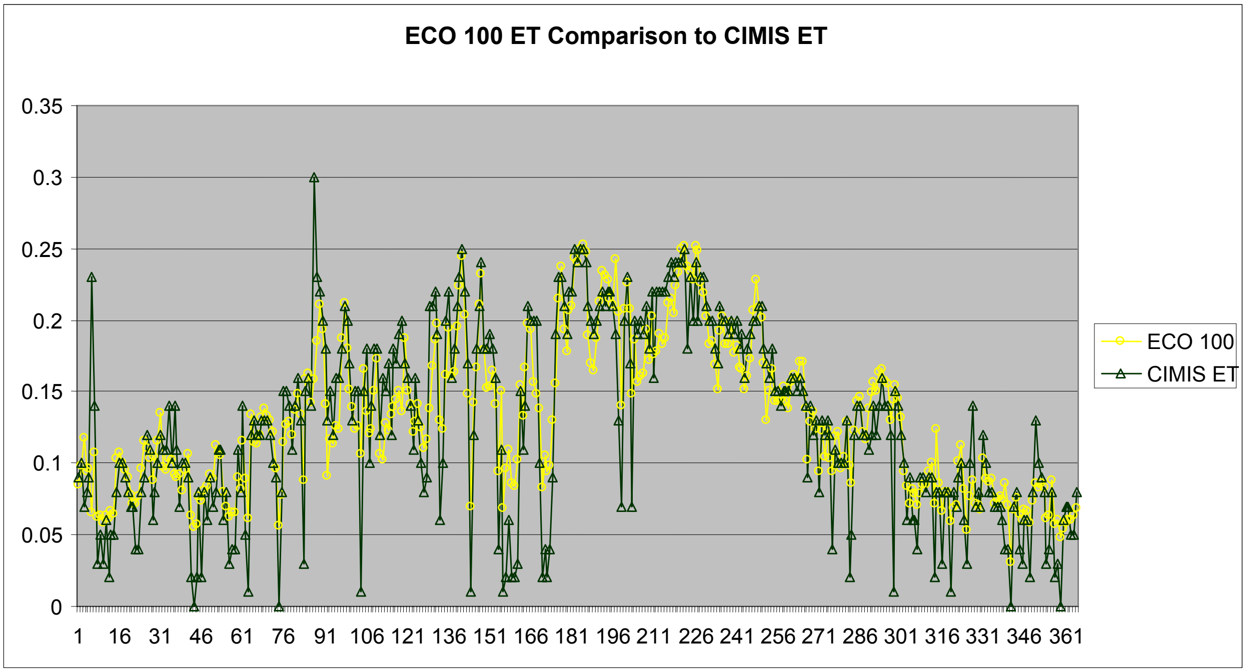
The ECO 100 has no specific number of zones that it can control. The only limit is that the zones all have to be set to water in a single 24-hour period. This is because when the ECO 100 determines that watering is needed, it enables the connection from the station valves common circuit to the controller for 24 hours. There are existing installations with 36 station controllers. The ECO 100B Sprinkler Optimizer, planned for later in 2006, will enable watering for up to 48 hours. This will allow additional watering options such as the use of two programs watering on alternate days.

The ECO 100 cabinet is a 4” x 6” x 1.5” extruded plastic unit and the panel includes a 2.6” x 0.6” two-line LED information display. The panel controls are touch pad type. A lockable steel weatherproof enclosure is available for outdoor installations. The ECO 100 has non-volatile memory and battery backup to retain all settings in the event of a power failure. A 24 VAC power supply must be provided by the controller to which the ECO 100 is connected.

The retail price for the ECO 100 is $198, as is the planned price for its upcoming replacement, the ECO 150. The weatherproof enclosure is priced at $79. The ECO 100 and accessories may be purchased from ECO Research or from its distributors which are listed at www.ecoresearch.com.

During the development of the ECO 100, the ET algorithm was tested by comparing simulated EC100 ET to reference ET for an Orange County, California CIMIS station using the temperature data from the CIMIS station. The results of this test are shown in the graph below. The graph shows the ECO 100 calculated ET pattern generally follows that of the CIMIS ET.

ECO Research reports water savings of 20 to 40 percent with the ECO 100, based on its own pilot testing. The ECO 100 is included in an ongoing study being conducted at Lake City Community College, Lake City, Florida. This study is comparing the performance of several ET and soil moisture based controllers and preliminary results are anticipated late in 2006. The ECO 100 is also included in



an ongoing study being conducted by the Salt Lake City, Utah Department of Public Utilities. This study includes ease of installation, landscape appearance and water savings evaluations. Results from the Salt Lake City study will also be available late in 2006. A SWAT test performance report for the ECO 100 was not available for this report.

The ECO 100 provides a relatively economical weather based irrigation system control option, using real time onsite sensors.

ET Water Systems

ET Water Systems LLC, based out of Corte Madera, California, is a manufacturer of weather based irrigation controllers for the residential and commercial markets. ET Water™ controllers operate under its centralized weather-based irrigation management system. ET Water was incorporated in 2002 and began manufacturing controllers in March 2005. The company sells its system in California, Nevada, Colorado, Texas, Oregon, Washington and Idaho and will soon expand sales to other states.

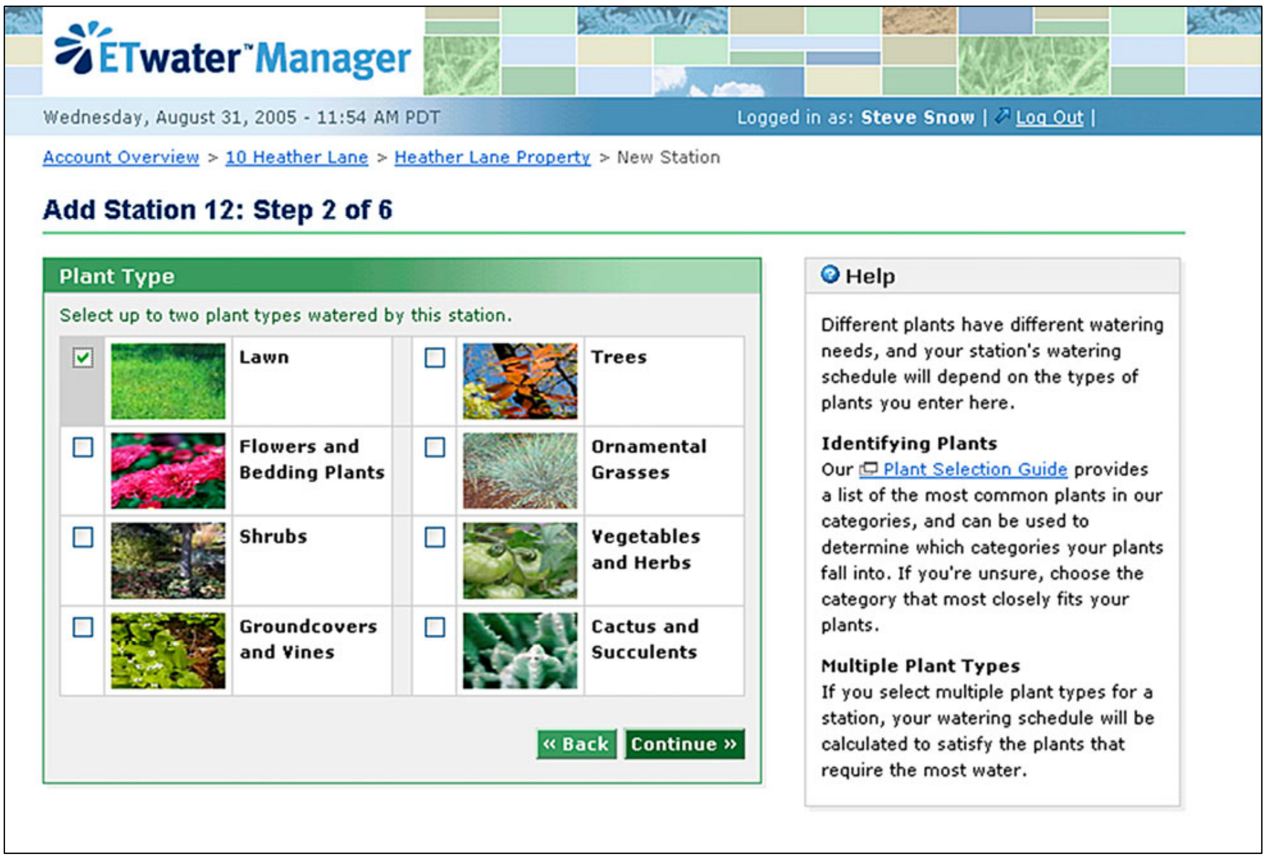
The ET Water system schedules irrigation based on ET and precipitation data received from existing weather stations and user programmed information associated with specific landscape features. Currently, the ET Water system uses a data network of approximately 8,500 public and private weather stations, most of which are located in populous areas. The option to install an on-site weather station, rain sensor or rain gauge is also available. ET Water controllers are sold in single station increments from 6 to 48 stations, thus the customer only pays for what it uses. Additional stations may later be activated by paying a per station fee. The ET Water commercial controller models begin at 12 stations, and the 2-way communication service offered with the commercial controllers provides features similar to a central control system.

With the ET Water System, ET and precipitation data are automatically retrieved daily from the weather station network by the ET Water's host server. The data are obtained from existing weather stations that provide localized weather, most often available at the town or even the suburb level in most metro areas. A WeatherBug® weather station can be installed on-site and the on-site data is utilized via the ET Water server as discussed below.

The ET Water server automatically processes the ET and rainfall data in combination with the user-programmed landscape information to develop irrigation schedules. The user enters the landscape information from any computer with an Internet connection via the ET Water website (www.etwater.com); however, a personal computer is not required at the installation site for the system to function. In commercial applications, the user may access special screens that enable selection of multiple accounts and thereafter select any controller or zone for each account. Scores of accounts may be accessed remotely from any computer at any time.

Communication between the user's controller and the ET Water server may be by wireless connection or land-based telephone link. Broadband access is planned for later in 2006. The ET Water central server communicates with each field controller on a daily basis to send any required watering adjustments. In addition, all ET Water controllers send a 30-day log of all watering activity so users can review their watering history on the ET Water website. ET Water controllers can operate independently if communication to the server is temporarily interrupted. In such a case, the controller continues to operate using the latest schedule stored in memory, and then revises the schedule once communication is re-established with the server. The ET Water controller can accommodate schedules of any duration and frequency, including schedules that require watering on a very infrequent basis (e.g., every 30 days).

To enter landscape information, users go to the ET Water website and log into their account using a user name and password. The program interface to enter the site-specific landscape information is set up with Windows® based pull-down menus and is intuitive and easy to use. The program is well organized and covers a comprehensive set of landscape factors including; plant type, irrigation type or optional application rate, soil type, slope, root depth, sun exposure and distribution uniformity. User-defined sprinkler precipitation rate (PR) and distribution uniformity (DU) may be entered or default measures may be selected in the absence of precise PR and DU information. A wide selection of plant types is available. Multiple plant types may be selected for one station and the program will automatically set the watering schedule based on the plants with the highest water requirement. Irrigation types available include spray, rotor, impact, stream spray, drip emitter, and bubbler. The default distribution uniformity factor is 55 percent for pop-up spray heads. The user may specify customized distribution uniformity for any zone. All default settings can be changed at any time by ET Water and each water agency can select the default settings it wishes to use for its customers.



The user may also enter non-irrigation days, adjust the total station run times by a percentage factor, and initiate manual irrigations by station. The user may also review system and irrigation history information on the website. The ET Water setup program includes help screens to answer questions common to first time users. Once the user becomes familiar with the program, an advanced setup mode may be used which offers a more efficient means of programming. Adjustments to specific site factors may be made at any time via the ET Water website. Site factor changes will generate new irrigation schedules.

The ET Water controller also has an offline programming feature that allows users to manually set a watering schedule for each station. This feature is intended for use during periods when phone service is temporarily unavailable (e.g., a newly constructed home prior to sale). Offline programming may be performed at the controller using the keypad and the 2-line LCD display. The manual start mode may also be initiated at the controller. ET Water's objective is for the system to automatically generate and execute irrigation schedules. The need for program modification in the field is typically limited.

ET Water provides email alerts when there is a failure of communication between the field controller and central server. It also provides email alerts when manual adjustments are made on the field controller – the user may review such changes and override them remotely from any PC if desired.

The irrigation scheduling algorithms used in the ET Water system are reportedly based on current state-of-the-art horticultural science. The program reportedly incorporates all landscape factors needed to accurately determine soil moisture depletion and irrigation scheduling. ET Water uses a different algorithm for scheduling sprinkler and drip irrigation stations. The company's proprietary algorithms automatically generate daily schedules for each station with run and soak times based on a station's sprinkler application rate, soil intake rate, and slope conditions. The station run/soak cycles for each irrigation period remain constant, based on replenishment of a 50 percent plant root zone moisture depletion level. Irrigations are delayed until a soil moisture depletion level of 50 percent is calculated, based on the measured daily ET and rainfall. If the user desires more frequent watering, it may adjust the depletion level downward.

All ET Water controllers are currently constructed of weatherproof fabricated aluminum enclosures with a key lock. Starting later in 2006, ET Water will manufacture residential controllers with an injection molded plastic enclosure. In addition to the regular station circuits, the controllers provide a master valve/pump start circuit. The station circuit capacity is sufficient to operate three valves at once, or a master valve and two zone valves, and the terminals will accept 12-20 gauge wire.

The use of a standard rain sensor will cause circuit interruption and suspend irrigations when significant rainfall occurs. Alternatively, a standard rain gauge may be connected and the gauge data are transmitted to the server for use in irrigation scheduling.

Remote monitoring features for commercial applications include email notification of any adjustments to a controller; such as suspend, power interruption, failure to connect to the internet, increase in percent watering for any zone and flow monitoring. For response to these occurrences, the user may remotely re-set or adjust these features from its PC.

An ET Water residential controller sells for approximately $399 to $549, depending upon the number of stations and the communication method – a 6 station telephone connected unit costs about $399, while a 12 station “powerline” connected unit sells for $549. The ET Water controller will accommodate popular brands of rain sensors or rain gauges. The annual residential service fee is $59 per year, but multiple year service plans reduce this amount as discussed below.

An ET Water commercial controller sells for approximately $1,099 to $2,399, depending upon the number of stations and the communication method – a 12 station telephone connected unit costs about $1,099, while a 48 station wireless connected unit sells for $2,399. The ET Water Manager Service includes daily watering schedule updates, telecommunication and wireless access charges, ability to remotely monitor and adjust the controller from any PC, email alerts in case of on-site problems, and online and phone-based customer service. The annual service fee ranges from $139 per year for commercial telephone connect to $199 for wireless connectivity.

Five and ten year service plans are available for both residential and commercial controller service, providing 33 and 50 percent savings off of the annual rate, respectively. This can bring annual service costs down to approximately $30 for residential service, and as low as $70 for commercial service.

ET Water offers panel replacements for certain non-weather based models of popular brand controllers. These panels make installation very rapid and sell for less than a full ET Water controller, saving the customer up to 40 percent off of the price of a new controller.

Since telephone or wireless communication allows two-way information transfer, ET Water can manage the information received from individual controllers. This may be beneficial to water agencies by allowing analysis of customer water use data. ET Water plans to provide this information through its website. Also, ET Water plans to sell its software program to water agencies that would maintain the server and provide the service for their water users. In this case, the water agency could absorb the ongoing service cost.

The ET Water controller does not require professional installation, although the company recommends professional installation and will provide factory trained individuals or irrigation contractors to install all units. A typical professional commercial installation should take 1 to 3 hours, which includes a site assessment and discussion of the assessment with the user. Typical residential installations can be completed in less time. The professional installation/consultation cost is estimated to be $75 - $225 depending on location, size, and other site conditions. Technical support is available by toll free telephone (800-438-3400), in addition to the support provided on the company’s website.

The ET Water system has completed SWAT testing and a performance report is posted on the Irrigation Association website. Although water savings data were not available for this report, based on the SWAT test report, it is reasonable to assume use of the ET Water will produce similar water savings to the other products reviewed.

The ET Water Manager Service includes daily watering schedule updates, telecommunication and wireless access charges, ability to remotely monitor and adjust the controller from any PC, email alerts in case of on-site problems, and online and phone-based customer service.

The ET Water computer interface method of programming and monitoring the system is comprehensive and user friendly. The water use monitoring option should also be attractive to progressive water agencies interested in quantifying water savings.

Hunter

Hunter Industries was established in 1982 and is headquartered in San Marcos, California. Hunter® manufactures and distributes a full line of landscape irrigation products worldwide. Hunter introduced its ET System™ to the market early in 2006. The ET System consists of the ET Sensor (onsite weather station) and the ET Module (add-on irrigation scheduler). It is compatible with most Hunter irrigation controllers less than ten years old, including any Hunter controller equipped with a SmartPort™. The ET System is not compatible with other brands of controllers. Depending on the controller, the ET System is suitable for residential and commercial applications.

The ET System creates an irrigation program automatically based on weather conditions measured onsite. The programs are operated via the compatible irrigation controller and run automatically on water days and at start times set by the user. Compatible controllers include Hunter Models SRC/SRC Plus, Pro-C, ICC, and ACC with SmartPort® technology. The irrigation schedule is based on the ET Sensor's calculated ET value and programmed plant, soil, slope, sun/shade and sprinkler type information provide the basis for calculation of the irrigation schedule. The result is a new revised irrigation program every water day, based on the weather conditions measured onsite. Once installed, each zone is scheduled from the ET Module, rather than the controller itself.

The ET Sensor calculates ET by its daily measurement of solar radiation, air temperature, and relative humidity. The accuracy of the ET calculation can be improved with the addition of an optional anemometer (ET Wind), along with an automatic wind shutdown capability. The ET System will also shutdown irrigation if the air temperature drops below 35^{o} F. The ET Sensor includes a tipping bucket type rain gauge, which measures rainfall to one-hundredth of an inch. The user programs the ET Sensor to stop irrigation in progress at a specific rainfall depth, and a percentage of the rainfall is accounted for in the irrigation schedule. The ET Module calculates specific run times for each zone individually. The ET Module also possesses a wilt guard feature (Wiltgard™) that triggers irrigation when extreme temperatures occur. The user-selectable WiltGard triggers emergency irrigation (regardless of time of day) when the ET System determines that plants are threatened by monitored conditions.

To program the ET Module, the user first enters the type of controller used, date and time, water days and start times. Then the site condition settings are made for each station. These settings consist of plant type, soil type, sprinkler type, percent ground slope, sun/shade, and plant maturity. The rain sensor setting is programmed for the minimum amount of rainfall that will cause interruption of irrigation with a range of 1/8 to 1 inch.

Available plant type settings include numerous types of grasses, shrubs, ground covers, vines, trees, perennials and desert plants. Alternatively, a custom crop coefficient setting can be used in place of plant type. Available soil type settings consist of sand, sandy loam, loam, clay loam, silt, clay and silty clay. Soil type selection determines both infiltration rate (used for cycle-and-soak calculation, along with the slope setting) and water-holding capacity of the soil. Sprinkler type can be set to rotor, spray, drip, bubbler or custom. The custom option allows for entering a sprinkler application rate (inches/hour or increments of 0.254mm). The ground slope setting is by percentage. Available sun/shade settings consist of full sun, part shade (75 percent sun), part sun (50 percent sun) and full shade. The maturity setting is set to either new or established. The ET source setting can be set to manual to override automatic ET calculation. The wilt guard feature is programmed either on or off (default out of the box is Off).

The ET Module is plugged into the controller's SmartPort, and once programmed; it uses the controller's Program "A" to create and run irrigation on water days (except with the Hunter ACC controllers where it works independently of any programs). Each day, the ET System evaluates the current soil moisture depletion level, ET rate, plant type (crop coefficient and root zone), and whether the next day is an allowable watering day. Then the system performs a "look ahead" on the allowable watering days, to see if not watering at that time would deplete soil moisture critically by the time a watering day is scheduled. Irrigation will not occur, however, if the calculated quantity is below the minimum irrigation amount, to prevent shallow watering. The calculation for minimum sprinkler runtime is based upon the soil type and capacity.

The ET Module is housed in a weatherproof extruded plastic cabinet and it dimensions are 6" x 4" x 1.8". The ET Sensor standard model dimensions are 10.5" x 7.3" x 12", and the ET Sensor with ET Wind standard model dimensions are 11.5” x 7.3" x 20". The ET Module operates on 24 VAC from the controller’s SmartPort and requires no additional AC wiring. It has non-volatile memory and a replaceable 10-year lithium battery.

Installation and programming of the ET System can be performed by the user or irrigation professional. First time installation and programming for a typical setup is reported to require 2 hours. The ET Module is wall mounted near the controller and the ET Sensor is installed within 100 feet of the ET Module. The ET Sensor can be wall mounted or attached to a pole or eave. The ET System owner’s manual is available at Hunter’s website (hunterindustries.com). It contains detailed installation and programming information.

The ET System is available from Hunter distributors worldwide and a distributor search engine can be accessed at Hunter’s website. The retail price for the ET System basic model is $399, and the optional ET Wind is an additional $399. The price range for the ET System compatible Hunter controllers is from $115 to $799. The ET System comes with a 2-year warranty.

The ET System’s ET calculation algorithm uses the Modified Penman-Monteith equation. In creating the ET System’s crop coefficients for the various plant type settings, Hunter has generally followed the principles of Water Use Classification of Landscape Species as prescribed on the State of California Office of Water Use Efficiency website (www.owue.water.ca.gov/index.cfm). Use in other states may require some adjustment for crop coefficients, which can be customized in the ET System.

ET System is currently in the SWAT testing process, but a performance report was not available for this report. The ET System was two years in development and beta testing. Hunter has had 10-15 years experience with ET-based irrigation, but this is its first ET System aimed at stand-alone residential applications.

Although Hunter did not provide water savings data for this report, it reports an approximate water savings of 30 percent, which is similar to the study results for other weather based irrigation control products discussed in this report.

HydroPoint

WeatherTRAK® ET is the line of residential and commercial weather based irrigation controller products by HydroPoint Data Systems Inc. of Petaluma, California. WeatherTRAK ET provides a wireless, real-time ET data service combined with the controller's Scheduling Engine™ software that updates irrigation schedules daily for each valve in a landscape. Network Services, which developed patents on the broadcasting of ET data used by HydroPoint, began business in 1997. HydroPoint was incorporated in 2002 and entered into a partnership with The Toro Company in 2003. Toro manufactures irrigation controllers under its name and under its subsidiary, Irritrol, which also use the WeatherTRAK system (see Toro and Irritrol sections).

HydroPoint's WeatherTRAK ET plus residential controller comes in 9, 12, 18 and 24 station models, and its WeatherTRAK ET pro commercial controller comes in 24 station models. The new WeatherTRAK ET Pro^2 commercial controller series provides 12 to 48 station capacity and integrated flow management. The irrigation scheduling features are similar for all models, but the commercial controllers offer optional 2-way communication ability and other features.

The WeatherTRAK system uses data from over 14,000 weather stations across the U.S., including the National Oceanic and Atmospheric Administration's (NOAA) network, state and county networks and private weather stations. The WeatherTRAK system uses advanced climatologic modeling techniques developed at Penn State University. This proprietary system is called ET Everywhere™, and has proven accuracy to a standard deviation of .01 inch of daily ET down to one square kilometer. The WeatherTRAK ET Everywhere service provides local ET (microzone) without the need for any additional weather stations or single sensors on a site. The WeatherTRAK system calculates ET using the standardized Penman-Monteith equation. The HydroPoint Data Center validates the weather data and transmits calculated ET through three satellite servers to each controller everyday. The three satellite servers provide over-lapping coverage of the U.S. to ensure signal reception to WeatherTRAK controllers located anywhere.

The WeatherTRAK ET controller calculates irrigation schedules for each independent valve on a site. The controller does not use pre-set irrigation schedules input by the user. Instead, it asks a series of questions to define the site variables that influence water need. The controller is programmed by entering the following station specific information: sprinkler type or precipitation rate, plant type, root depth, soil type, microclimate (sun or shade), slope (including if the valve is at the top, middle or bottom of the slope, and system efficiency (percentage). The schedule for each station is adjusted daily according to the local weather data received via the ET Everywhere service.

With these inputs, the WeatherTRAK ET calculates an irrigation schedule for each irrigation valve. Soil moisture depletion tracking, triggered at a 50% depletion level, along with daily ET updates allow the controller to adjust schedules as the weather changes. The number of water days, minutes and cycles (with appropriate soak times between cycles) are generated automatically and change as weather and water need fluctuates. The WeatherTRAK ET has an eight-week scheduling window. This allows for infrequent watering of low water use or native plants.

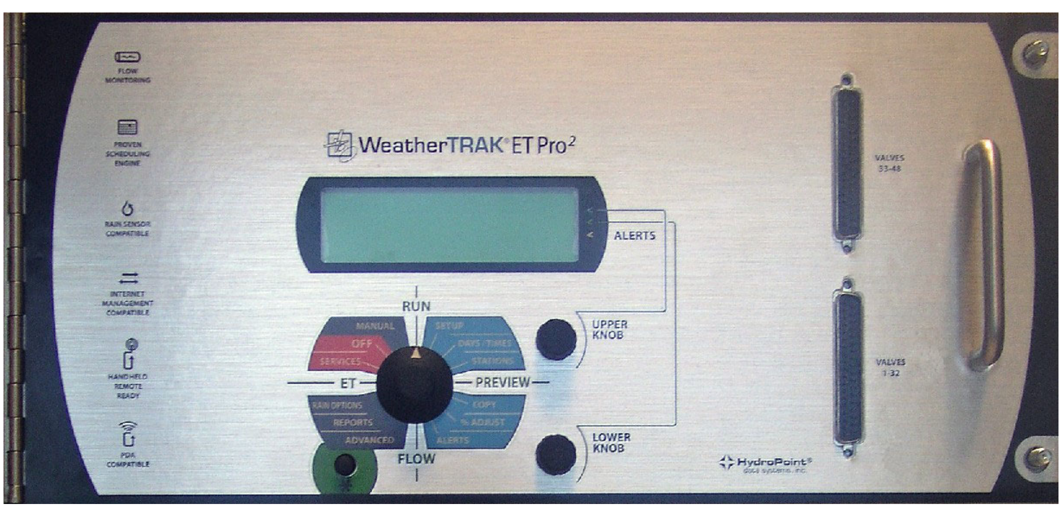
Programming options for all WeatherTRAK ET controllers include sequential stacking of overlapping start times, or the ability to run two programs simultaneously. The WeatherTRAK ET controllers have a manual feature providing any amount of time setting for plant establishment or to check the irrigation system on a valve by valve basis. An adjust feature provides percentage adjustments (in 5 percent increments) to increase or decrease the run time for any station. The controller accepts rain, wind, freeze and flow sensors and possesses a master valve circuit. A rain pause mode allows the user to shut-off irrigation for up to 14 days during or after rain. HydroPoint can also be contacted to automatically "rain pause" controllers and groups of controllers using the wireless data service. Non-waterering days can be selected. A "help" mode alerts the user to the WeatherTRAK customer service center toll free telephone number (800-362-8774) to answer questions and walk users through any situation occurring on the site.

Other features include inputs for crop coefficient values, community water restrictions (odd/even or selected watering days) and unlimited programs. The independent station adjust feature allows for individual station adjustments from -50 to +25 percent in 5 percent increments. All WeatherTRAK ET controllers have heavy duty surge protection on the 24 VAC output board. The WeatherTRAK ET controllers have non-volatile memory and do not require a back-up battery to maintain date and time information. The controller terminals will accept 12 to 20 gauge size wiring. In some cases, an optional antenna is required to receive the scheduling signal.

The WeatherTRAK ET plus is an indoor/outdoor residential controller. Its cabinet is of extruded plastic with dimensions of 8.6" x 11" x 4.7". Programming is done with the programming dial, copy button, two selector knobs and three-line LCD display. The internal power transformer for the 9 and 12 station models includes a 2.0 ampere fuse, has a maximum total circuit capacity of 1.0 amperes and the individual station circuit current capacity is 0.375 amperes. The 18 and 24 station models include the same fuse and individual circuit capacity, but the total circuit capacity is 2.0 amperes. The 18 and 24 station models also include a manual valve test program to identify open valves and short circuits. A 2 year subscription to the ET Everywhere service is included with the purchase of 9 and 12 station models, and a 1 year subscription is included with the 18 and 24 station models.

The WeatherTRAK ET pro commercial controller comes in an indoor chassis model with dimensions 14.5” x 27” x 4” and two indoor/outdoor lockable stainless steel cabinet models. The wall mount cabinet dimensions are 8.5” x 18.5” x 8” and the front access pedestal cabinet dimensions are 16.8” x 30” x 8.3”. The ET pro does not include a typical front panel with programming access, but programming is done from a remote location using the WeatherTRAK.net service, as discussed below. Additional features included with the ET pro include automatic short circuit detection and alarm, programming conflict alarm, ability to run two stations concurrently, and additional circuit capacity. The ET pro comes with a vandal resistant antenna. The internal power transformer includes a 2.4 ampere fuse, has a maximum total circuit capacity of 2.4 amperes and individual station circuit current capacity of 0.5 amperes.

The ET pro is compatible with the WeatherTRAK.net service that allows Internet-based irrigation control 24/7 with a secure web-hosted service. With WeatherTRAK.net, the user can manage single or multiple controllers from any location with access to the Internet. WeatherTRAK.net delivers instant



notifications of adjustments made in the field and enables fast, one-click synchronization. Through wireless, two-way communication, WeatherTRAK.net transmits real-time updates and system alerts to the user's personal computer, mobile phone or PDA (personal data assistant). HydroPoint sells a Hewlett Packard® iPAQ PDA with all necessary hardware and software to utilize Weather TRAK.net. A 3-month subscription to WeatherTRAK.net and ET Everywhere is included with the purchase of a WeatherTRAK ET pro.

The WeatherTRAK ET controllers do not require professional installation, although it is recommended. Typical installation times, as seen in public agency studies and distribution programs, range from 1 hour to 2.5 hours, depending upon the size of the landscape covered and mounting issues. Installation should include a site assessment, and discussion with the user about the site irrigation system and how the controller operates with the user. Technical support is available by a toll free number, at HydroPoint's website (www.weathertrak.com) or through field-certified contractors.

WeatherTRAK ET controllers are available directly from HydroPoint or local distributors. A distributor search engine can be accessed at HydroPoint's website. WeatherTRAK ET controllers come with a 3 year warranty, and toll-free telephone customer service is available Monday through Saturday during business hours, and on-line customer service is available 24/7. A partial listing of WeatherTRAK ET controller list prices is provided in the table below (a complete price list is available from HydroPoint Sales through its toll free telephone number or website).

WeatherTRAK Controller and Accessories Prices and Fees

Description	Model	Price
9-Station Residential Controller	WTPLS-09	$549-$559
12-Station Residential Controller	WTPLS-12	$579-$589
18-Station Residential Controller	WTPLS-18	$759-$769
24-Station Residential Controller	WTPLS-24	$859-$869
24-Station Chassis Commercial Controller	WTPRO-24-CHA	$3,125
24-Station Wall Mount Commercial Controller	WTPRO-24-SSW	$3,325
24-Station Pedestal Commercial Controller	WTPRO-24-SSP	$4,525
Hewlett Packard iPAQ PDA	WT-PDA-KIT	$1,200
WeatherTRAK.net Annual Fee	CIM-PROC-24-1Y	$225
9-12 Station ET Everywhere Annual Fee	ETE-912-1Y	$48
18-24 Station ET Everywhere Annual Fee	ETE-1824-1Y	$84

WeatherTRAK ET has completed SWAT testing and a performance report is posted on the Irrigation Association's website. The WeatherTRAK ET controllers have been tested in 20 public agency settings since 1998. The overall results from these tests indicate significant water savings (16 to 58 percent) and reductions in runoff (64 to 71 percent). Information about several of these studies is summarized in the table below.

Summary of WeatherTRAK Demonstration Projects

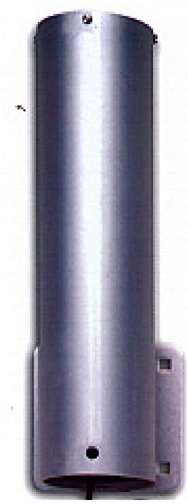
Test Sponsor	No. of Test Sites
Irvine, California	180
Los Angeles Dept. of Water and Power	540
Boulder, Colorado	10
Colorado State University, Ft. Collins	3
University of Las Vegas, Nevada	15
Santa Barbara, California	200
Lake Arrowhead, California	78
Victor Valley, California	12
Marin, California	8
Park City, Utah	24
Santa Clara Valley Water District, California	125
Newhall County Water District	25

Hydrosaver

Water Conservation Services (WCS) Hydrosaver™, of Signal Hill, California, has been a manufacturer of water conservation based commercial landscape irrigation technologies for 20 years. Hydrosaver entered the market 14 years ago with a soil moisture based controller. Its current ET controller, the ETIC, was introduced in 1994. The Hydrosaver ETIC functions as either a stand-alone controller, or as a satellite controller of a centralized control system, managed by WCS' partner HydroEarth Solutions. WCS developed its own electronic tensiometer soil moisture sensor, electronic rain sensor and ET sensor. It reports over 2,500 of their commercial weather based controllers have been installed, mostly in Southern California.

The ETIC controller comes in standard sizes from 12 to 56 stations and can be customized with the WCS Hydromaster to handle up to 164 stations. The ETIC adjusts irrigation schedules based on ET data received from the WCS Hydrosaver ET sensor. The controller comes with the ET sensor and the Hydrosaver Rain Guard™ rain sensor. Optional soil moisture and flow sensors may also be connected to the ETIC.

As a stand-alone controller, the user programs the ETIC with a base irrigation schedule. The base schedule includes irrigation days and run times. Total run times are entered for July and the controller automatically decreases the run times based on the accumulated ET sensor inputs since the last irrigation. The controller includes an ET percent feature that allows the user to vary the ET adjustment rate by program up to 300 percent, in 10 percent increments. The ET schedule adjustment function can be switched ON or OFF. The controller's ET scheduling feature is based on real time ET utilizing historical ET as a baseline. Historical ET data are programmed into the controller by the user.



The Hydrosaver ET sensor measures temperature, humidity and solar radiation. The controller calculates ET using these measurements. (The ET calculation assumes a 3 mph wind speed.) The ET sensor is in a vandal resistant housing and is maintenance-free. ET is calculated to within 100th of an inch using the Penman-Monteith equation. When the Rain Guard detects one-quarter of an inch of rain, irrigation is interrupted and the controller can be programmed for a rain delay up to 99 days. The Rain Guard includes a built-in bypass switch for controller testing during periods of extended rain.

The controller accepts Data Industrial or Fluidyne flow sensors. Once the user programs flow limits, the flow-sensing feature will trigger an alarm and shut off irrigation when flow limits are exceeded in the event of line breaks and valve failure. A shut off delay feature is provided and the flow sensing capability can also be used for fertigation purposes. The controller also possesses a faulty circuit feature that senses valve and wiring problems.

The ETIC includes 6 regular programs with up to 12 start times each. The controller has a valve test program and up to 4 stations may run concurrently. In addition to the regular station circuits, the controller has 3 independently programmable master valve outputs. There is also a pump start output that goes on with all irrigation. The controller automatically divides total run times into appropriate cycle-and-soak times to minimize runoff based on soil and slope conditions entered by the user for each zone. The irrigation schedule calendar options include 7, 14 and 28 day and even or odd day. Irrigation days can be specified and the controller has a watering window feature.

The ETIC comes in standard wall mount models and complete stainless steel (CSS) top entry enclosure models The standard wall mount cabinet is constructed of rolled steel with dimensions of 12" x 16" x 6". The CSS dimensions are 16" x 14" x 36" and the enclosure must be mounted to a concrete foundation. Both models are designed for outdoor installation and are lockable, weatherproof and vandal resistant. The controller's 4-line by 48 character LCD display can be set to English or Spanish. Current and historic irrigation, ET, weather and flow information is displayed. All ETIC controllers include an internal transformer and the station circuit capacity is 2 amperes. The controller has non-volatile memory and the date and time information is protected without backup batteries. Surge and lightning protection is provided through a relay system to create circuit isolation protection, separate power transformers for controller processing and valve circuitry, metal oxide varistors (MOV), and an isolation transformer.

WCS Hydrosaver products are available directly from Hydrosaver and HydroEarth (949-636-7749 or hydroearth.com), or from commercial distributors. The current retail price for a standard wall mount 24-station ETIC controller with the Rain Guard and ET sensor is $1,800. A 24-station CSS controller is currently priced at $2,800. Prices for other controller sizes and accessories can be obtained from Hydrosaver or HydroEarth. The CSS controllers come with a 5-year warranty and the standard controllers come with a 3-year warranty. The warranties include free field service, with a renewable option. The ETIC should be installed by an irrigation professional. Installation and programming time will vary depending on system size and site conditions. Toll-free telephone customer support is available during business hours at 800-821-1322.

WCS Hydrosaver reports its controllers are being included in several current studies including research work on wireless valves and ET controllers. Hydrosaver reports significant variance in ET measurements by multiple ET sensors tested within close proximity to a CIMIS weather station. Specifically, hill top ET measurements were found to be significantly higher than those at the bottom of the hill and at the nearby CIMIS site. A SWAT test performance report for Hydrosaver controllers was not available at the time of this study.

Irrisoft

Irrisoft Inc. offers weather-based control to residential and commercial irrigation systems through the Weather Reach Water Management System™. Established in 1999, Irrisoft™ became a subsidiary of Campbell Scientific Inc. in 2001 and has now partnered with Rain Bird Corporation to offer weather-based irrigation control solutions to both homeowners and commercial water users. Rain Bird® has a longstanding relationship with Irrisoft and Campbell Scientific, Inc.

The Weather Reach Water Management System provides wireless, real-time ET data to any standard irrigation controller through a Weather Reach Receiver. There are two "smart" receivers offered with this system; the WR-7 Weather

Reach Receiver and the ET Manager™, which is offered through Rain Bird Corporation (see Rainbird Section).

The Weather Reach Water Management System uses Campbell Scientific weather stations with a full set of sensors to gather accurate weather data. The Weather Reach Signal Providers maintain computer servers with an Irrisoft computer software program to communicate with the weather stations (often using existing stations in an area), and broadcast weather information hourly through a pager network to Weather Reach Receivers. Data includes temperature, wind speed, relative humidity, solar radiation and rainfall. Weather Reach Receivers use this information to calculate ET accumulation on an hourly cycle, and process it into a running ET balance.

The WR-7 and ET Manager are used in combination with a user's existing irrigation controller to schedule irrigation based on ET demand. These receivers are compatible with any standard irrigation controller and interrupt irrigation until it is needed.

Weather Reach manages the frequency of irrigation and does not adjust run times. To help a user create an irrigation schedule for a controller, Weather Reach provides a free program called InSite Irrigation Scheduling™. InSite tailors the schedule to a specific sprinkler controller's capabilities as well as the capabilities of the sprinkler system and factors in the landscape dynamics such as plant type, soil type, root depth, slope and sprinkler precipitation rates.

Users enter the information through a series of questions that help to tailor the schedule to each station on the property. InSite performs all the calculations automatically but still allows a user to adjust any of the calculations for a custom schedule and gives users the opportunity to see how the calculations are made. InSite can also calculate accurate settings for programming the Weather Reach Receiver.

Once the schedule has been created, the user enters it into the sprinkler controller, and programs the Weather Reach Receiver with the proper settings. Weather Reach will then automatically manage the frequency of irrigation based on ET. Weather Reach Receivers can accommodate any available or non-available watering day requirement.

Most weather conditions are relatively constant over large areas, but rainfall can be very localized. A tipping bucket rain gauge is offered as an optional add-on component to a receiver to measure on-site rain as opposed to the rain measurement provided at the weather station. This allows the receiver to more accurately calculate the amount of water a landscape will need, and to interrupt irrigation when a user specified amount of rainfall occurs.

A growing network of Weather Reach Signal Providers exists throughout the U.S. For a covered area, data from multiple weather stations are received, processed, and then transmitted by a Signal Provider. The Weather Reach Receivers are programmed to receive data from the appropriate weather station based on a weather region code. The data are transmitted hourly by the provider using a Motorola® Flex® paging system.

Potential ongoing costs are dependent on the signal provider for a given area. Public providers typically absorb the cost of the weather stations, computer server and software, and paging system, and there is no ongoing user cost. Commercial providers pass on these costs to the end user. Private providers offer the service to a specific entity such as a Home Owners Association. A list of current Signal Providers is maintained at www.irrisoft.net. The typical price range for private providers surveyed for this report is $50 to $350 per year. Where a signal is not available, Irrisoft offers a variety of solutions to establish a public or private Weather Reach Signal. (Irrisoft should be contacted for details.)

The existing controller is programmed based on a plant root zone moisture depletion and ET threshold balance concept using the InSite software. This balance is maintained based on ET minus effective rainfall. This type of schedule will allow the root zone to dry out to a manageable level before irrigation occurs, and then irrigation is set to refill the root zone without over-watering.

The controller schedule is set to irrigate every day, unless certain days are to be excluded for a variety of reasons. The receiver then allows the controller to irrigate when the ET threshold is reached, and the prescribed irrigation amounts are applied to replenish the root zone depletion. The receiver includes two programs so that two ET thresholds and landscape adjustment percentages may be used. This provides for different stations to be scheduled separately to meet the needs associated with varying plant types and conditions.

The WR-7 is a small (4.8” x 5.3” x 1.5”) plastic cabinet designed for indoor installation. A lockable fiberglass outdoor enclosure is available as an accessory for both receivers. In the event a power supply is not available from the existing controller, an optional power transformer is available. A 9-volt backup battery is included for operation during power outages. In some cases, an external antenna is required for the receivers. Irrisoft recommends installation by a professional irrigation system specialist, and it markets its products through specialty irrigation product suppliers. The typical installation cost ranges from $100 to $400. Receiver and add-on component prices are summarized in the table below.

WR-7 Prices

Component	Model No.	Price
Weather Reach Receiver	WR7	$795
Pronamic Rain Gauge	WR-PRG	$165
Power Supply	WR-PS	$42
External Antenna	WR-ANT-B	$58
Outdoor Enclosure	WR-OE	$230

During recent years, numerous demonstration projects using the Irrisoft System have proven its ability to save water. The overall results from these ongoing projects indicate water savings of 20 to 50 percent. A sampling of these projects is provided in the table below.

Summary of Irrisoft Demonstration Projects

Sponsor	No. of Test Sites
Denver Water Department	12
Utah Division of Water Resources	8
Northern Colorado Water Conservancy District	10
Southern Nevada Water Authority	10
EPA Evaluation Project (Massachusetts)	25
Aquasave, Ipswich, Massachusetts	118
WaterLogic, Houston, Texas	40

Irritrol

Irritrol™ Systems is a brand of professional irrigation products manufactured by the Toro™ Irrigation Division, located in Riverside, California. The Toro Company was established in 1914, and acquired the Irritrol brand of products in the early 1990s. The Irritrol Smart Dial™ series of residential and commercial weather based irrigation system controllers entered the market during 2005.

The Smart Dial controllers utilize the ET Everywhere™ subscription service and WeatherTrak™ scheduling engine to provide weather based irrigation control. Toro and Irritrol are partners with Hydropoint Data Services. Toro and Hydropoint controllers also utilize ET Everywhere and WeatherTrak, as discussed in the Toro and Hydropoint sections of this report.

The Smart Dial series includes six residential controllers, comprised of indoor and outdoor models for 6, 9 or 12 zones (plus a pump/master valve circuit), and a 24 zone commercial model. The controllers' WeatherTrak-enabled software creates a scientifically calculated zone-specific baseline irrigation schedule. The schedule is updated daily using weather data delivered by the ET Everywhere subscription service.

ET Everywhere uses data from the NOAA's system of 14,000 nation-wide weather stations to deliver ET to any area in the US. ET Everywhere has a proven accuracy to a standard deviation of .01 inch of daily ET at a resolution of one square kilometer. The ET Everywhere data service provides local ET (microzone) without the need for a weather station on site. The ET Everywhere Data Center validates the weather data and transmits calculated ET through three satellite servers to each controller everyday. The three satellites provide over-lapping coverage of the U.S. to ensure signal reception anywhere.

The Smart Dial controllers calculate schedules for each irrigation zone. The controller does not use pre-set irrigation schedules input by the user. Instead, a series of questions are answered by the user to define the site variables that influence water need. The controller is programmed by entering the following station specific information: sprinkler type or precipitation rate, plant type, soil type, microclimate (sun or shade), slope (including if the zone is at the top, middle or bottom of the slope), and system efficiency (percentage). The schedule for each station is adjusted daily according to the local weather data received via the ET Everywhere service.

With these inputs, the controller calculates an irrigation schedule for each zone. Soil moisture depletion tracking, triggered at a 50 percent depletion level, along with daily ET updates allows the controller to adjust schedules as the weather changes. The number of water days, minutes and cycles (with appropriate soak times between cycles) are generated automatically and change as weather and water need fluctuates. The controllers have an eight-week scheduling window. This allows for infrequent watering of low water use plants. The controllers can initiate irrigation even if the daily ET page is not received by using the last download and loop-up table included in the WeatherTrak software. Non-watering days can be specified in the controllers' schedule programming. The controllers are compatible with Irritrol's Wireless RainSensor™ series (rain and rain/freeze), which eliminate irrigation during rainfall and freezing weather if added as an optional accessory.

Both the indoor controller models' cabinet is constructed of ABS plastic while the outdoor units are comprised of Lexan. The dimensions of the indoor models are 7.8" x 7" x 3.8" and the dimensions of the outdoor models are 7.8" x 10.8" x 4". The controllers have a large (3.5" x 0.8") LED information display, dial type controls, and a copy button for simplifying setup. All controllers include internal UL/CSA listed transformers. The current capacity for each zone circuit is 0.5

amperes, and the current capacity for pump/master valve circuit is 0.375 amperes. The controllers will accept wire sizes from 12 to 18 gauge. The non-volatile memory maintains programming, and the back-up battery maintains the date and time during power outages.

Other controller features include surge protection up to 6 kilovolts and valve malfunction detection. The irrigation schedule, irrigation history and program review can be viewed with the LED information display. In addition to the wireless rain and rain/freeze sensors, an external bow tie antenna kit, pump starter relay and wired rain sensor are available as optional accessories.

A snap-in Smart Dial Module is also available which directly interchanges with a users existing Rain Dial™ Plus controller panel to convert it to a WeatherTRAK-enabled controller. A converted controller possesses all of the same features as the Smart Dial controllers.

The Smart Dial controllers, modules and accessories may be purchased from authorized Irritrol distributors and retailers. Current controller, module and accessory prices are summarized in the table below. Purchase of a Smart Dial controller requires a paid subscription to the ET Everywhere service. The ET Everywhere annual service fee is $48 for the 6 to 12 station controllers and $84 for the 24 station controller, as discussed in the Hydropoint section of this report.

Smart Dial Controller, Module and Accessory Prices for 2006

Description	Model	Price
6-station Indoor Controller	SD-600-INT	$399
9-station Indoor Controller	SD-900-INT	$449
12-station Indoor Controller	SD-1200-INT	$499
6-station Outdoor Controller	SD-600-EXT	$419
9-station Outdoor Controller	SD-900-EXT	$469
12-station Outdoor Controller	SD-1200-EXT	$524
24-station Outdoor Controller	SD-240-OD	$889
6-station Module	SD-600-MOD	$299
9-station Module	SD-900-MOD	$349
12-station Module	SD-1200-MOD	$399
Wireless Rain Sensor	RS1000	$85.33
Wireless Rain/Freeze Sensor	RSF1000	$114.71
Wired Rain Sensor	RS500	$25.20
Pump Starter Relay	SR-1	$75.60
External Bow Tie Antenna	SD-ANT	$87.50

The Smart Dial controllers and modules do not require professional installation, although trained installation is recommended. Typical installation times range from 1 hour to 2.5 hours, depending upon the size of the landscape covered and mounting issues. Installation should include a site assessment and discussion with the user about the irrigation system and how the controller operates. Installation and setup instructions are included in the owner's manual. Technical support is available from Irritrol at its website (www.irritrolsystems.com), by toll free telephone (800-634-8873) and through field certified contractors.

The technology behind the Smart Dial controller and module series is proven by several multi-year independent studies showing water savings. These studies were performed using Hydropoint's WeatherTrak controller and the ET Everywhere service. The studies are discussed in the Hydropoint section of this report. The Smart Dial products come with a 5-year warranty.

A Smart Dial controller SWAT test performance report is posted at the Irrigation Association's website. Given Irritrol's long-standing reputation for reliability combined with the track record of WeatherTrak and ET Everywhere, the Smart Dial controllers and modules should provide consistent, accurate and reliable weather based irrigation system control.

Micromet

Founded in 1997, Micromet™ is a water management company with offices in Santa Ana, California and in Australia. Micromet combines horticultural and irrigation management expertise with recent technological advances to provide weather based plant demand irrigation management for public entities and commercial water users. Micromet's patented ET Drive signal receiver works with an existing irrigation controller to provide plant demand driven weather based and environment-aware irrigation control. Micromet integrates with all irrigation systems and requires no purchase of additional equipment.

With ET Drive, Micromet monitors daily soil moisture depletion levels and initiates irrigation as dictated by weather, plant demand and individual site conditions. Irrigation is shut down during rain events, and ET Drive accounts for the amount of rainfall received at the site before initiating future irrigations.

ET Drive is marketed by Micromet as a combined hardware and service package. The service portion of the package includes an initial site evaluation, installation, programming, control signal, and ongoing maintenance and support. The Micromet service is currently available to Southern California municipalities, and commercial clients, and Micromet plans to expand this service area as demand increases.

The ET Drive signal receiver can be connected to any type of existing irrigation controller. The controller is programmed by Micromet based on site conditions established by the survey. Micromet transmits a signal to operate the controller via the receiver. Micromet calculates irrigation schedules based on local weather conditions measured with their own network of weather stations, public weather stations, and rainfall totals based on NOAA Doppler radar data. The user can access up-to-date site conditions together with reports on water usage through Micromet's website (www.micrometonline.com).

Site conditions are determined during the initial site evaluation. The evaluation includes determination of soil type, root depth, sprinkler precipitation rate and ground slope for each station, which are then used to calculate total run times. The moisture holding capacity is a function of soil type, root depth, and the time to refill a certain depletion of this capacity (usually 50 percent) is calculated as a function of the precipitation rate. Total run times are divided into multiple cycle-and-soak times to minimize runoff. These times are a function of soil type (infiltration rate) and ground slope. The controller will refill the prescribed soil moisture depletion level when activated by the signal receiver.

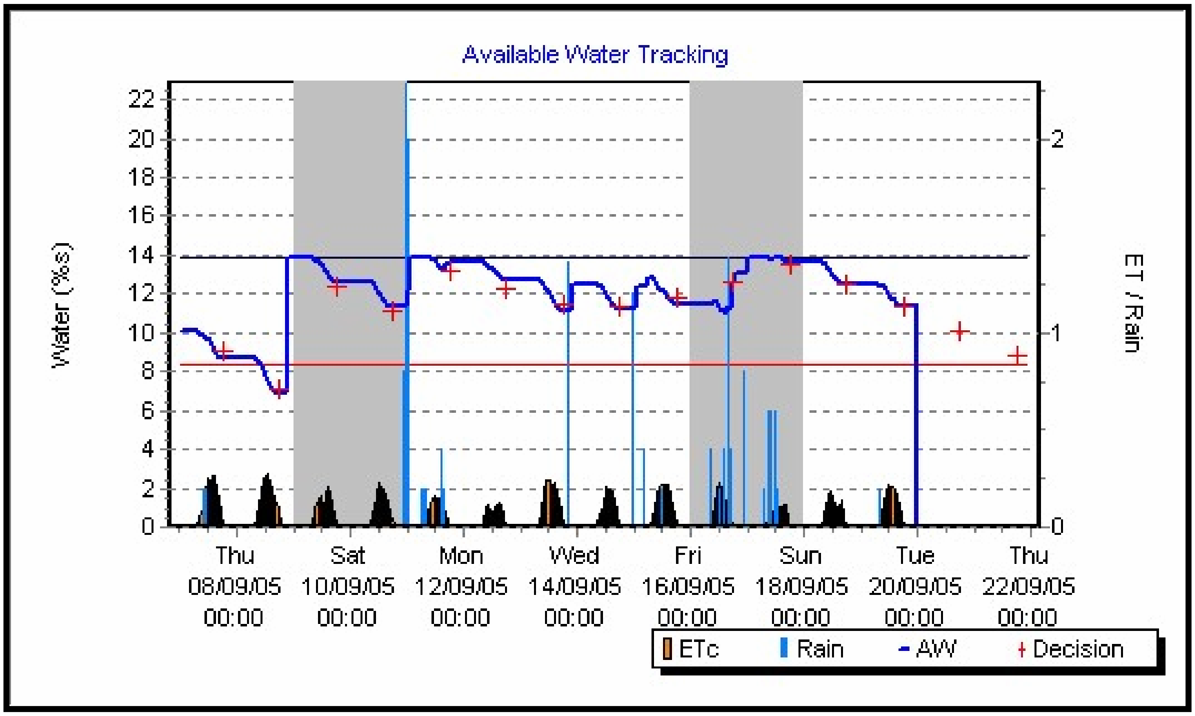
The calculated run times are summarized on a "Site Sheet" which is posted near the controller. This schedule is referred to as the Optimum Irrigation Event (OIE). The controller is programmed to irrigate each station for the OIE every night.

Micromet receives weather information from their weather station network and public weather stations located throughout their service area. This information is passed on to the Micromet Central Control System. To complete the weather picture, Micromet accesses NOAA's rain radar system (Doppler) information. This enables Micromet to pinpoint rainfall and the amount of rainfall to within 0.05 inches, rather than using rain gauges at every site. The Micromet System adds the amount of rain that falls into the soil moisture content. Should rain fall during an irrigation event; as detected by rain radar, weather station, or a combination of means, the irrigation in the rain affected sites is immediately switched off.

Micromet's scheduling algorithm calculates soil moisture content based on soil texture, root zone depth, temperature, wind, solar radiation and rainfall. Using the algorithm, the Micromet system determines the amount of available water left in the root zone at the end of each day. It monitors rain and rain radar information constantly, and samples other weather information twice per day. The soil moisture tracking process is illustrated in the available water (AW) graph on the following page.

The soil moisture depletion scheduling described above is a plant physiology-based method, which reportedly encourages the development of deep, drought resistant root zones, as well as promoting general plant health.

The ET Drive signal receiver is constructed of ABS plastic and its dimensions are 5" x 2.6" x 1.6". It is installed in the controller housing, or in a suitable weatherproof, lockable cabinet, and is typically installed near the controller. Power is supplied by an external power transformer (12 VDC) and an external antenna is required for the receiver.



Micromet offers the ET Drive package under a service agreement. This package includes the receiver and its installation, initial site evaluation, controller programming, control signal, site inspections, ongoing maintenance and support.

The price for the system includes a one-time $300 site establishment fee per controller, and an ongoing cost of $30 or $60 per month, depending on the size of the controller. Under the terms of the Metropolitan Water District Water District of Southern California's rebate program, Micromet sells the receiver device, site survey, designs a schedule of irrigation for the site, and provides twenty-four (24) months of management for a rebate eligible cost of $1,890. Micromet provides unlimited telephone support and reports that field issues are addressed within 24 hours.

The Micromet Water Management System is reportedly a tested and proven system that has been in commercial operation for nine years. With over 1,600 sites under management, Micromet reports the system saves in water much more than it costs, reduces run-off, and has even greater savings when manpower and other associated costs are considered.

The Monash University Engineering Department (Victoria, Australia) conducted a study evaluating 15 sites with Micromet systems installed. The study evaluated water usage, labor efficiency, turf quality and other impacts. The findings are positive overall with more efficient water use at most sites and significant water savings at some sites. A SWAT test performance report is not posted for Micromet.

Micromet does not make any changes to the existing system of controllers, pipes, valves and sprinklers. Micromet works with all controllers, from the oldest to the newest, including hydraulic, battery, and Solatrol/LEIT. Normal pipe and sprinkler testing and maintenance can be performed in the usual way.

Rain Bird

Rain Bird Corporation, based in Glendora, California, began business in 1933. Over 4,000 Rain Bird® products are sold domestically and in more than 120 countries. Rain Bird owns more than 130 patents and 30 additional trademarks. For more than two decades Rainbird has used weather technology in the golf and commercial irrigation markets with their central control products, including the Maxicom™, SiteControl™ and Nimbus™ II systems.

Rain Bird recently joined forces with Irrisoft Inc., a Campbell Scientific company, to offer a weather-based solution for homeowners and commercial water users. The ET Manager™, or ETMi, is an add-on scheduler that works with an existing controller to manage irrigation frequency based on weather conditions. Rain Bird began field testing the ET Manager in the Fall of 2005 and it entered the market in June 2006. Its predecessor, Irrisoft's WR7 Weather Reach Receiver, has been in use since 2001. Rain Bird has used private-labeled Campbell Scientific weather stations for nearly 20 years with its central control systems.

The Rain Bird ET Manager uses weather information, typically from fully instrumented Rain Bird and or Campbell Scientific weather stations. The ET Manager receives the weather data in the form of an hourly broadcast through a paging network provided by a local Weather Reach Signal Provider. This approach enables thousands of users to benefit from accurate, reliable weather data from a single or network of weather stations depending on the size of the region covered. The weather data broadcast includes temperature, wind speed, relative humidity, solar radiation, and rain. An optional rain gauge is available for on-site rainfall measurement, and to interrupt irrigation when a user specified amount of rainfall occurs.

A growing network of Weather Reach Signal Providers exists throughout the U.S. Potential ongoing costs are dependent on the Signal Provider for a given area. Public providers typically absorb the cost of the weather stations, computer server and paging system, and there is no ongoing user cost. Commercial providers pass on these costs to the end user. Private providers offer the service to a specific entity such as a Home Owners Association. A list of current Signal Providers is maintained at Irrosoft's website (www.irrisoft.net). The typical price range for private providers surveyed for this report is $50 to $350 per year.

The ET Manager uses the ASCE standardized ET equation to calculate ET on an hourly basis and maintain a user specified soil moisture balance. Typically, controllers irrigate on time-based (day, time, and minutes to water) schedules regardless of changing weather and landscape needs, whereas the Rain Bird ET Manager interrupts the controller only allowing it to irrigate when calculated soil moisture levels reach user set levels. Historical ET is programmed into the ET Manager and used as back-up in the event the Weather Reach Signal is not received.

The ET Manager is compatible with nearly any existing standard irrigation controller by interrupting the common wire thus managing the frequency of irrigation. The Rain Bird ET Manager schedules the irrigation frequency (how often watering occurs), but not controller run times. Additionally, the ET Manager provides pulse output of ET and rainfall to compatible controllers (0.01-inch per pulse). This feature allows for automatic scheduling by the clock controller based on ET accumulation and rainfall amounts as reported by the ET Manager.

To help users create an irrigation schedule for an irrigation controller and program settings in the ET Manager, Rain Bird offers the ETMi Scheduler. This computer program tailors an irrigation schedule to a specific irrigation controller's capabilities, and the characteristics of the irrigation system. The user enters information for each station and landscape characteristics including plant type, soil type, root depth, ground slope, and sprinkler precipitation rates to create the schedule. All calculations are done automatically and the user has the ability to adjust any of the results for a custom schedule. Once a schedule has been created with ETMi Scheduler, it can be printed out and entered into the irrigation controller. The ETMi Scheduler program can be downloaded at no charge from Rain Bird's website (www.rainbird.com).

The optional ETMi Programming Software allows settings for the ET Manager to be programmed quickly and easily. Users select the appropriate local weather station, site elevation, and available watering days (the ET Manager can accommodate any available or non-available watering day requirement). When the required parameters have been entered, the user can transfer the settings automatically into the ET Manager through the cable supplied with the optional ETMi Programming Software kit. This kit is very convenient for professionals performing higher volumes of ET Manager installations.

The controller schedule is set to irrigate every day, unless certain days are to be excluded for a variety of reasons. The ETMi then allows the controller to irrigate when the Irrigation Amount is reached. The Irrigation Amount is the amount of water that is allowed to evaporate and be used by the plants before irrigation will occur. The ET Manager “enables” watering cycles to refill the plant root zone by applying the Irrigation Amount. The irrigation controller is programmed to apply the Irrigation Amount. By applying the Irrigation Amount, the root zone is refilled without over-watering.

The ET Manager includes two programs so that two Irrigation Amounts may be used. This provides for different stations to be scheduled separately to meet the needs associated with varying plant types and conditions.

The Rain Bird ET Manager has a large graphic display and is designed for indoor installations for convenient viewing of hourly weather conditions, ET and irrigation amounts. Its dimensions are 5.6” x 6.5” x 2”. A lockable outdoor enclosure is available as an accessory. In the event power is not available from the existing irrigation controller, an optional external power transformer is available. A 9-volt backup battery is included for operation during power outages. In some cases, an external antenna is required for the receiver. Installation by a Rain Bird trained professional is preferred.

Rain Bird has field tested 150 ET Managers throughout the U.S. and a SWAT test performance report is posted at the Irrigation Association’s website for the ET Manager.

Rain Bird products are available from irrigation supply distributors throughout the U.S. A distributor search engine can be accessed at Rainbird’s website. Current suggested list prices for the ET Manager and accessories are summarized in the table below. All Rain Bird controller products come with a 3-year warranty.

ET Manager and Accessories Prices

Description	Model No.	Price
ET Manager	ETMi	$701.50
Optional ET Manager Antennae	ETM-ANT	$238.10
Optional ET Manager Outdoor Cabinet	ETMi-OE	$230.00
Optional Transformer Power Supply	ETMi-TRAN	$23.95
Optional Tipping Rain Gauge	ETM-RG	$200.00
Optional ETMi Programming Software Kit	ETM-PS	$603.18

The ET Manager combined with any standard irrigation controller should provide users with accurate real-time weather based irrigation scheduling and help maintain healthy landscapes.

Rain Master

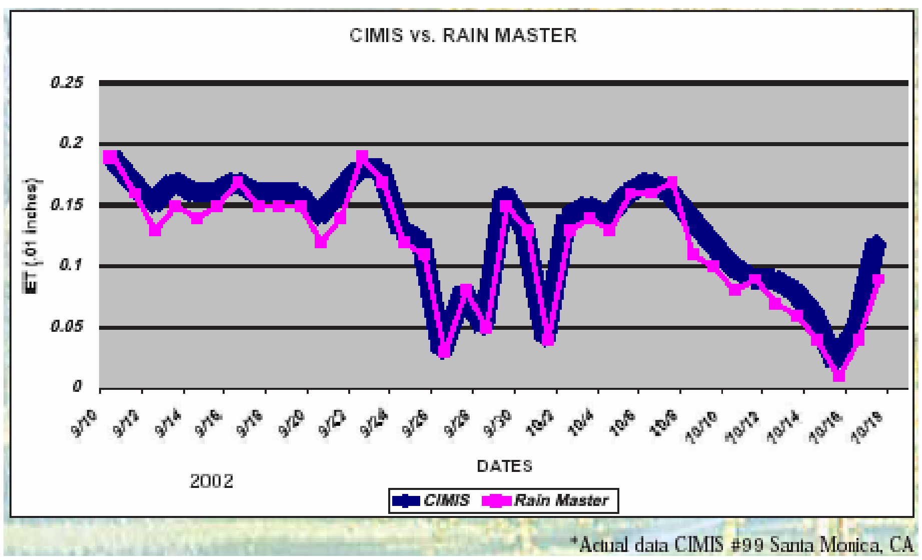
For the past 25 years, Rain Master Irrigation Systems has specialized in the design and manufacture of commercial irrigation controllers, handheld remote controls, and central computerized irrigation control systems. Located in Simi Valley, California, Rain Master introduced its first ET based water management system in 1990. In 2002, Rain Master introduced the RME Eagle™, weather based commercial irrigation controller that functions either as a stand-alone unit, or as a satellite controller component of the Rain Master iCentral™ Internet-based system. The RME Eagle /iCentral system (Patent No. 6,823,239) was designed to address the single controller as well as low to mid-sized control system markets.

Rain Master provides several ET source options for the Eagle. ET may be manually entered into the controller; alternatively the controller may be directly connected to a Rain Master Weather Center II weather station, or receive CIMIS data. When configured with Rain Master's iCentral 2-way wireless card, ET may be disseminated over the Internet using Rain Master's ZipET national dissemination weather service, or California users may obtain their daily ET from CIMIS.

When the Eagle's programs are enabled for ET operation, station runtimes are automatically adjusted on a daily basis when connected to the Internet or a Weather Center II weather station. If daily ET is unavailable, the controller will intelligently utilize average monthly historic ET entered by the user to adjust its daily schedules. Historic ET data by zip code are available at Rain Master's website (www.rainmaster.com). The controller computes ET adjustment granularity to the nearest second, which eliminates rounding errors commonly found in controllers that round on incremental minute basis (i.e., a 5 percent programming error can occur based on just a 10 minute run time).

Rain Master's ZipET is an ET data collection and dissemination service for Rain Master iCentral Internet customers. Rain Master collects raw weather information on a daily basis from thousands of Federal Aviation Administration and NOAA weather stations throughout the U.S. The weather information is validated, and converted as necessary to generate industry accepted ET values. The ET values are interpolated by zip code using a three-dimensional surface regression model. Site-specific ET information is then automatically delivered to each controller via the 2-way wireless communications card (iCard). Rain Master's iCentral website provides daily reports on all ET weather information which was successfully delivered to each controller (2-way confirmation).

An alternative to the ZipET service is available for users who require the accuracy of an on-site weather station. Rain Master's commercial grade, computer controlled, Weather Center II measures wind, rain, temperature, solar radiation and relative humidity and calculates ET at a frequency of ten seconds. A contact closure signal is transmitted from the weather station to the controller by wired connection to signal accumulation of 0.01 inch of ET. The electrical signals are counted and stored in the memory of the controller, which uses the ET data to adjust the irrigation schedule. The Weather Center II measuring devices are permanently mounted on a 10-foot tall, vandal-resistant tower with all connections made within the tower's terminal block. The controller supplies power to the system. The graph below shows the accuracy of the Weather Center II as compared to a nearby CIMIS station.



The Eagle user also has the ability to manually enter daily ET information at any time. When used in conjunction with historic ET, manually input ET can mitigate for extreme conditions. Utilization of manually entered ET data in conjunction with historical ET data can significantly improve irrigation efficiency. The controller will utilize the manually entered ET value for a period of one week, and then automatically revert back to the use of the selected ET data source. Manual ET data can be entered at any time; each time it is entered it will over-write the last data value stored and supersede all other ET data sources.

When the RME Eagle controller is coupled with the optional 2-way wireless iCentral plug-in card, irrigation control and monitoring may be performed via the

Internet. Activation of the wireless service to the controller is performed directly from the Rain Master website. Because it is wireless, installation is reportedly simple for either new or retrofit applications. A knock-out at the bottom of the controller enclosure is provided for mounting the 3-inch antenna.

The iCentral website automatically informs the user anytime a field change has occurred, including controller alarms (sensors and wiring fault detection) which are also e-mailed to the user. The website allows the user to command a rain shutdown, modify controller setup information, and manually turn on/off any station or program. The website also provides an automatic schedule generator so that users may generate representative irrigation schedules taking into consideration plant type, irrigation system design, and climatic conditions. Once the user enters all the *scheduling constraints and station attributes* for a controller, as described below, suitable programs are downloaded throughout the year in addition to the daily ET adjustments that are sent to the controller. The scheduler algorithms utilize the Irrigation Association "Landscape Irrigation Scheduling and Water Management" equations dated March 2005.

The *scheduling constraints* define the irrigation season, the controller water window, the stations, programs, and the allowable water days that are available for the scheduler, and any hydraulic constraints the system may have.

The *station attributes* include plant type, precipitation rate, soil type, root zone depth, slope, station efficiency, allowable soil moisture depletion, distribution uniformity, and seasonal plant crop coefficients.

In the absence of the iCentral scheduler, the user must program the controller with a base schedule. The base schedule's total run times and soak/cycle times are adjusted automatically each day by the controller based on ET.

The RME Eagle controller is available in 6, 12, 18, 24, 30, and 36 station configurations. It has four independent programs each with five start times. Water days may be programmed on a weekly basis or by skip-by-day water day cycles with skip days ranging from 1 to 30 days. Station runtimes may be programmed up to 10 hours in one-minute increments, and may be increased/ decreased using the program percent feature from 0 to 300 percent in 1 percent increments. Programmable overlap protection provides for programs to be stacked or run concurrently, and provision is made for a separate master valve and or pump. The controller has non-volatile memory and the time and date are updated without backup batteries. Electronic overload protection is provided, with automatic reset (no fuses or circuit breakers). The Eagle's standard water savings features are summarized in the bullets below.

- Programmable rain shut off in order to delay the start of irrigation after a rain event (1 to 7 days)

- Manual Rain Switch (Automatic Watering – No Watering) provides a means of quickly turning off all irrigation programs without disturbing the stored program(s)
- Connectivity for any one of the following options: rain, moisture, or freeze sensor devices on a per program basis - when the sensor is "active" irrigation will stop and the display will indicate that the sensor is active
- The ability to select either ODD or EVEN day watering on a per program basis
- Selectable cycle-and-soak irrigation programming or conventional programming on a per-program basis
- Programmable cycle runtime, Max Cycle Time, and Soak time on a per station basis
- Automatic minimization of the water window by intelligently scheduling station starts when other stations are satisfying their SOAK TIMES
- The controller provides the ability to display total program duration, real time flow in GPM, alarm information related to flow and station field wiring conditions, daily ET values, sensor status and total water usage

When connected to an optional Rain Master Flow sensor, the RME Eagle controller will suspend irrigation in the event of a station break, catastrophic main line failure, or unscheduled flow. Station limits may be automatically "learned" by the controller and irrigation will be suspended for any station that fails its limit checks while it irrigates. The controller display shows real-time flow measured in GPM as well as flow and station field wiring fault conditions.

The standard size RME Eagle controller dimensions are 13.1" x 10.4" x 4.4", and the extended size cabinet is approximately 7 inches taller. The enclosures are constructed of rolled steel with jet coat®, and are suitable for outdoor installation. An optional stainless steel pedestal mount is available. The controller is UL approved and includes an internal 24 VAC transformer and the current capacity is 1.0 ampere per station or master valve circuit. The controller has terminal screw connections and will accept 12 gauge wire. Optional heavy duty lightning and surge protection is available. Installation of the controller is reportedly straightforward. The AC power however has to be hard-wired, and a contractor is recommended. Installation time and cost varies depending on site-specific conditions.

Rain Master's products are available throughout the U.S. at all major irrigation distributors. A distributor search engine can be accessed at Rain Master's website. The MSRP for the standard RME Eagle 6 station controller starts at $640. A 36 station price of $4,264 includes a full year of on-line technical support, internet service and ZipET. Individual internet service plans for wireless 2-way communications range from $9.95 to $14.95 per month. The MSRP for the

Weather Center II is $3,500. All Rain Master Controllers come with a 5-year warranty. Nationwide product support is available by a network of Rain Master sales representatives. Toll free factory phone support is available from 8:00 AM thru 5:00 PM PST at 800) 777-1477.

Rain Master reports that thousands of Eagle controllers have been installed throughout the U.S. The Rain Master RME Eagle controller has been recognized and accepted by more than 40 water purveyors/agencies across the nation. A list of water agencies that accept Rain Master's products in their water saving incentive programs can be accessed at Rain Master's website.

Although water savings data were not available for this report, it is reasonable to assume use of the RME Eagle will produce similar water savings to the other products reviewed. Rain Master's reputation and the controller's 5-year warranty are significant factors when considering the reliability and overall performance of their products. SWAT performance testing for the RME Eagle was being conducted at the time of this report.

Toro

The Toro Company, which was established in 1914, is a Fortune 1000 internationally recognized supplier of irrigation and landscape products. Toro's corporate headquarters is located in Bloomington, Minnesota and its Irrigation Division resides in Riverside, California. Toro's Intelli-Sense series of residential and commercial controllers utilize the ET Everywhere^{TM} subscription service and WeatherTrak^{TM} scheduling engine to provide weather based irrigation system control. Toro also manufactures Irritrol products and is a partner with HydroPoint Data Services. Irritrol and HydroPoint controllers also utilize ET Everywhere and WeatherTrak, as discussed in the HydroPoint and Irritrol sections of this report.

The Intelli-Sense series entered the market in 2005 and includes seven controllers, comprised of indoor and outdoor models for 6, 9, 12 and 24 zones (plus a pump/master valve circuit). The WeatherTrak-enabled software creates a scientifically calculated zone-specific baseline irrigation schedule. The schedule is updated daily using weather data delivered by the ET Everywhere subscription service.

ET Everywhere uses data from the NOAA system of 14,000 nation wide weather stations to deliver ET to any area in the U.S. ET Everywhere has a proven accuracy to a standard deviation of .01 inch of daily ET at a resolution of one square kilometer. The ET Everywhere data service provides local ET (microzone) without the need for a weather station on site. The ET Everywhere Data Center validates the weather data and transmits calculated ET through three satellite servers to each controller everyday. The three satellites provide over-lapping coverage of the U.S. to ensure signal reception anywhere.

The Intelli-Sense controllers calculate irrigation schedules for each zone. The controller does not use pre-set irrigation schedules input by the user. Instead, a series of questions are answered by the user to define the site variables that influence water need. The controller is programmed by entering the following station specific information: sprinkler type or precipitation rate, plant type, soil type, microclimate (sun or shade), slope (including if the zone is at the top, middle or bottom of the slope, and system efficiency (percentage). The schedule for each station is adjusted daily according to the local weather data received via the ET Everywhere service.

With these inputs, the controller calculates an irrigation schedule for each zone. Soil moisture depletion tracking, triggered at a 50 percent depletion level, along with daily ET updates allows the controller to adjust schedules as the weather changes. The number of water days, minutes and cycles (with appropriate soak times between cycles) are generated automatically and change as weather and water need fluctuates. The controllers have an eight- week scheduling window. This allows for infrequent watering of low water use plants. The controllers can initiate irrigation even if the daily ET page is not received by using the last download and loop-up table included in the WeatherTrak software. Non-watering days can be specified in the controllers' schedule programming. The controllers are compatible with Toro's wired & wireless rain and rain/freeze sensors, which eliminate irrigation during rainfall and freezing weather if added as an optional accessory.

The indoor controller models' cabinet is constructed of ABS plastic while the outdoor units are comprised of Lexan. The dimensions of the indoor models are 7.5" x 6.5" x 3.3", and the dimensions of the outdoor models are 7.5" x 9.5" x 5.8". The controllers have a large (3.5" x 0.8") LED information display, dial type controls, and a copy button for simplifying setup. All controllers include internal UL/CSA listed transformers. The current capacity for each zone circuit is 0.5 amperes, and the current capacity for pump/master valve circuit is 0.375 amperes. The controllers will accept wire sizes from 12 to 18 gauge. The non-volatile memory maintains programming, and the back-up battery maintains the date and time, during power outages.

Other controller features include surge protection up to 6 kilovolts and valve malfunction detection. The irrigation schedule, irrigation history and program review can be viewed with the LED information display. In addition to the rain and rain/freeze sensors, pancake and bow tie antennas are available for sites with poor reception.

The Intelli-Sense controllers may be purchased from authorized Toro distributors and retailers. Current controller and accessory prices are summarized in the table below. The purchase of an Intelli-Sense controller requires a paid subscription to the ET Everywhere service through WeatherTrak. The ET Everywhere annual service fee is $48 for the 6 to 12 station controllers and $84 for the 24 station controller, as discussed in the HydroPoint section of this report.

Intelli-Sense Controller and Accessory Prices for 2006

Description	Model	Price
6-station Indoor Controller	TIS-06-ID	$399
9-station Indoor Controller	TIS-09-ID	$449
12-station Indoor Controller	TIS-12-ID	$499
6-station Outdoor Controller	TIS-06-OD	$419
9-station Outdoor Controller	TIS-09-OD	$469
12-station Outdoor Controller	TIS-12-OD	$524
24-station Outdoor Controller	TIS-24-OD	$889
Wireless Rain Sensor	TWRS	$99.70
Wireless Rain/Freeze Sensor	TWRFS	$120.70
Wired Rain Sensor	TRS	$27.25
Pancake Antenna	TIS-ANT	$87.50

The Intelli-Sense controllers do not require professional installation, although trained installation is recommended. Typical installation times range from 1 hour to 2.5 hours, depending upon the size of the landscape covered and mounting issues. Installation should include a site assessment and discussion with the user about the site's irrigation system and how the controller operates. Installation and setup instructions are included in the owner's manual. Technical support is available from Toro by a toll free number (800-664-4740), or www.Toro.com, and through field certified contractors.

The technology behind the Intelli-Sense controller series is proven by several multi-year independent studies showing water savings. These studies were performed using Hydropoint's WeatherTrak controller and the ET Everywhere service. The studies are discussed in the Hydropoint section of this report. The Intelli-Sense controllers come with a 5-year warranty.

An Intelli-Sense controller SWAT test performance report is posted at the Irrigation Association's website. Given Toro's long-standing reputation for quality and reliability combined with the track record of WeatherTrak and ET Everywhere, the Intelli-Sense controllers should provide reliable weather based irrigation system control.

Tucor

Tucor, Inc. is headquarted in Wexford, Pennsylvania and has been in business since 1995. Tucor®, along with their Danish partner, SRC, manufactures commercial irrigation controllers which use decoder-based two-wire technology. Two-wire technology carries both power and signal to each irrigation valve, eliminating the need to run individual wires by instead using decoders at each valve, sensor or pump. Two-wire systems are easily extended without the need to install additional wires back to the controller.

The Tucor PROCOM© is a stand-alone controller with weather-based irrigation scheduling capability. The PROCOM is a modular, commercial grade controller that comes in its base form as a 50 valve (station) model. The controller's capacity can be increased through simple software registrations to 100, 200, 300, 400 or 500 valves. The controller connects to a PC (via wired or wireless) using software supplied with the controller, which provides a Windows®-based interface for programming and monitoring.

The Tucor ProCom ET-100 Weather Station is connected to the PROCOM controller to provide automatic weather-based irrigation scheduling. The controller calculates ET from the weather station sensor inputs and develops a daily irrigation schedule that provides efficient landscape watering. Housed in a sealed enclosure, the weather station is powered by a rechargeable (AC or solar panel) battery.

Weather station standard sensor inputs include solar radiation, air temperature, relative humidity, rainfall and wind speed and direction. Optional sensor inputs include soil temperature and moisture content. The station's battery charger is powered by either a 10 watt solar panel or AC power.

The weather station data are transmitted to the controller by telephone modem, and ET is calculated using the FAO-56 Penman Monteith equation. The irrigation schedule is calculated based on station application rates entered by the user.

Other parameters that can be used in calculating the irrigation schedule include vegetation type, growing degree days, wet bulb temperature, dew point, and wind chill. The ET-100 comes with software and modem, a two or three meter pole mount, battery charger with solar panel or AC transformer and optional sensor inputs.

The PROCOM can run up to 40 stations simultaneously, manage up to 16 pumps and monitor up to 10 flow sensors. It can execute up to 30 schedules with up to 12 start times per schedule. Schedules can be executed sequentially as programmed, in priority as programmed with automatic execution based on flow data, or fully automatic based on a flow optimization protocol. Scheduling is based on a 14 day cycle.

The controller includes a rain sensor input for utilizing the automatic rain delay feature. The rain delay feature can be independent of the weather station. An auxiliary sensor input can be used for non irrigation related alarms. These are typically pump related. Additionally, the controller will actuate an alarm on wind speed, rain limits and temperature.

The PROCOM can monitor and react to flow conditions for up to 10 flow points. The controller can distinguish between multiple flow meters that are used for water sources and those flow meters that are used for monitoring main and sub main failures within a large system. Select flow meters can be identified for inclusion in the water consumption reports. In the event of a high flow condition during irrigation, the controller can shut down that sequence, continue to the next sequence, send an alarm to a pager, and report to an Excel® file. In the event of an unscheduled flow event (main line failure), the user has the option to activate or deactivate a valve or device. The controller can then alarm to a pager and report to an Excel file.

While considered to be a stand alone controller, the PROCOM must be programmed through the RMS management software that is included with the controller. The RMS software allows for the management of up to 25 individual controllers. All data logged by the controller can be exported to the Tucor Logviewer program, which is a series of Excel-based reports. This format allows for the customization of usage reports, unique to each application. The controller can perform a dry run prior to the actual running of a schedule, to project total run times and water usage. The dry run can be displayed as a flow graph to help manage the efficient use of water and time. The controller allows for the option to apply water based on time, application rate, or ET. Communication to the controller can be a choice of a direct serial connection, phone line, cellular, or GSM/GPRS. Internet connectivity is also available utilizing an existing LAN/WAN or WIFI broadband. A WIFI network, featuring mesh technology, can be created in the event of the existence of multiple controllers on a single site.

The PROCOM is designed for indoor installation, but several optional outdoor cabinets are available. The controller's dimensions are 11.5" x 13" x 3". The outdoor cabinets come in wall mount or top entry models.

The PROCOM has automated diagnostics capabilities. The controller detects wiring faults and turns off power and sends an alarm to the user when detection occurs. Diagnostics can be performed with the controller, to trace short circuits, line current and solenoid ground faults. Optional lightning protection is available for protection against lightning on the two-wire path.

Tucor products are available through certified distributors. A list of distributors is available from Tucor upon request (800-272-7472). Current retail prices for the PROCOM controller, ProCom ET-100 Weather Station, and accessories are summarized in the table below. Tucor products come with a 3-year warranty that can be extended to 5 years through an installation certification process.

Tucor Controller Product Prices

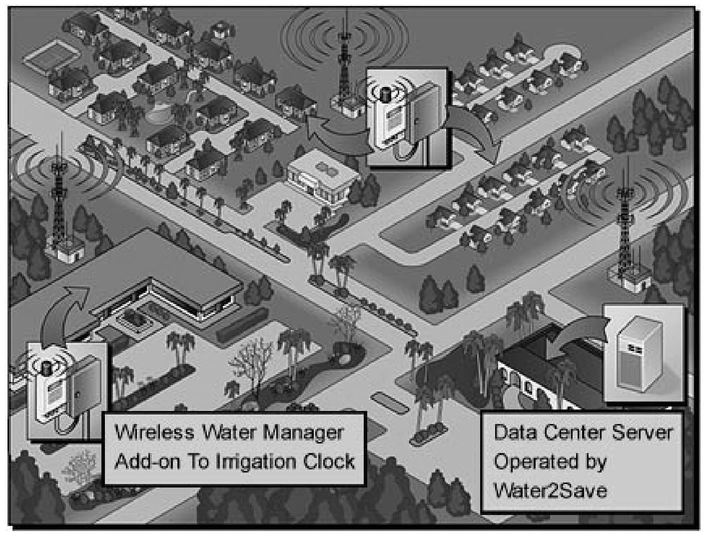
Description	Model No.	Price
50 Station PROCOM Controller	ProCom 50	$ 7,150.00
100 Station PROCOM Controller	Procom 100	$ 7,750.00
200 Station PROCOM Controller	Procom 200	$ 8,500.00
300 Station PROCOM Controller	ProCom 300	$ 9,250.00
400 Station PROCOM Controller	ProCom 400	$ 10,000.00
500 Station PROCOM Controller	ProCom 500	$ 10,750.00
Stainless Steel Outdoor Wall Mount Cabinet	CAB-200	$ 740.00
Weather Station	ProCom ET-100	$ 13,000.00
Surge Protection	SP-100	$ 55.00
1-inch Inline Flow Sensor*	FS-100	$ 730.00
4-inch Inline Flow Sensor*	FS-400	$ 730.00
Decoder: 1 address	LD-050	$ 95.00
Decoder: 1 address, 2 valves per address	LD-100	$ 120.00
Decoder: 2 addresses, 2 valves per address	LD-200	$ 190.00
Decoder: 4 addresses	LD-400	$ 270.00
Decoder: 6 addresses	LD-600	$ 330.00
Sensor decoder	SD-100	$ 280.00

* Inline flow sensors in intermediate sizes and larger saddle models are available. Flow sensors require an SD-100.

Although Tucor did not provide water savings data for this report, it appears proper use of the PROCOM controller may potentially result in water savings and runoff reductions similar to the other weather based irrigation control products discussed in this report. A SWAT test performance report is not posted for the Tucor PROCOM.

Water2Save

Water2Save, LLC is located in San Diego, California, and is a subsidiary of WaterLink Systems, Inc. WaterLink specializes in weather-based irrigation control and conservation management. In 1992, WaterLink began research and development, patent applications, and beta testing of a weather based irrigation control and feedback monitoring system using wired and wireless data telecommunications. WaterLink obtained two patents in 1997 and 1999 for a method of using forecasted weather and ET data to adjust irrigation schedules. Water2Save was formed in 2000 under a technology license from WaterLink to market and sell the patented technology along with its patented forecasted weather based ET adjustment service to optimize irrigation water use for large residential and commercial irrigation systems. Both Look-Ahead ET ™ and WaterLink System® are trademarks or registered trademarks of WaterLink Systems, Inc.

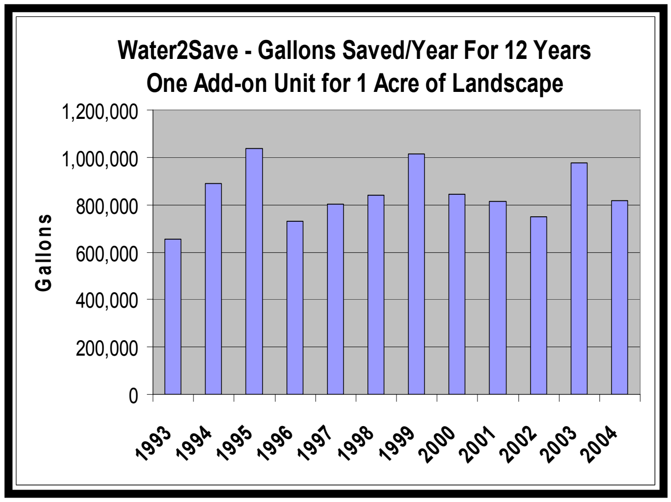


Property owners contract with Water2Save to be their remote irrigation water manager on a performance guarantee basis. Water2Save offers a multiple-controller add-on hardware package, fully automatic Look-Ahead ET irrigation scheduling, landscape audits, historic and real time irrigation runtime monitoring, savings tracking/reporting, and guaranteed savings.

Two patents, Evapotranspiration Remote Irrigation Control System and Evapotranspiration Forecasting Irrigation Control System, cover methods of using forecasted ET, called Look-Ahead ET, with any type of wired or wireless communications to provide weather-based irrigation system control. According to patent claims, approximately 15% more water savings can be achieved when predictive data are used with the ET equations versus when only real-time or historic weather data are used. Water2Save is the only ET irrigation control service provider that can offer its patented forecasted weather based irrigation control.

In 1993, Water2Save began testing its first prototype ET controller. The initial technology replaced the existing controller and required site-specific data for each irrigation zone (plant type, soil type, root depth, irrigated area, flow rate, precipitation rate, and distribution uniformity). The programmed site information and Look-Ahead ET weather data were used to automatically calculate the irrigation schedule.

After years of testing, the company concluded that obtaining and entering site-specific data for each landscape zone was impractical and too labor intensive for most users. In addition, the company determined that many users did not want to learn how to install and operate a new high-tech controller. Therefore, in 1996, the company developed a 2-way (send and receive) add-on technology using its patented method which factors down runtimes set in the controller in accordance with forecasted and measured weather data. Further, the technology monitors watering schedule changes made by the user for each zone and sends such information to Water2Save's Data Center for analysis. This technology has now been in operation with customers for over 12 years. Water2Save has proven to deliver maximum achievable savings reliably year after year with a guarantee. Savings reports show typical savings of over 2,000 gallons per day from installation of Water2Save on a one-acre site.



The City of Los Angeles, California Department of Water and Power recently performed a pilot study of Water2Save over a one-year period. Water2Save reports the average percentage water savings achieved for the properties installed with its system was over 28 percent.

Water2Save's add-on technology is fully transparent and independent of the irrigation controller and is not operated by the user. Hardware is operated remotely by Water2Save and no training is required for the user. The user continues to use the familiar irrigation controller to set and "fine tune" baseline watering schedules. Water2Save is developing a commercial controller that will function similar to the add-on unit for those customers that wish to replace their existing controller with an integrated wireless ET based controller using Water2Save's Look-Ahead ET, valve runtime monitoring service and water usage/savings reporting.

With Water2Save, the user is responsible for setting a baseline schedule that is consistent with recommended summertime irrigation schedules and runoff guidelines established by Water2Save. Baseline schedules are set to the maximum peak ET or 100 percent that remain set at the summertime level the entire year. However, the user may "tune" specific valve schedules as needed. These changes are remotely monitored by Water2Save. The installed technology will interrupt runtimes and reduce irrigation based on normalized weather data (ratio of Look-Ahead ET to the peak summer ET). Normalizing the data reduces the need to obtain site-specific absolute values for ET. Such percent adjustments are not a straight percentage per cycle. The technology considers both daily and weekly runtime minutes. This allows the technology to "store-up" minutes so as to drop cycles and or drop days from the irrigation schedule as appropriate. Water2Save monitors all start-times for daytime irrigation runs and records all manual valve activations that are made by the landscaper using the existing controller.

Although the user can manually run one or more stations during a daytime window of time with no interrupt, Water2Save can prevent all daytime manual watering from the controller if over-watering occurs from excessive runtime programs. Water2Save remotely monitors and manages each valve independently (e.g., color, turf, shrubs, ground cover, drip, slopes, etc.).

Measured weather data and weather forecasts are reviewed daily from numerous sources including the National Weather Service and other government operated weather stations such as CIMIS and AZMET in California and Arizona. Weather data review is done by qualified technical staff knowledgeable in meteorology and evapotranspiration, as well as weather forecasting. Water2Save retrieves forecasts and weather changes for numerous climate zones where its systems are installed. Once the climate zone adjustments are determined, sending weather adjustment factors to the technology installed at customer sites is done via the Internet and wireless networks with confirmation of receipt of the adjustment update.

Water2Save operates a dual redundant server Data Center that retrieves data from properties installed with the company's equipment and monitors both the runtimes programmed by the landscaper and those adjusted by Look-Ahead ET factors. These factors (updated with both forecasts and corrections from measured weather data) are sent and then "receipt" is confirmed by Water2Save staff at its Data Center everyday. Water2Save staff review the meteorological measurements for bad data, out of range data, calibration problems with weather instrumentation, and rainfall errors. This allows Water2Save staff to troubleshoot and then correct problems before processing, thus preventing incorrect adjustments from occurring.

Using 2-way wireless cellular data communications, Water2Save's Data Center retrieves irrigation runtime minutes (those programmed by the user into the controllers and those actually watered after the daily weather adjustments were made). Irrigation history is compiled into a database for analysis by Water2Save and is also made available to the user via the Internet. Servers automatically scan data to find baseline schedule changes that have been made by the user, which are flagged for investigation by Water2Save staff.

Water2Save's staff also obtains monthly or bi-monthly utility billing information to track water meter consumption. A baseline is established using water consumption history prior to installation and the monthly or bi-monthly use after install allows Water2Save to track and calculate achieved savings for "like periods" of the year. Utility meter read data are correlated with watering minutes to identify potential discrepancies. Water2Save mails or e-mails utility meter specific savings reports to its customers to document if and how much savings is being achieved.

The company's Wireless Water Manager (WWM) is designed to enable Look-Ahead ET control for up to 64 irrigation valves on up to 4 separate existing or new irrigation controllers (any type of electronic controller with low voltage solenoid operated valves). Each WWM receives weather-based adjustments via wireless data communications from the Data Center over a national cellular data network and optimizes irrigation. WWM adjusts runtimes using an electronic relay to turn-off water when a daily allowance is reached.

Modular multi-valve sensing monitoring cards are used with the WWM. Each electronic card measures activation time for 12 or 16 separate irrigation valves and records the number of seconds-on of all watering cycles. Up to 4 sensing monitoring cards (maximum of 64 valves) can be connected to one WWM via direct cable or wireless link. Each multi-valve sensing monitoring card is connected between the existing irrigation controller and solenoid driven valves. Also, the common wire is connected between the card and controller to turn-off water to each valve according to the Look-Ahead ET requirement. Each valve is programmed to run a specific schedule at the controller and the sensing monitoring card interrupts the run time specific for each valve in accordance with the adjustments.

The WWM panel, wireless cell modem (activated on Cingular's network) and antenna are shipped inside a steel housing (10.8" x 6.5" x 2.5") that is to be mounted next to the existing irrigation controller. The valve sensing monitoring cards are usually mounted below each of the existing controllers to be enabled with Look-Ahead ET. The wireless modem is a completely separate module (not designed into the electronic circuit board) and is easily upgradeable should wireless technology infrastructure change over time. A standard rain sensor or rain gauge can be connected to the WWM to enhance the system's scheduling capability by triggering rain delays and or accounting for effective precipitation. The WMM power supply is an external 9 VDC transformer that is fused for power line surges, and the multi-valve sensing monitoring cards have opto-isolation type surge protection. The reported installation time for a WWM system with one controller is 2 hours and professional installation is usually required.

The price for a basic add-on WWM model, with the capacity to schedule up to 16 valves on a single controller is $1,598. This price includes the main panel and CPU, a 5-year lithium ion battery, housing, power supply, wireless 2-way cell modem, antenna, a 16-valve sensor card, and all necessary cables. When connected to 4 controllers with three additional valve sensing cards for up to 64 valves, the price is $ $2,108 (or about $527 per controller). The basic service fee for wireless airtime and Look Ahead ET daily adjustments is $39 per month ($468 per year total or $117 per year per controller- $9.75 per month assuming that all 4 controllers are connected to one WWM) and includes feedback confirmation that schedule data were received. Equipment rental plans are also available directly from Water2Save. Water2Save provides a 3-year parts and labor warranty with equipment purchase.

Planned pricing on Water2Save's forthcoming commercial ET controller was not available at the time of this report. A SWAT test performance report for the WWM was not available for this report.

Additional services include tracking runtimes, number of cycles, start times, time of day watering, and manual watering time. The Data Center also checks to confirm that each valve's runtime does not exceed a range of weekly watering minutes established by Water2Save for specific head type and plant type. The Data Center checks if the number of cycles set for slopes have been modified in the existing controller. If so, user follow-ups are conducted until such issues are resolved.

Additional data monitoring includes power outages, future day factors, daytime irrigation, start-time of each valve, end time, number of cycles, and the default factors (based on long-term meteorological conditions). Should wireless communications be interrupted, the WWM will use a set of specific climate zone default factors (provided that updated factors are not received over a several day period).

Water2Save offers a complete turn-key water manager package which includes hardware, patented Look-Ahead ET adjustments with receipt confirmation, runtime monitoring, flagging of problems, on-site field support, full reporting via the Internet, consumption tracking and guaranteed performance savings agreements.

This system appears to provide significant water savings and requires minimal on-site monitoring and adjustment. The Data Center interface provides an easy and effective method for remotely monitoring an extensive set of irrigation related information.

Weathermatic

Weathermatic®, established in 1945, is a worldwide manufacturing company of a full line of irrigation products. The company, headquartered in Dallas, Texas, began developing water conserving products in the 1950's when it used soil moisture sensors which were later followed by its innovation of the industry's first rain sensor shut off device in the 1970's. Weathermatic's SmartLine^{TM} residential and commercial irrigation controllers operate based on weather conditions using onsite sensors.

The Weathermatic SmartLine controller technology patent was filed in 1998 and granted in 2000. SmartLine controllers accept user inputs by zone for sprinkler type, plant type, soil type, slope, and a zone fine-tune adjustment factor. The units then incorporate a ZIP code input (for solar radiation) and an on-site weather monitor (sensing temperature and rainfall) to calculate real time ET estimates that are used with user inputs to calculate proper zone run times, including cycle/soak, at user selected start times and watering days. The Weathermatic SmartLine controller/weather monitor package operates stand-alone and does not require communication with remote servers to obtain weather data or irrigation schedules and no ongoing service costs are associated with the unit. After 8 years of development, testing, and field trials, the SmartLine controller line entered the market in November of 2004. As of July 2005, Weathmatic reports shipment of tens of thousands of SmartLine controllers with less than 60 units returned.

The Weathermatic controller platform is built around zone modules that allow expandability from 4 to 16 zones for their SL1600 model and 4 to 24 zones for their SL1624 model to accommodate various size residential and commercial landscapes. A larger commercial model, the SL4800 (scheduled for release in 2007) will provide module and wiring space for up to 48 zones. The SL1600, SL1624 and the SL4800 are all suitable for indoor or outdoor installation.

An indoor model, the SL800, is scheduled for release in the fall of 2006. The SL800 will use 2 zone modules for expansion from the base of 4 zones to 6 or 8 zones. The SL800 is designed to offer the same Smart features at a price point that will fit any budget.

The SL1600 controller is shipped standard with a 4-zone module, a pre-wired plug-in line cord and mounting bracket for easy installation. The SL1624 controller is shipped standard with one 4-zone module and one 12-zone module, and also a pre-wired plug-in line cord and mounting bracket. The SL4800 will be shipped with 12 zones included. All SmartLine controllers are powered with an internal transformer accepting 120 or 240 volts with 24 VAC output (1.5 amps) to zones capable of running 4 zone valves concurrently or 3 zone valves with a master valve. Accepted wire sizes range from 14 to 18 gauge.

The SmartLine controllers have advanced functions including zone-to-zone and master valve timing delays, a built-in valve locator, as well as a unique diagnostic function that displays the electrical current by zone for troubleshooting. Additionally, the user can omit specific calendar event dates, days of the week, and times of the day when no watering is allowed. A remote control option planned for late 2006 will feature a handheld remote nested in the back of the programming module. The handheld will have a 600 foot line-of-sight range. Units with the remote capable operating panel will also enable a second remote capable operating panel to be mounted independent of the base housing in a user-friendly location (e.g., kitchen or utility room).

The on-site weather monitor includes a temperature sensor and rain sensor. The unit has a microprocessor to record and process measurements. The temperature-sensing unit, designed for very precise measurement of ambient air temperature, is encased in a solar shield and is white in color to avoid strict mounting location requirements. The hygroscopic disc type rain sensor can be set to trigger rain delay at rainfall depths from 1/8" to 1". A wired weather monitor is currently available and a wireless unit is planned for late 2006.

SmartLine controllers are distributed through Weathermatic's established wholesale suppliers (specialty irrigation suppliers) and installation professionals. The list prices for currently available and planned residential controllers and components are listed in the table below.

Weathermatic SmartLine Controllers and Component Prices

Description	Model	Availability	Price
4 to 8 Zone Indoor Controller*	SL800	Currently Available	$99.95
4 to 16 Zone Residential Controller*	SL1600	Currently Available	$156.95
16 to 24 Zone Commercial Controller*	SL1624	Currently Available	$336.90
48 Zone Commercial Controller*	SL4800	early 2007	na
2-Zone Module for SL800	SLM2	Currently Available	$14.95
4-Zone Module for SL1600/SL1624	SLM4	Currently Available	$46.95
12-Zone Module for SL1624/SL4800	SLM12	Currently Available	$179.95
Wired Residential Weather Monitor	SLW10	Currently Available	$199.95
Wireless Residential Weather Monitor	SLW15	late 2006	na
Wired Commercial Weather Monitor	SLW20	Currently Available	299.95
Hand-held Remote Control for SL1600	SLHRR	late 2006	na
Control Panel Remote Module for SL1600	SLCPX	late 2006	na

* Weather Monitor required for weather-based irrigation scheduling not included in controller price

Installation and programming of SmartLine controllers are designed to be simple and intuitive for both the novice homeowner and the advanced professional who are familiar with the unit's industry standard programming dial. Advanced user functions are located in an "Advanced Functions" position on the programming dial so as to not complicate the set up for novice users. While programming the unit is simple, Weathermatic recommends installation by a professional who will give the site the highest rate of success not only for controller programming, but also for complete system operations with an emphasis on water conservation. Based on Weathermatic's solid reputation and well-established support network, it appears the SmartLine controllers' technical support system is outstanding.

Installation and programming instructions are available on Weathermatic's internet site (weathermatic.com), and a programming video and DVD are available to supplement the standard user manual.

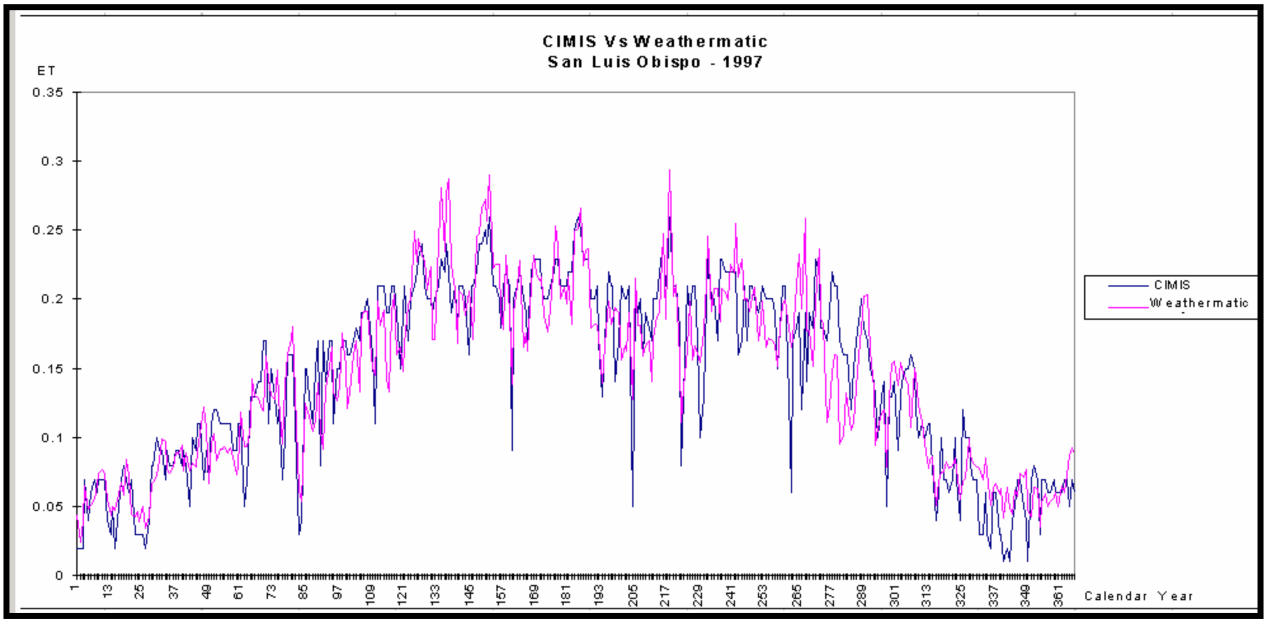
Programming of the "Auto Adjust" ET portion of the controller requires inputs by zone for sprinkler type, plant type, soil type, and slope. Sprinkler type can be entered on a basic level by the user by selecting the type of sprinkler in a zone – SPRAY, ROTOR, or DRIP. A more advanced user can scroll past these basic inputs with default precipitation rates and prescribe an exact numerical precipitation rate for the zone from 0.2"/hour to 3.0"/hr. Plant type works similarly to the sprinkler type input in that the user can simply select the type of plant life in the zone – COOL TURF, WARM TURF, ANNUALS, SHRUBS, NATIVE, or TREES. Again, a more advanced user can scroll past these basic inputs with default percentages and prescribe an exact numerical percentage for the zone from 10 to 300% based on the plant life in the zone and sun/shade consideration. The soil type – CLAY, SAND, LOAM - and slope (numerical degree of slope 1 – 25+ degrees) are used to automatically calculate the cycle/soak function by zone.

In addition to these inputs by zone, the user programs the ZIP CODE of the site, or primarily for locations outside the United States, the latitude of the site. This input and the calendar day of the year is used to determine the solar radiation at the site, which is a variable in ET calculation. These static inputs are combined with the dynamic on-site weather monitor inputs to perform the overall equation that determines proper zone run times.

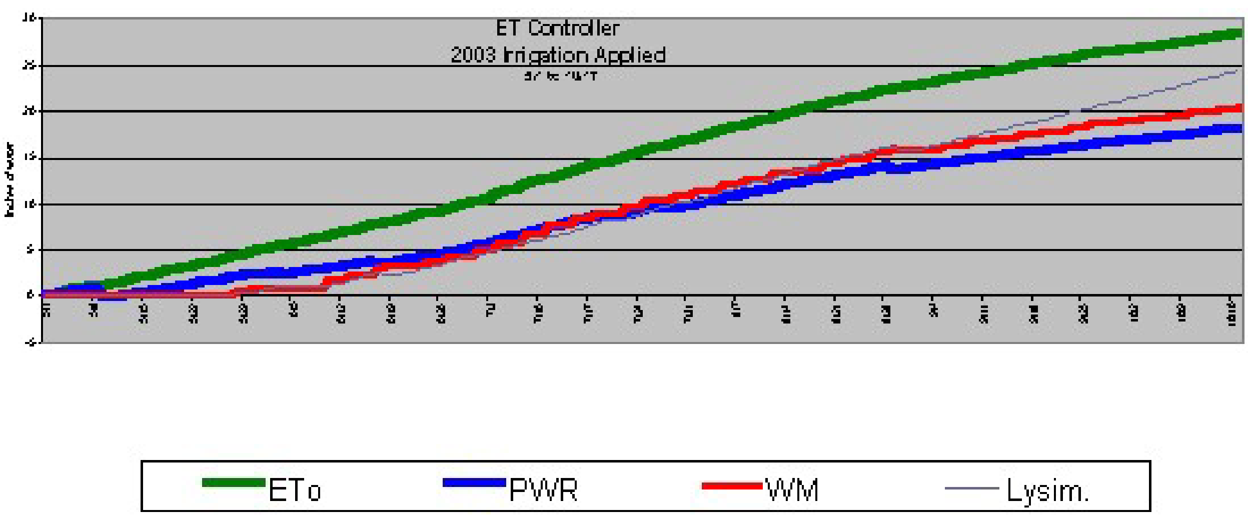
The SmartLine user has the ability to fine tune the zone run times by zone through a MORE/LESS function. This allows the user to increase watering by zone up to 25 percent or decrease watering by up to 50 percent.

The controller's irrigation schedule is based on the user prescribed irrigation days, start times, and omit times (dates, days, and times of day) so as to conform to local watering restrictions and also accommodate site-specific hydraulic issues, which vary by time of day. Once programmed, the controller calculates ET for the period beginning at the end of the last irrigation cycle, or measurable rainfall, and ending at the next prescribed irrigation day. Irrigation will occur if the calculated run time is sufficient for an effective irrigation watering. If sufficient demand has not been reached, irrigation will not occur and the controller will carryover the accumulated ET to the next prescribed irrigation day and time. This accumulation threshold, which prevents ineffective irrigation, is calculated based on a default accumulation factor.

Weathermatic tested its Hargreaves equation based ET calculation algorithm and controller functionality extensively for 8 years. For comparing ET calculations, CIMIS weather station reference ET values were compared to those using the Weathermatic controller/weather monitor methodology at 10 geographically diverse sites over a seven-year period for 70 years of combined data. Weathermatic reports good correlation between the CIMIS and Weathermatic ET data at all sites. The graph below is one example that is representative of the study:



In addition to comparing the ET calculation, the Weathermatic SmartLine controllers were included in a field study performed by a Rocky Mountain Region Water Conservancy District. This three-year study analyzed the Weathermatic controller's accumulated water output in comparison to actual ET (as measured by lysimeter), reference ET (ET_0 calculated with on-site weather station data), and net plant watering requirements (PWR). The study results sample in the graph below show the Weathermatic unit watered consistent with plant demand.



The Weathermatic SmartLine controllers were also part of a field pilot program conducted by the Marin Municipal Water District. In this study, 13 controllers were installed at 7 sites to compare water usage in 2002 and 2003 to the base year usage in 2001. In 2002, sites installed with the Weathermatic ET controller saved 26%. In 2003, the water savings climbed to 32%. Based on documentation from this program submitted by Weathermatic, it appears the Weathermatic controller performs well and yields significant water savings.

Weathermatic's test center has conducted testing on the controllers and weather monitors in the following areas affecting reliability: mechanical stress testing, environmental testing, software testing, and functional/characterization testing. A SWAT test performance report for the SmartLine controllers was not available for this report.

The SmartLine controllers are relatively economical and appear to offer effective real time onsite ET measurements and inputs by zone for key programming parameters.

Accurate WeatherSet

Accurate WeatherSet is located in Winnetka, California. WeatherSet has manufactured commercial weather based irrigation controllers for landscapes, golf courses and greenhouses since 1979. The company started development of its first residential controller prototypes in 2000, and began marketing the residential controllers in September 2001. All WeatherSet controllers utilize a solar sensor and rain sensor to automatically adjust irrigation schedules. The solar sensor, designed and fabricated by WeatherSet, measures solar radiation which is the major factor affecting the controller's ET calculation.

The WeatherSet controller is called the Smart Timer™, and it comes in 8, 12, 16, 24, 32, 40 and 48 station models. The Smart Timer is a stand-alone controller and does not require communication with remote servers to obtain weather data or irrigation schedules, and there are no ongoing service costs. The controller calculates ET with input from an onsite solar radiation sensor. WeatherSet reports the solar sensor has functioned reliably in demanding environmental conditions to control greenhouse and outdoor misting systems since the early 1990's.

The WeatherSet controller calculates a daily ET estimate based on solar sensor SunFall™ measurements that are logged by the controller on a 2-minute frequency. The sensor must be installed in a mostly sunny location in order to function accurately. Adaptive control logic allows the controller to function with some shading. From their work with commercial controllers, WeatherSet reports that SunFall reduces by about two-thirds from a clear day in summer to a clear day in winter, and that their 5 self-adjusting programs follow these changes.

The calculated ET information is combined with rain sensor data and user programmed information to schedule irrigation. To program the controller for automatic adjustments, the user assigns each station to one of three programs, which are labeled Flowers™, Lawns™ and Shrubs™. The Flowers, Lawn, and Shrubs programs are for shallow, medium and deep-rooted plants, respectively. A fourth program called LWU (low water use) will deliver water to California native plants that expect no rain from May through September and winter rains from October through April. A runoff limit, in minutes per hour, may also be entered for each station to stop runoff. The user enters a MAX Runtime for each station and the Smart Timer automatically adjusts the watering days and runtimes for each valve. The controller has a manual start function, and an optional irrigation history review function. With the H-option, the controller keeps a running tab of total run time for each station.

The controller's rain sensor is an Ecologic RainBrain™. The sensor signals the controller to interrupt irrigation in its rain shut-off mode, and the rain sensor signals are also used by the controller for irrigation scheduling. The WeatherSet controller is preprogrammed to account for the duration that the rain shut-off circuit has been interrupted when scheduling irrigations.

The WeatherSet irrigation controller provides 7 different runoff limits that are set for each station. A maximum cycle run time of 2, 4, 6, 8, 11, 15, 20 and unlimited number of minutes per hour may be set for each valve. The default cycle limit factor is four minutes per hour. As an example, if the controller calculates a total 12-minute run time for a station, this station will be irrigated in three 4-minute increments over a 3-hour period, with the default setting. For stations that generate runoff, WeatherSet recommends the user measure the time required to cause runoff (using the manual run mode), divide the time by two and use that time to choose the runoff factor for the station. The runoff factor may be shut off to allow continuous watering when required. For example, valves controlling drip systems in LWU programs may best be watered with the runoff limit shut off.

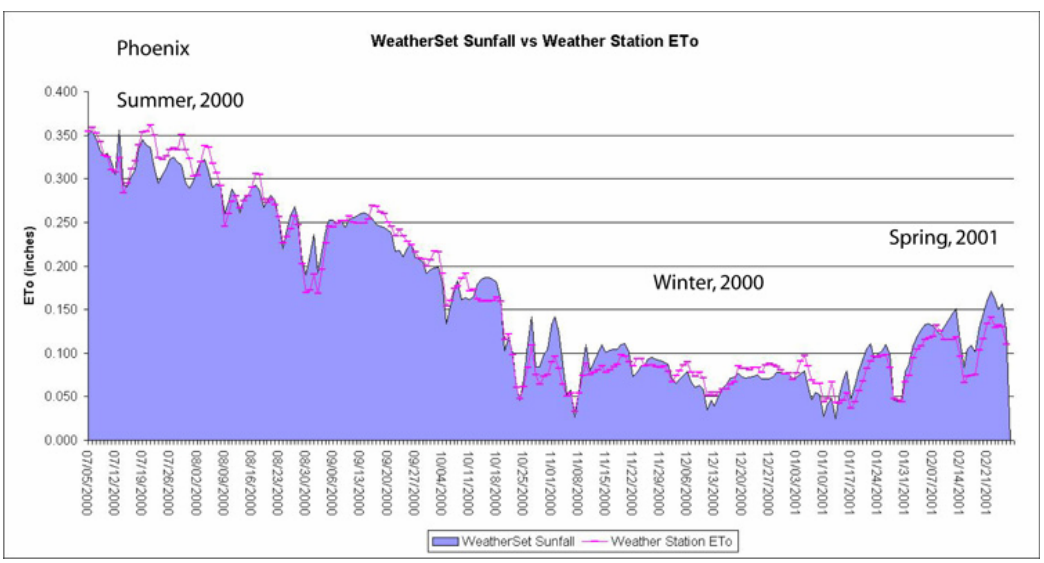
Two Smart Timer indoor residential controller models and seven outdoor commercial models are available. Low volume rebate program prices for each of the models are summarized in the table below. (Retail prices are approximately 150 percent higher.) The prices include the solar and rain sensors. The controllers are available directly from WeatherSet by telephone (818-993-1449) or e-mail (www.weatherset.com). The company plans to also distribute the product through select specialty irrigation contractors. The Smart Timer controllers come with a 3-year warranty.

WeatherSet Prices (Include Solar and Rain Sensors)

Controller Type	Model No.	Price
8-Station Indoor	ST8R	$148
12-Station Indoor	ST12R	$168
8-Station Outdoor	ST8C	$240
12-Station Outdoor	ST12C	$275
16-Station Outdoor	ST16C	$320
24-Station Outdoor	ST24C	$480
32-Station Outdoor	ST32C	$640
40-Station Outdoor	ST40C	$800
48-Station Outdoor	ST48C	$960
Irrigation History Function	H-option	$35

The indoor controller cabinets are constructed of aluminum with dimensions of 5.5” x 7.5” x 1.5”, and the indoor power transformer is an external plug-in type unit. The lockable outdoor cabinets are constructed of zinc plated steel with powder coating and stainless steel hinges, and they come in three sizes. The respective dimensions for 8-12, 16-24 and 32-48 station models are 9” x 10.5” x 4”, 10.5” x 9.5” x 4.5” and 14” x 12” x 4.5”. The outdoor models include internal power transformers. The 16-station and larger models include flow sensor connectivity, station circuit testing and surge/lightning protection features. The station circuit current rating for the indoor units is 0.75 amperes and it is 1.5 amperes for the outdoor units. All models’ station circuit terminals will accommodate wiring sizes from 12 to 20 gauge. The controller’s program memory is non-volatile, and the time-keeping microprocessor chip uses a 3.3-volt coin-type battery that has a reported life of ten years

WeatherSet has provided data showing close correlation between ET estimate calculation by their controller and that calculated by an AZMET (Phoenix, Arizona ET network) weather station. A graph of this data is shown below.



WeatherSet controllers have not been included in any formal demonstration studies and no water savings data were evaluated for this report. However, WeatherSet reports field data will soon be available from water agencies that have included WeatherSet controllers in their rebate programs. A SWAT test performance report for the Smart Timer controller was not available for this report.

WeatherSet reports that 95 percent of homeowners included in the Municipal Water District of Orange County rebate program using the Smart Timer installed the controller themselves. Based on this, it appears that the typical homeowner can understand and program the WeatherSet Smart Timer. Technical support is available by telephone and through the company's internet site. Service by factory-trained contractors is limited to California, Oregon, Washington, and Colorado at this time. WeatherSet reports this area will grow as their market expands. The installation and programming instructions, which include directions for locating the solar sensor, appear to be adequate and easy to follow.

The WeatherSet controller is a simple and relatively economical stand-alone weather based irrigation controller which comes with onsite rain and solar sensors.

Soil Moisture Based Irrigation Control System Principles

All of the soil moisture based products reviewed operate on the principal of scheduling irrigation as a function of soil moisture conditions measured onsite with one or more soil moisture sensors. The concept is for an appropriate amount of irrigation to occur when needed to maintain optimum soil moisture levels.

Landscape soil moisture conditions should be maintained such that root zone moisture levels are between field capacity and above the wilting point. Field capacity conditions occur following irrigation or precipitation when the maximum amount of water is retained in the soil after seepage and surface drainage ceases. The wilting point occurs when soil moisture is depleted to the point at which plants wilt without recovery during the night. The soil moisture percentages at which field capacity and wilting point occur are a function of soil characteristics. The soil moisture percentage is the ratio of the volume of water in the soil to the volume of void spaces between the soil particles.

Most of the soil moisture based products reviewed function such that a preset irrigation quantity is applied when the measured soil moisture level drops to a preset threshold. Ideally, the irrigation quantity applied replenishes the soil moisture to field capacity with minimal surface runoff and seepage below the root zone (over-watering). Some of the products reviewed begin and end irrigation based on two preset thresholds; the first is set at a moisture percentage above the wilting point and the second is set at near field capacity. One product adjusts run times based on soil moisture data. Most of the devices, however, do not automatically calculate total run times and cycle and soak times.

As with the weather based products, some of the soil moisture based systems include a stand-alone controller and others include an add-on controller that works with an existing clock-type controller. Regardless of stand-alone versus add-on controller type, some of the devices control the irrigation of all zones based on measurements from one soil moisture sensor. Others control individual zones or groups of zones based on measurements from multiple sensors placed in representative zones.

Several different types of soil moisture sensors are used with the systems reviewed. Within approximately the last 10 to 20 years, significant technological advances have been made in the soil moisture sensing field. This has resulted in the availability of accurate and inexpensive sensors appropriate for landscape irrigation applications, and the emergence of several new landscape irrigation products.

In general, the soil moisture based systems' operation principles are simple and comparison is more straight-forward relative to the weather based systems. Several of the products operate very similarly and possess similar features. All of the systems reviewed provide potentially effective methods for scheduling irrigation based on soil moisture sensing which should result in water savings.

Soil Moisture Based Control Product Features and Comparison Criteria

Significant product components and features are discussed below. The discussion identifies different methods used to achieve similar results by the various products, and associated advantages and disadvantages.

Soil Moisture Sensor Types

Soil moisture sensors have been used successfully in laboratory and outdoor testing and agricultural applications for over 50 years. There are many types of sensors, but only those used in the present generation of landscape systems are discussed.

Electrical Resistance Granular Matrix – This type of sensor consists of two electrodes embedded in a reference matrix material which is confined within a corrosion-proof and highly permeable case. The matrix typically includes gypsum to buffer against the effects of salts and fertilizer, but these devices are unlike gypsum blocks in that they do not dissolve. Soil moisture is constantly absorbed or released from the sensor as the surrounding soil moisture conditions change. As the soil moisture changes, the sensor moisture reacts as reflected by the change in electrical resistance between the electrodes. As the moisture level increases, conductivity increases and resistance drops. This type of sensor has been used in agricultural and landscape applications for approximately 20 years and their performance is well documented.

Electrical Conductivity Probes – This type of sensor measures soil moisture by how well a current of electricity is passed between two probes. The concept is similar to that for the electrical resistance granular matrix type, but the probes (electrodes) have direct contact with the soil and are not buffered against salt and fertilizer affects. This method is very sensitive to the spacing of the probes as well as being influenced by soil type, salts and fertilizers. Specifically, bent probes and improper calibration for soil type can result in poor performance. Also, fluctuations in salt and fertilizer levels can affect measurement accuracy.

Time Domain Transmission (TDT) – This type of sensor measures the time required for an electromagnetic pulse to travel a finite distance along steel rods or length of wire (wave guide), and is dependent upon the dielectric properties of the soil surrounding the wave guide. As moisture increases in the soil, the pulse travel time decreases and the sensor's time signal is converted into a soil moisture measurement. This technology, which evolved from and is similar to time domain reflectometry, provides high accuracy which is independent of low and moderate salt and fertilizer levels in the soil. The original time domain reflectometry type sensors were expensive and difficult to use. The recently developed time domain transmission devices are less expensive, and more suitable for landscape irrigation applications.

Frequency Domain Reflectometry (FDR) – This type of sensor (also known as capacitance) contains a pair of electrodes (can be multiple rods or rings) separated by a dielectric. The electrodes are inserted into the soil or in an access tube in the soil and the soil becomes part of the dielectric. An oscillating frequency is applied to the electrodes, which results in a resonant frequency, the value of which depends upon the dielectric constant of the soil. The moisture content changes the dielectric constant of the soil, thereby changing the resonant frequency. The change in frequency is then converted to a soil moisture measurement. FDR sensors which operate at high frequency (greater than 20 mega hertz) are relatively independent of soil salt and fertilizer levels. This type of sensor is especially sensitive to undisturbed soil contact. (See discussion of undisturbed soil contact under Installation discussion below.)

Tensiometers – This type of sensor measures the soil moisture tension, or suction, as it changes with soil moisture content. Tensiometers operate by allowing the soil solution to come to equilibrium with a reference pressure indicator through a permeable ceramic piece that is in contact with the soil. A vacuum gauge measures the soil moisture tension and high tension reflects low soil moisture. Tensiometers accurately measure soil moisture independent of salt and fertilizer levels, but can require maintenance to refill the tensiometer with liquid and maintain the integrity of the soil/ceramic tip interface. (This typically occurs only when the soil dries beyond the wilting point.) Some tensiometers must be removed from the soil during winter months in northern climates where the soil freezes.

Installation

All of the soil moisture system manufacturers recommend professional installation and programming of their commercial products, and report that installation and programming of their residential models can be done by a non-professional. Based on discussions with third party individuals with experience installing most of the reviewed residential models, it appears homeowner installation may not be a realistic option with certain products. The degree of difficulty to install any of the products can vary significantly depending on site specific conditions. A significant factor is the soil moisture sensor wiring configuration. Some sensors are connected to the existing nearby valve wiring, and some must be connected to the controller with potentially long runs of new wiring. Wiring the sensors to the irrigation valves should be easy in most cases, but the ease of connecting to the controller depends on site specific conditions (distance, obstacles, etc.). It is difficult to determine what percentage of homeowners successfully install and program the various residential products. Installation and programming instructions are available for some of the products at their websites. All potential customers should review this information when shopping for a device regardless of whether they plan to do their own installation and programming.

An additional installation issue is that of the placement of the soil moisture sensor(s) in the root zone. A soil moisture sensor should be in contact with relatively undisturbed soil that is representative of the irrigated landscape. Contact with disturbed soil with a higher void space ratio may result in soil moisture readings that are not representative of the landscape. Some sensor types are more sensitive to this than others. Therefore, the sensor shape and method of placing the sensor with regard to undisturbed soil contact should be considered when comparing systems.

Stand-alone Versus Add-on Controller

The controller component for most of the soil moisture products reviewed is an add-on device which works with an existing clock type controller. The other products include a stand-alone controller with many of the features of typical clock type controllers. In some cases, the cost of the add-on device is a significant attraction. Regardless of cost, the quality of an existing controller should be a factor when considering replacement with a stand-alone control device. If the existing controller is a high quality unit with adequate features, an add-on device may be an attractive alternative.

The primary stand-alone controller features which should be considered include: automatic scheduling, number of programs and start times, cycle and soak, master valve circuits, compatibility with other sensors (rain, flow, temperature, wind, etc.), remote control, and system testing capabilities.

Irrigation Schedules and Run Time Calculation and Adjustment

Most of the devices reviewed do not automatically calculate irrigation run times, although some adjust user-entered run times based on soil moisture measurement data or control run times with on and off soil moisture thresholds. None of the soil moisture sensor devices automatically calculate cycle and soak times. Some manufacturers (stand-alone and add-on) provide guidelines or computer programs to assist the user in calculating total run times and cycle and soak times. The product descriptions identify the manufacturers that provide guidelines or computer programs for determining appropriate run times and cycle and soak times.

Single Versus Multiple Soil Moisture Sensors

Most of the residential systems reviewed use one soil moisture sensor to control operation of the entire system, and varying zone conditions are accommodated for by adjustment of run times. For complex residential landscapes and commercial systems, some systems have the capacity to use multiple sensors to control a single valve or groups of valves. For complex systems, the user should consider the sensor capacity of the controller. In some cases, multiple controllers with single sensor capacity can be used to build a multiple sensor system. Some of the multiple sensor controllers allow for bypassing the soil moisture control mode and running in clock mode by station. All of the products reviewed will allow for system-wide clock mode operation.

Soil Temperature and Conductivity Measurement and Display

Some of the soil moisture sensors included with the products reviewed also measure soil temperature and conductivity. Soil temperature is necessary for adjustment of the soil moisture measurement by certain types of sensors. Some of the controllers allow for display of the temperature and conductivity measurements. Display of the conductivity measurements is a significant feature for users irrigating with wastewater effluent or water that contains high levels of salts in order to know when to flush the soil. Wen the user is informed that the salt levels in the soil have reached a critical point based on the conductivity readings, the landscape should be irrigated heavily to leach (flush) the salts below the root zone.

Power Supply and Surge and Lightning Protection

All of the controllers operate on 24 VAC power. The stand-alone devices include a power transformer that converts 110-120 VAC to 24 VAC. The transformers are either hardwired inside the controller cabinet (internal), or plugged into a power outlet (external). The add-on scheduling devices operate on 24 VAC and either receive power from the existing clock/controller or from an external transformer. Most of the transformer devices include some type of current overload protection such as a fuse or breaker switch. Some of the controllers include lightning and or surge protection, or offer these as an optional feature. Surge and lightning protection limits damage to the controller's circuitry from transient voltage and current from the power source (surge) and from the valve circuits (lightning).

Station Circuit Rating, Wiring and Terminal Wire Sizes

The compatibility of the existing electrical circuits (wiring from the controller to the station valves) should be considered in the selection of a stand-alone controller. If the station wire terminals on the controller will not accept the existing wire, adapters must be used. Also, the circuit current capacity required for an existing system should be checked prior to installing a new unit. Installation problems associated with insufficient circuit capacity to operate some irrigation valves with high circuit resistance are a possibility.

The traditional wiring system (circuitry) used for most controllers consists of a common and a dedicated wire from the controller to each valve and sensor. Some controllers utilize "2-wire" circuitry that consists of a single pair of wires connected to all of the valves and sensors in the system. These systems require the installation of a decoder device for each valve and sensor. Applications include large systems and linear systems (e.g., highway corridors) with large quantities of wiring required for traditional circuitry.

Warranties and Reliability

All of the products reviewed include a warranty. Warranty details are discussed in the product descriptions section. Although the warranty periods may or may not be indicative of the life expectancy of the products, in some cases there appears to be a correlation between the cost and overall quality of the product to the warranty period. It is assumed the cost of a product somewhat reflects the quality of the construction materials and electronic components. Hence the less expensive residential devices should not be expected to last as long and function as reliably as the more expensive residential and commercial products. Since most of the devices are relatively new products, it is difficult to speculate on how long they should last. Based on reports from the manufacturers of soil moisture systems with long track records, the life expectancy of the controllers and sensors should be at least 5 to 10 years.

Soil Moisture Based Product Descriptions

The following product descriptions address operational characteristics and features, and include discussions of available information from demonstration and pilot studies relative to documented water savings and operation. Each of the manufacturers were provided copies of the product descriptions for input prior to being incorporated into this report.

Acclima

Acclima, Inc., located in Meridian, Idaho, manufactures soil moisture sensor based landscape irrigation control systems. Acclima began development of its system components in 1997, and Acclima products entered the market in 2003.

The Acclima Closed Loop Irrigation™ systems are governed by real-time soil moisture content as measured by Acclima's patented Digital TDT™ (time domain transmission) soil moisture sensor. All systems include one or more soil moisture sensors and either a stand-alone controller or an add-on controller that interfaces with an existing clock-type controller. Acclima manufactures systems that are suitable for residential and commercial applications.

The heart of all Acclima systems is the Digital TDT™ sensor. The sensor's dimensions are 14.5" x 3" x 1" and it is constructed of stainless steel and heavy duty plastic materials with built in lightning arrestors. The sensors are buried three to four inches deep in the root zone, and communicate moisture information to the controller via the same wiring used for valve control. A single sensor can control multiple irrigation zones. A typical residential system includes just one sensor, and a commercial system may use numerous sensors associated with various microclimates or landscape types.

The patented Digital TDT sensor is unique in that it provides the absolute percentage water content of the soil by volume, regardless of changing temperature and soil conductivity, as opposed to yielding a relative reading. The sensor generates a pulse along the outer rod of the buried sensor, propagating a step function with a rise time approximating 0.3 nano-seconds and a spectral content of 2 to 3 gigahertz. This unique high frequency minimizes the dielectric relaxation properties found in clay soils, resulting in superior performance regardless of soil type. Acclima's direct contact transmission lines allow a sampling volume of 600 cubic centimeters without an intervening dielectric. The pulse is received at the distal end of the transmission line through a patented digitizing receiver. The sampling interval is 5 picoseconds, or the time it takes light to travel 1.5 millimeters in air. The digitized, stored waveform is processed using proprietary digital signal processing algorithms to calculate water content. The resolution of the sensor is one part per thousand or 0.025 percent at 25 percent soil moisture content. This means the sensor can detect the addition of 0.002 inches of water to 4 inches of soil, yielding maximum water savings. The sensor automatically takes an average moisture reading over the length of the stainless steel rods every time a sensor program is scheduled to begin and whenever a manual reading is required.

All Acclima irrigation controllers utilize the Digital TDT Moisture Sensor as a "closed loop" feedback mechanism in controlling the irrigation process. The controller polls the sensor for actual soil moisture readings, allowing the system to intelligently apply only the amount of water lost through ET. Thus, root zone moisture levels are perpetually maintained at user specified levels and water use is optimized.

Acclima offers an add-on controller which works with an existing timer/controller and three stand alone controller models. The add-on controller works with a single moisture sensor and the stand alone controllers may utilize multiple sensors. The soil moisture reading for all controllers is displayed as volumetric water content from 0 to100 percent. Soil temperature is displayed in degrees Fahrenheit or Celsius and soil conductivity in dS/m (10^{-1} siemens per meter). The controllers also include a Watering On Hold indicator.

The Acclima RS500 is an add-on controller that supports most existing timed systems. It has the ability to set, maintain and monitor any desired moisture level. The RS500 operates under Acclima's Suspended Cycle^{TM} system which suspends timer/controller activity when soil moisture is above the user set threshold level.

The sensor wiring is connected to the valve that waters the sensor location and this spot represents the moisture level for the entire landscape. The sensor readings are transmitted via the valve wiring to the controller. The controller closes the common circuit allowing irrigation of all zones when the soil moisture is at or below the threshold level set by the user. Since the other zones may have different watering needs based on microclimate variations, total run times for each zone are programmed accordingly. Total run times for each zone are based on the user's observations and experience, written guidelines available from Acclima, or may be determined through a site audit by a landscape professional.

The RS500 includes a Moisture Control ON/OFF switch for allowing the traditional timer/controller to run as if the RS500 were not present. It will continue to take moisture readings, but will not inhibit the timer from watering when the moisture control switch is off. Also, one or two zones may be operated by the timer/controller independently of the RS500 for xeriscape or germination needs.

The RS500 cabinet is extruded plastic and its dimensions are 4.5" x 2.4" x 1". It is suitable for indoor installation and the timer/controller connection cable is 18-inches long. The 24 VAC power supply is from either the timer/controller or from an external transformer (not available from Acclima). The RS 500 is sold with a Digital TDT Moisture Sensor and 25-feet of sensor wiring.

The Acclima SC Series controllers are stand alone units which also operate under the Suspended Cycle™ system. They are available in 24 and 36 station models. The SC controllers' valve wiring is traditional configuration and they provide 4 programs with up to 6 start times. Up to 24 soil moisture sensors may be connected to the SC24, and up to 36 may be connected to the SC36. Each soil moisture sensor added to the system also adds a sensor program to the system with 6 start times each.

For a single moisture sensor setup, an SC controller functions like the RS500. For multiple sensor setups, each sensor is connected to the valve for each reference zone and sensor readings are transmitted to the controller via the valve wiring. Zones without a sensor are assigned a reference zone and irrigation occurs zone by zone based on the soil moisture measured in the reference zones. Unique soil moisture level thresholds may be programmed for each reference zone.

The SC controllers may be operated in automatic soil moisture based or manual modes. Up to 4 zones, plus a master valve circuit, may run concurrently dependent on system water volume capacity. Multi-zone watering may be configured per-zone based on the water usage of that zone versus available water. This may be done automatically when a flow meter is attached to the system, or the configuration can be adjusted manually at any time. These controllers support rain, wind, and freeze sensor inputs to shut off the water when weather does not permit irrigation. Flow meter support monitors for broken pipes and valves. Connection of a flow meter requires an interface device manufactured by Acclima.

The controller's calendar/clock automatically compensates for leap years and optionally for daylight savings time. The clock can be maintained for up to 2 months without power using 2-AA alkaline batteries. The non-volatile program memory maintains configuration information even if the power fails and the batteries are dead. Watering day schedules include Custom, Every Day, Odd Day, Even Day, and Every Nth Day watering (where N may range from 3 to 31). Zone stacking ensures that all zones will eventually be watered even though program start times may overlap. Other features include soak/cycle, valve circuit test, programmable pause, rain delay (0-14 days) and water budget adjustment (5 to 500 percent). Remote control is available with optional hand-held radio and interface devices.

The SC Series controller cabinets are extruded plastic and the controllers are suitable for outdoor installation, with dimensions of 12.3" x 10" x 5.9". The internal power transformer includes an over-current detector that automatically detects loads exceeding 2.1 amperes and an over-load backup fuse (slow-blow, self-healing fuse: 2.5 A). Station circuit capacity is 0.6 amperes. The controllers possess surge and lightning protection which consists of the following:

Input: Transient Voltage Suppressor (TVS)
Common Wires, Signal Ground: 5000 Amp Gas Discharge Tube to Earth Ground
Each Terminal: Metal Oxide Varistor (MOV)
Earth Ground Terminal: Up to #6 copper wire for diverting electrical surges to a ground rod

The CS3500 Controller operates under a water-on-demand protocol as discussed below. It includes central control system features and uses a 2-wire valve wiring configuration. This controller has a station capacity of 64 zones. Up to 10 soil moisture sensors may be connected to it. It provides all of the basic features included with the SC Series controllers, except for rain, wind and freeze sensor compatibility. Additional features are discussed below.

With a water-on-demand system, water is applied when the soil moisture levels fall below a set threshold and only the amount needed is applied to raise the moisture to an upper threshold. Hence, lower and upper thresholds are programmed into the CS3500. The CS3500 constantly monitors the soil moisture levels. When the level falls below the lower threshold the controller irrigates until the moisture reading reaches the upper threshold. The system will only water when needed and will only apply the necessary water, maintaining the soil moisture level in a constant range.

With a 2-wire valve circuit, Valve Adapter devices (decoders) are needed to interface the valves to the 2-wire bus. These adapters contain electronic switches that apply power to the solenoid valves under command from the controller. Acclima sensors also contain a single electronic switch so that there is no need to install a valve adapter device when a sensor is installed using existing zone wiring to a single valve.

The CS3500 offers central control capabilities using Acclima Irrigation Manager™ Software and advanced communications capabilities through serial cable, dial-in modem, or radio communications. The controller's clock can be maintained for up to 10 years without power using a CR2032 battery.

The cabinet for the CS3500 is the same size and material as for the SC Series controllers and is suitable for outdoor installation. The power supply and circuit capacities are also the same. The surge and lightning protection for the CS3500 is the same as for the SC Series, except for the absence of the copper wire for diverting electrical surges to a ground rod.

Prices for selected Acclima products are summarized in the table below. Acclima products may be purchased directly from Acclima (www.acclima.com) or through its distributors listed on its website. Acclima provides a 2-year warranty with its products.

Acclima Product Retail Prices

Description	Model No.	Price
RS500 Add-on Controller*	ACC-SYS-0500	$369
SC 24-Station Controller	ACC-SYS-0024	$995
SC 36-Station Controller	ACC-SYS-0036	$1,500
CS 64-Station Controller	ACC-SYS-3500	$2,978
Digital TDT Sensor	ACC-SEN-003	$325
Flow Meter Interface	ACC-FPM-015	$650

* Includes Digital TDT Soil Moisture Sensor

Installation instructions are included in the controller manuals which are available on Acclima's website. Additionally, RS500 installation videos are available on the website. Acclima reports installation of the RS500 can be performed by most homeowners, but recommends professional installation of the SC Series and CS3500 systems.

The accuracy of Acclima's Digital TDT Soil Moisture Sensor technology is well documented, and their patented irrigation systems have been tested and researched by numerous academic institutions. Acclima reports average water savings are approximately 30 to 40 percent. Acclima submitted their technology for independent testing and verification before placing their products on the market. Testing entities include the following:

University of Arkansas	New Mexico State University
Oregon State University	University of Tennessee
University of Florida	Brigham Young University
Utah State University	California State University, Fresno

Information on the above testing and research, and certain study report documents are available on Acclima's website.

Baseline

Baseline, LLC, located in Boise, Idaho, manufactures soil moisture sensor based landscape irrigation control systems. Baseline began business in 1998, and its first soil moisture sensing products entered the market in 2002. Its systems include add-on and stand-alone controllers, as well as centralized control systems.

The Baseline irrigation control systems are based on real-time soil moisture content as measured by Baseline's patented biSensor™ TDT (time domain transmission) soil moisture sensor. All systems (non-centralized) function with one or more soil moisture sensors that are offered with three controller options: a stand-alone controller, an add-on controller that interfaces with an existing clock-type controller, or a computerized system of multiple stand-alone satellite controllers. Baseline manufactures systems that are suitable for both residential and commercial applications.

The biSensor comes in three models: a 6-inch rigid sensor used with the S100 controller, a 1.5-foot rigid sensor and a 5-foot flexible sensor. All measure the volumetric soil moisture content near the sensor. The sensors are buried in the root zone, and transmit soil moisture and temperature information to the controller via the same wiring used for valve control. A single sensor can control multiple irrigation zones. A typical residential system includes just one sensor. A commercial system may use numerous sensors associated with various microclimates or landscape types. Baseline recommends installation in a v-shaped trench to minimize soil disturbance where contact is made to the sensor. The biSensor is constructed of corrosion-resistant fiberglass.

The biSensor functions by sending an electronic pulse along an imbedded wire path. The wire is embedded in fiberglass providing desired characteristics by not being in contact with the soil, but the speed of the pulse is delayed by the soil's water content. The higher the water content, the slower the pulse moves around the biSensor. The biSensor measures the pulse speed to determine the amount of water in the soil. biSensors can reportedly resolve the travel time in increments as small as 10 pico seconds. Baseline's biSensors measure distortion caused by salts and temperature changes and adjust moisture readings accordingly. All sensor-related electrical components are insulated from the soil, including the actual sensing elements.

Baseline's controllers include two add-on models and four stand-alone models. Two of the stand-alone controllers utilize two-wire valve control wiring and the others support conventional valve wiring. The add-on models are designed for use with a single biSensor and function with any clock/controller. The stand-alone models can be connected to multiple biSensors. All of Baseline's controllers are rain sensor compatible and have a bypass feature that disables the soil moisture based control. The soil moisture reading for all controllers is displayed as volumetric water content from 0 to100 percent. The stand-alone models include an internal power transformer and the add-on models power supply is from the clock/controller or from an external transformer. The stand-alone controllers operate on Baseline's Time/biSensor control system allowing for several smart watering strategies from fully automatic to timer type controls and many options in-between.

The Baseline WaterTec™ S100 controller is an add-on device for use with an existing clock/controller and a single biSensor. The S100 cabinet is constructed of heavy duty plastic and is available in an indoor model. Its dimensions are 5.8" x 2.6" x 1.5" and it has a 3-character, one line LCD display and touch pad type controls. The S100 comes with a 6-inch biSensor soil moisture sensor.

The WaterTec S200 is an add-on device with all of the features of the S100 plus water window and irrigation history features. The S200 cabinet is constructed of heavy duty plastic and it is suitable for indoor installation. Its dimensions are 4" x 7.1" x 1.5" and it has a 32-character, 2-line LCD display and touch pad type controls. The S200 comes with a 1.5-foot biSensor soil moisture sensor.

Guidelines for performing a site audit and determining appropriate total run times and soak and cycle times are available from Baseline for programming the clock/controller connected to the S100 and S200 devices.

The Baseline BaseStation™ BL2000 is a stand-alone commercial controller with conventional valve wiring configuration. It is expandable from 16 to 48 zones in 8-module increments and accommodates up to 6 biSensor sensors. The BL2000 offers 5 programs with 8 start times for each program. The user programs a base schedule and then the total run times are adjusted by the controller based on its evaluation of soil moisture data. (Guidelines are provided for determining an appropriate base schedule.) Other features include day interval calendar, event scheduling, self-test diagnostics and adjustable soak cycles. The BL2000 is remote access capable with Baseline's BaseManager™ computer software package.

The BL2000 is available in lockable indoor wall mount and outdoor pedestal models. The wall mount cabinet is constructed of powder coated steel, and its dimensions are 12" x 10" x 4". The pedestal cabinet is constructed of stainless steel and its dimensions are 36" x 17.5" x 12.5". The controller face includes a dial and touch pad controls. The controller's 3.5-inch QVGA display provides 240x320 resolution.

The BaseStation BL3000 is a stand-alone commercial controller with two-wire biLine™ valve wiring configuration. The two-wire system requires the use of biCoder™ devices at each valve to convert the two-wire signal to power and control the valve. The BL3000 has 200 zone and 25 biSensor capacities. This controller offers all of the features of the BL2000 plus it has 10 programs with 8 starts and an event scheduling feature that allows for restrictions for future events. Also, the user has the option of setting the controller to adjust run times or run frequency. The BL3000 is available in wall mount or pedestal cabinets of the same construction and sizes as the BL2000. The control and display features are also the same.

Although Baseline recommends installation by a landscape professional, it reports the S100 and S200 can be installed by most homeowners. The reported average homeowner installation time is about an hour.

Current suggested retail prices for Baseline products are summarized in the table below. Baseline products are available from its distributors, and a distributor list is available at the Baseline website (www.baselinesystems.com). Baseline controller products have a 1-year warranty and the biSensors have a 3-year warranty.

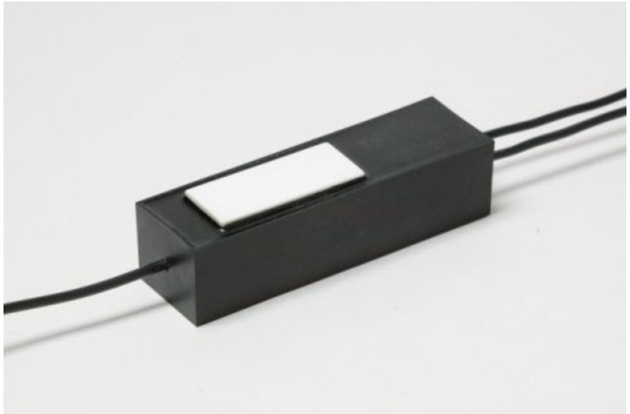
Baseline Product Suggested Retail Prices

Description	Model No.	Price
Indoor Add-on Controller	S100	$149.00*
Indoor Add-on Controller w/ Addl. Features	S200	$350.00*
16-Station Stand-alone Wall Mount Controller	BL2016C	$1,795.00
48-Station Stand-alone Pedestal Controller	BL2048P	$3,895.00
200-Station Stand-alone Wall Mount Controller	BL3048C	$1,495.00
200-Station Stand-alone Pedestal Controller	BL3048P	$2,795.00
biSensor Soil Moisture Sensor (1.5-foot)	BL5315	$249.00
biSensor Soil Moisture Sensor (5-foot)	BL5305	$249.00
biCoder Two-wire Valve Adapter (single zone)	BL5201	$137.50
biCoder Two-wire Valve Adapter (two zone)	BL5202	$192.50
biCoder Two-wire Valve Adapter (four zone)	BL5204	$270.00

* Price includes biSensor

Although no information was submitted for this report on formal studies and testing, Baseline submitted documentation from numerous customers reporting significant water savings (30 to 50 percent) resulting from installation of Baseline systems.

Calsense



As discussed in the Weather Based Product Descriptions section, Calsense manufactures water management systems for large commercial customers. The Calsense Model 1000-S soil moisture sensor measures and transmits soil moisture readings to a Calsense ET2000e irrigation controller to provide efficient landscape irrigation. The ET2000e will automatically suspend irrigation when the soil moisture level is above the threshold set by the user. A full description of the ET2000e and its features is included in the Calsense discussion in the Weather Based Product Descriptions section.

The 1000-S is a solid-state tensiometer type soil moisture sensor that provides consistent long-term soil moisture readings to the Calsense irrigation controller. The moisture sensor electronics are encased in epoxy and the sensor is constructed of heavy duty plastic. There is no maintenance or calibration required for the life of the sensor. The 1000-S readings are unaffected by temperature, salinity or changes in soil pH. The sensor's dimensions are
6.4" x 1.9" x 1.6".

The 1000-S is installed in the root zone and is connected to the valve that controls the area where the sensor is located. Soil moisture data are transmitted to the irrigation controller via the valve control wiring. Special wire runs between the irrigation controller and the sensor are not necessary. The only additional wiring required is between the valve and the 1000-S sensor. The total combined maximum wire run between the moisture sensor and the irrigation controller is 3,000 feet. Calsense reports that maintenance of the 1000-S is only required when the soil becomes extremely dry, requiring the device be removed and soaked and then placed into moist soil. If the soil freezes, removal is not required.

The Calsense ET2000e controller, using the sensor to measure available water in the pore space of the soil, makes a decision before the start of each cycle/soak run whether or not to apply water. This decision is based on the actual moisture reading compared to the user-input moisture set point. Total run times and cycle and soak times are included in the base program entered by the user, based on field knowledge and soil moisture content for the time of year.

A 1000-S is connected to a representative station for each different climatic and plant material zone, which is defined as a master station. Slave stations are stations without sensors and are assigned to a master station that shares similar water requirements. The user chooses groups of stations controlled by the same sensor during initial setup. Stations can be easily changed or moved from one sensor to another through user friendly programming. Calsense recommends a general guideline of one moisture sensor per four active valves to cover varying moisture needs. Up to one soil moisture sensor per every valve may be connected using the ET2000e controller. The 2000e features are discussed in more detail under the Calsense portion of the Weather Based Products section.

Calsense products are available from many distributors located throughout the U.S. A list of these distributors is available from Calsense upon request (800-572-8608 or www.calsense.com). The current retail price for the 1000-S is $199. It has a 5-year warranty. The price range for the various ET2000e models is from $1,290 to $3,680, as detailed in the Calsense discussion in the Weather Based Products section. Calsense provides technical support at no-charge to assist in the proper installation of the moisture sensors for the most efficient system.

Dynamax

Dynamax, Inc. manufactures a wide variety of products used for water status applications, water cycle measurement, plant-water relations, carbon flux instruments, as well as ET weather stations. Dynamax is located in Houston, Texas and has been in business for 20 years. Distribution of its soil moisture based landscape irrigation control systems began in 1999.

Dynamax offers two add-on controller systems: the Moisture Clik™ (IL2-MC) and the Moisture Switch™ (IL2-MS). Both function with newer model non-mechanical clock/controllers and utilize the Dynamax IL2 soil moisture sensor. The IL2 is a frequency domain reflectometry (FDR) type of dielectric sensor that measures volumetric soil moisture content from 0 to 60 percent with a reported 1.0 percent accuracy.

The IL2 soil moisture sensor consists of a waterproof housing that contains the electronics and four sharpened stainless steel rods that are inserted into the soil. The rods are threaded and may be removed from the housing for replacement if damaged or bent. Each IL2 is adjusted during manufacture to provide a consistent output when measuring media of known dielectric constant, making them readily interchangeable without system re-calibration. Specifically, Dynamax reports soil temperature effects and low to moderate salt and fertilizer (conductance levels below 2,000 micro siemens) effects are negligible. The overall length of the sensor is 8.16" and the housing diameter is 1.57". It comes with 85-feet of 4-wire cable. The IL2 is installed into the root zone by pushing the rods into the wall of a shallow trench, resulting in contact with relatively undisturbed soil. The sensor cable is connected to the add-on controller.

The Dynamax add-on controller systems regulate water applied by continuously monitoring the soil condition at the sensor, and interrupting the clock/controller schedule when enough water is available in the root zone. As soon as the soil dries out below the recommended set point, an internal switch closes the signal to the clock/controller to irrigate. The clock/controller to which the device is connected operates as programmed by the user to replenish the depleted soil moisture. The Dynamax owner's manuals include information regarding appropriate cycle and soak times, and total run times are dictated by the Dynamax controller by interrupting the clock/controller common when the irrigation set point is reached and not allowing additional cycle runs.

These controllers come with normally open, and separate hot or neutral outputs providing for several connection options. Specifically, a single Moisture Clik or Moisture Switch controller may be connected to the existing clock/controller such that one Dynamax controller and soil moisture sensor will control all stations or multiple Dynamax controllers and sensors may be used to control groups of stations, or individual stations by direct connection to the irrigation valves.

The Moisture Clik is recommended for residential and smaller commercial applications. It may be connected to a clock/controller to control and regulate all valves or it may be connected to up to 3 valves directly. The Moisture Clik controller may be used where multiple sensors are desired for individual soil moisture control of stations. However, only one IL2 soil moisture sensor may be attached to each individual Moisture Clik. The Moisture Clik may be programmed using its dial settings based on soil type and the desired allowable soil moisture depletion level. Alternatively, advanced users may verify sensor settings and measure soil moisture field capacity with a voltage meter to improve performance.

The Moisture Clik controller cabinet is constructed of polycarbonate and ABS plastics, and is rated for indoor or outdoor installation. Its dimensions are 4.6" x 4.6" x 2.4 ". The 24 VAC, 3 amperes power supply is either from the clock/controller or from an external transformer. It possesses a 3 ampere input fuse and 0.5 ampere internal fuse. Approximately 6-foot of minimum 12 gauge wiring is required to connect the Moisture Clik to the existing clock/timer.

The Moisture Switch controller features are suited for large landscape applications where simultaneous control of multiple valves is necessary, regulating up to 10 valves/zones simultaneously. It may be connected to a clock/controller to control and regulate all valves or it may be connected to up to 10 valves directly. Multiple Moisture Switch controllers may be used where multiple sensors are desired for individual soil moisture control of stations. However, only one IL2 soil moisture sensor may be attached to each individual Moisture Switch. The Moisture Switch requires the use of a standard voltage meter for installation and programming.

The Moisture Switch controller cabinet is constructed of fiberglass reinforced polycarbonate plastic, and is rated for indoor installation only. Its dimensions are 5” x 3.5” x 3”. The 24 VAC, 10 amperes power supply is either from the clock/controller or from an external transformer. It possesses a 10 ampere input fuse and 1.0 ampere internal fuse. Approximately 6-foot of minimum 12 gauge wiring is required to connect the Moisture Switch to the existing clock/timer. The Moisture Switch includes an alarm display and a terminal for connection of an external alarm mechanism. As discussed above, installation of the Moisture Switch requires the use of a voltage meter to determine the irrigation set point.

Dynamax recommends both controllers be installed by an irrigation professional, however, it reports installation and programming of the Moisture Clik is relatively easy and may be accomplished by some homeowners. Dynamax reports installation time reportedly varies from 1 to 1 1/2 hours.

Current retail prices for Dynamax soil moisture sensor based irrigation control products are summarized in the table below. (Moisture Clik and Moisture Switch prices include one IL2 soil moisture sensor, cable and owner’s manual.) Dynamax products may be ordered directly by contacting the sales department through their website (www.dynamax.com) or toll free telephone (800-896-7108), and through its distributors and irrigation design consultants. A distributor search engine is also available at its website. Dynamax provides a one year warranty with its soil moisture sensor control systems.

Dynamax Current Retail Prices

Description	Model No.	Price
Moisture Clik Add-on Controller	IL2-MC	$395*
Moisture Switch Add-on Controller	IL2-MS	$475*
Moisture Sensor	IL2	$300
Power Transformer	IL2-ADP	$30

* Price includes one soil moisture sensor, 85-feet of cable and owners manual

The IL2 soil moisture sensor is an OEM version of the ML2 – Theta Probe. The Theta Probe is designed to measure volumetric soil water content using a novel technique that the manufacturer reports matches other methods, such as time-domain reflectometry (TDR) or capacitance measurement, for accuracy and ease-of-use, while reducing the complexity and expense.

A simplified standing wave measurement is used to determine the impedance of a sensing rod array and hence the volumetric water content of the soil matrix. The Macaulay Land Use Research Institute, Aberdeen and Delta-T Devices, Cambridge have developed Theta Probes jointly. Since its’ development and release, the ML2 – Theta Probe has sold over 17,500 units into the scientific and research community.

The IL2 Theta Probe applies a 100-megahertz sinusoidal signal via a specially designed transmission line to a sensing array whose impedance depends on the dielectric constant of the soil matrix. Because the dielectric constant of water (80) is significantly greater than that of the other soil matrix materials (3-4) and of air (1), the dielectric constant of the soil depends primarily on soil water content. The signal frequency has been chosen to minimize the effect of ionic conductivity.

Dynamax reports there have been many scientific research and practical application studies performed on the Theta Probe, all reportedly having successful results. A list websites for the comparisons results, technical reports, and completed studies are available from Dynamax. Dynamax will also provide a list of their IL2 customers upon request.

Irrometer

The Irrometer Co., Inc., located in Riverside, California, has been in business since 1951. Irrometer manufactures irrigation optimization equipment including soil moisture sensors and control devices, soil solution access tubes for nutrition management, and pressure gauges. Their original tensiometer type soil moisture sensing products have been on the market since 1951. The Watermark resistance type sensor was introduced in 1985.

Irrometer offers 4 different add-on control devices for soil moisture based residential and commercial landscape irrigation control. The controllers use one or more of the Watermark soil moisture sensors to interrupt the existing clock/controller schedule until the soil moisture reaches the user prescribed level. Included with the purchase of an Irrometer control system is its WaterPerfect turf and landscape irrigation scheduling and water management software. This software program aids the user in the proper scheduling of irrigation utilizing Watermark soil moisture sensors, including calculation of total run times and cycle and soak times based on site conditions.

The Watermark is a solid state electrical resistance type sensor which Irrometer reports provides accurate readings from 0 to 200 centibars. This covers the entire soil moisture range required in irrigated landscapes, including heavy clay soils. The sensor is installed by placing it into a hole made with a 7/8" diameter rod to the desired sensor depth. If a larger diameter hole is made, then a "grout" of the soil and water is poured into the hole.

The sensor consists of two concentric electrodes embedded in a reference matrix material, which is surrounded by a synthetic membrane for protection against deterioration. The exterior surface is of ABS plastic and a stainless steel mesh. The internal matrix includes gypsum, which provides some buffering for the effects of salinity levels normally found in irrigated landscapes. The sensor is 7/8" in diameter by 3" long. The original Watermark (model 200) was improved in 1993 to the current model 200SS, which has improved its soil moisture response characteristics. The sensors are maintenance free and are not damaged by freezing. The reported minimum life span for a Watermark sensor is five to seven years.

Irrometer's soil moisture sensor based control devices include the WaterSwitch (WS1), Watermark Electronic Module (WEM), Battery WEM (WEM-B), and Watermark Multiple Hydrozone System (MHS). As mentioned above, all of these devices use the Watermark sensors and interrupt the common power supply to the clock/controller or interface with the controller's sensor circuit, and the WEM may be used to control individual valves. The sensor wiring is connected directly to the control module, which is connected to either the clock/controller or the valve(s). The maximum run between the sensor and controller is 1,000 feet using 18 gauge wire. Larger wire sizes can be used for longer distances.

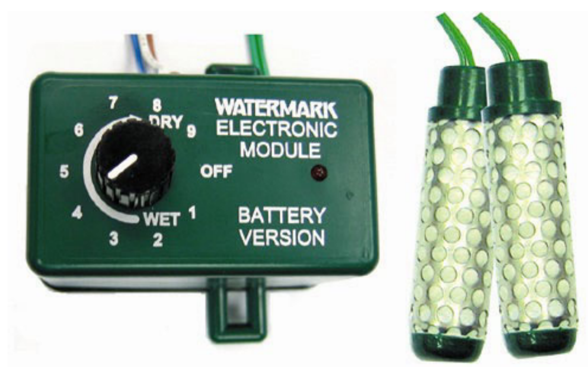
The Watermark Electronic Module is Irrometer's flagship controller. It is a versatile device that can be used in multiple connection scenarios, and in combination with the Multiple Hydrozone System as discussed below. The WEM can be used to control an individual valve, a group of valves watering areas of similar water demand, or all the valves on any clock/controller. In a typical residential application, a pair of Watermark sensors is connected to the WEM and the wiring configuration for the connection to the clock/controller provides for interruption of the power supply common connection. Alternatively, a pair of sensors and a WEM may be installed and connected to a single valve at the valve box. When a new system is being installed for a large landscape with a need for multiple sensor pairs, multiple common wires can be installed to provide for the use of multiple WEMs and sensors. For a retrofit of an existing system where multiple sensors are needed, a Multiple Hydrozone System device should be used rather than installing the needed additional common wiring.

The WEM's cabinet is constructed of heavy duty plastic and it can be installed indoors or outdoors. It may be installed at the controller or at the valve. The WEM's dimensions are 3" x 2" x 1.5". The WEM is adjustable from 10 to 120 centibars by a simple dial that has an OFF position to allow for overriding the sensors. The WEM's indicator light comes on when the clock/controller is powering a valve controlled by the WEM, and the soil moisture conditions are drier than the selected setting indicating irrigation is allowed. It is powered by a 24 VAC supply from the clock/controller.

The WaterSwitch and the Battery WEM are designed for use with clock/controllers that possess switch terminals (rain, master valve, etc.). This provides for a simple wiring configuration and easy installation. Both function similar to the WEM and possess the same features.

The WaterSwitch is constructed of heavy duty plastic and is suitable for indoor or outdoor installation. Its cabinet dimensions are 2" x 2" x 1.25" which make it small enough to mount inside many controller cabinets. The WaterSwitch is powered by the 24 VAC supply from the clock/controller.

The Battery WEM is designed for use with a DC powered clock/ controller. It is constructed of heavy duty plastic and is suitable for outdoor installation. Its cabinet dimensions are 2.5" x 1.5" x 2". The Battery WEM is powered by a 9-volt battery housed inside its waterproof battery compartment.



The Multiple Hydrozone System device functions with multiple WEMs and is designed for commercial applications where numerous sensor pairs are used, or retrofit of an existing system with a need for more than one sensor pair. The MHS can control valves for up to 8 separate moisture sensing areas. Each area is monitored using a WEM and Watermark sensors allowing for individual adjustment of the soil moisture threshold and a manual override feature is included. This device communicates with the clock/controller such that individual valves or groups of valves can be controlled without the need for multiple power supply common connections.

The MHS is constructed of heavy duty plastic and is suitable for indoor installation. A weatherproof stainless steel cabinet (shown in photograph) is available for outdoor installations. Its dimensions are 11" x 16" x 2" and the outdoor cabinet dimensions are 18" x 18" x 7". The MHS is powered by a 24 VAC supply from the clock/controller.

Irrometer recommends professional installation, but it reports a typical residential system can be installed by some homeowners in approximately 2 to 4 hours.

Current retail prices for Irrometer soil moisture sensor based irrigation control products are summarized in the table below. Irrometer products are available through irrigation equipment distributors, some of which are listed at its website (www.irrometer.com). Irrometer provides a one year warranty with its soil moisture sensor control systems.

Irrometer Current Retail Prices

Description	Model No.	Price
WaterSwitch Add-on Controller	WS1	$100*
WEM Add-on Controller	WEM	$200
Battery WEM Add-on Controller	WEM-B	$250
MHS Device	MHS-_-_	$655 and up
MHS Stainless Steel Cabinet	-CM	$870
Watermark Soil Moisture Sensor	200SS-5	$30

* Price includes one Watermark soil moisture sensor

Irrometer's Watermark sensors have been used in soil science research by universities, as well as in production agriculture and landscape applications, worldwide for over 15 years. Their use in landscape applications has been documented for the longest period of time by a study that originated in 1993 for the city of Boulder, Colorado. The consulting firm conducting the study, Aquacraft, Inc., published numerous papers from 1995 to 2001 for the Irrigation Association, the American Society of Agricultural Engineers, the American Water Resources Journal and the American Water Works Association. Below is an excerpt from one of the reports and a graph that summarize the savings:

"The results of this study were quite encouraging from the standpoint of both irrigation efficiency and cost effectiveness. On a seasonal basis, the systems limited applications to an average of 76% of theoretical requirement when all sites are combined."

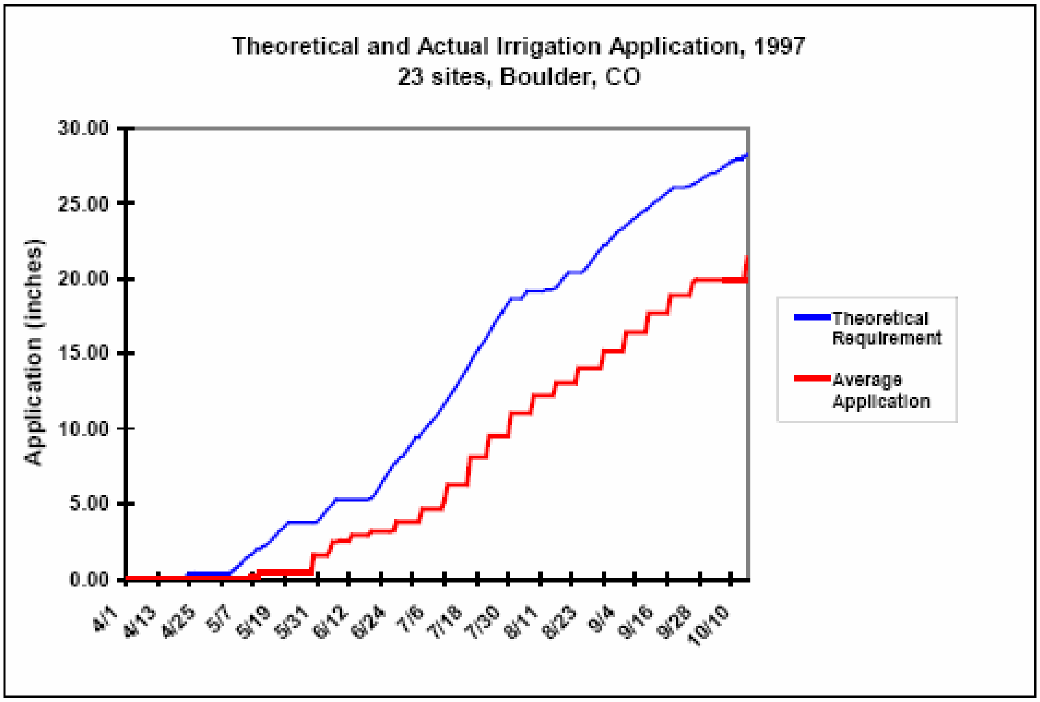


Figure 4: Average Application Curve for All Sites

Irrometer's Watermark control products have also received the *Smart Approved WaterMark* designation**,** Australia's water saving labeling program for products to reduce outdoor water use.

LawnLogic

LawnLogic® products are manufactured by Alpine Automation, Inc., of Aurora, Colorado. The company began business in 1997 as a soil moisture based irrigation systems supplier. Research and product commercialization began on the LawnLogic system in 2003 and it was introduced in the spring of 2004. As of this writing it is reported that over 400 LawnLogic systems are in place, many of which are operating in their third irrigation season.

The LawnLogic system works with any clock/ controller to independently control individual irrigation zones. Each system consists of a control module and multiple electrical conductivity type soil moisture sensors. The system is compatible with any combination of sub-surface, pop-up and rotary irrigation system designs.

The LawnLogic soil moisture sensor measures the current and resistance between two non-corrosive stainless steel probes that are 3" long and 3" apart from each other. The sensor body is 1/2" wide. Sensor readings are calibrated to volumetric soil moisture content. The probes are embedded in an impact resistant plastic housing and the wiring and electronics are encased in electrical potting epoxy. The sensors are installed by pushing the probes into relatively undisturbed soil in the wall of a shallow trench.

The LawnLogic controller module (model No. LL-1004) connects to any existing 24 VAC clock/controller. The instrument operates with exclusive Alpine Automation developed MLD (Mixed Logic-Dynamic) and MCC (Measurement and Control) software. The sensors communicate over the existing irrigation wiring. When a sensor determines the moisture level within a root zone is at or above the user-defined set point the system does not allow an irrigation cycle. When moisture levels drop below the user adjustable setting, irrigation cycles are allowed. The control module wiring is connected to the existing clock/timer and the sensor wiring is connected to the valve for each respective zone.

The LawnLogic system automatically tailors a moisture profile for each zone when the appropriate zone button is held down. For example, the switch marked "2" controls irrigation zone 2 and when the switch is held down for 5 seconds, the LCD displays the message "READING ZONE 2". The LawnLogic sensor buried in zone 2 measures the amount of soil moisture present. The message "CALIBRATING 2" then appears on the screen. The system is then operational and the user can increase or decrease the soil moisture threshold in each zone by four levels. If no sensor is present in the zone the message "NO SENSOR 2" appears.

Each module has a one-line,16 character backlit LCD display which displays auto-prompt information for installation and programming. Zone selection, bypass and moisture adjustment controls are two position rocker switches. The module is rated for use with solenoid valves holding 0.5 ampere circuit capacity maximum. Power to the control module is typically from the existing clock/controller, but an external transformer may be used. Surge suppression is integrated into the measurement and control circuitry.

Each irrigation zone can be bypassed independently, which allows the clock/controller to operate without the benefit of the LawnLogic system. All settings are stored in non-volatile memory and no battery backup is required in the case of a power outage. Soil moisture status is updated every 15 minutes and the real time status of each zone is displayed 24/7.

The module enclosure is constructed of heavy duty plastic. Its dimensions are 5" x 3.2" x 2.5". It is designed for indoor installation, but an optional locking outdoor plastic cabinet is available for mounting outdoors. Up to four modules can be installed in the outdoor cabinet. The dimensions of the outdoor cabinet are

12” x 12” x 4”. Up to 6 modules can be combined to control up to 24 zones, and up to 32 zones can be accommodated for custom projects.

Alpine Automation recommends installation of large systems by an irrigation professional, however, it reports most homeowners can install a small system. The reported first-time installation time for a small system is estimated to be 1 hour, depending on site specific conditions.

Current retail prices for LawnLogic systems are summarized in the table below. Prices include the control module and all sensors. LawnLogic products are available through its distributors, which are listed at its website (www.lawnlogic.com). The company can make arrangements for professional installation through its distributor/dealer network. Alpine Automation provides a one year warranty with its LawnLogic soil moisture sensor control systems.

LawnLogic Current Retail Prices

Description	Model No.	Price
4-Station Add-on Controller System	LL-1004	$379.95
8-Station Add-on Controller System	LL-1008	$749.00
12-Station Add-on Controller System	LL-1012	$1,099.00
16-Station Add-on Controller System	LL-1016	$1,449.00
20-Station Add-on Controller System	LL-1020	$1,799.00
24-Station Add-on Controller System	LL-1024	$2,149.00

Prices include soil moisture sensors to compliment the number of zones

Based on performance and warranty tracking, Alpine Automation reports successful overall performance of LawnLogic systems and negligible problems.

LawnLogic was included in the University of Florida County Extension Madera home project study of soil moisture sensor based irrigation control. Study results submitted for this report showed a 44 percent average water savings during April to October 2005 for a single study site.

Alpine Automation reports LawnLogic systems have been successfully integrated with dozens of different clock/controllers ranging from unsophisticated 25 year old controllers to state of the art systems

LawnLogic systems are installed across North America and Australia, and are in use on a variety of landscapes. The University of Florida recently initiated a study that incorporates LawnLogic systems on St. Augustine grass. Alpine

Automation is working with both standard and ET controller manufactures, and companies that produce automated fertilization systems to facilitate the integration of LawnLogic with their products.

Waternomics

Waternomics soil moisture sensor based irrigation control products are manufactured by ManyWaters, Inc. of Denver, Colorado. ManyWaters has been in business since 2001, and carries a variety of water conservation related products. Distribution of its soil moisture based landscape irrigation control systems began in 2001.

ManyWaters offers the WW1 System which is an add-on soil moisture sensor landscape controller system that functions best with any clock/controller and utilizes an electrical conductivity type soil moisture sensor. The WW1 can also be used to control individual valves with or without the use of a clock/controller.

The WW1 soil moisture sensor consists of a stainless steel and plastic probe that is inserted into the root zone. The sensor measures volumetric soil moisture content based on the electrical impedance measured between the probe's two electrodes. Each sensor is calibrated at the factory to provide a consistent output when measuring media of known dielectric constant. The reported accuracy of the sensor is plus or minus 5 percent, but no information on sensitivity to salts/fertilizer was provided for this report. The overall length of the sensor is 6" and the housing diameter is 0.25". It comes with 25 feet of 4-wire cable. The sensor is installed into the root zone by pushing it into the wall of a shallow trench, resulting in contact with relatively undisturbed soil. The sensor cable wiring may be connected to the existing valve wiring or to the add-on controller.

The WW1 System regulates water applied by continuously monitoring the soil condition at the sensor, and interrupting the clock/controller schedule or individual valve when enough water is available in the root zone. When connected to a clock/controller, the WW1 serves as a switch by overriding the common circuit to all station valves. When one or more controllers are used without a clock/controller, the controller causes irrigation to occur when the soil moisture falls below the user specified threshold and then irrigation ceases once the soil moisture content is measured to be at the threshold. This mode does not allow for prescribing irrigation days, times or soak/cycle periods.

The WW1 controller comes with normally open, and separate hot or neutral outputs providing for several connection options. It may be integrated with an existing clock/controller such that one soil moisture sensor will control all stations or multiple sensors may be used to control groups of stations. The controller may be set from zero to 100 percent saturation soil moisture content in 5 percent increments.

For control of all stations using one sensor, the WW1 controller is typically installed near the clock/controller. When using multiple sensors, the controller may be installed in the individual valve box(es) or at the clock/controller.

The WW1 controller cabinet is constructed of high impact shock resistant plastic, and is rated for indoor or outdoor installation. Its dimensions are 3" x 2" x 1" with a rotating moisture level control knob and LED indicator lights. The controller's circuitry is epoxy-encapsulated. The power supply is either from the clock/controller or from an external transformer. Approximately 6-foot of minimum 12 gauge wiring is required to connect the WW1 to the existing clock/timer.

ManyWaters recommends installation by an irrigation professional; however, installation and programming a one sensor setup may be accomplished by some homeowners. Reported installation time for a simple residential system is less than 1 hour.

The current retail price for the Waternomics WW1 System is $179. Waternomics products may be ordered directly from ManyWaters by contacting them at 720-529-3980. ManyWaters provides a one year warranty with their Waternomics soil moisture sensor control systems.

Waternomics is participating in an ongoing demonstration program with the State of New Mexico which includes the installation of its soil moisture based irrigation control systems at several urban parks and school grounds. These systems are being monitored to evaluate performance and water savings, and monitoring results should be available from Many Waters during 2007.

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Weather Based Irrigation Technologies - Summary of Product Information and Features

Company Name		Accurate WeatherSet	AccuWater	Alex-Tronix	Aqua Conserve	Calsense	ECO Research	ET Water Systems	Hunter Industries	HydroPoint WeatherTRAK	HydroSaver
Telephone		(818) 993-1449	(512) 331-9283	(888) 224-7630	(951) 352-3891	(800) 572-8608	(208) 562-3680	(415) 945-9383 ext. 205	(760) 591-7344	(800) 362-8774	1-562-494-8686
Contact Person		Andrew Davis	Tom Watson	George Alexanian	Dan Oshaben	Rick Capitanio	Larry Haley	Bruce Cardinal	Dave Shoup	Chris Manchuck	Tom Carr
Website		www.weatherset.com	www.accuwater.com	www.alex-tronix.com	www.aquaconserve.com	www.calsense.com	www.ecoresearch.com	www.etwater.com	www.hunterindustries.com	www.weathertrak.com	www.hydrosaver.net
Number of Residential Model Types		2	1	1	2	0	1	2	1	1	0
Number of Commercial Model Types		1	1	1	2	1	1	4	1	1	1
Date Product(s) Entered Market		1994	2004	2005	1998	1993	2005	March 2005	February 2006	1997	1994
Method of Operation											
Basis for Schedule	Historical Data				●	●				Back-up	●
	On-site Sensor(s)	●	●[1]	●	●	●[1]	●	●[1]	●	●[1]	●
	Remote Weather Station(s)/Sensors		●					●		●	
Weather Data Source		On-site solar and rain sensors	On-site sensors or weather station and/or public data managed by centralized server	On-site temperature sensor and solar radiation estimated based on geographic location	16 preprogrammed ET curves with on-site temperature sensor	Historic ET data or evaporative atmometer type ET sensor	On-site temperature sensor and solar radiation estimated based on geographic location	Public & ETWS weather station data managed by centralized computer server	On-site weather station	Public and private weather stations managed by central computer and wireless delivery	Historic ET data and on-site "ET sensor"
Product Features											
Stand-alone Controller or Add-on to Existing		Stand-alone	Stand-alone	Stand-alone	Stand-alone	Stand-alone	Add-on	Stand-alone	Add-on	Stand-alone	Stand-alone
Station or Zone Capacity		8-48	16-48	4-24	6-66	8-48	Not Applicable	1-48	Not Applicable	6-48	12-56
Master Valve or Pump Circuit(s)		1	1	1	1-4	2	Not Applicable	2	Not Applicable	1	1
Internal Power Transformer		Outdoor Models Only	Commercial Only	Not Applicable	Commercial Only	●		●		●	●
Battery Powered - DC				●							
Station Circuit Current Rating (Amperes)		0.75 and 1.5	0.75	5.0 (DC pulse)	1.0	1.5	Not Applicable	1.0	Not Applicable	0.375 and 0.5	2.0
Terminal Wire Size Range (Gauge)		12-20	14 and smaller	12-18	12-18	14	Not Applicable	12 and smaller	Not Applicable	12-20	12-20
Outdoor Installation		●	Commercial Only	●	All Comm. & 2 Res.	●	●[1]	●	●	●	●
On-site Rain Gauge or Sensor w/ Rain Shutoff/Delay		●	●[1]	●[1]	Incl. w/ Res, Comm Option[1]	●[1]	●[1]	●[1]	●	●[1]	●
Rain Shutoff by Remote Sensor or Rain Radar			●					Not currently, Planned for 2007		●	
Rainfall Irrigation Schedule Compensation		●	●			●	●	●	●	●	
On-site Wind Gauge w/ High Wind Shut-off			●[1]			●[1]		●[1]	●[1]	●[1]	
High Wind Shut-off by Remote Sensor			●							●[1]	
On-site Temperature Sensor w/ Freeze Shut-off			●[1]	●	●		●	●[1]	●	●[1]	
On-site Temperature Sensor w/ High Temp On or Off			●[1]						●		
Freeze or High Temp Shut-off by Remote Sensor			●							●[1]	
On-site Evaporative Atmometer Type "ET Sensor"						●[1]					
Onsite Weather Station or "ET Sensor"			●[1]			●[1]		●[1]	●[2]		●[2]
Flow Sensor(s) Connectivity		5 models	●		12 Models	●		●		●[1]	●
Additional Sensor Terminals			●		With Adaptor[1]	●		●		●	
Remote Control Device(s) for Controller			●[1]			●[1]		●		●[1]	
Two-way Communication between Server and Receiver			●					●		Commerical Model	
Station Circuit Testing		5 models	●			●		●		●	
Surge and/or Lightning Protection		5 models	●	●	Etu & ET-SP Models	●[1]		●		●	●
SWAT Test Performance Report Available								●		●	
Scheduling Features											
Fully Automatic Schedule (No Base Schedule Required)			●					●	●	●	
Base Irrigation Schedule Required		●		●	●	●	●	Optional			●
User May Define Non-Irrigation Days		●	●	●	●	●	●	●	●	●	●
Operable in Manual Clock Mode		●	-[6]	●	●	●	●	●	●	●	●
Manual Operation by Station or Program		●	●	●		●	●	●	●	●	●
Variable Total Run Times		●	●	●	●	●		●	●	●	
Irrigation Schedule Period(s)		Weekday or daily to 40 days	Unlimitted Days	Week or up to 99 Day	Week or Odd/Even	7, 14, 21 or 28 Day	Not Applicable	Unlimited Days	Not Applicable	8 Weeks,Odd/Even&Weekday	7,14 & 28 Days, Odd/Even
Available Start Times		10	Unlimited	4 per program	4-8	6 per manual program	Not Applicable	Unlimited		8 starts with 20 repeat cycles	12
Cycle/Soak Manual Input		●	●	●	●	●	Not Applicable			Optional	
Cycle/Soak Periods Automatically Calculated			●				Not Applicable	●	●	●	●
Runs Concurrent Stations		●		●		●	Not Applicable	Not currently, Planned for 2007		●	3
Number of Programs		5	Unlimited	4	4	7	Not Applicable	Unlimited	Not Applicable	Unlimited	6
Percent Irrigation Adjust Feature			●	●	●	% of ET Adjust per station	Not Applicable	●		●	●
Station Distribution Uniformity/Efficiency Setting			●					●		●	
Syringe Cycle or Program		●	●		●	●				●	
Review of Recent Irrigation Information		●	Using Web Browser	●	●	●	●	●	●	●	●
English and Spanish LanGauges Display			Cell Phone Remote Only			●					●
Review of Weather and/or Other Addl Info			Using Web Browser		12 Models	●		●		●	●
Product Support and Warranty											
Warranty		3 Years	1 Year	2 Years	3 Years	5 Years	1 Year	3 Years	2 Years	3 (Res) and 5 (Comm) years	3 and 5 years
Support	On-site Service Technicians	In Southern California	●			●		●		●	In Southern Califonia
	Telephone Technicians	●	●	●	●	●	●	●	●	●	●
	Local Distibutors	In Southern California		●	●	●	●	●	●	●	
Installation and Maintenance Requirements											
Professional Installation & Programming Recommended		●	●	●	Commercial Models	●		●	●	●	●
Ongoing Maintenance Required			Clean Sensors			Clean Sensors			Clean Sensors		
Clock Battery Replacement Required		●		●	●		●	●	●		
Cost											
Controller Suggested Retail Price		$220-$1,440	$549-$2,999	$995-$2,794	$240-$5,630	$1,290-$3,680	$198	$399-$2,399	$399	$449-$3,675	$1,800-$2,800[5]
Annual Service Cost		0	$149 minimum	0	0	0	0	$40-$199	$0	$48-$225	0

1 - Optional add-on feature not included in controller price(s) shown
2 - Consists of temperature, solar, and humidity sensors
3 - Scheduling computer software or on-site technician assistance provided with purchase
4 - Purchase for rebate programs includes 2 years of service
5 - Complete pricing information was not available for this report
6 - Controller back-up schedule based on recent ET good for 21 days without network connectivity which can be modified by user
7 - Includes remote monitoring of irrigation operation and tracks meter usage for savings reports

Weather Based Irrigation Technologies - Summary of Product Information and Features (cont.)

Company Name		Irritrol Systems	Micromet	Rainbird	Rain Master	Toro Company	Tucor	Water2Save	Weathermatic	Weather Reach
Telephone		(800) 664-4740	(714) 979-9119	(520) 741-6162	(805) 527-4498	(800) 664-4740	(800) 272-7472	(858) 361-9700	(972) 278-6131	(435) 755-0400
Contact Person		Robert Starr	Barry Battiscombe	Kraig Wilson	Steve Springer	Robert Starr	Larry Sarver	Gary Gelinas	Brodie Bruner	Steven Moore
Website		www.irritrol.com	www.micrometonline.com	www.rainbird.com	www.rainmaster.com	www.toro.com	www.tucor.com	www.water2save.com	www.weathermatic.com	www.irrisoft.net
Number of Residential Model Types		1	0	1	0	1	0	1	1	1
Number of Commercial Model Types		1	1	1	1	1	1	1	1	1
Date Product(s) Entered Market		2005	1997	April 2006	2002	2005	1995	1996	2004	2002
Method of Operation										
Basis for Schedule	Historical Data			Back-up	●			Back-up		Back-up
	On-site Sensor(s)	●[1]		●[1]	●[1]	●[1]	●	●[1]	●	●[1]
	Remote Weather Station(s)/Sensors	●	●	●	●[1]	●	●	●		●
Weather Data Source		Public weather station data managed by centralized computer server	Public & private weather station data managed by centralized computer server	Public & private weather station data managed by centralized computer server	Automatic, historic or manually entered ET or with optional on-site weather station	Public weather station data managed by centralized computer server	On-site weather station	Public & patented forecasted weather data managed by their centralized computer server	On-site temperature sensor and solar radiation estimated based on geographic location	Public & private weather station data managed by centralized computer server
Product Features										
Stand-alone Controller or Add-on to Existing		Stand-alone	Add-on	Add-on	Stand-alone	Stand-alone	Stand-alone	Add-on (up to 4 controllers)	Stand-alone	Add-on
Station or Zone Capacity		6-24	Not Applicable	Not Applicable	6-36	6-24	50-500	12-64	4-24	Not Applicable
Master Valve or Pump Circuit(s)		1	Not Applicable	Not Applicable	1	1	16	Not Applicable	1	Not Applicable
Internal Power Transformer		●			●	●				
Battery Powered - DC										
Station Circuit Current Rating (Amperes)		0.5	Not Applicable	Not Applicable	1.0	0.5	Not Reported	Not Applicable	1.5	Not Applicable
Terminal Wire Size Range (Gauge)		12-18	Not Applicable	Not Applicable	12	●	14	14-22	14-18	Not Applicable
Outdoor Installation		●	●	●[1]	●	3 Models		●	●	●[1]
On-site Rain Gauge or Sensor w/ Rain Shutoff/Delay		●[1]		●[1]	●[1]	●[1]	●	●[1]	●	●[1]
Rain Shutoff by Remote Sensor or Rain Radar		●	●	●	●[1]			●		●
Rainfall Irrigation Schedule Compensation		●	●	●	●[1]			●	●	●
On-site Wind Gauge w/ High Wind Shut-off		●[1]					●			
High Wind Shut-off by Remote Sensor				●	●[1]					
On-site Temperature Sensor w/ Freeze Shut-off		●[1]		●	●[1]	●[1]	●		●	●
On-site Temperature Sensor w/ High Temp On or Off					●[1]					
Freeze or High Temp Shut-off by Remote Sensor				●	●[1]					●
On-site Evaporative Atmometer Type "ET Sensor"										
Onsite Weather Station or "ET Sensor"					●[1]		●			
Flow Sensor(s) Connectivity					●		●			
Additional Sensor Terminals					●					
Remote Control Device(s) for Controller					●[1]					
Two-way Communication between Server and Receiver					●[1]			●		
Station Circuit Testing		●			●	●				
Surge and/or Lightning Protection		●			●[1]	●	●[1]	●	●	
SWAT Test Performance Report Available		●				●				
Scheduling Features										
Fully Automatic Schedule (No Base Schedule Required)		●			●[1]	●	●		●	
Base Irrigation Schedule Required			●	●[3]	●			●[3]		●[3]
User May Define Non-Irrigation Days		●	●	●	●	●		●	●	●
Operable in Manual Clock Mode		●	●	●	●	●		●	●	●
Manual Operation by Station or Program					●			●		
Variable Total Run Times		●			●	●	●	●	●	
Irrigation Schedule Period(s)		Not Applicable	Not Applicable	Not Applicable	7 or 30 Day	Not Applicable	14 Day	Not Applicable		Not Applicable
Available Start Times			Not Applicable	Not Applicable	5		12	Not Applicable		Not Applicable
Cycle/Soak Manual Input			Not Applicable	Not Applicable	●					Not Applicable
Cycle/Soak Periods Automatically Calculated		●	Not Applicable	Not Applicable	●	●		●	●	Not Applicable
Runs Concurrent Stations			Not Applicable	Not Applicable	●		●	●	●	Not Applicable
Number of Programs		Up to 64 cycles	Not Applicable	Not Applicable	4	Up to 64 cycles	30	Not Applicable	4	Not Applicable
Percent Irrigation Adjust Feature		●	Not Applicable	Not Applicable	●	●		●	●	Not Applicable
Station Distribution Uniformity/Efficiency Setting			Not Applicable	Not Applicable	●					Not Applicable
Syringe Cycle or Program					●					
Review of Recent Irrigation Information		●	●	●	●	●	●	●	●	●
English and Spanish LanGauges Display										
Review of Weather and/or Other Addl Info		●	●	●	●	●	●	●		●
Product Support and Warranty										
Warranty		5 years	2 Years	1 Year	5 Years	5 Years	3 Years	3 Years	2 Years	1 Year
Support	On-site Service Technicians		●					●		
	Telephone Technicians	●	●	●	●	●	●	●	●	●
	Local Distibutors	●		●	●	●	●	●	●	●
Installation and Maintenance Requirements										
Professional Installation & Programming Recommended		●	Included with Purchase	●	Recommended	Recommended	●	Included with purchase		●
Ongoing Maintenance Required			Included with Service Cost		Clean Sensors		Clean Sensors	Included with service cost		
Clock Battery Replacement Required		●		●		●			●	●
Cost										
Controller Suggested Retail Price		$399-$899	$1,890[4]	$702	$640-$4,264	$399-$889	$20,150-$23,750	$527-$1,598	$299.90-$816.80	$795
Annual Service Cost		$48-$84	$360-$720[4]	0-$350	0-$180	$48-$84	0	$117-$468[7]	0	0-$350

1 - Optional add-on feature not included in controller price(s) shown
2 - Consists of temperature, solar, and humidity sensors
3 - Scheduling computer software or on-site technician assistance provided with purchase
4 - Purchase for rebate programs includes 2 years of service
5 - Complete pricing information was not available for this report
6 - Controller back-up schedule based on recent ET good for 21 days without network connectivity which can be modified by user
7 - Includes remote monitoring of irrigation operation and tracks meter usage for savings reports

Soil Moisture Based Irrigation Technologies - Summary of Product Information and Features

Company Name	Acclima	Baseline	Calsense	Dynamax	Irrometer	LawnLogic	Waternomics
Telephone	(866) 887-1470	(866) 294-5847	(951) 352-3891	(800) 896-7108	(951) 689-1701	(303)-564-9367	(760) 591-7344
Contact Person	Sam Lundstrom	Jon Peters	Rick Capitanio	Gary Woods	Tom Penning	Terry Zenner	Dean Cramer
Web Page	www.acclima.com	www.baselinesystems.com	www.calsense.com	www.dynamax.com	www.irrometer.com	www.lawnlogic.com	
Number of Residential Model Types	1	2	0	1	3	1	1
Number of Commercial Model Types	3	2	1	1	1	1	1
Date Product(s) Entered Market	2002	2002	1993	1999	1985	2004	2001
Method of Operation							
Interupts Operation of All Stations	Residential Models	●		●	Residential Models		●
Interupts Operation of Individual or Groups of Stations	Commercial Models	●	●	Requires Multiple Controllers	Commercial Models	●	Requires Multiple Controllers
Product Features							
Stand-alone Controller or Add-on to Existing	Both	Both	Stand-alone	Add-on	Add-on	Add-on	Add-on
Type of Soil Moisture Sensor(s)	Digital Time Domain Transmission	Time Domain Transmission	Tensiometer	Frequency Domain Reflectometry	Elec. Resistant Granular Matrix	Elec. Conductivity	Elec. Conductivity
Multiple Soil Moisture Sensors May Be Used	●	Commercial Models	●	Requires Multiple Controllers	Commercial Models	Multiple Sensors Required	Requires Multiple Controllers
Soil Moisture Sensor Capacity	1-36	6 & 25	48	1per Controller	1 to 8	1-32	1
Soil Moisture Sensor(s) Connect to Existing Valve Wiring	●	●	●		Commercial Models	●	●
Number of Soil Moisture Settings	600	Unlimitted		51	4, 9 and 11	9	20
Measures and Adjusts for Soil Conductivity	●						
Controller Displays Soil Conductivity	●						
Measures and Adjusts for Soil Temperature	●	●					
Controller Displays Soil Temperature	●	Commercial Models					
Controller Station Capacity	24, 36 & 64	16-200	8-48	Unlimited	Unlimited	1-32	Unlimited
Master Valve or Pump Circuit(s)	Commercial Models	Commercial Models	2	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Internal Power Transformer	Commercial Models	Commercial Models	●			●[1]	
Battery Powered - DC				Option Available	1 Model		
Station Circuit Current Rating (Amperes)	0.7	Not Reported	1.5	3 & 10	Not Applicable	0.5	Not Applicable
Outdoor Installation	Commercial Models	●[1]	●	●[1]	All Models, Commercial option	●[1]	
Rain Gauge or Sensor Compatible w/ Rain Shutoff/Delay	Commercial Models	●	●			●	
Flow Sensor Compatible	Commercial Models	Commercial Models	●	Not Applicable	Not Applicable	●	Not Applicable
Additional Sensor Terminals	Commercial Models	Commercial Models	●	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Remote Control Device for Controller	Commercial Models[1]	Commercial Models	●[1]				
System Testing and Diagnostics by Controller	Commercial Models	●	●			●	
Surge and/or Lightning Protection	●	●	●[1]			●	
Scheduling Features							
Fully Automatic Schedule (No Base Schedule Required)	Commercial Models	Commercial Models				●	
Variable Run Times	Commercial Models	Commercial Models					
User May Define Non-Irrigation Days	Commercial Models	Commercial Models	●	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Operable in Manual Clock Mode	●	●	●	●	●	●	●
Manual Operation by Station or Program	Commercial Models	Commercial Models	●	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Irrigation Schedule Period(s)	Odd/Even, Nth Day & Custom	All options available	7, 14, 21 or 28 day	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Available Start Times	Up to 6 or On Demand	8	6	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Irrigation Pause/Resume	Commercial Models	Commercial Models	●	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Runs Concurrent Stations	Commercial Models	Commercial Models	●	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Number of Programs	Up to 40	Up to 10	7	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Syringe Cycle or Program	Programmable	Commercial Models	●	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Review of Recent Irrigation Information	Commercial Models	Commercial Models	●	Not Applicable	Not Applicable	Not Applicable	Not Applicable
English and Spanish LanGauges Display	●		●	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Product Support and Warranty							
Warranty	2 Years	1 and 3 (sensor only) Years	5 Years	1 Year	1 Year	1 Year	1 Year
Support: On-site Service Technicians	Some Locations			Some Locations			
Support: Telephone Technicians	●	●	●	●	●	●	●
Support: Local Distibutors	Some Locations			Some Locations	●	●	
Installation and Maintenance Requirements							
Professional Installation & Programming Recommended	Commercial Models	Commercial Models	●	Commercial Models	Commercial Models	Commercial Models	●
Clock Battery Replacement Required	5 to 10 years						
Cost							
Suggested Retail Prices[2]	$369-$2,978	$149-$10,120	$1,489-$6,068	$395-$475	$100-$3,040	$379.95-$2,149	$199

1 - Optional add-on feature not included in controller price(s) shown

2 - Prices include controller and soil moisture sensor(s)

A New Method of Calculating the Wetted Radius of Sprinklers

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ASABE standard S398.1 January 2001 contains an arbitrary definition of how to characterize the wetted radius of sprinklers under test conditions. As a result, data reported by manufacturers can be open to interpretation. Unfortunately serious system design work is frequently based on this data and may further be modified by the consultant's perception of the data's integrity.

The method proposed here uses the total of the pattern data to develop a curve of the accumulated catchment volume vs. radius. The definition of the wetted radius is then defined as the radius that accounts for 99.5% (for example) of the accumulated volume. The definition applies equally well to sprinklers of any size and avoids the problem of trying to account for the significance of light water depositions that characteristically occur near the end of the deposition pattern.

The calculation is illustrated by using actual data from a Center for Irrigation Technology (CIT) test (record No. 3054P). This is a 28.0 gpm sprinkler operating at a base pressure of 80 psi. The actual deposition pattern is given in the record along with the ASABE defined wetted radius of throw of 67 ft. The deposition data was used to calculate the accumulated volume vs. radius curve shown in Figure 1.

This new method proposes to define the wetted radius as the radius that accounts for a high percentage of the water deposited in the catchment devices. The method includes then fitting a function to the data given in Figure 1. Also shown in Figure 1 is the result of the curve fitting as a 5th order polynomial. This function fits with a correlating coefficient of 0.999. This correlation utilizes all of the deposition data and avoids the arbitrary values noted in the ASABE standard (e.g. 0.01 in./h plus 1.0 ft for flowrates over 2.0 gpm) that only focuses on the end of the deposition pattern.

The selection of the minimum accumulated volume represented by the design data can be specified by the manufacturer and given in a footnote in their design tables. Alternatively, the Irrigation Association could establish a recommended value that would then provide a common basis when comparing data from different manufacturers. The following Table 1 gives the relationship between the accumulated volume and the radius for the sprinkler characterized in Figure 1.

Table 1 Accumulated Volume vs. Radius from Figure 1

Accumulated Volume, %	Radius, ft
99.00	66.3
99.50	66.8
99.90	67.2
100.00	67.3

A suggested value of 99.5% shows a wetted radius of 66.8 ft. The manufacturer's literature shows the radius as 67 ft.

The proposed method is thought to be applicable to sprinklers of all sizes. It utilizes all of the data measured in the deposition test instead of concentrating on the last one or two catchment devices. No arbitrary judgments are required and the calculation lends itself to computerized program analysis.

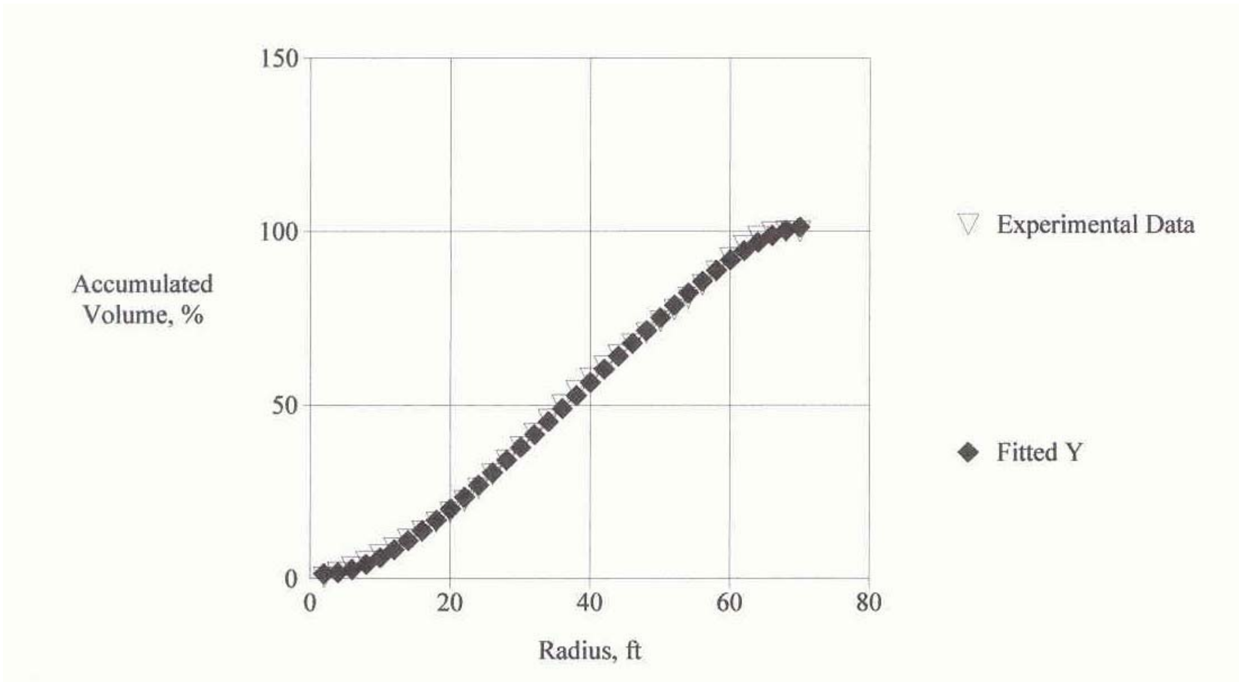

Figure 1. The deposition data (CIT record No. 3054P) was used to calculate the accumulated volume vs. radius curve.

Sprinkler Irrigation and Soil Moisture Uniformity

Michael D. Dukes[1], Melissa B. Haley[2], Stephen A. Hanks[3]

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Abstract

Uniformity of soil moisture under sprinkler irrigation is important for plant quality; however, sprinkler systems are typically gauged by the uniformity of application above the crop canopy. The objectives of this study were to measure and analyze both application uniformity with catch cans and soil moisture uniformity to quantify the relationship. Under testing on bare soil and turfgrass, soil moisture uniformity was always higher than catch can uniformity when quantified by the low quarter distribution uniformity. During the testing of this project, the low quarter distribution uniformity of soil moisture in the upper 10 cm of soil approximated the low half distribution uniformity from catch can data.

Introduction

The uniformity of sprinkler irrigation is a central design goal (Keller and Bliesner, 2000). Uniformity of water application is sought to minimize variability of crop yield, or plant quality in the case of turfgrass and landscapes. The catch can test is a commonly used measurement tool to assess the uniformity of sprinkler systems. Standards have been developed for center pivot and linear move irrigation machines (ASAE, 2001) and testing protocols have been developed for turfgrass and landscape irrigation (IA, 2005). Once the data are collected by catch cans, a number of different calculations can be performed. A common measurement of variability in water application on turfgrass and landscapes include the low quarter distribution uniformity (DU_{lq}),

$$DU_{lq} = \frac{\overline{V}_{lq}}{\overline{V}_{tot}} \quad [1]$$

where: $\overline{V}_{lq}$ = average of the lowest one-fourth of catch-can measurements, mL
$\overline{V}_{tot}$ = average depth of application over all catch can measurements, mL

To distinguish between a measure of uniformity and efficiency, DU_{lq} should be expressed as a decimal as suggested by Burt et al. (1997). The lower half distribution uniformity can be calculated from DU_{lq} as follows (IA, 2005),

$$DU_{lh} = 0.386 + (0.614 * DU_{lq}) \quad [2]$$

The Christiansen Uniformity Coefficient is (Christiansen, 1941; ASAE, 2001) is commonly used in agricultural sprinkler uniformity assessment and is expressed as,

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[3] Former Undergraduate Research Assistant, Agricultural and Biological Engineering Dept., University of Florida

$$CU = 100 * \left[1 - \frac{\sum_{i=1}^{n} \left| V_i - \overline{V} \right|}{\sum_{i=1}^{n} V_i} \right] \quad [3]$$

where: V_i = individual catch can measurement, mL

$\overline{V}$ = average volume of application over all catch can measurements, mL

In addition, the coefficient of variation (CV) in application volume can be computed as the standard deviation of all catch can measurements divided by the average catch can volume for a test. Both DU_{lq} and CU have been related to the CV analytically (Warrick, 1983) and verified experimentally on center pivot and linear move irrigation machines (Heermann et al., 1992; Dukes, 2006).

Analysis of catch can data ignores the process of water redistribution on the soil surface in the case of bare soil, as water moves through the crop canopy, and horizontally as the water infiltrates. There is some indication in the literature that variability in catch can data does not adequately represent soil moisture variability. Mateos et al. (1997) found that the CV of infiltrated water was one-third of the applied water as measured by catch cans under sprinkler irrigation. Sprinkler uniformity below the canopy of winter wheat was improved compared to the uniformity of application as measured above the canopy (Li and Rao, 2000). This finding indicates that the canopy can redistribute water to achieve improved uniformity before redistribution within the root zone is considered. Stern and Bresler (1983) found that the CV of catch can data was two to three times higher than soil water CV in the top 40 cm one day after sprinkler irrigation on sand and sandy loam soils. Since there was no runoff, the authors speculated that the high soil water uniformity was due to redistribution within the soil profile. Li and Kawano (1996) evaluated sprinkler uniformity and soil water uniformity on a bare volcanic soil (0.74 g/cm^3 bulk density, saturated water content of 0.64 m^3/m^3) and a bare sandy loam (1.2 g/cm^3 bulk density, saturated water content of 0.40 m^3/m^3). Soil water CU after irrigation approximated initial soil water CU after several hours. Hart (1972) modeled the redistribution of soil water and showed that soil water uniformity was consistently higher than application uniformity due to influence of initial soil water content, average application rate, and total water applied. Mecham (2001) showed that TDR measurements in the top 12 cm of soil after irrigation of turfgrass resulted in 26%-35% higher DU_{lq} results (DU_{lq} increase of 0.18-0.20) compared to catch can testing. The author attributed this difference to horizontal water distribution as it moved through the turfgrass and thatch layer into the soil. Wallach (1990) described the distribution of infiltrating water over an irrigated area as a sinusoidal function and presented the solution for two dimensional steady state flow equations where variability of water application was damped as water infiltrated.

Although there has been much work relating irrigation uniformity to yield analytically (Letey et al., 1984; Stern and Bresler, 1983; Varlev, 1976; Seginer, 1979 to name a few) or with simulation models (Mantovani et al., 1995; Pang et al., 1997), there are fewer studies that have measured the influence of uniformity on crop yield. Application CV as high as 0.48 did not influence yield of cotton compared to uniformly irrigated (CV = 0.20) plots (Mateos et al., 1997). Although the authors speculated that part of the reason for no influence on yield was because cotton is a drought tolerant crop, the CV of applied water was 2-4 times higher than the CV of infiltrated water. The yield of winter wheat did not vary when irrigated with different sprinkler irrigation uniformity treatments with seasonal CU ranging from 72% to 84% Li et al. (2005). The authors speculated that uniformity of sprinkler irrigation may have not impacted results in this project due to redistribution of applied water via canopy interception, redistribution of water in the soil, the extensive root system of wheat, and adequate rainfall over the crop season. However, these results may not apply to shallow rooted crops. In another study on winter wheat, Li and Rao (2003) found that yield was not influenced by sprinkler CU ranging from 62% to 82%. Ayers et al. (1990) found that nonuniformity as low as CU = 60% in a width of six to nine rows was insufficient to negatively impact sugar beet yield on a silty clay loam soil due to water redistribution within the soil. However, they found that nonuniformity at the same level (CU = 60%) across 16 to 24 rows reduced average yield.

Thus, there is a body of evidence that in agricultural systems soil moisture uniformity is generally higher than catch can values after sprinkler irrigation. However, there is only limited literature supporting this finding on turfgrass and bare soil. The Irrigation Association has recommended DU_{lq} as a performance measure of sprinkler systems; however, this measurement index may not adequately represent conditions in the soil.

The objective of this project was to compare the variability of irrigation application over a bare soil and established turfgrass areas with residential sprinklers as measured by water captured in catch cans and soil moisture content in the upper root zone. Our hypothesis was that the soil moisture content after irrigation is more uniform that water captured in catch can testing which may limit negative impacts on landscape quality due to low sprinkler uniformity.

Materials and Methods

Plot testing

Uniformity testing was conducted at the University of Florida Irrigation Research Park, Gainesville, Florida between February and November 2005. Tests were conducted on bare soil that was maintained by a combination of tillage, mowing, and herbicides. The site is mapped as an Arredondo fine sand soil (Thomas et al., 1985) which is well-drained with 7.3% to 10.3% field capacity by volume (all moisture contents in this manuscript reported on a volumetric basis) and 2.2% to 3.3% range wilting point based on laboratory measurements in the top 20 cm. This soil has a sand content in the 90.7% to 93.5% range and silt content in the 2.2% to 5.6% range. Organic matter content is less than 1% (Carlisle et al., 1978; Carlisle et al., 1981; Carlisle et al., 1989). The steady state infiltration rate has been measured on this site as 179 mm/hr (Gregory et al., 2005)

A sprinkler system was established in two identical 4.6 m X 4.6 m plot areas side by side. Quarter circle spray head sprinklers (Prospray model, Hunter Industries, Inc.; 15Q MPR nozzles, Rain Bird, Inc., Glendora, CA) on each corner were used to irrigate the plots.

Catch cans were placed within the sprinkler grids 0.5 m from the edge of the sprinkler coverage area with a can to can spacing of 0.9 m for a total of 25 catch cans in each grid. The catch cans were plastic containers with a 0.16 m diameter and 0.20 m height. This size catch can has been shown to have similar uniformity results compared to larger diameter catch cans under center pivot sprinkler irrigation testing (Dogan et al., 2003). Pressure gauges were installed on the supply line and the looped piping network at the furthest point from the supply to document any pressure losses in the system.

Weather data were collected within 100 m of the site with an automated weather station that measured rainfall, temperature, relative humidity, solar radiation, wind speed, and wind direction.

Before testing, soil cores were collected with an intact core sampler (10 cm length, 5.7 cm diameter, 260 cm^3 core volume) within 15 cm of each catch can and a measurement was taken with a portable Time Domain Reflectometry (TDR) probe (Field Scout 300, Spectrum Technologies, Inc., Plainfield, IL) with 20 cm long rods for an approximate sensing volume of 565 cm^3 estimated by assuming an approximate 3 cm radial sensing zone around the probe rods (Muñoz-Carpena et al., 2005). The TDR measurement was taken on an opposite side of the bucket compared to the intact soil core sample. After the irrigation system was run approximately 30 minutes, another intact core sample was collected in a 90 degree rotation around the catch can and within 15 cm of the catch can. Also, a final TDR measurement was taken across from this intact core sample. Soil water content in the intact cores was determined gravimetrically (Gardner, 1986) and bulk density was used to calculate moisture content by volume in the soil samples (Blake and Hartge, 1986). Tests were only performed when initial soil moisture content was less than or equal to 8-10% (approximate field capacity).

Three pressure levels were used in uniformity testing to induce varying levels of non-uniformity of water application. These type of sprinklers tend to have better uniformity with a minimum pressure of 207 kPa (Baum et al., 2005), thus one pressure level above this level was tested (414 kPa) while two pressure levels below 207 kPa were tested (138 and 69 kPa). A 30 minute irrigation cycle resulted in average application depths of 18, 12, and 10 mm at these respective pressures. After sample collection, the sample holes were filled with surrounding soil and tamped to approximate the original bulk density. Only on one occasion were tests performed within four days and on other occasions, weeks or months passed before testing could occur usually due to frequent rainfall that kept soil moisture content above field capacity for extended periods. In any case, sample collection around the catch cans was rotated to obtain a relatively undisturbed sample each time. Each test at a particular pressure level was replicated five times. Catch can volumes were measured with a 1000 mL graduated cylinder.

Since DU_{lq} is recommended by the IA (2005) as a sprinkler irrigation system performance measure, this quantity was calculated according to Equation 1 for catch can and soil moisture data. Data were analyzed with an analysis of variance using the general linear models procedure in SAS (SAS, 2001) with pressure, replicate, and test site as main effects on pre-irrigation and post-irrigation DU_{lq} and soil moisture content of both TDR and gravimetrically determined soil moisture content. Other main effects included catch can DU_{lq} and volume caught. In addition, DU_{lq} of the soil moisture content and catch can means by measurement method were compared using analysis of variance and checked for interaction with pressure.

Residential and Plot Testing on Turfgrass

As part of a project to measure and reduce residential irrigation water use through proper irrigation design and scheduling, intensive catch can measurements were performed on 21 residential homes throughout Marion, Lake and Orange counties in Florida (Haley et al., 2006). Uniformity testing is detailed by Baum et al. (2005); however, in general the tests were conducted in a similar manner as the plot testing described previously except that TDR readings were collected prior to testing on 9 of 21 tests and TDR readings after irrigation were collected on all tests. In addition, all tests were conducted on turfgrass with adequate system pressure during testing. Gravimetric samples were not collected.

Uniformity tests were conducted under controlled conditions on a turfgrass plot at the University of Florida Agricultural and Biological Engineering Turfgrass Test Area to determine the effect of equipment type on uniformity (Baum et al., 2005). Testing consisted of catch can collection of irrigation depth and TDR readings at each catch can after irrigation. Gravimetric samples were not collected. A detailed statistical analysis of the catch can test data is described by Baum et al. (2005). A t-test was used to determine if DU_{lq} determined by TDR measurements was the same as catch can DU_{lq}.

Results and Discussion

Plot Testing

Table 1 shows a summary of the calculated DU_{lq} and the average values of soil moisture content from both TDR and gravimetric measurements. A range of significantly different ($p = 0.0014$) DU_{lq} values were obtained as measured by the catch can method due to adjustment of the system supply pressure. The low test pressure of 69 kPa resulted in a DU_{lq} of 0.39 while increasing the pressure to 138 kPa resulted in a DU_{lq} of 0.55. The 138 kPa pressure level is within the minimum suggested operating pressure of 101 kPa by the manufacturer (Hunter Industries, 2006); however, increasing the pressure to 414 kPa resulted in the highest measured DU_{lq} of 0.63. The DU_{lq} results across increasing pressure levels would be rated as less than "Poor", "Good", and "Good", respectively by the IA (2005) irrigation system quality rating guidelines. As can be seen in Figure 1, although catch can DU_{lq} clearly decreased due to lower irrigation system pressure, the soil moisture DU_{lq} measured gravimetrically was reduced weakly and the TDR measured soil moisture DU_{lq} was not obviously affected by the reduced uniformity in water application. Similar results have been reported by Mateos et al. (1997) and Stern and Bresler (1983) for agricultural sites and by Mecham (2001) on turfgrass.

The soil moisture uniformity prior to irrigation was similar to that after irrigation (Fig. 1), although actual moisture content in the soil increased (Fig. 2). This observation points to a dampening effect on nonuniformity as infiltration occurs that was postulated by Wallach (1990). In addition, soil moisture uniformity before irrigation as measured by the TDR and gravimetrically was not significantly different ($p = 0.734$ and $p = 0.463$, respectively) across pressure levels (Table 1). In fact, soil moisture content as measured by both TDR and gravimetric methods prior to irrigation were well related ($R^2 = 0.76$), indicating relatively steady state moisture conditions in the top 10-20 cm (Fig. 3). This result is not surprising since the test area was relatively homogeneous in the top 10-20 cm of soil due to tillage prior to set up of the test site.

The increase in soil moisture content from irrigation ranged from 0.02 m^3/m^3 to 0.14 m^3/m^3 in the top 10 to 20 cm of soil. This increase was strongly related to an increase in volume of water applied for irrigation (Fig. 2). On average, the TDR measured soil moisture content increased 0.08, 0.04, and 0.03 m^3/m^3 for pressures of 414, 138, and 69 kPa, respectively. Similarly, the soil water content determined by gravimetric measurement increased 0.13, 0.08, and 0.07 m^3/m^3 for the same respective pressures (Table 1; Fig. 2). The larger change in gravimetric moisture content compared to TDR measured moisture content was likely due to the fact that gravimetric measurements were taken from the top 10 cm while the TDR measurements were taken in the top 20 cm of soil. However, the slope of the linear regression in soil moisture change relative to irrigation volume indicates that the change in soil moisture was similar for both gravimetric and TDR measurement techniques (Fig. 2). Thus, although both methods were sensitive to changes in soil moisture content as a result of varying irrigation levels, the upper 10 cm of soil produced larger magnitude changes (Fig. 2) for measurements that were collected immediately after irrigation. Gravimetric measurements showed consistently lower soil moisture values before and after irrigation events (Fig. 3).

Though the TDR measurements showed soil moisture response to varying levels of irrigation, soil moisture content uniformity was not significantly ($p = 0.538$) changed across varying application uniformity due to pressure changes (Table 1; Fig. 1). Gravimetric soil moisture DU_{lq} of 0.69 was significantly ($p = 0.0005$) lower at 69 kPa compared to the other two pressures (DU_{lq} = 0.83 at 414 kPa and 138 kPa). Gravimetric DU_{lq} was likely affected to a greater degree compared to TDR DU_{lq} due to the shallower sample depth. Authors of previous studies speculated that canopy interception acts to redistribute water (Mateos et al., 1997; Stern and Bresler, 1983; Mecham, 2001). However, in our work on bare soil there was no canopy interference. Thus, any redistribution was purely lateral movement prior to infiltration and or horizontal redistribution within the soil.

When DU_{lq} of soil moisture and catch cans was compared, it was found that there was an interaction between pressure and measurement type (i.e. catch can, gravimetric, or TDR). Thus, means of testing method were compared within each pressure category (Table 2). The uniformity as determined from catch can data was consistently lower than post-irrigation soil moisture measurements. Uniformity tended to remain the same when comparing soil moisture content before and after irrigation; however, gravimetric uniformity at 69 kPa was significantly reduced after irrigation (Table 2).

Although catch can DU_{lq} is recommended as an irrigation system performance indicator, catch can DU_{lh} is recommended for scheduling. When used for scheduling, DU_{lq} has been found to unrealistically overestimate irrigation requirements (IA, 2005). DU_{lh} was calculated from DU_{lq} data according to Equation 2. Since the conversion from DU_{lq} to DU_{lh} is a linear relationship (Eq. 2), the variability explained by linear regression was not improved. However, the catch can data better represented the soil moisture uniformity for bare soil testing (Fig. 5) and tests performed on turfgrass (Fig. 6).

Residential Testing

Similar to the bare soil plot experiment, the uniformity of TDR measurements was always significantly higher than catch can measurements (Table 3). In particular, the soil moisture was very uniform regardless of decreasing uniformity due to irrigation equipment (i.e. from rotary sprinkler to spray heads) despite the fact that Baum et al. (2005) found rotary sprinklers to have significantly ($p = 0.043$) higher average DU_{lq} of 0.49 compared to 0.41 for a spray heads across a variety of brands. Redistribution on residential sites and on turfgrass plots can be attributed to canopy interception as well as surface and subsurface lateral redistribution. When catch can DU_{lq} varied between 0.30 to 0.80, soil moisture DU_{lq} varied from 0.50 to 0.80 (Fig. 5). Overall, the average IA (2005) quality rating of residential homes tested was lower than "Poor", whereas the average quality rating across all rotor and spray head testing was "Very Good" and "Poor", respectively. In contrast, the respective soil moisture uniformity rating was "Good", Very Good", and "Excellent". Thus, redistribution of applied water can increase the effective uniformity to acceptable levels.

During the residential irrigation experiment, monitoring of water use was conducted for 30 months. A reduction in turf quality was not apparent due to uniformity problems. This likely occurred due to plentiful rainfall (Haley et al., 2006). Thus, in humid region problems associated with nonuniform irrigation are also buffered by input of rainfall.

Conclusions

Although catch can measurements have been used for many years to quantify sprinkler irrigation application uniformity, it is clear that this method neglects the important process of water redistribution through the plant canopy, on the soil surface, and beneath the soil surface. The complex process of redistribution acts to effectively compensate for non-uniform application of water down to 10 cm when catch can DU_{lq} is not lower than approximately 0.45-0.50. Despite testing on a highly permeable sandy soil, soil moisture testing in the top 10 cm is more sensitive to sprinkler application variability compared to 20 cm; however, testing should be performed at the depth where water extraction will occur by crop roots. Soil moisture variability is less sensitive as depth increases and variation in application depths are dampened. Finally, soil moisture distribution uniformity approximates DU_{lh} calculated from catch can measurements.

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Table 1. Summary of catch can, time domain reflectometry (TDR) probe soil moisture content, and gravimetric (Grav.) soil moisture content uniformity.

			Distribution Uniformity (DU_{lq})						Volumetric Soil Moisture Content			
Date	Pressure (kPa)	Rep[a]	TDR Pre-Irr	Grav. Pre-Irr	TDR Post-Irr	Grav. Post-Irr	Catch Can	Catch Can Depth (mm)	TDR Pre-Irr (m^3/m^3)	Grav. Pre-Irr (m^3/m^3)	TDR Post-Irr (m^3/m^3)	Grav. Post-Irr (m^3/m^3)
23-Feb	414	1	0.74	0.80	0.64	0.83	0.72	17	0.054	0.064	0.113	0.189
5-Apr	414	2	0.79	0.87	0.80	0.86	0.70	18	0.076	0.084	0.159	0.216
5-Apr	414	3	0.89	0.88	0.77	0.82	0.61	21	0.088	0.092	0.170	0.200
10-Jun	414	4	0.71	0.79	0.68	0.80	0.58	19	0.059	0.062	0.191	0.197
8-Nov	414	5	0.72	0.83	0.83	0.85	0.56	17	0.054	0.062	0.106	0.201
9-Apr	138	1	0.84	0.89	0.81	0.88	0.64	11	0.102	0.119	0.144	0.184
9-Apr	138	2	0.91	0.91	0.81	0.85	0.53	12	0.108	0.122	0.160	0.190
13-Jun	138	3	0.71	0.79	0.79	0.84	0.56	12	0.048	0.069	0.095	0.165
27-Sep	138	4	0.84	0.82	0.77	0.78	0.54	11	0.036	0.060	0.064	0.160
27-Sep	138	5	0.77	0.88	0.78	0.78	0.49	14	0.039	0.064	0.071	0.165
13-Jun	69	1	0.84	0.85	0.77	0.69	0.37	6	0.076	0.111	0.093	0.152
3-Aug	69	2	0.83	0.82	0.71	0.66	0.33	10	0.079	0.110	0.130	0.192
3-Aug	69	3	0.69	0.71	0.67	0.70	0.39	12	0.046	0.056	0.070	0.126
18-Oct	69	4	0.74	0.84	0.81	0.71	0.37	10	0.059	0.056	0.095	0.143
18-Oct	69	5	0.82	0.83	0.82	0.69	0.49	12	0.061	0.055	0.080	0.152
Avg[b]	414		0.77a	0.83a	0.74a	0.83a	0.63a	18a	0.07a	0.07a	0.15a	0.20b
	138		0.81a	0.86a	0.79a	0.83a	0.55b	12b	0.07a	0.09a	0.11b	0.17b
	69		0.78a	0.81a	0.75a	0.69b	0.39c	10c	0.06a	0.08a	0.09b	0.15c

[a]Test replication within a pressure group.
[b]Numbers in columns followed by different letters are statistically different at the 95% confidence level by Duncan's Multiple Range Test.

Table 2. Mean distribution uniformity (DU_{lq}) of soil moisture determined from time domain reflectometry (TDR) probes, gravimetrically, and catch can measurement from bare soil plot testing at each pressure level.

	DU$_{lq}$ by Measurement Method				
Pressure (kPa)	TDR Pre	Grav Pre	TDR Post	Grav Post	Catch Can
414	0.77AB[a]	0.83A	0.74B	0.83A	0.63C
138	0.81AB	0.86A	0.79B	0.83AB	0.55C
69	0.78A	0.81A	0.76A	0.69B	0.39C

[a]Numbers in rows followed by different letters are statistically different at the 95% confidence level by Duncan's Multiple Range Test.

Table 3. Distribution uniformity (DU_{lq}) of soil moisture determined from time domain reflectometry (TDR) probes and catch can measurement from residential testing and on plot testing on turfgrass.

	DU$_{lq}$ by Measurement Method			
	TDR Pre-Irr	TDR Post-Irr	Catch can	Prob*
Residential	0.61	0.68	0.44	<0.0001
Rotor		0.77	0.72	0.0037
Spray		0.80	0.47	<0.0001

*Probability value from a paired t-test where $p < 0.05$ indicates a significant difference between post-irrigation TDR soil moisture DU_{lq} and catch can DU_{lq}.

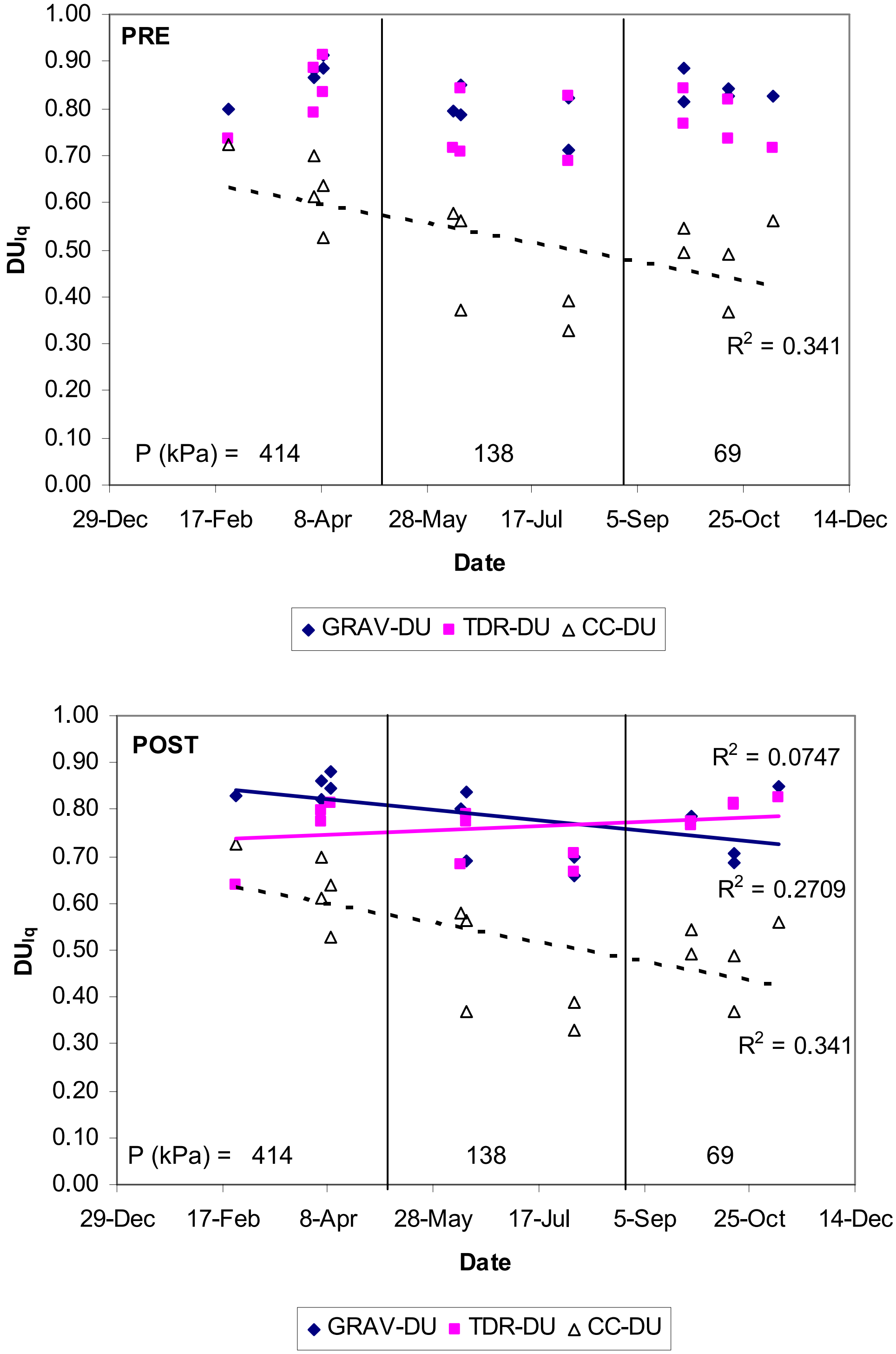

Figure 1. Gravimetric (GRAV-DU), TDR (TDR-DU) soil moisture DU$_{lq}$ and catch can (CC-DU) DU$_{lq}$ pre-irrigation and post-irrigation as a function of irrigation system pressure.

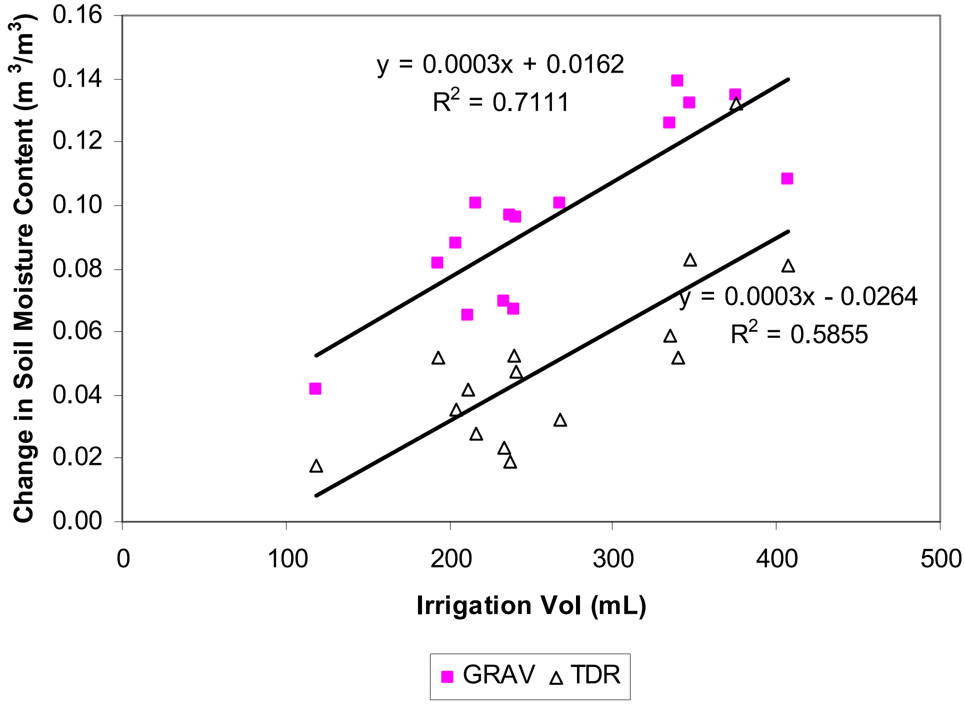

Figure 2. Change in soil moisture content as a function of irrigation volume.

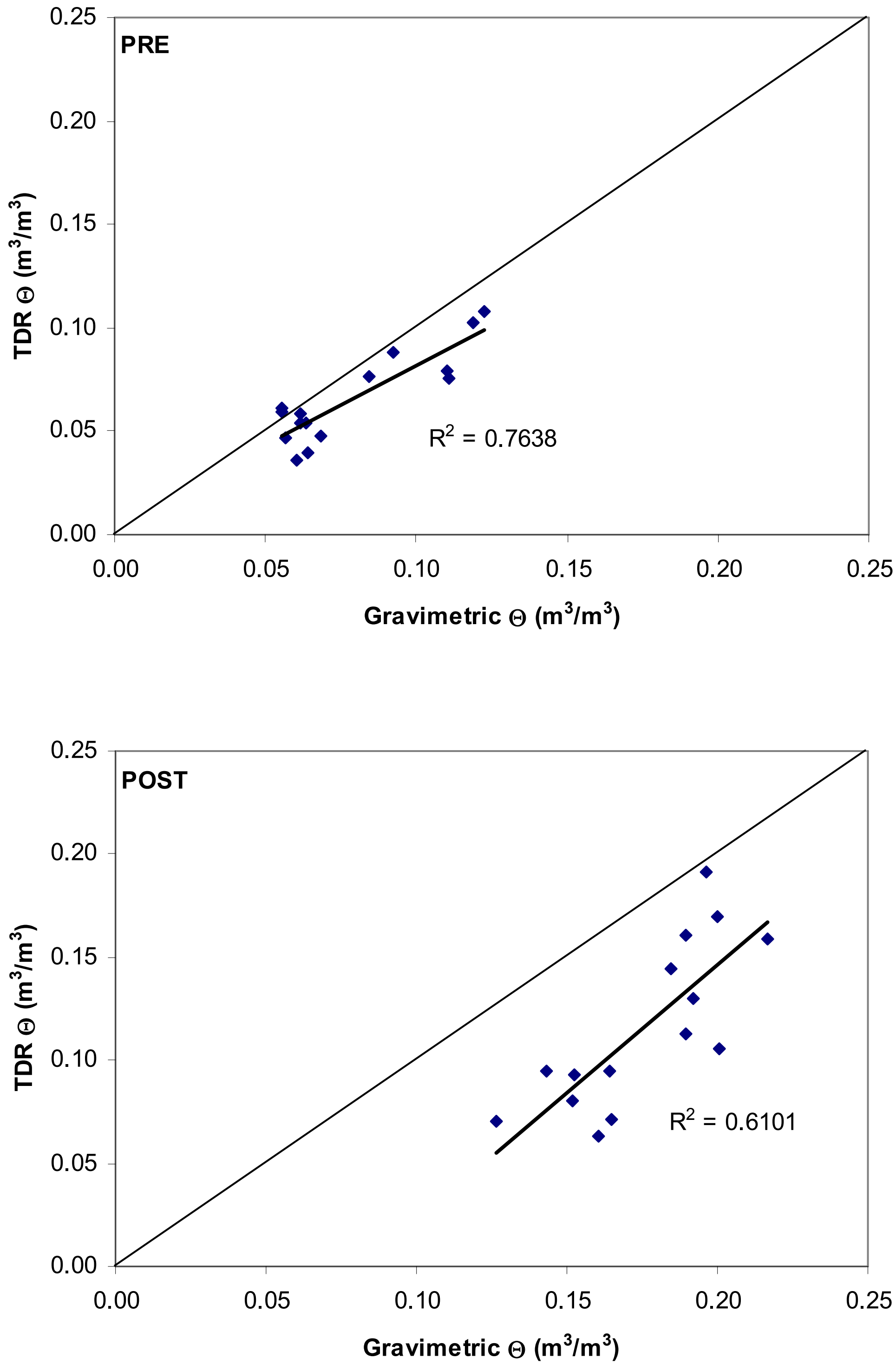

Figure. 3. Soil moisture content (Θ) as measured by time domain reflectometry probe (TDR) in the top 20 cm and gravimetric samples in the top 10 cm before (PRE) and after (POST) irrigation.

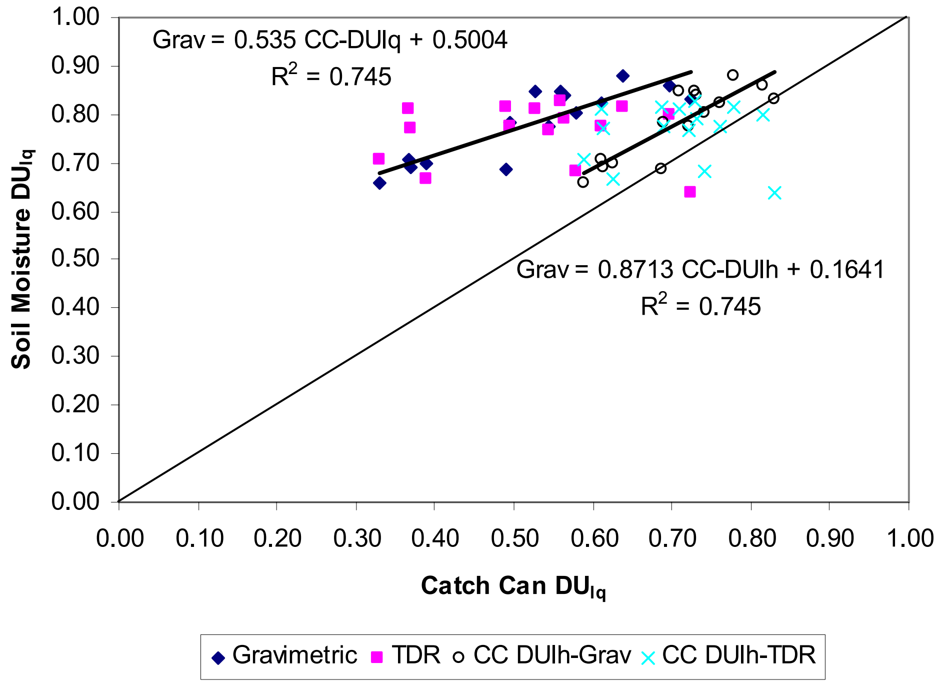

Figure 5. Soil moisture low quarter distribution uniformity as measured by time domain reflectometry probe in the upper 20 cm of soil, gravimetrically in the top 10 cm, and catch can uniformity on bare soil plot studies of spray heads. Note that linear regression is on gravimetric data only.

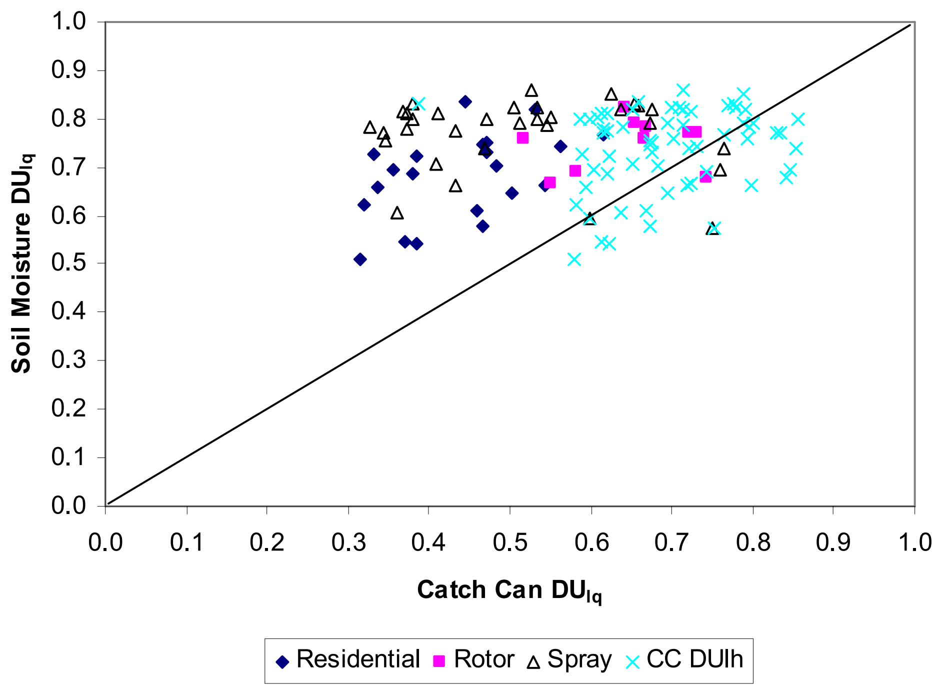

Figure 6. Soil moisture distribution uniformity (DU_{lq}) compared to catch can DU_{lq} for residential, rotary sprinkler, and spray head tests on turfgrass. Note that all soil moisture DU_{lq} data are also plotted against calculated DU_{lh}.

Spacing and Pattern Effects on DU_{LQ} of Spray Nozzles

Brent Q. Mecham[1]
September 11, 2006

Introduction

One of the current Turf and Landscape Best Management Practices published by the Irrigation Association states that the lower-quarter distribution uniformity (DULQ) should be a minimum of 55% for pop-up spray heads. In a paper presented in 2004 at the Irrigation Association technical conference entitled "A Summary Report of Performance Evaluations on Lawn Sprinkler Systems" by the author of this paper, shows that the average DULQ for pop-up spray heads from more than 6600 sprinkler system audits to be less than the desired minimum DULQ of 55%. The purpose of this paper was to explore how individual nozzles apply water compared to the intended area of coverage and how mixing the different arcs together in a sprinkler zone with different spacings and patterns will affect how evenly water is applied or the distribution uniformity.

The study procedures

To facilitate the study, the work was done on an asphalt test pad with ready access to a water source. The study has two aspects. One is to look at how an individual nozzle will perform compared to the anticipated or expected area of coverage. The spray nozzle was attached to a stand that included a water meter and a pressure regulator. These tests were conducted by connecting to the city water supply which averaged 60-65 psi static pressure. A one-inch rubber hose was used to connect the sprinkler stand to the water source to minimize friction losses when doing the tests. The nozzle was mounted on the stand to be four inches above the surface of the test pad, or approximately the height that the nozzle would be if mounted on a four-inch pop-up spray body. The sprinkler nozzle would be turned on for approximately 20 seconds to wet the pavement sufficiently to see the pattern but not long enough so that there would be run-off to distort the pattern of coverage when a photograph was taken, usually from a ten foot tall ladder oriented to see the coverage compared to the chalked out-line that the nozzle was to spray. This was done for full circle, half circle and quarter circle patterns. The nozzles were purchased off of the shelf from local distributors.

The other aspect was to look at how well the nozzles would work together in a sprinkler zone that was built on the test pad. The "sprinkler zone" was created to measure how evenly the sprinklers applied water to the test area. Catch cans were laid in a grid format four to six feet apart depending on the spacing of the nozzles being tested. Tests that included catch can data were for areas that measured 30 x 75 for 15 foot radius nozzles, 24 x 72 for 12 foot radius nozzles. Square, triangle and equilateral triangle patters were measured. Operating pressures were at 30 psi as the preferred operating pressure for spray nozzles and at 45 psi which seems to be the typical

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operating pressures found in most residential audits. The nozzles were attached to shrub adapters which were attached to fixed risers so that the nozzles were slightly above the top of the catch cans on the test pad as seen in the following photograph. The water source is raw water that is pumped via a variable frequency drive pump that can deliver up to 80 gpm at 80 psi. A water connection for this study consisted of an 1.5 inch ball valve, 1.5 inch pipe connect to 1.5 inch Badger compound meter and a 1.5 inch electric valve with a pressure regulator and pressure gauge. Pressure gauges were also attached just below the spray nozzle to monitor operating pressures. All tests were conducted utilizing the Irrigation Association guidelines for auditing, that is the wind speed average is less than five miles per hour and a minimum of 24 catch devices were used to measure uniformity and precipitation rate.

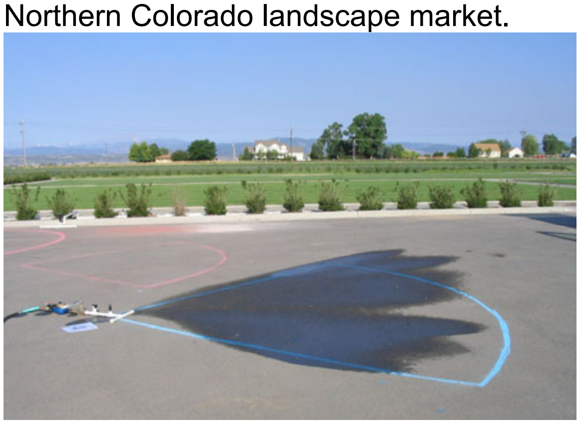
Technicians Rachel Waite and Tessa Berry gather data. A Windtronic anemometer is used to monitor wind speed during the test. It will show current speed, average wind and maximum gust during the test time. Most tests were done with an average wind speed less than three miles per hour to minimize the impact of wind on readings.

Results of individual nozzles coverage

Individual nozzles were attached to the test stand and allowed to run for a very short duration to see how the coverage compared to the anticipated coverage we have often assumed. As a designer, I have almost always thought that the radius of the nozzle meant that it would spray as far as it was indicated, that is a 15 foot radius nozzle would throw the water 15 feet from the nozzle. I have also assumed that the pattern of coverage would be quite close to the arc as shown in the manufacturer's catalog, that is a quarter, half and full spray would have patterns of coverage as indicated:

Arc	Pressure PSI	Pattern
90°	20	Q
	25	
	30	
	35	
	40	
180°	20	H
	25	
	30	
	35	
	40	
360°	20	F
	25	
	30	
	35	
	40	

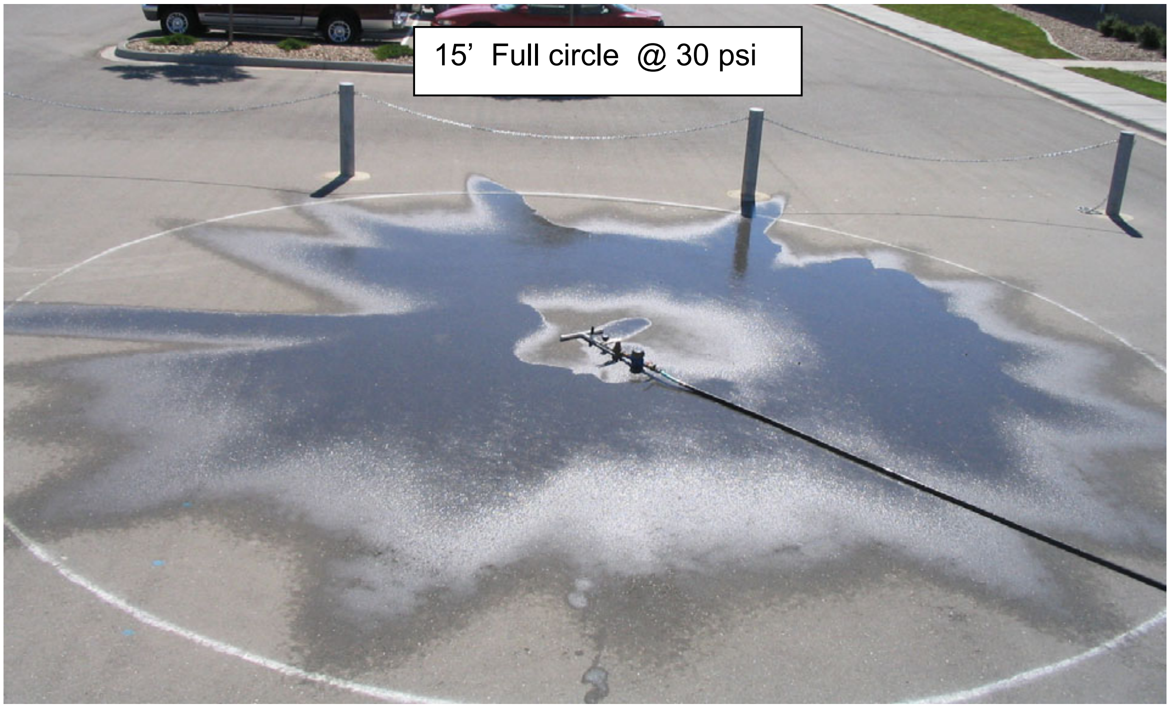
The following photographs are of nozzles selected at random from off of the shelf at local distributors. The study selected those nozzle most often sold and installed in the Northern Colorado landscape market.

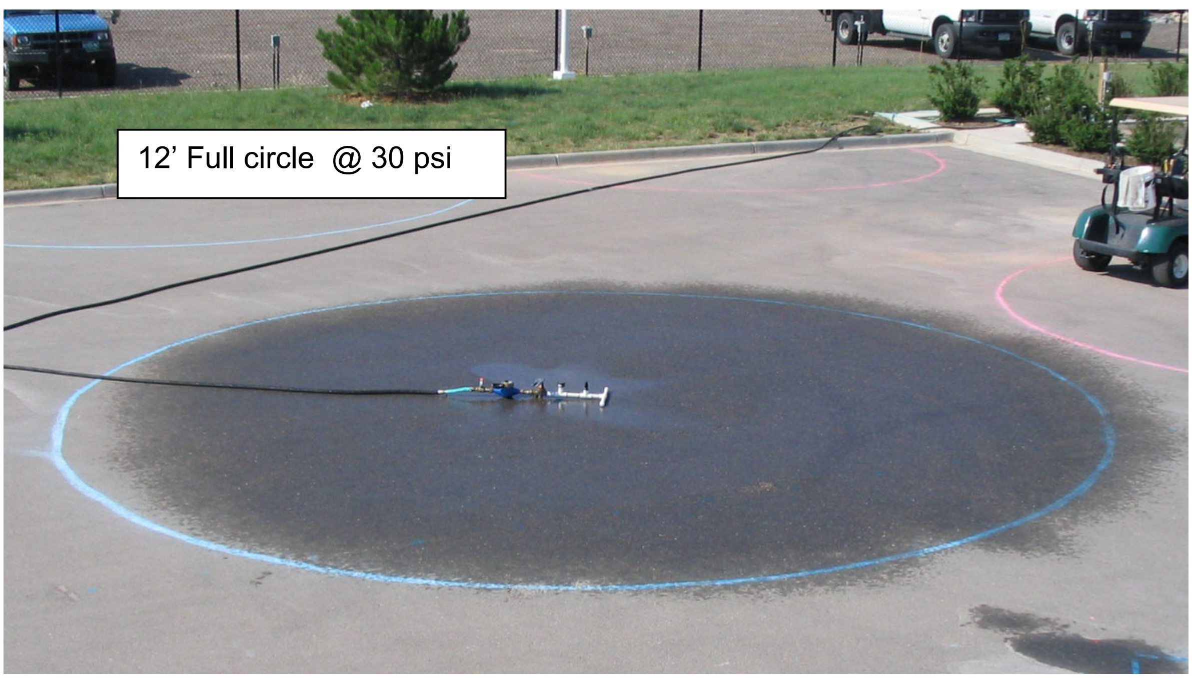


Photographs of nozzles that were tested on the asphalt pad. The photos show more than can be explained even by a catch can test.

Nozzles are not manufactured equally, and most likely one batch of nozzles will not perform exactly the same as another because of molding issues. The challenge is to understand how they perform individually and then compensate for individual performance when put together in a sprinkler zone. A few of the nozzles had excellent coverage for the pattern intended, but most were not as good as would have been expected.

The study looked at individual nozzles for 10', 12', 15' radii in fixed pattern as well as adjustable or variable arc patterns.


15’ Full circle @ 30 psi


12’ Full circle @ 30 psi

Same nozzle at two different operating pressures. As we know pressure will affect distribution uniformity. It is usually assumed that a higher pressure will affect it adversely, but as these photos show, that may not necessarily be the case.

Results of catch can audits

In most landscapes, pop-up spray heads are often used for small turf areas that usually have curves or irregular shapes. This makes it challenging to design a sprinkler zone that will water the area properly and very efficiently, meaning it will have a very even application of water. This study focused primarily on a nearly "ideal" arrangement of sprinkler heads where regular spacing could be achieved. Zones were created using fixed arc and also considered using all variable or adjustable arc nozzles for all patterns. The tests were only done one time at each pressure. Wind speed was measured during each test which was typically five minutes long. The catch cans were placed in a grid pattern so that on the 15' radius nozzle with an area of 30 x 75 feet there were 90 catchments which is nearly twice the minimum number if done "at the head" and "half-way between the head" method as taught in the certified landscape irrigation auditor training. Catch-can audits were done for square spacing, triangle spacing and equilateral triangle spacing for the 15' radius nozzles and 12' radius nozzles. The tests were conducted at 30 psi which is typically considered the preferred pressure and at 45 psi. 86 catch-can tests were completed.

For the 15' radius nozzles at 30 psi, the highest DU measured was 76% on square spacing and the lowest DU was 39% on a variable arc nozzle at equilateral triangle spacing. At 45 psi operating pressure the results were the same as for the 30 psi tests.

For the 12' radius nozzles at 30 psi, the highest DU measured was 78% on equilateral triangle spacing with a variable arc nozzle and the lowest DU was 29% on an a variable arc nozzle on square spacing. At 45 psi the highest DU was 71% on both a fixed nozzle and a variable arc nozzle from two different manufacturers on equilateral triangle spacing and the lowest DU_{LQ} of 32% on a variable arc nozzle.

When averaging the results for each of the tests, the 15' square spacing had the highest overall average of all of the different 15' nozzles tested at nearly 64% while the 12' nozzles on equilateral triangle spacing averaged just over 64% DU_{LQ}.

The average of all of the tests conducted showed that the DU_{LQ} at 30 psi was slightly better than the tests done at 45 psi, 57.25% compared to 55.6%. As an overall average

Perhaps of more significance is the change in precipitation rate when systems are operating at a higher pressure. For both the 15' and 12' radius nozzles, the average increase in flow was 17.8%. This has a significant impact on the amount of water applied to a landscape. Most schedules are probably created assuming the preferred operating pressure, but the actual operating pressure is more, therefore more water is applied than is intended which means scheduled run times could be shorted by an equal amount. The variation was quite large in some of the lines of nozzles and others it was minimized because the nozzles included a pressure compensating disc that can minimize the effect of pressure on flow. However if the pressure compensating device is removed, then the increase in flow becomes significant. In most of the audits, the net precipitation rate was less than the catalog stated value. Perhaps part of this is due to the fact that the nozzles do not throw the water as far as expected, but at the same time frequently the gross precipitation rate calculated based upon water meter readings is higher than the catalog flow.

One last test was done to more represent the real world of spray head design. An amoeba shaped lawn area was outlined and a sprinkler zone designed to apply water to the target area. The test was done utilizing a single manufacturer of nozzle and mostly utilizing mostly 12' radius throw nozzles. In one area a 15 foot nozzle was included to make sure that there was adequate coverage. The heads were place @12' apart around the perimeter edge and the middles filled in with full circle patterns. After the fixed arc nozzles were tested at various pressures, the heads were "tilted" to represent what is most often seen in the real world. Nothing sever, but enough that the pattern of coverage would be changed. Finally, a variable arc nozzle was selected to see what the results would be if they were used on all heads versus the fixed arc nozzles. The following results were measured

	60 psi 12' Fixed Arc	45 psi 12' Fixed Arc	30 psi 12' Fixed Arc	30 psi 12' Fixed Arc Tilted Heads	30 psi 12' Variable Arc
DU_{LQ}	**53%**	**58%**	**62%**	**52%**	**43%**
Precip.Rate	**2.17 in/hr**	**1.91 in/hr**	**1.70 in/hr**	**1.66 in/hr**	**1.93 in/hr**

Conclusion

Since only one test was done with each nozzle or head layout, spacing and pressure it is hard to make any real conclusions that could be used decisively. A number of tests need to be conducted to have some averages that can smooth out some of the anomalies that happen when doing snap-shot audits of sprinkler performance. Based upon visual observations; 15' nozzles were not as adversely affected by the increased operating pressure as were the 12' nozzles. This seems to make sense since the orifice is smaller and so increased pressure would change the droplet size. At 60 psi, the misting of the nozzle was significant. Square spacing or equilateral triangle spacing definitely improved distribution uniformity over triangle space which stretches the head spacing because of the geometry of the area. There is not a definite conclusion that equilateral triangle spacing is better than square spacing, in fact from the few tests conducted, it would probably indicate just the opposite. Square spacing tends to be easier to design with and if the distribution uniformity is not adversely affected, this helps with the design and installation of sprinkler systems. The testing of individual nozzles to see the true pattern of coverage has been the most enlightening. To see where the water is actually applied compared to the catalog picture of coverage may help to improve the designs. Frequently many irrigation managers are frustrated with the dry edges that occur or dry spots near corners. From the photo images it is now easier to see why they dry up because in many instances there is very little water falling in those locations. The problem seems to be shared by all of the manufacturers and additional work on nozzle design and coverage will greatly assist in creating more efficient irrigation systems. As nozzles improve, this could be a solution to improve existing sprinkler systems that have already been designed and installed correctly.

Lastly with the many irregular shapes that exist in most landscapes to make them aesthetically pleasing, but very difficult to water efficiently I think the current BMP of 55% DU_{LQ} for pop-up spray heads is reasonable. More water will be saved by having the spray heads operate at the preferred operating pressure of 30 psi with the proper run times programmed into the controller than by trying to raise the bar for higher uniformity for difficult areas to irrigate.

Special thanks to Ron Boyd, Tessa Berry and Rachel Waite for assistance in doing the audits and gathering the data.

Improving Landscape Irrigation Efficiency with ET Calculations, Aerial Photography, and On-site Evaluations

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Abstract

Utilities are constantly looking for innovative ways to save water in the summer months when outdoor water use is at an all time high. With outdoor water use accounting for up to fifty percent of the total summer potable water use in the City of Austin, much attention has been focused on reducing the demand for irrigation water among residential customers. For the past fifteen years, the City of Austin has offered free irrigation evaluations to its customers to help educate and assist homeowners in understanding their landscape's water needs; however, getting the highest residential water customers interested in this service has proven to be difficult in the past.

In the spring of 2005, the Austin Water Utility's Water Conservation Division initiated a program that provided the top 1,000 residential customers with an approximation of how much outdoor "over-watering" had been occurring at their property for the past three years based on evapotranspiration (ET) data. These customers use approximately 35,000 gallons or more during the summer months, with the top ten residential customers using a combined amount of over 2 million gallons during August of 2004 alone. By specifically targeting this group of customers, the program aimed to increase water use awareness among the residential customers who needed it most.

Irrigation in the City of Austin

Austin is located in central Texas and receives approximately 32 inches of rainfall on average each year. The summer months are often very dry, increasing overall water use in the summer by almost 100 percent over winter use, especially during extended dry periods throughout the months of July and August. The increased water use places stress on the City's water treatment infrastructure and necessitates the expansion of current infrastructure to accommodate the irrigation needs of customers during peak times. Water conservation efforts in Austin have evolved into programs designed to reduce peak day demand and average per capita use aimed at delaying the construction of additional water treatment plant capacity.

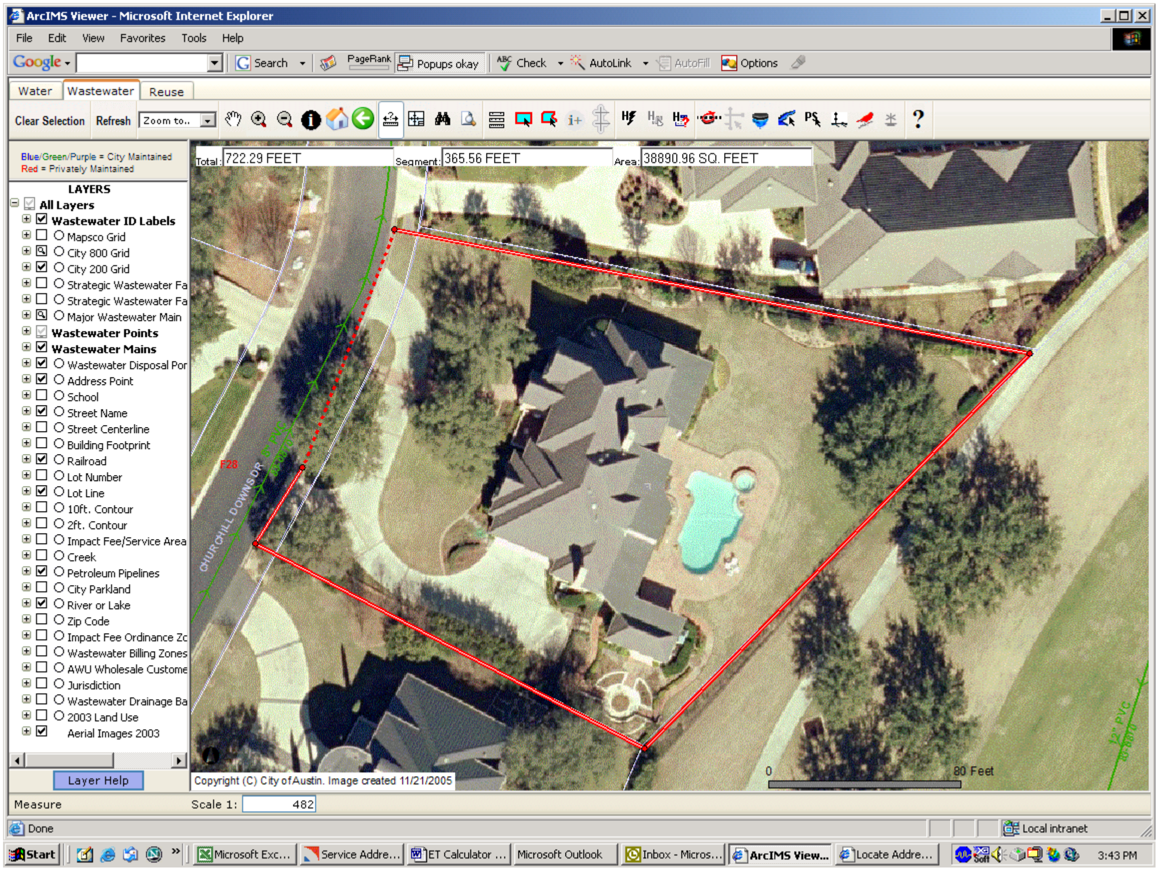
In response to noticeably excessive outdoor watering by both residential and commercial customers, an irrigation evaluation program was introduced in order to help customers water more efficiently. Residential customers often have a poor understanding of how their controllers work, have multiple programs or start times that they are unaware of, lack a backup battery in their controller, or have heads that mist due to too-high pressure. The City water auditor checks the system for leaks, water application rates and adequate coverage, and helps determine an efficient watering schedule. This watering schedule also takes into account specific factors such as plant type and shade coverage to develop an optimum irrigation schedule for the landscape area. In addition, the auditor assesses the adequacy of the equipment and recommends replacement of components if appropriate. These audits often result in reductions of 30 percent or more in irrigation water usage.

For the past few years, the City of Austin has sent a letter to the 1,000 highest residential water users to get them to participate in the City's free irrigation evaluation program. The response rate from previous mail-outs to these customers has been less than desired, with an average response rate of approximately 5 percent. Previous initiatives from the past mail-outs have included a letter signed by the City's mayor urging customers to reduce their outdoor watering during the summer months, as well as an incentive offering customers money back on their utility bill if they agreed to have an irrigation evaluation by one of the City's licensed irrigators.

ET Calculation Methodology

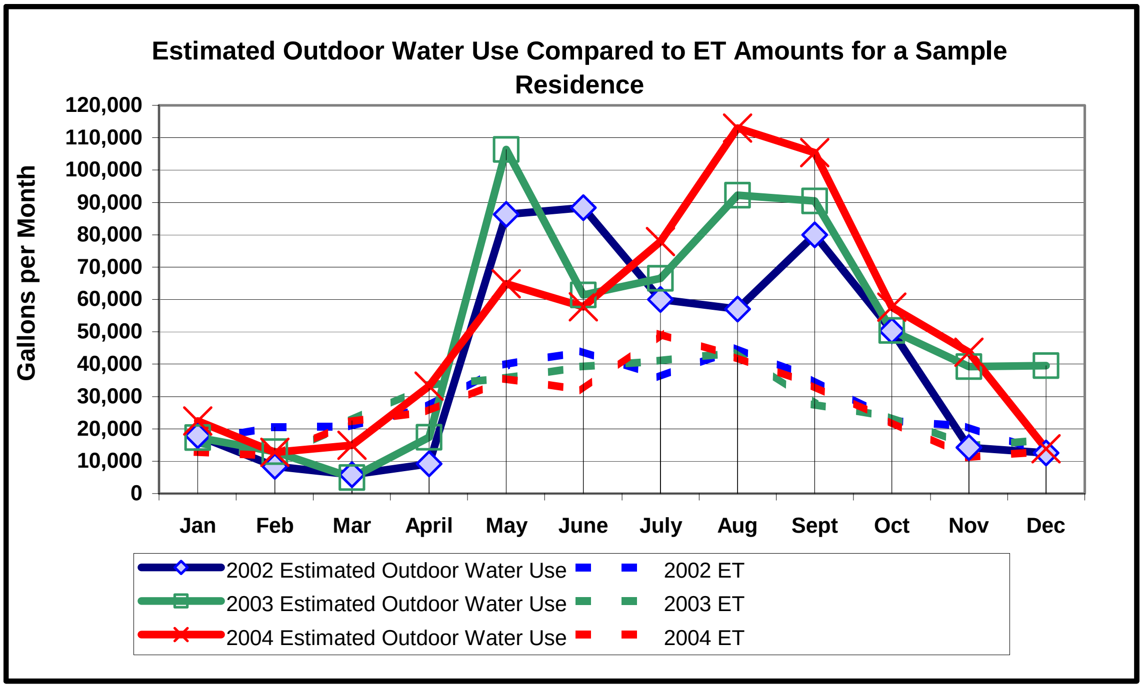
In response to the lackluster participation by the top 1,000 customers in the irrigation evaluation program and the increased interest in evapo-transpiration during the past couple of years, the City's Water Conservation Division began an ET calculation program. The focus on ET has been steadily increasing as weather based controller technology has begun to surface within the marketplace. Evapotranspiration (ET) is a measurement of the total amount of water needed to grow a healthy landscape. This term comes from the words evaporation and transpiration, and specifically refers to the amount of moisture evaporated from the soil and transpired by the plant. The ET amount varies depending upon both plant type and the amount of shade coverage in a given area.

The ET calculations were completed using address-specific aerial photographs available online through the Austin Water Utility GIS Access Site. The aerial photographs, taken in 2003, provide the lot lines of the individual properties as well as some clarity on the properties' landscape components. Using a polygonal measurement tool created by the Utility's GIS staff, the total outdoor area of the properties was measured and divided up into categories based on the type of plant (cool season turf, warm season turf, or drought tolerant shrubs/groundcover) and the amount of shade (full sun, partly shady, full shade). An example of the aerial photographs available through the Utility's website is shown on the following page with the polygonal measurement tool outlined in red.



The landscape amounts were entered into an ET calculator spreadsheet, created by the Water Conservation staff, which determined the specific ET requirements for the residence's irrigated area for the past three years based on historical weather station data. The weather station data was recorded and made available through the Texas Evapotranspiration Network of the Texas A&M University Program.

In order to calculate the amount of water that had been "wasted" each month on unnecessary irrigation, the properties' ET amounts were compared with the homeowners' actual water use (made available through the Utility's billing system), with a standard amount deducted for an estimated indoor water use amount. The homeowners were sent a personalized letter as well as information about how much water they could potentially save if they watered at the ET rate, a graph depicting their water use versus the ET rate (an example of which is on the following page), as well as estimates of potential dollar savings for both water and wastewater. For the top users, the savings calculations reached into the thousands of dollars and served as a stunning reminder of just how much money they were wasting each year.



Results

The ET mail-out received a 16 percent response rate, with customers contacting the conservation staff for an irrigation evaluation by a licensed irrigator. Once the irrigation audit was complete, the customers were provided with an efficient schedule that would align their outdoor watering with the calculated ET amounts. An initial comparison of water use amounts from before and after the irrigation audit was performed yielded mixed results, with an average reduction the month following the audit of 37.5 percent. Two months after the audit was conducted, however, the water use reduction was approximately 19.42 percent. Much of this could be due to the temperatures during the month of September increasing to record amounts of over 100 degrees for five days in a row, causing people to increase their irrigation use.

Many of the on-site irrigation evaluations revealed that the ET calculations had underestimated the customers' recommended outdoor water use. A distribution uniformity (DU) factor was not incorporated into the initial calculations, which would have increased the usage estimates by 40 to 50 percent on average, which would align them more with the auditor's recommendations. Irrigation system efficiency can vary greatly depending on factors such as head spacing and design, as well as pressure, but selecting a base number for the DU such as a 60% efficiency rate would have increased the accuracy of the ET amounts.

A handful of the customers who received the ET mailout showed interest in evapo-transpiration, and wanted more information on ET controllers. The majority of the customers who contacted the Water Conservation Division staff for an irrigation audit as a result of the mailer cited both the amount of water they had used and the amount of money that they had spent each year on irrigation were the reasons they had sought the irrigation evaluation. Having a personalized mailer, that had the customer's address, landscape information, water use amounts, and billing history worked to get the attention of the City of Austin's hardest to reach residential customers.

Irrigation Analysis for Water Savings - A New San Antonio City Ordinance

In an effort to maximize year around water conservation efforts the San Antonio City Council passed a water conservation ordinance addressing a variety of water conservation opportunities. One of the provisions included in the ordinance requires that properties over 5 acres, athletic fields and golf courses with in-ground irrigation systems submit an annual irrigation check up to the San Antonio Water System Conservation Department by May 1 each year. The intent of this ordinance provision is to ensure that a minimum standard of irrigation system maintenance is performed. Regularly scheduled maintenance of irrigation systems contributes significantly to water savings. A typical commercial irrigation system uses on average 20,000 gallons each time the irrigation system is run. A poorly maintained system can use upwards of 60,000 gallons for each run. A well maintained irrigation system should be checked at a minimum, monthly, weekly in high traffic areas. Any maintenance issues found should be repaired in a timely matter.

Properties that do not have a current irrigation system check-up on file will loose their courtesy water waste warning if the irrigation system is reported being run outside designated irrigation hours or if water from the irrigation system is found running down the street or other impervious cover. The property will immediately be placed on the water waster list and the property owner or manager will receive a personal citation if any Conservation Enforcement Officer observes an additional violation.

Design issues such as the desire to change a spray zone to drip, cap off a zone that is irrigating well established trees and shrubs, or if the landscape design has changed should be considered. San Antonio Water System customers may qualify for rebates for these design changes that result in water savings.

“Water Checks”- Free Water Audits for Homeowners and Large Public and Private Properties

Slow the Flow, Save H_20

Earl K. Jackson, Professor
Rachel M. Lopez, Water Audit Supervisor
Utah State University Extension

Abstract

The water check program has been a well received public relations campaign enabling residential homeowners and managers of large public and private properties to successfully cut back on water waste. The water check program was initiated in 1999 as part of Utah’s *Slow the Flow, Save H_20* water conservation program and has continued to grow through 2006. The program was made free to the public by the partnering agencies of the Central Utah Water Conservancy District, serviced by Utah State University Extension. Between 1999 and 2005, a total of 7,960 residential sites and 382 large water use properties have been evaluated for distribution uniformity, precipitation rate, sprinkler head pressure, turf root depth, soil type, and irrigation scheduling. Water use records were tracked for the year before the irrigation audit and at least three years after the initial audit for the residential participants. The average residential property reduced water consumption by 9.6%, 12.4%, 22.2% and 25.6% respectively for the audit year and the following three years. The large properties were divided into nine categories, with each category responding somewhat differently to the audit (usually dependent upon the budget for a system tune-up). Small businesses hardly saved any water, while parks, schools and churches saved about 20% over a two year period. Large public and private properties reduced outdoor water consumption over the growing season by an overall average of 15% during the audit year combined with the year following the audit.

Introduction

The *Slow the Flow, Save H_20* water check program has been instrumental in facilitating the state of Utah’s long-term water conservation goals. Water checks offered free to the public for both residential and large public and private properties followed the methods for water audits outlined by the National Irrigation Association. Information about operational irrigation systems obtained from water checks as well as water savings realized from the program was collected and compiled by Utah State University Extension and funded by the Central Utah Water Conservancy District. The compilation of the data collected from the 7,960 residential sites and the 382 large properties is shown in the first two tables. Comprehensive and detailed reports outlining program need and background, methodology, and results as well as special studies for both the residential and large water check programs can be obtained in the following Utah State University Extension Publications: NR/Water Conservation/2006-01, *Data Summary of Water*

Audits Conducted for Large Water Users Through 2005; NR/Water Conservation/2006-2, Residential Water Check Summary 1999 Through 2005.

Data from the Utah Division of Water Resources in 1999 indicated that about 50% of Utah's culinary, treated water was used outdoors, primarily in the landscape (*Utah Division of Water Resources, 2003*). Outdoor water waste was targeted by offering irrigation system audits or "water checks" free to the public under a grant provided to Utah State University Extension by the Central Utah Water Conservancy District and its partnering agencies. The water check program was initiated in 1999 as part of Utah's *Slow the Flow, Save* H_20 water conservation program and has continued to grow through 2005 (*Jackson and Rosenkrantz, 2004*). The *Slow the Flow, Save* H_20 water conservation program, including water checks was adopted and endorsed as the statewide water conservation program in 2003 by Utah's Governor, Mike Leavitt (*Jackson and Mohadjer, 2003*). Water audits that were performed for commercial, institutional, industrial, large private and public properties were coined "large water audits" for the purpose of differentiating the large water use properties from a residential water check program also serviced by Utah State University Extension. (*Jackson, 2000; Lopez and Jackson, 2004*).

Information on Irrigation Systems

Data collected for operational irrigation systems for both residential properties (**Table 1**) as well as large water use properties (**Table 2**) is summarized in the tables below.

Table 1 shows the characteristics of an average residential site receiving a water check along the Wasatch Front Mountains. Operational sprinkler head pressure, irrigation system distribution uniformity (irrigation system efficiency) and precipitation rate (system output) were particularly useful indicators of how water could be saved in the landscape. Residents received advice on water conservation based on the results of these indicators. Information from the number of people per household was useful in calculating the *per capita* water use.

Table 1 Residential Water Check Participant Sprinkler Summary

Characteristics of an Average Residential Water Check			
Criteria	**Average**	**High**	**Low**
# in Household (Summer)	3.6	18	1
# in Household (Winter)	3.6	18	1
Lot Size (Sq. Ft.)	14,242	43,560	560
Landscape Size (Sq. Ft.)	8,631	33,461	299
Hardscape Size (Sq. Ft.)	5,612	23,444	90
Percentage of Lot Landscaped	60%	91%	12%
Root Depth (inches)	5.8	26.8	0.5
Head Pressure Fixed (psi)	48.8	132.6	9.6
Head Pressure Rotor (psi)	50.4	140.3	15.8
Distribution Uniformity Fixed (%)	58%	93%	7%
Distribution Uniformity Rotor (%)	59%	95%	5%
Precipitation Rate Fixed (in/hour)	1.4	4.4	0.1
Precipitation Rate Rotor (in/hour)	0.7	3.5	0.1

1999-2005 Water Check Database of 7,960 Water Checks
PSI= pounds per square inch
Fixed= small, non rotating fixed sprinkler heads
Rotor= large, rotating sprinkler heads

Table 2 Large Water Check Participant Sprinkler Information Summary

Large Water Check Sprinkler Data Averages 2001-2005 Participants							
	Rotor Data			Fixed Data			Root
Property Type	PSI	PR	DU	PSI	PR	DU	Depth
Apartments	53	0.6	53	44	1.6	57	4.9
Businesses	58	0.6	56	52	1.6	57	4.3
Churches	55	0.7	61	70	1.8	59	4.7
Golf Courses	71	0.6	67	n/a	n/a	n/a	3.5
HOA'S	58	0.7	57	53	1.6	55	4.7
Public Facilities	52	0.6	59	52	1.5	53	4.6
Parks	65	0.5	55	60	1.5	46	5.2
Schools	56	0.5	55	55	1.6	53	5.1
Database AVG	**59**	**0.6**	**58**	**55**	**1.6**	**54**	**4.6**

PSI= pounds per square inch
PR= Precipitation Rate, system output rated in inches per hour
DU= Distribution Uniformity, system efficiency as percentage from 0-100%, with 70% or greater considered efficient
Fixed= small, non rotating fixed sprinkler heads
Rotor= large, rotating sprinkler heads

For the purposes of data summarization, the 382 participants in the large water audit program were placed into categories. Number of audits completed within each category is listed in parentheses: Apartments (21), Businesses (57), Churches (19), Golf Courses (6), Homeowner Associations (60), Public Facilities (57), Parks (107), and Schools (53), along with two private properties deemed as "Others." **Table 2** provides a comprehensive comparison of sprinkler and landscape characteristics among the various property types that were among the large private and public properties audited. This information will continue to increase in importance as water conservation practices in the state become more prolific.

Catch cup tests from the large properties revealed that the average precipitation rate (system output) for rotor heads (large, rotating heads) was 0.6 inches per hour with an average distribution uniformity (system efficiency) value of 58%. The average precipitation rate for fixed heads (small, non-rotating heads) was 1.6 inches per hour, with an average distribution uniformity value of 54%. This data for sprinkler precipitation rate and distribution uniformity values represents 830 total catch cup tests for rotor heads and 534 total catch cup tests for fixed heads from the properties tested.

Water Conservation

The following tables show the water savings realized as participants in both the residential and large water check programs followed recommendations provided for outdoor water conservation. Water use records from both property types were obtained and evaluated over several years and were compared to water use prior to the properties receiving a water check. **Tables 3 and 4** show savings realized by residential properties and **Tables 5 and 6** show savings from large private and public properties.

Residential Water Savings

Irrigation system audits concentrated on outdoor water conservation. The first column in **Table 3** shows the actual year the water check evaluation was completed for the residential properties. The second column shows the number of 1,000 gallon units used on the average, of all water check participants for the year before the audit. Column 3 shows the average number of gallons used by all the participants during the year of the audit and continues for the following four years after the audit in the remaining columns. These numbers include both indoor and outdoor water use and vary by the size of the irrigated landscape. By this method, the 4,366 participants in the water consumption database saved an average of 9.6% the year of the audit followed by an additional reduction of 3.1% the year following the audit. The bottom line of **Table 3** shows that the water check program participants conserved about 20% over a five year period. Water conservation continued after the year of the water check. A year of wait time will be needed to determine if the water conservation trend will continue into the wet years of 2005 and 2006.

Table 3 Residential Participant Water Savings Total Water Use – May through October

Total Water Use - May through October					
YEAR	YEAR BEFORE	AUDIT YEAR	1st year after audit	2nd year after audit	3rd year after audit
2000	197.9	195.5	201.3	161.6	151.2
2001	227.1	222.2	194.3	167.4	171.6
2002	237.2	193.1	187.9	183.1	171.7
2003	215.8	193.6	192.8	177.9	
2004	218.4	202.9	194.8		
2005	233.4	195.2			
AVERAGE	**221.7**	**200.4**	**194.2**	**172.5**	**164.8**
% SAVED FROM PREVIOUS YEAR	**100.0%**	**9.6%**	**3.1%**	**11.2%**	**4.5%**
% SAVED FROM YEAR 2000	**100.0%**	**9.6%**	**12.4%**	**22.2%**	**25.6%**

Data is in 1,000 Gallon Units
Data includes both Indoor and Outdoor Water Consumed Each Year
Year Before Audit Data is Specific for the Participants by Year Before the Water Check
Database (4,366 records) Sorted by Year of Water Check

Table 4 uses the same format (summarizing water use before the water check and after a water check) demonstrating water conservation in the landscape over the entire growing season for residential properties. With this method, the amount of water used outdoors required calculation. This was not always an easy task since some water providers did not always read the water meters on a monthly basis. Often times, the water consumption values provided by the water districts for the winter months was an estimate with corrections made in later months. With this method of calculation (outdoor water use) the results indicate a saving of 8.2% the year of the audit and 2.0% the year following the audit. The final result was about an 18% reduction in water use over a five year period. In the Water Consumption database, outdoor water use is separated from indoor water use. The *Slow the Flow, Save H_20* water conservation program includes both indoor and outdoor programs along with demonstration gardens, alteration of landscapes at residential sites, rebate options and other programs. The residential water check program was specifically designed to improve irrigation systems and alter the lawn watering schedule. When comparing **Table 3** and **Table 4** it is evident that some water was conserved indoors as well as outdoors.

Table 4 **2005 Database Before and After for Residential Water Check Records**

Outdoor Water Use – May through October					
YEAR	YEAR BEFORE	AUDIT YEAR	1st year after audit	2nd year after audit	3rd year after audit
2000	168.2	151.0	173.1	160.1	167.0
2001	179.8	175.3	151.7	146.0	147.2
2002	186.8	171.3	151.1	152.9	139.8
2003	165.8	149.7	155.8	145.3	
2004	159.0	135.8	133.4		
2005	160.2	152.8			
AVERAGE	**170.0**	**156.0**	**153.0**	**151.1**	**151.3**
% SAVED FROM PREVIOUS YEAR	**100.0%**	**8.2%**	**1.9%**	**1.3%**	**-0.2%**
% SAVED FROM YEAR 2000	**100.0%**	**8.2%**	**10.0%**	**11.1%**	**11.0%**

Data in 1,000 Gallon Units
Database (4,366 records) Sorted by Year of Water Check

Water Savings by Large Properties

Large private and public properties were able to save a significant amount of water as well. Outdoor water consumption records were available for 189 of these large water use properties. Large water users were able to reduce outdoor water use by an average of 8.2% the year of the audits. These water and landscape managers continued to conserve water by 11.1% the following year and by 18.4% the second year after the audit. This is a total of about 37% reduction during the drought over a three year period.

Data Summarization

Calculation of water conserved from irrigation water audits can vary by the methods used for calculation. Three-year water records for 189 properties were evaluated in several ways as shown in **Table 5** which includes: 1) total gallons used per property 2) total gallons used per acre 3) outdoor gallons used 4) outdoor gallons used per acre 5) inches of water used per acre 6) percent reduction in evapotranspiration (ET).

Total Gallons Used per Property: The first row in **Table 5** shows the evaluation using the total number of gallons used per property for each of the three years. This number includes both indoor and outdoor water use and varies by the size of the irrigated landscape which ranged from 0.2 of an acre for a small business up to 388 acres for a golf course. By this method, the 189 properties in the water record database saved an average of 7.8% the year of the audit and followed by another reduction of 7.4% the year following the audit. By this method of calculation, the large golf courses and parks had more influence on the average than the smaller businesses and apartment complexes.

Total Gallons Used per Acre: The second method of evaluation reduces the variation caused by property size through calculating the total gallons used per season per one acre of landscape. Results from line two of **Table 5** indicate a reduction in water use by 5.8% the year of the audit. The year following the audit, water was reduced by 2.0% and shows less savings than total gallons alone.

Outdoor Gallons Used: As irrigation system audits concentrated on outdoor water conservation, line three of the table is based only on outdoor water used during the growing season. With this method, the amount of water used outdoors required calculation. This was not always an easy task since some water districts did not read the water meters on a monthly basis. Often times, the water consumption values provided by the water districts for the winter months were estimated with corrections made in later months. This method of calculation (outdoor water use) indicates a savings of 8.2% the year of the audit and 11.1% the year following the audit resulting in 19.4% reduction in water use over a two year period.

Outdoor Gallons Used per Acre: Line 4 shows outdoor gallons used on a per acre basis. Again this method lessens the influence of property size on average savings, indicating that properties were able to save 14.8% over two years.

Inches of Water Used per Acre: The fourth set of calculations converted outdoor gallons of water used into inches for use in comparison to evapotranspiration values. The results of calculation through this method were very close to the outdoor gallons of water used.

Percent Reduction in Evapotranspiration (ET): Outdoor water use can be evaluated through comparing usage to the turfgrass water requirement (net ET_{turf}). This comparison is valuable because it accounts for variability in weather patterns which may influence irrigation schedules. For this study a comparison was made to the net ET_{turf} value for each year of water use. Since net ET_{turf} values change each week, month and year, this set of calculations has the most room for error due to the number of calculations and conversions required. Additionally, the method is not as consistent as the others due to the fact that ET changes yearly, thus the comparison the year before, of and after the audit are not compared to the same standard. The average property in the database saved

2.7% of ET the year of the audit and only 3.9% the following year indicating a total savings of 6.6% over the two year period.

Table 5 Large Water Checks: Water Saved by Different Calculation Methods

2001-2004 Water Savings Summary			
Percent Water Saved by Different Calculation Methods			
Calculation Method	Percent Water Saved Audit Year	Percent Water Saved Year After Audit	Percent Saved Over 2 Years
Total Gallons Used per Property (indoor + outdoor)	7.8%	7.4%	15.1%
Total Gallons Used per acre (indoor + outdoor)	5.8%	2.0%	7.8%
Outdoor Gallons Used	8.2%	11.1%	19.4%
Outdoor Gallons Used per acre	7.2%	7.6%	14.8%
Inches of Water Used per acre	7.3%	7.6%	14.9%
Percent Reduction in Evapotranspiration (ET)	2.7%	3.9%	6.6%
Database of 189 complete water use records with information before audit, year of the audit and the year following the audit			

Properties audited saved the most water the year of and the year after the water audit, **Table 6**. One concern among those involved with the water audit program was if participants would be able to maintain water savings in the future. Preliminary data for properties with more than three years of data indicate that properties should be able to maintain the savings as shown in **Table 6**. For this table the average outdoor gallons per acre used per property was summarized by the number of years for which data were available. Properties with four and five years of data show that water consumption varies by an average of only 3% following the initial two years of savings.

The data in **Table 6** is calculated as outdoor gallons consumed per acre over the growing season. This table also demonstrates how values can change as the size of the database increases. As more information is obtained from properties receiving water audits, the conclusion from the 34 audits with four years of post-audit consumption numbers should be sustained showing that properties continue to save water after an audit. At this point it appears that water conservation from the water audits is sustained for more than one year.

Table 6 **Maintained Water Savings**

2001-2004 Maintained Water Savings					
Water Saved by Year: Average Outdoor Gallons per Acre					
Summary Category	Year Prior to Audit	Year Of Audit	Year After Audit	Two Years After Audit	Three Years After Audit
189 Audits With 3 Years of Data	1,699,770	1,576,665 (7.3%)	1,457,169 (14.3%)	n/a	n/a
72 Audits With 4 Years of Data	1,848,402	1,693,937 (8.4%)	1,580,821 (14.5%)	1,509,859 (18.3%)	n/a
34 Audits with 5 Years of Data	1,691,297	1,446,174 (14.5%)	1,298,550 (23.2%)	1,291,730 (23.6%)	1,261,078 (25.4%)

Actual Acre Feet of Water Saved by the Water Check Program

The following tables summarize the water saved from both types of water checks (water checks for residential and water audits for large properties) as shown in acre feet.

Water savings realized from residential water checks is shown in **Table 7**. If each of the 7,960 participants in the residential water audit program from 2000-2005 saved the average amount of water per acre discussed above, a total of 386,152 gallons per acre could be saved each year. When multiplied by the 1,577 total acres maintained by the 7,960 participants, a total of 1,869 acre feet of water could be saved each year (Utah State University Extension Summary, *Residential Water Check Summary 1999 Through 2005)*.

Likewise, if each of the 382 participants in the large water audit program from 2001-2005 saved the average amount of water per acre discussed above, a total of 121,300 gallons per acre could be saved each year. When multiplied by the total acres of 3,046 maintained by the 382 participants, a total of 1,134 acre feet of water could be saved each year. The average amount of water per acre indicates the average savings from the participants evaluated from 2001-2004 for which water use records could be obtained (Utah State University Extension Publication NR/Water Conservation/2006-01, *Data Summary of Water Audits Conducted for Large Water Users Through 2005)*.

Table 7 **Water Savings by Residential Water Check Participants Shown in Acre Feet**

Average Yearly Water Savings by Residential Water Check Participants	
Total Number of Audits	7,960
Total Landscaped Acres for 7,960 Audits	1,577
Average Gallons Saved per Acre per Year	386,152
Total Savings (Acre Feet)	1,869

Table 8 **Water Savings by Large Water Check Participants Shown in Acre Feet**

Average Yearly Water Savings by Large Water Check Participants	
Total Number of Audits	382
Total Landscaped Acres for 382 Audits	3,046
Average Gallons Saved per Acre per Year	121,300
Total Savings (Acre Feet)	1,134

Conclusions

An extensive radio and television water conservation campaign was initiated in 1999 when a dry year turned into a six year drought. Irrigation system audits of residential and commercial properties were made free to the public by the Central Utah Water Conservancy District and its partners.

The results of this water conservation study are unique as they reflect tangible, real-life situations where beneficial changes were made to watering habits and where data was collected for existing, functioning irrigation systems. Although the nature of this study made it impossible to control all aspects of the data collection process from six counties and 32 cities in the state of Utah, adaptability as well as consistency and quality from all contributors to this project proved effective.

The overall objective of this study was to determine the practicality of reducing landscape water use through recommending irrigation scheduling for turf based on actual irrigation system precipitation rates and historical evapotranspiration data. Data demonstrates that landscape water use could be reduced as participants followed the site specific recommendations provided to them through participation in the water check program (*Jackson and Leigh, 2004; Lopez and Jackson, 2004).*

Both the residential (water check) and the large property (water audit) programs were successful in terms of educating the public on preventing outdoor water waste. The water districts determined them to be an effective public relations campaign. The program enabled both residents and managers of large landscapes to successfully cut back on water waste by at least 15%.

Modified irrigation water audits are now being conducted in several other states with similar results (*Mecham, 2004; Graham and Lander, 2005*).

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Irrigation Runoff from Urban Turf and Landscape

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Abstract:
Irrigation runoff was measured from a turf plot with 8 % slope on a loamy sand soil using rotor sprinklers. Moisture levels in the root zone before irrigation and wind direction during irrigation both affect the volume of runoff. Turf cultural practices such as core aerification of the soil increased infiltration and decreased the volume of runoff. Prediction of the maximum irrigation runtime by the equation developed by Hung was longer than the actual time to the beginning runoff. The amount of fertilizer constituents in the runoff was measured. The research protocol including experimental design, equipment, and procedures to collect and quantify irrigation runoff from turf on slopes will be used to continue research in this area.

Introduction:
Runoff from urban landscapes in California has at least two areas of regulatory interest. The first is winter storm water runoff that is channeled to rivers and coastal waters. Runoff quantity, peak flows, and water quality from winter rains are important in watershed management. Urban runoff is related to infiltration; hardscapes such as streets, parking lots, buildings decrease water infiltration resulting in potential of more runoff. Landscape areas serve as infiltration areas and can attenuate peak flows.

A second area of regulatory interest for runoff from landscapes is runoff during the dry weather irrigation season. These surface flows, generally labeled nuisance flows, occur during the March through November irrigation season in Southern California. The quantity of runoff in an ideal landscape irrigation world should be zero. However, the norm for most urban communities with existing landscape is that there is significant summer runoff unto hardscapes, gutters and storm drains that can degrade rivers and coastal waters. It is often assumed that chemical applications of fertilizers, herbicides on landscapes and grass clipping contribute to pollution in urban runoff.

The focus of this research is the second area – dry season irrigation runoff. With Southern California water supplies stressed, any runoff from landscapes is considered a waste of this limited resource. This research will correlate the quantity and quality of runoff from landscapes with respect irrigation runtime, wind, and soil moisture. A theoretical equation proposed by Hung (Hung 1995) to predict the maximum sprinkler run time without runoff for sprinkler irrigation is also of interest. Therefore, time was recorded when ponding and runoff from the plot to correlate with the predicted maximum run time.

Recent studies completed or in progress include a residential runoff reduction study by the Municipal Water District of Orange County (MODOC), which showed a 49% reduction results in watershed runoff with the installation of ET controllers on residential sites (Anonymous, 2004). The city of Tustin and the Irvine Ranch Water District (2002-03) installed a WICK irrigation system on a large street median, which virtually eliminated runoff that had previously occurred at the same site with sprinkler irrigation (www.irwd.gov 2004) The research we are proposing would complement current work.

The implementation of Phase II of the Clean Water Act will impact landscape irrigation. The California State Water Resources Control Board has identified Urban Management Measures (www.swrcb.ca.gov/stormwtr/). Municipalities are required to develop plans to address non point source pollution of "sensitive waters". The initial focus in some areas appears to be on identifiable sources such as nursery and greenhouse operations in areas such as San Diego (private communication Jim Brazie, Hydroscape Products).

Dry weather urban runoff in the City of Santa Monica required the construction of SMURF, a nine million dollar project to intercept surface water running into the Bay. The runoff volume of 500,000 gal per day (1.5 acre –foot/day) is treated for reuse. The city has recently passed an ordinance to prohibit runoff from landscapes.

It is clear from the above examples that in California, water districts, and the agricultural enterprises near urban areas have a stake in urban runoff. Horticultural enterprises that service the urban landscape markets will be affected by efforts to limit landscape areas and irrigation water availability that may be driven in part by irrigation runoff management issues. Water management for urban landscapes can be improved through BMP's that are supported by applied scientific studies.

Procedures:

An existing 50 ft by 50 ft plot of hybrid GN-1 bermudagrass turf maintained under golf course fairway management on the Cal Poly University Pomona campus was used for these tests. Rotor sprinklers with nozzles for 50 foot radius at 50 psi operated at each corner of the plot. Catch Can tests (IA Procedures) conducted to determine distribution uniformity showed the system had a low quarter distribution uniformity of 65% and a precipitation rate of 1.2 inches per hour. Seven WaterMark moisture sensors were installed at 4 locations within the plot at 4 and 8 inch depths. The moisture sensors recorded the soil matric potential at 5 minute intervals before and after each irrigation event.

The plot had an average slope of 8% in the general direction where the runoff collection containers were located. Runoff from the low side of the rectangular plot was collected in two components, 1. surface flow off the low end of the plot, 2. wind borne water carried past the low end of the plot. These two sources of urban runoff are commonly experienced where irrigation water runs over the curb as surface flow and wind carries water from sprinklers beyond landscape borders; both sources of water combine to form runoff into the storm water system. Two troughs made of rain gutters were installed at the lower end of the plot. The first trough collected surface runoff from low edge of the plot; the second trough collected overspray or wind drift at the low edge of the plot. A four foot high plastic barrier about 2 feet beyond the lower end of the plot, collected the wind drift and directed that water into the second trough. A metal deflector, mounted above the first trough, prevented the wind drift from falling into the surface runoff trough, and directed that water into the surface runoff trough. Catch cans were also positioned outside the plot to monitor wind drift on each side.

50’ x 50’ BermudaTurf Plot

Figure 1. Layout of the irrigation runoff plots on a GN-1 hybrid bermudagrass turf with an 8% slope

A normal runtime for this plot with loamy sand soil and an 8 inch root zone was 25 minutes to bring the root zone from 50% depletion to field capacity. The irrigation runtime was set for 60 minutes to insure runoff so that the beginning of actual runoff could be compared with predicted maximum irrigation runtime without runoff. Runtime was reduced to 40 minutes for several of the tests because the volume of runoff exceeded the runoff collection device capacity. The runtime for these irrigation events will be referred to in the rest of this report as the “extended runtime”.

Objectives and Results:

Objective 1. Does the maximum runtime equation accurately predict the sprinkler runtime to prevent runoff from turf on slopes?

The following equation (Hung 1995) predicts the maximum irrigation runtime without runoff.

$$T_{max} = (1/Pb)\ \{f_o - P + f_c\{\ln(f_o - f_c)/(P - f_c)]\}$$

Where; T_{max} = maximum irrigation runtime without runoff(hours)

P = average sprinkler precipitation rate

b = Horton’s constant

f_o = infiltration rate at the start or at time = 0

f_c = basic infiltration rate or saturated infiltration rate = constant

There is a graphical method to convert T_{max} for 0% slope to slopes up to 20%.

Results:
The results are based on nine irrigation events on one plot. The time interval from the beginning of an irrigation to the time that ponding of water was visible at selected locations in the plot was recorded. This time for ponding to occur was compared with T_{max} as determined by the above equation. Using the equation for a sandy loam soil with a Horton constant of 2.48, for a 6-8% slope resulted in a calculated maximum runtime approximately 100 minutes. The results of a one double ring infiltrometer test conducted on this plot had a Horton's constant of 5.89. Using this equation with this Horton's constant, the maximum irrigation runtime without runoff changed to 42 minutes. The actual times for ponding of water to be visible ranged from 15 – 29 minutes with a mean of 20 minutes. These results suggest that the Horton's equation over estimates the time before runoff would begin.

Figure 1 suggests that the initial soil moisture affects the time when ponding of water was visible, as would be expected.

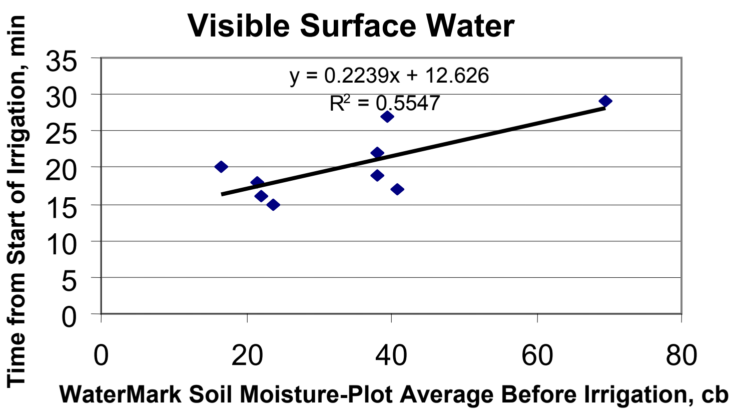

Figure 1. Effect of soil moisture on the time when first visible runoff was observed.

Objectives 2 and 3.

2. What is the relationship between extended irrigation runtimes and volume of runoff surface off the edge of the landscape and wind drift of water over the edge of the landscape?
3. What effect does turf cultural practices such core aeration of turf with top dressing of sand have on volume of irrigation runoff?

Results:

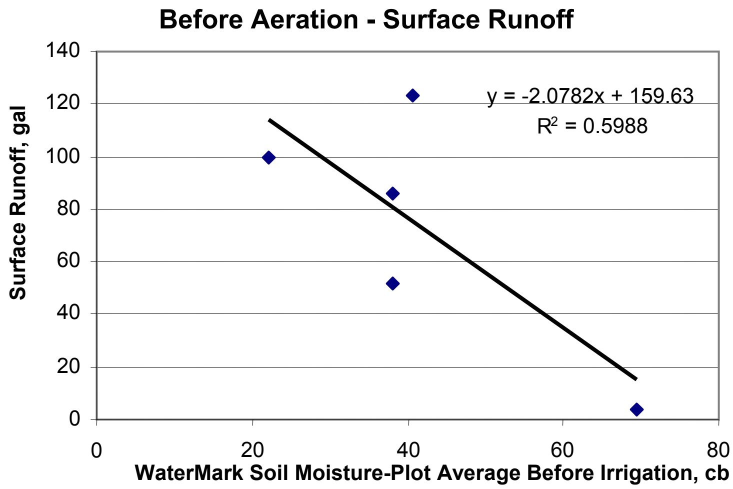

Figure 2. Surface runoff for the plot in the untreated condition (before core aeration) with extended irrigation runtime.

Irrigation runoff was collected as two components: surface runoff and wind drift. The mean moisture content for the seven moisture sensors ranged from 22 – 70 cb. Soil matric potential of 40 cb for loamy sand soil is near 50% of plant available water. The least runoff volume (4 gal) occurred, as expected, for the irrigation event when the soil moisture was lowest before irrigation.

Wind direction and wind speed also influenced the surface runoff; this will be discussed later. The highest runoff volumes appear to depend on both wind direction and soil moisture before beginning of irrigation.

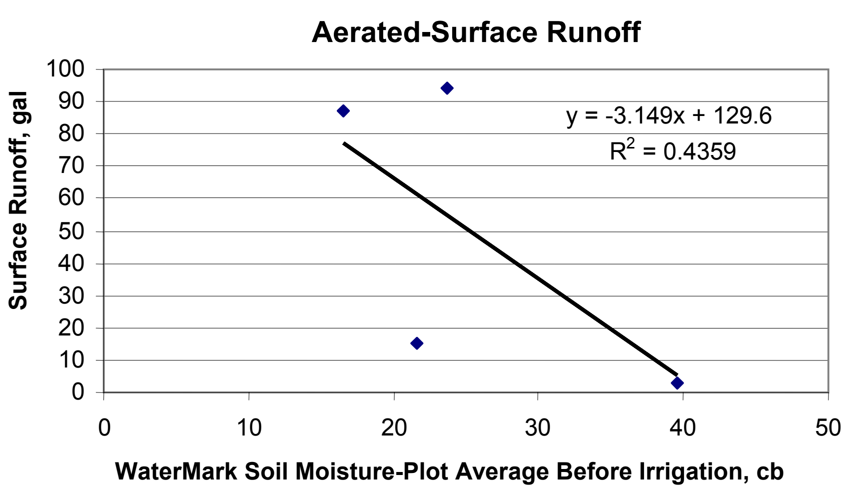

Figure 3. Surface runoff for four irrigation events after core aeration and top dressing with sand.

The volume of surface runoff was compared for four irrigations for both the non-aerated and aerated plot with similar initial moisture contents. The non-aerated plot had mean matric potential before the irrigation events of 35 cb that resulted in a mean surface runoff of 73 gallons and the aerated plot with mean moisture of 26 cb had a mean surface runoff of 50 gallons. This would suggest aeration does decrease runoff. Additional aspects of this study are discussed in another publication (Mitra et al., 2006).

Runoff as percent of total amount of applied irrigation water, when combining data from both treated and untreated tests, ranged from 0.4 to 9.6% with mean of 5.3%. It is important to note that the runtime for these irrigation events were approximately twice the normal runtime to fill the root zone.

Overspray due to wind drift

It is well known that wind distorts sprinkler distribution patterns and contributes to runoff when landscapes border a hard surface area. The hourly wind speed during the irrigation events ranged from 2.9 – 4.2 mph, affecting the radius of throw of the sprinklers. Wind direction appeared to have a more pronounced effect than wind speed on this component of runoff. Runoff was collected from only one side of the plot. Therefore, when the wind direction was perpendicular and in the direction toward the runoff collection device (approximately 340^{o}), the volume of runoff increased (Figure 4). There was more overspray anytime the wind direction was in range from 250 – 360 degrees. The raised plastic barrier deflected this water into the runoff collection system for measurement.

When the wind was in the range of 30 – 250 degrees, there was wind drift off one or more of the other three edges of the rectangular plot. A sampling of overspray measured by catch cans stationed around the other three sides of the plot suggest a similar volume of water drifted off the plot in the other directions. This water could become runoff if there was hardscape on those sides as well, if the other sides had additional landscape that water may not become runoff. The volume of overspray included in the data was the water collected at the lower edge of the plot.

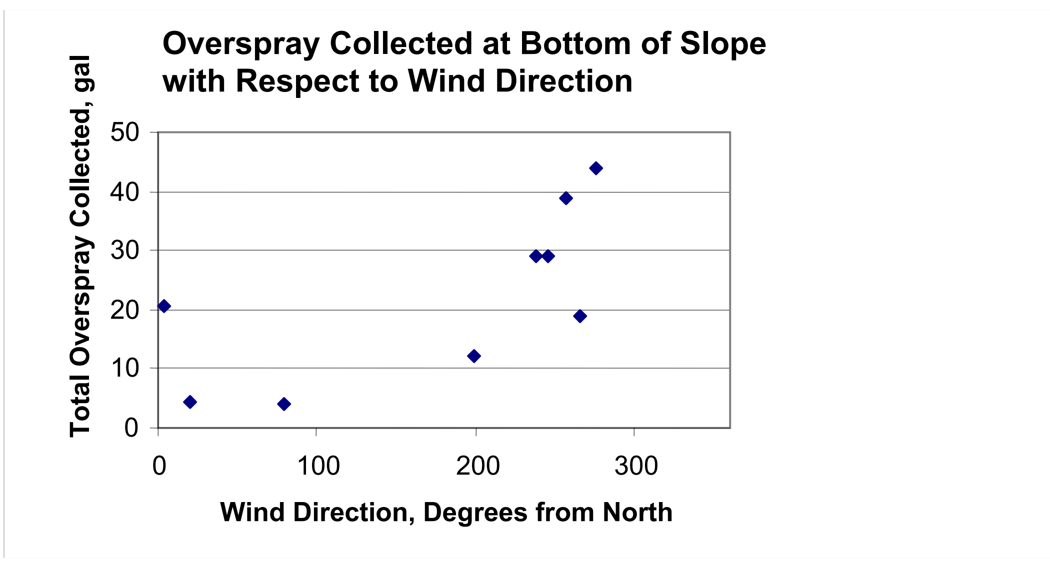

Figure 4. Wind at 340 degrees would direct water into the overspray collection device.

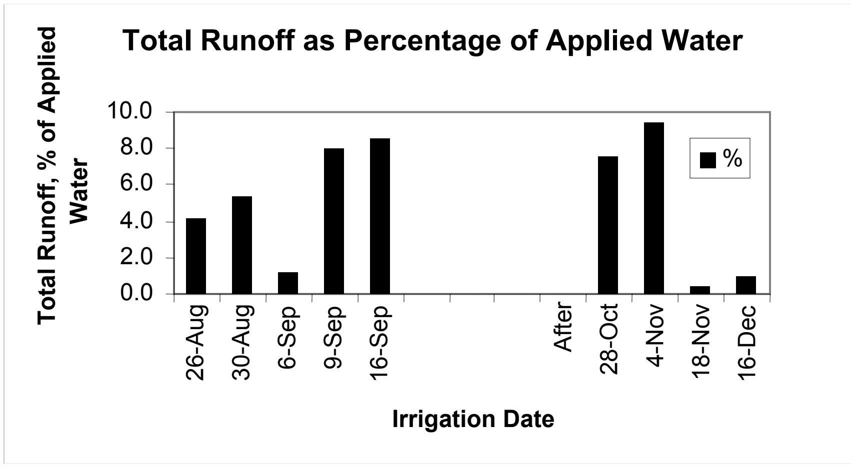

Figure 5. Total runoff for each test date with extended runtime.

The total runoff collected at the lower edge of plot ranged 0.4 to 9.5 % of the applied water (Figure 5).

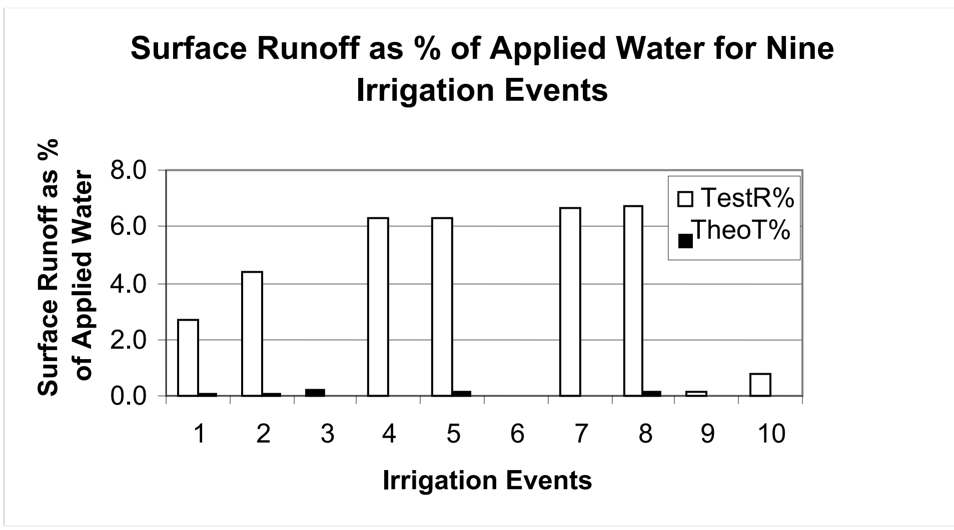

Figure 6. Surface runoff for the nine test with extended runtime (TestR%) and estimated surface runoff if system had run for a theoretical runtime (TheoT%) to fill the root zone.

Figure 6 compares the surface runoff for each test runtime and the estimated runoff if the system had been run for the theoretical runtime of 25 minutes. Runtimes could be adjusted for each irrigation event to take into consideration the initial soil moisture conditions, but for the purposes of this comparison 25 minutes in used for all irrigation events. It is evident that surface runoff was near zero for all events with a runtime of 25 minutes (Figure 6). Therefore, proper scheduling of runtime would minimize most surface runoff.

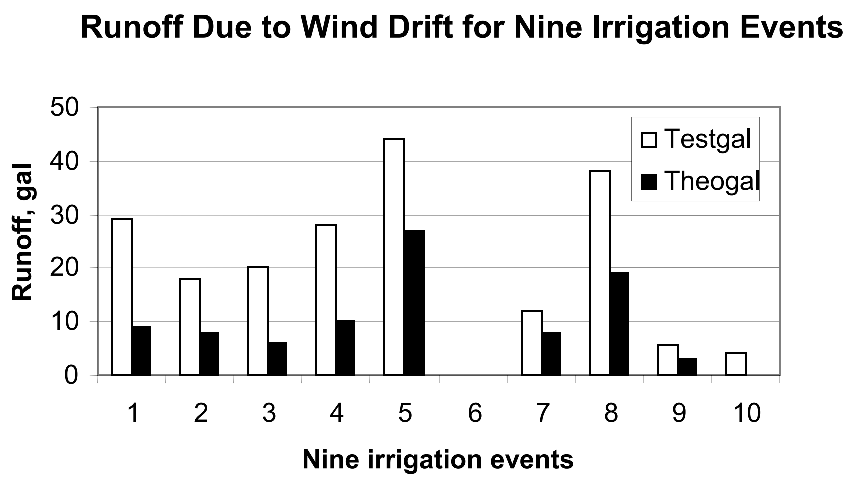

Figure 7. Actual volume of wind drift runoff for each test with extended runtime (Testgal) and estimated wind drift (Theogal) runoff if system had run for theoretical runtime to fill the root zone.

The runoff volume due to wind drift is obviously greater for the extended test runtimes than the shorter theoretical runtimes. Runoff volume due to wind drift with the shorter theoretical runtimes ranged from 0 – 27 gallons with a mean of 10 gallons.

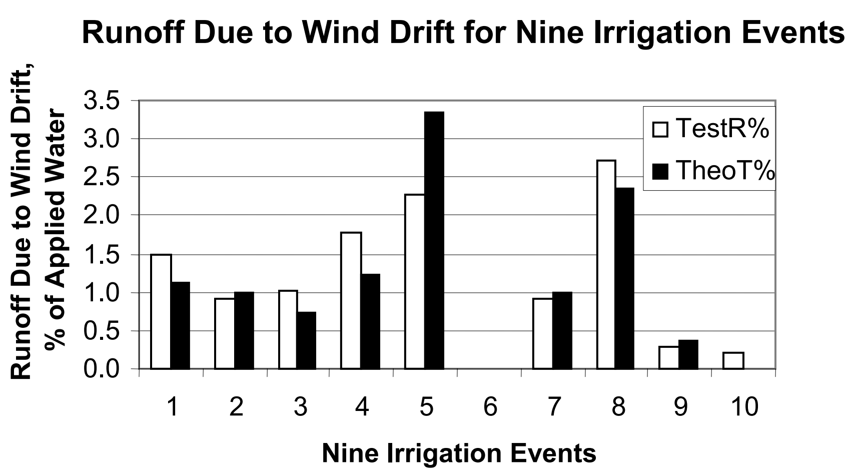

Figure 8. Actual wind drift runoff for each test with extended runtime (TestR%) and estimated wind drift (TheoT%) runoff as percentage of applied water.

Runoff due to wind drift, as percent of applied water, was greater for the shorter theoretical runtime greater for some irrigation events (Figure 8). Overspray runoff data as percentage of applied irrigation water may assist in estimation of potential runoff from irrigated landscape sites where volume of water applied by sprinklers adjacent to hardscapes is measured by meters.

Objective 4.
What is the chemical loading of the runoff after a standard application of fertilizer or herbicide?

Fertilizer (22-4-4 at lb/1000ft^2) was applied one day before one irrigation event. Water sample 2, which had the highest total N, was mixture of surface flow and some subsurface flow. The amount of fertilizer peaked at 56 minutes, and decreased at 69 minutes which was the end of the runoff that occurred. Runoff water had much higher concentrations of ammonium nitrogen and total N than the recycled water used for irrigation.

		Ammonium Nitrogen	**Total N**
Sample	**Sample Description**	**ppm**	**ppm**
1	Irrigation Water Source	0.0319	5.6419
2	Surface/Subsurface(Pit) runoff 45 minutes after begin of irrigation	41.5	131.5
3	Surface runoff 54 minutes after begin of irrigation	10.7	51.5
4	Surface runoff 56 minutes after begin of irrigation	48.8	114.2
5	Surface runoff 69 minutes after begin of irrigation	38.6	99.7
6	Surface runoff 69 minutes after begin of irrigation	35.4	98.4

Summary and Discussion:

1. The current form of the maximum runtime equation overestimated the time for runoff for this type of soil, slope and landscape. Development of Horton's constants for a range of landscape soil conditions would assist in more accurate estimations of maximum runtimes.
2. Soil moisture before irrigation and wind direction both affect the total runoff. Sensor technology could measure soil moisture and wind direction and adjust irrigation schedules accordingly.
3. The mean volume of runoff was 101 gallons for the non aerated plot and 64 gallon for the aerated plot. This runoff was off the lower edge of a turf plot with an 8 % slope.
4. Proper scheduling would have reduced total runoff from mean of 5.1% of applied water with extended runtime to an estimated 1.3%..
5. Proper scheduling would have reduced surface runoff from mean of 3.8% of applied water with extended runtime to an estimated 0.1% or less.
6. Proper runtime would decrease wind overspray runoff slightly from 1.3% to 1.2%.
7. Methods and equipment was developed to collect and quantify irrigation runoff from a plot.

References:

1. Anonymous. 2004. The Residential Runoff Study. Municipal Water District of Orange County and Irvine Ranch Water District. www.mwdoc.com/WaterUse/R3%20PDFs/R3%20Chapters%20&%20Appendix.pdf. Accessed October 2004
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6. Hung, J.Y. T. 1997 Sprinkler Soaking Time Between First and Second Irrigation Cycles Without Runoff. Proceeding The Irrigation Association's International Exposition and Technical Conference.
7. Irvine Ranch Water District, 2004. *Landscape & Agricultural Conservation.* Irvine, California. Available :Http://www.irwd.gov. Accessed October 2004.
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Green Industries of Colorado Partners with the Colorado WaterWise Council

International Irrigation Show

San Antonio, Texas – November 7, 2006

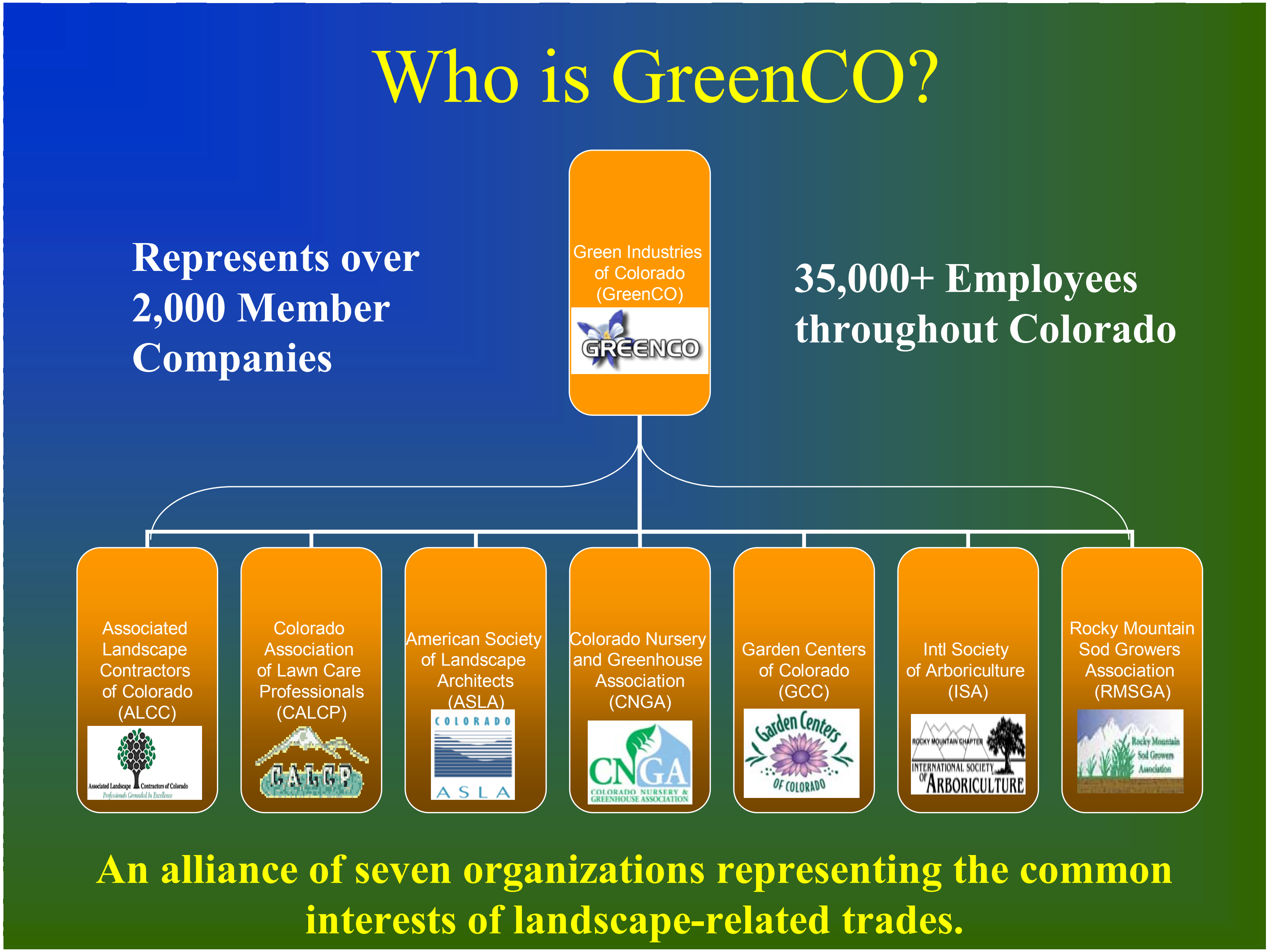
Technical Session Overview

~ Partners in Delivering Water Conservation and Water Quality Protection Education

- Introduction to Green Industries of Colorado
  - GreenCO's BMP Training and Certificate Program
- Introduction to Colorado Water Wise Council
  - How the partnership was formed
- Introduction to Town of Castle Rock
  - Landscape Rules and Regulations
- Program accomplishments and testimonials
- Q & A

An Introduction to the Green Industries of Colorado (GreenCO)

– GreenCO Overview
– GreenCO's Conservation Goals
– History of Best Management Practices (BMP) Development
– Overview of GreenCO BMPs
– A Snapshot of the BMP Training Program


Who is GreenCO?
Represents over 2,000 Member Companies
Green Industries of Colorado (GreenCO)
GREENCO
35,000+ Employees throughout Colorado
Associated Landscape Contractors of Colorado (ALCC)
Colorado Association of Lawn Care Professionals (CALCP)
CALCP
American Society of Landscape Architects (ASLA)
COLORADO
ASLA
Colorado Nursery and Greenhouse Association (CNGA)
CNGA
COLORADO NURSERY & GREENHOUSE ASSOCIATION
Garden Centers of Colorado (GCC)
Garden Centers
OF COLORADO
Intl Society of Arboriculture (ISA)
ROCKY MOUNTAIN CHAPTER
INTERNATIONAL SOCIETY of ARBORICULTURE
Rocky Mountain Sod Growers Association (RMSGA)
An alliance of seven organizations representing the common interests of landscape-related trades.

What is GreenCO?

- Unified organization preserving Colorado's built landscapes.
- Represents urban agriculture, providing a variety of goods and services in both wholesale and retail markets statewide.
- Voice for more than 2,000 small, medium and large wholesale, retail and agri-business member companies and their 35,000 employees in Colorado.
- Contributes nearly $2 billion to Colorado's economy.

Why Does Water Conservation Matter to the Green Industry?

- **Water is a limited resource.**
- **Water use increases with population growth.**
- **Improving urban water use efficiency aids in meeting increased demand.**
- **Water conservation: "Using less water to satisfy a particular purpose"- does not mean eliminating attractive landscapes.**
- **Sustainable growth is critical to the green industry.**

(Less Water - LESS WORK - Less business)

Why Does Water Quality Matter to the Green Industry?

Reduce non-point source pollution by:

- **Reducing runoff**
- **Encouraging vegetative buffers use**
- **Applying chemicals more efficiently**
- **Educating the end-user about water quality**

Reduce pollution at the source rather than correcting the impacts.

GreenCO's Water Program

Mission:

"To inform, encourage, and instill the practice of sound water use across Colorado and ensure that built landscapes remain an essential foundation of Colorado's quality of life, economic health and public image."

GREENCO

GreenCO's Water Program

As the most visible user of outdoor water, our goal is to provide industry-driven leadership to help address water issues proactively and identify solutions to landscape water waste and pollution.

Development and application of Green Industry "Best Management Practices" helps the industry respond to challenges posed by water shortages caused by population growth and drought.

Creating BMPs
First Step to Meet Goals

How?

- "Get our house in order"
- Inventory, evaluate and adopt industry-wide standards
- Integrate BMPs into training programs and public outreach
- Develop recognition for training

What are BMPs?

- For our purposes, Best Management Practices are:

  "Voluntary activities undertaken to reduce water consumption and protect water quality."

- Term is widely used by many local, state and government agencies.

GreenCO Developed these BMPs Because We Realize:

- Healthy landscapes enhance water quality and the environment.
- Over-irrigation is the primary source of water waste in landscaping.
- Preventing or reducing pollution at its source is easier than correcting its impacts.
- Improved water quality and conservation are dependent on behavior changes.

GreenCO BMP Manual

Revised
May 2004

Spanish
December 2005

Practicing and promoting water conservation is essential for the success of the Green Industry!


Drought Practices for Nurseries, Greenhouses and Growers Drought Practices for Landscape Management Drought Practices for Nurseries, Greenhouses and Growers Education of Employees Education of the Public Fertilizer Application Irrigation Efficiency (General Principles) Irrigation System Design Irrigation System Maintenance Irrigation System Installation and Erosion and Sediment Control Landscape Maintenance Lawn Aeration Lawn Mowing Mulching Park, Golf Course and Other Large Landscape Design and Management Pesticide and Herbicide Application Pesticide, Fertilizer and Other Chemical Storage, Handling and Disposal Plant Selection and Placement Production Practices

Green Industry
Best Management Practices (BMPs)
for the Conservation and Protection
of Water Resources in Colorado

Prepared for
The Green Industries of Colorado (GreenCO)
Denver, CO

Prepared by
WrightWater Engineers, Inc.
Denver, CO

With support from:

The Colorado Water Conservation Board

Headwaters Consulting, LLC

Colorado Department of Public Health and Environment
Water Quality Control Division
(under a grant from the U.S. Environmental Protection Agency)

2ND RELEASE, MAY 2004
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Green Industries of Colorado • www.greenco.org

Colorado Governor
Bill Owens
issued a
Green Industry
"BMP" Proclamation
December 9, 2005

"BMP Awareness Week"
December 12-16, 2005

Honorary Proclamation

BILL OWENS
GOVERNOR

GREEN INDUSTRY BEST MANAGEMENT PRACTICES AWARENESS WEEK
December 12 – 16, 2005

WHEREAS, the issue of water management and conservation is of the utmost concern and priority for the state of Colorado, to ensure our quality of life and economic viability; and

WHEREAS, Colorado's ability to recognize and implement management practices for water users that utilize the best of technology, design, and material use – based on Colorado's climate and soil conditions to conserve and manage water use in our environment – is highly advantageous; and

WHEREAS, the Green Industries of Colorado, in conjunction with representatives from Colorado State University Cooperative Extension, Colorado State University Department of Horticulture and Landscape Architecture, Colorado Water Resources Institute, Denver Water, and the Northern Colorado Water Conservancy District, have developed practices – through both the science and practical application of landscape or outdoor urban water use – that provide both efficiency and flexibility for planning agencies at the local and state level, as well as individual property owners, to maximize water use while preserving viable landscape options; and

WHEREAS, these best management practices (BMPs) are an evolving set of guidelines and standards, which will take advantage of future technological developments and future refined water practices, that can be adopted by local, county, and state agencies as a goal for water management and conservation; and

WHEREAS, BMPs are state-of-the-art practices for water conservation and water quality protection that help to ensure the future viability of our great state;

Now Therefore, I, Bill Owens, Governor of the State of Colorado, do hereby proclaim December 12 – 16, 2005,

GREEN INDUSTRY BEST MANAGEMENT PRACTICES AWARENESS WEEK

in the State of Colorado.

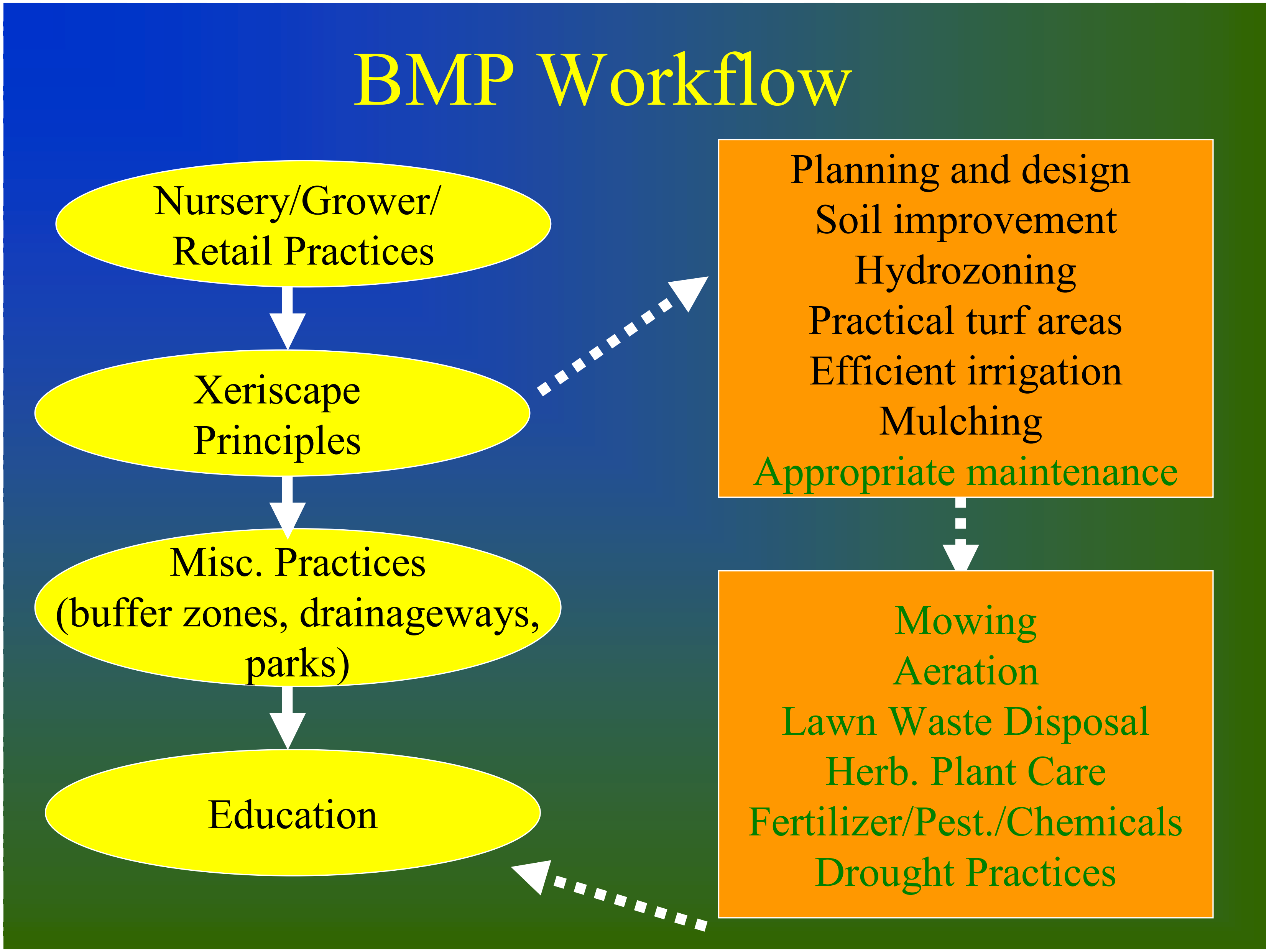
GIVEN under my hand and the Executive Seal of the State of Colorado, this first day of December, 2005

Bill Owens.

Bill Owens
Governor

GreenCO's 31 BMP Fact Sheets Basis of BMP Training

- Drought Practices for Landscapes
- Drought Practices for Nurseries, Greenhouses and Growers
- Education of Employees
- Education of the Public
- Fertilizer Application
- Herbaceous Plant Care
- Irrigation Efficiency (General) Irrigation System Design
- Irrigation System Installation
- Irrigation System Maintenance
- Landscape Design
- Landscape Installation and Erosion and Sediment Control
- Landscape Maintenance
- Lawn Aeration
- Lawn Waste Disposal/Composting
- Mowing
- Park, Golf Course and Other Large Landscape Design/Management
- Pesticide/Herbicide Application
- Pesticide/Fertilizer/Chemical Storage, Handling and Disposal
- Plant Selection and Placement
- Production Practices for Nurseries, Greenhouses and Growers
- Regulatory Awareness/Compliance
- Retail Practices for Nurseries, Greenhouses and Garden Centers
- Revegetation of Drainageways
- Riparian Buffer Preservation
- Soil Amendment/Ground Preparation
- Turf Management
- Water Budgeting
- Woody Plant Care
- Xeriscape


BMP Workflow
Nursery/Grower/ Retail Practices
Xeriscape Principles
Misc. Practices (buffer zones, drainageways, parks)
Education
Planning and design
Soil improvement
Hydrozoning
Practical turf areas
Efficient irrigation
Mulching
Appropriate maintenance
Mowing
Aeration
Lawn Waste Disposal
Herb. Plant Care
Fertilizer/Pest./Chemicals
Drought Practices

Water Conservation Practices Starts with Nurseries, Greenhouses & Growers

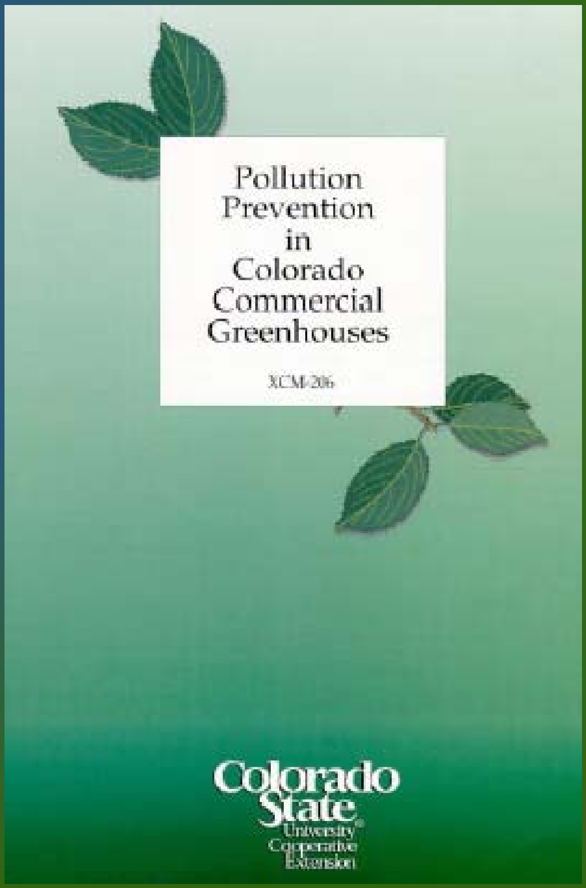
1. Reduce wasted water/runoff
   – Hydrozoning
2. Examine/improve irrigation system efficiency
   – Irrigation technology (e.g., drip, subirrigation)
3. Collect and reuse/recycle irrigation water
   – Increase attention to disease prevention practices and salt/nutrient build-up

Properly Use Technology to Maximize Irrigation Efficiency

Photo Source: Little Valley Wholesale Nursery.

Overview of Pollution Prevention in Greenhouses/Nurseries

- Manage irrigation systems to reduce transport of chemicals.
- Use IPM/PHC in pest control decisions.
- Apply pesticides only when needed.
- Maintain records of pesticide use.
- Protect groundwater/ surface water from leaks/spills.
- Protect wellheads from contamination.



Seven Principles of Xeriscape™

1. Planning and design
2. Soil improvement
3. Hydrozoning
4. Practical turf areas
5. Efficient irrigation
6. Mulching
7. Appropriate maintenance

XERISCAPE 25 a generation of waterwise landscaping

*Xeriscape is a term copyrighted by Denver Water in 1981. Permission to use granted.

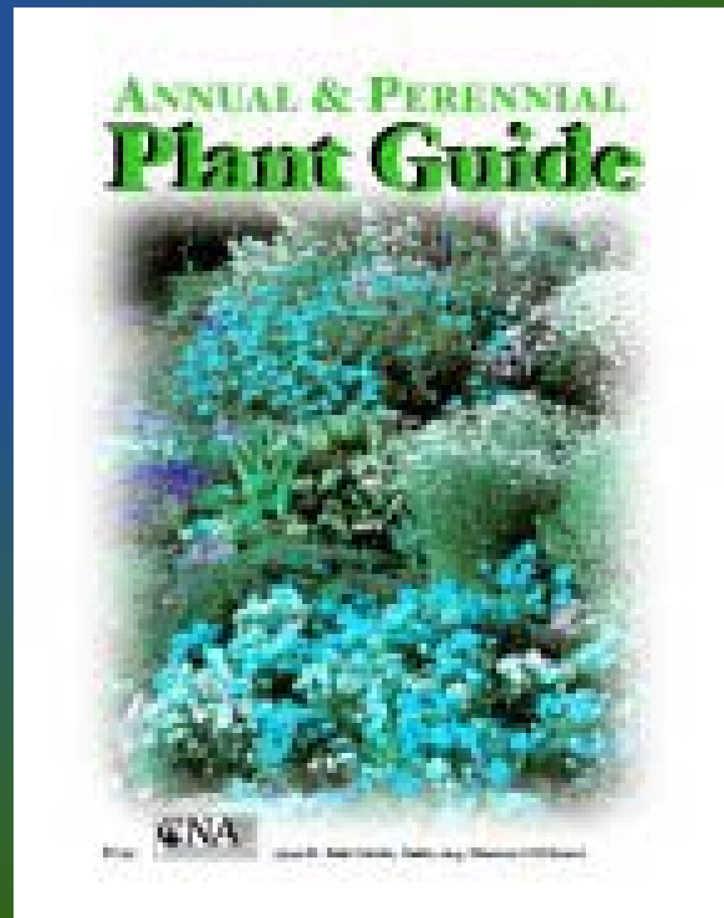
Planning and Design

(Xeriscape Principle 1)

- Select the right plants
- Place in the right spot
- Group by water need
- Space properly to avoid excessive water use.

Photo Source: Valerian, llc and Engle Homes 2003

Examples of Industry Tools to Aid in Plant Selection



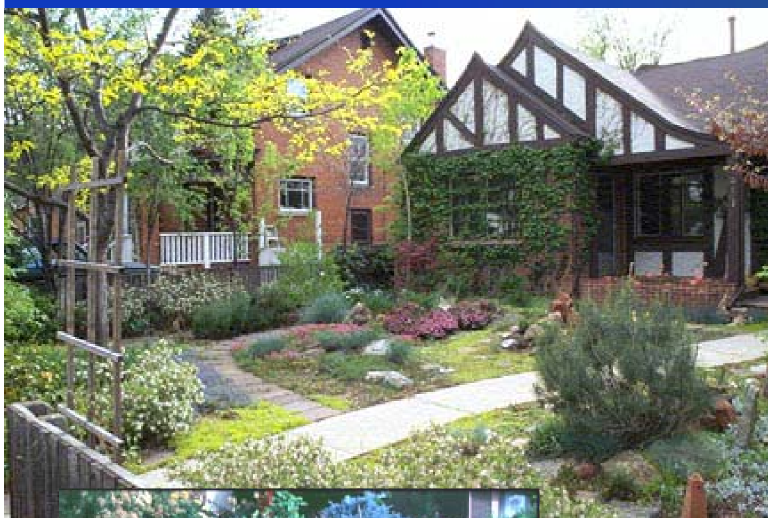
ALCC Award-Winning Xeriscape Landscape Designs

Source: Alpine Gardens, Williams Residence.

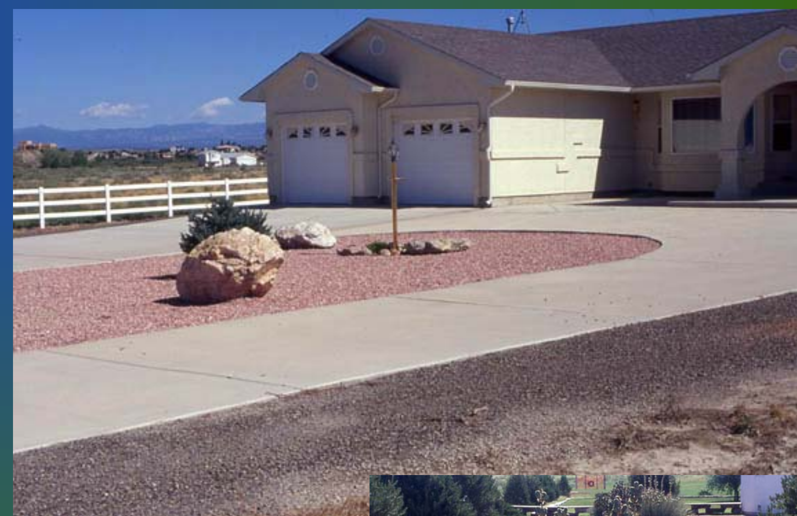
Source: Viriditas, Garden of the Aerie

Xeriscape™

IS….



IS NOT….



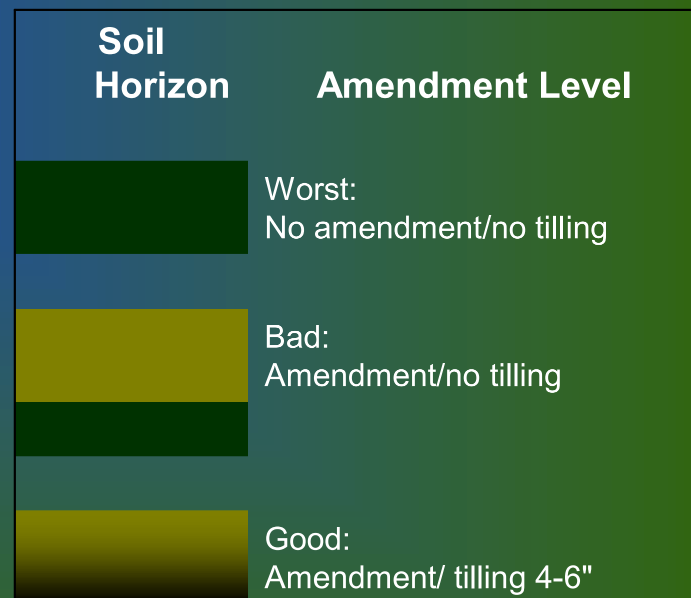
XERISCAPE 25 a generation of waterwise landscaping

Source: Xeriscape™ Colorado

Soil Amendment and Ground Preparation

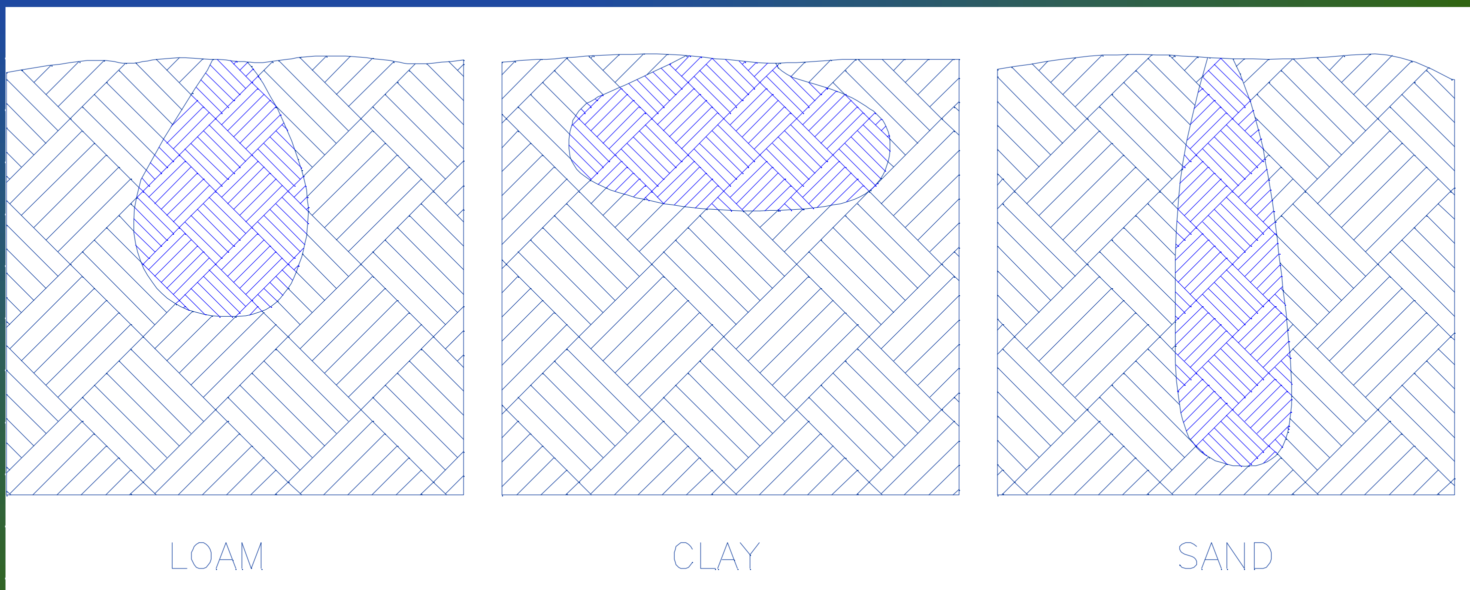
(Xeriscape Principle 2)

- Test soils to identify needed improvements (e.g., texture, nutrients, salts, pH)
- Proper soil preparation is critical to landscapes
  - 3-5 c.y. (1-2 inches) organic matter per 1,000 sq. ft., tilled 4-6 inches
- Preserve topsoil for reuse.



Soil Properties Affect Irrigation Requirements

- Organic matter improves the aeration of clay and the water-holding capacity of sand.



Graphic Source: Stephen Smith, Aqua Engineering.

Hydrozoning

(Xeriscape Principle 3)

- Group plants with like water needs
- Place low-water ground covers in difficult maintenance areas (steep slopes, narrow strips)
- Place low-water plants at top of slopes

Photo Source: www.xratedgardening.com

Water Budgeting

Knowing how much water you need +
Knowing how much water you use =
Knowing WHEN & HOW to adjust your system

- Not as complicated as it sounds
- Irrigating according to plant needs
- Need to understand ET
  - Water lost from soil/plant surfaces (evaporation)
  - Water used by plants (transpiration)

GreenCO Water Budget Calculator

(www.greenco.org)

Enter your Data in the White Areas

Name	Enter Customer's name
Acct #	999999
Address	99 Any Lane, My City
Agency	ncwcd

greenco — it's easy being green

1 Home/Interior Water Consumption Estimate

Enter Number of Residents	1	Persons
Low Flow Plumbing?	Yes	

2 Landscape Water Consumption Estimate

Enter Turf Area	1,000	sq.ft.	Automatic
Enter Shrubs/Ground cover Area	1,500	sq.ft.	Sprinklers? Yes
Enter Xeriscape Area	0	sq.ft.	
Or Total Area	0	sq.ft.	OK

3 Total Water Budget

Enter Restriction	0	% Target

** Units in Gallons*

2a. Acres to Sq.Ft. Calculator:

	Acres	sq.ft.
Enter Acres	2.00	87,120

Defaults Are:		Local Average ET (in) (enter if different than default)	Actual Usage*	Base Year Use
0.00	Jan	0.00	9,520	9,000
0.00	Feb	0.00	7,850	8,000
0.00	Mar	0.00	12,690	12,500
4.00	Apr	4.00	24,700	24,500
4.95	May	4.95	25,620	25,500
6.20	Jun	6.20	28,990	29,000
6.60	Jul	6.60	40,125	40,000
5.50	Aug	5.50	38,600	39,000
4.00	Sep	4.00	34,256	34,000
2.80	Oct	2.80	32,890	33,000
0.00	Nov	0.00	16,456	12,000
0.00	Dec	0.00	9,900	9,000

Provided by GreenCo and the Colorado Landscape and Nursery Businesses Association

Home or Single Meter Water Budget Calculator

Data in blue boxes comes from the "Input Table"

Site Info

Name	Enter Customer's name
Acct #	999999
Address	99 Any Lane, My City
Agency	ncwcd

greenco — it's easy being green

1 Home/Interior Water Consumption Estimate

Number of Residents	1	Persons
Low Flow Plumbing?	Yes	
Gallons Per Home Per Day	**55**	

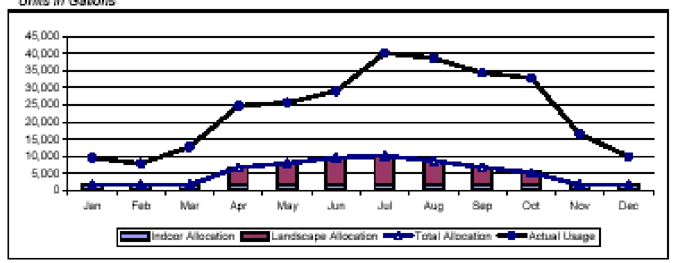
2 Landscape Water Consumption Estimate

Turf Area	1,000	sq.ft.	Automatic
Shrubs/Ground cover Area	1,500	sq.ft.	Sprinklers? Yes
Xeriscape Area	0	sq.ft.	
Or Total Area	0	sq.ft.	OK

3 Total Water Budget

Restriction Budget	0	% Target

** Units in Gallons*

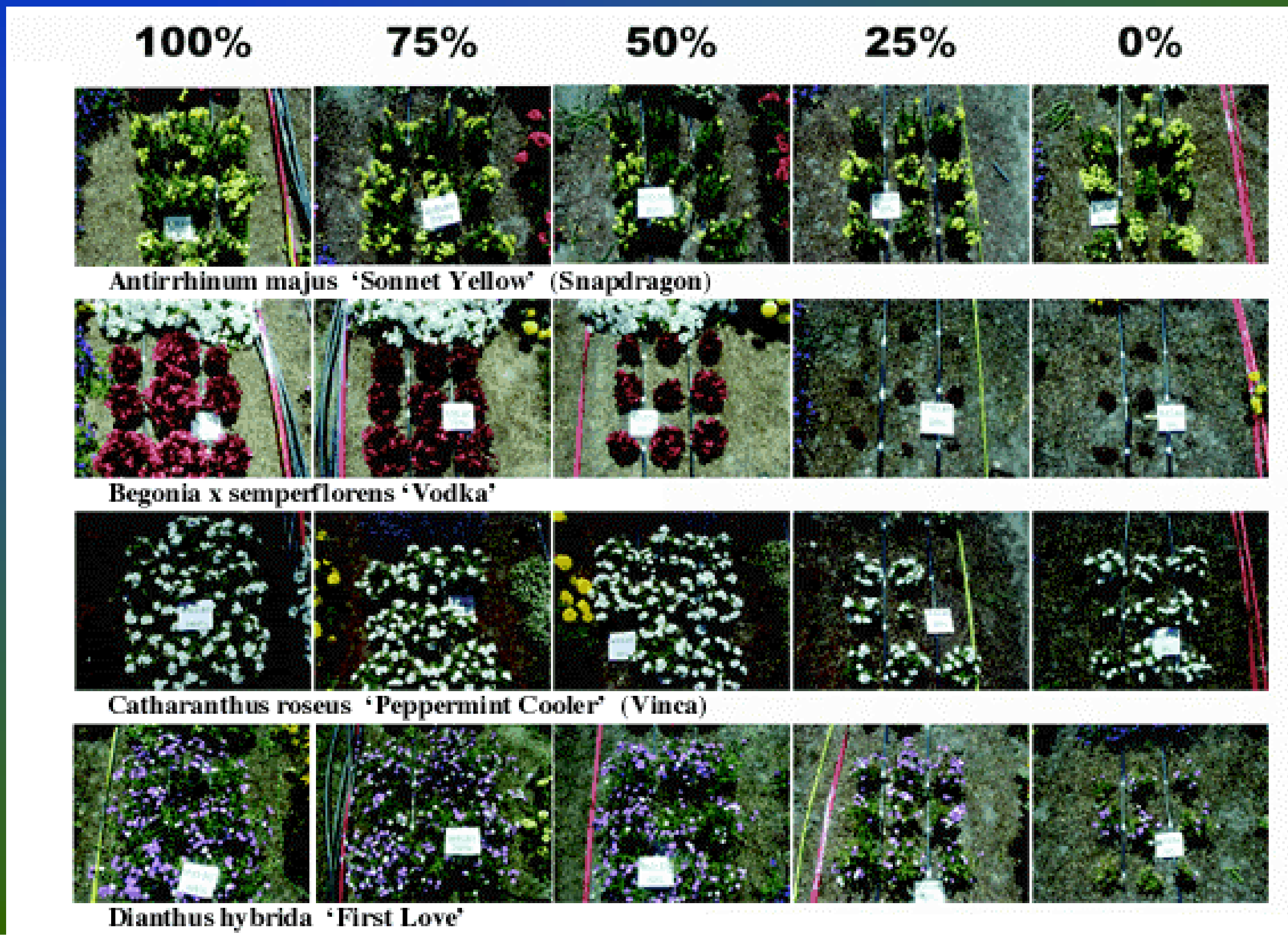


Month	Indoor Allocation	Landscape Allocation	Total Allocation	Actual Usage	Savings Potential	Drought Budget	Base Year Use
Jan	1,650	0	1,650	9,520	7,870	1,650	9,000
Feb	1,650	0	1,650	7,850	6,200	1,650	8,000
Mar	1,650	0	1,650	12,690	11,040	1,650	12,500
Apr	1,650	5,115	6,765	24,700	17,935	6,765	24,500
May	1,650	6,330	7,980	25,620	17,640	7,980	25,500
Jun	1,650	7,928	9,578	28,990	19,412	9,578	29,000
Jul	1,650	8,440	10,090	40,125	30,035	10,090	40,000
Aug	1,650	7,033	8,683	38,600	29,917	8,683	39,000
Sep	1,650	5,115	6,765	34,256	27,491	6,765	34,000
Oct	1,650	3,581	5,231	32,890	27,660	5,231	33,000
Nov	1,650	0	1,650	16,456	14,806	1,650	12,000
Dec	1,650	0	1,650	9,900	8,250	1,650	9,000

Provided by GreenCo and the Colorado Landscape and Nursery Businesses Association

How Much Water Do Plants Really Need?

Hardy Boy Bedding Plant Annuals Top 20 Water Efficiency Study
(Welby Gardens and CSU 2003)



Create Practical Turf Areas

(Xeriscape Principle 4)

- Value of turf:
  - Provides recreational benefit, good for high-use areas
  - Reduces wind and water erosion.
  - Provides cooling effect.
  - Filters and infiltrates runoff.
  - Aesthetics.
- Consider alternatives for narrow strips, hard-to-water and hard-to-maintain areas (steep slopes).

Photo Source: Valerian, llc and Engle Homes 2003

Irrigation Efficiency

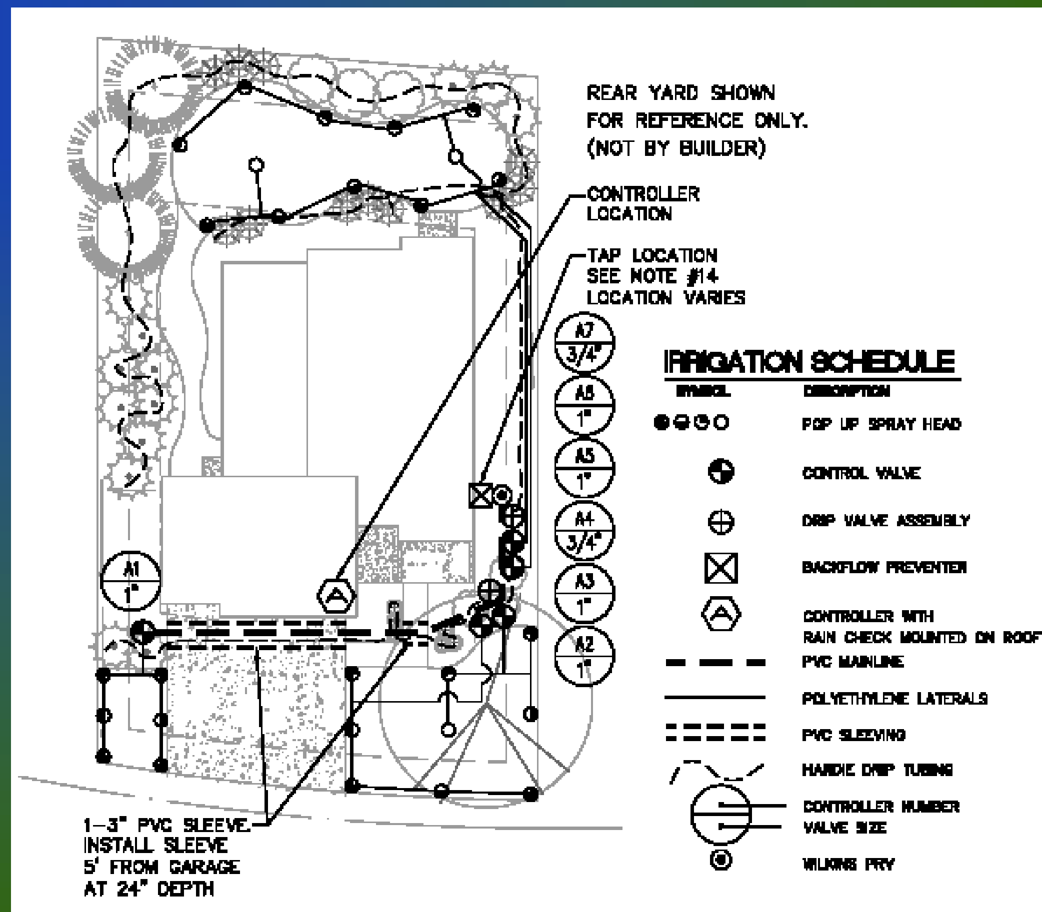
(Xeriscape Principle 5)

1. Assure the overall quality of the system.
2. Design the system for the efficient and uniform distribution of water.
3. Install the system to meet design criteria.
4. Maintain the system for optimum performance.
5. Manage the irrigation system to respond to the changing need for water.

Source of Recommendations: The Irrigation Association

Efficient Irrigation Design

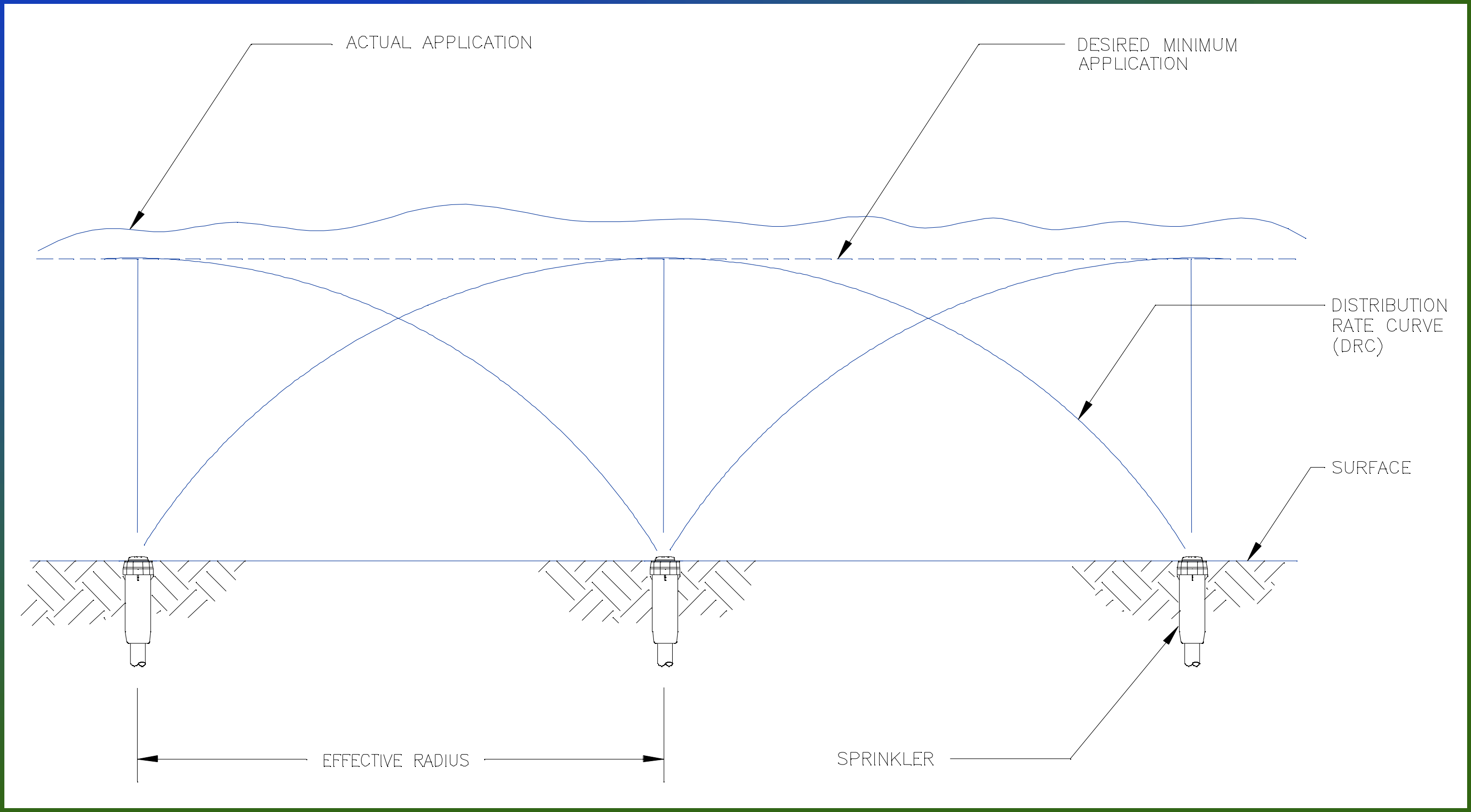
- Hydrozones
- Head-head spacing
- Drip emitters for beds
- Pop-ups for turf
- No overspray



Example Design Source: Valerian, llc and Engle Homes 2003

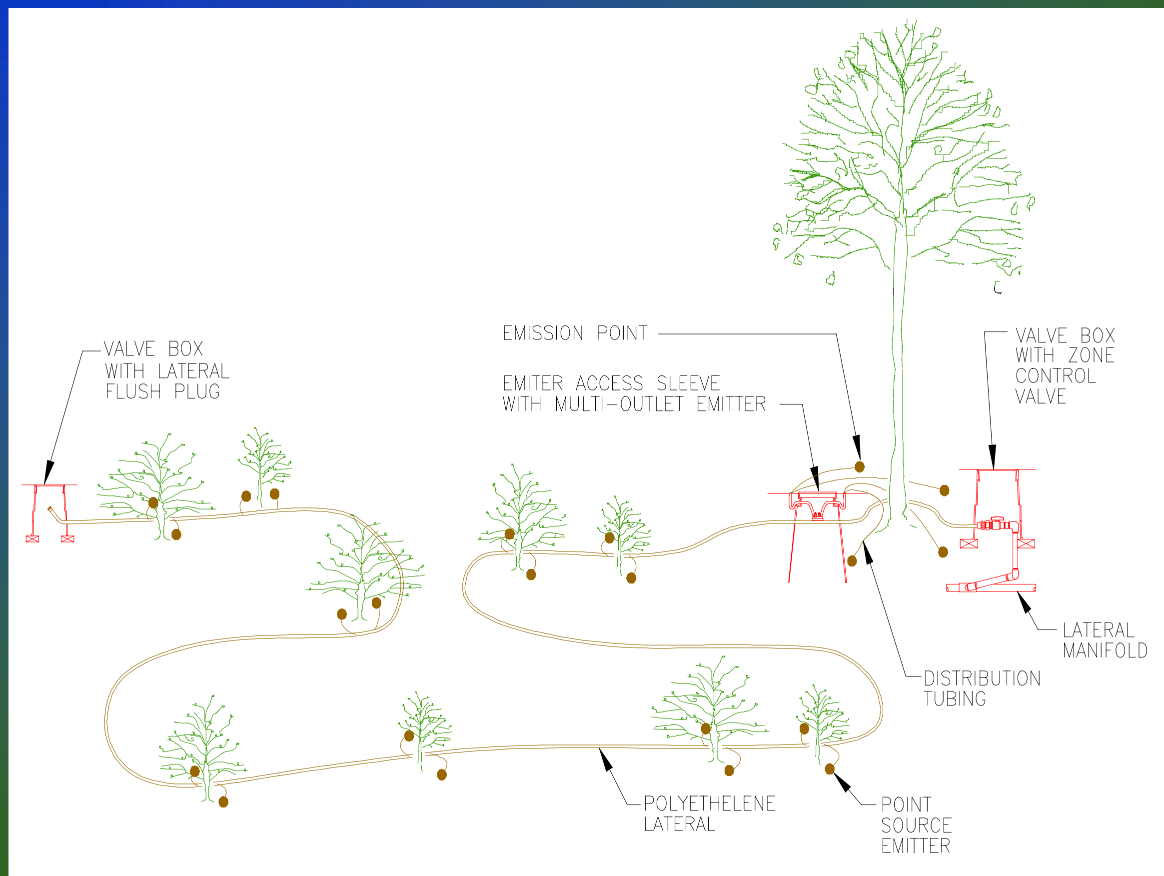
Irrigation System Design

Proper head spacing/configuration and operating pressures are critical for uniform water distribution.



Graphic Source: Stephen Smith, Aqua Engineering.

Drip Irrigation for Trees/Shrubs



Graphic Source: Stephen Smith, Aqua Engineering.

Irrigation System Installation/Retrofitting

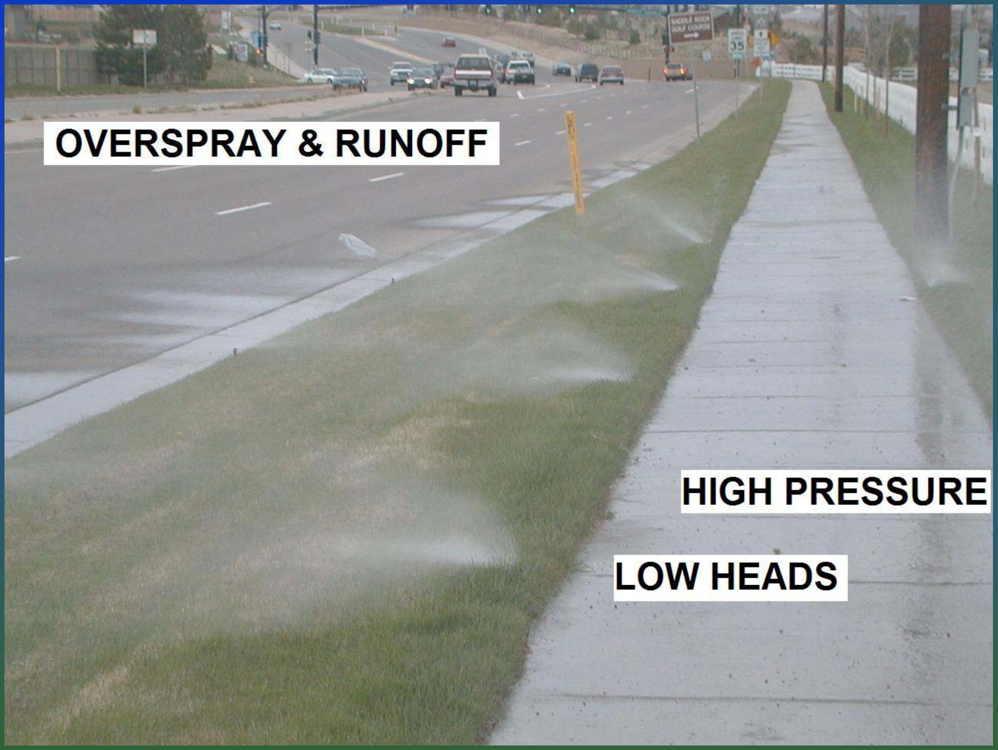
- Properly install equipment
- Install according to design specs.
- Install water conserving equipment
- Ensure owner knows how to operate

Soil Moisture Sensors

ET Controller

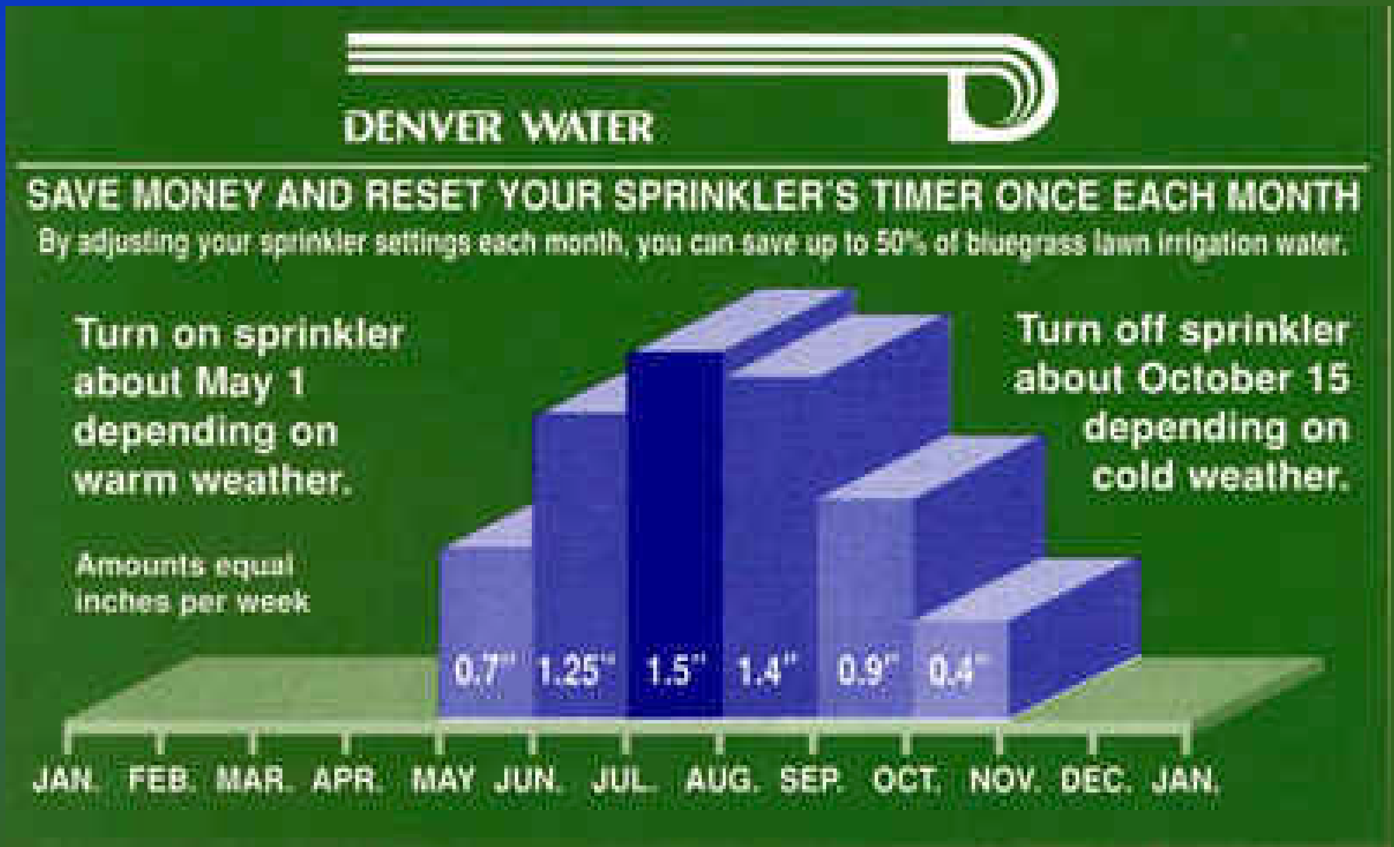
Graphic Sources: 1) Northern Colorado Water Conservancy District; 2) Aquacraft, WeatherTRAK

Irrigation Maintenance



- Check, adjust and repair irrigation equipment
- Shut off when damaged
- Reset automatic controllers to meet plant needs

Regularly Adjust Irrigation System



Source: Denver Water, http://www.denverwater.org/cons_xeriscape/cons_xeriscapeframe.html

Mulching

(Xeriscape Principle 6)

- Reduces water loss
- Reduces soil loss
- Suppresses weeds
- Promotes uniform temperature
- Promotes soil micro-organism activity
- Aesthetic amenity

Photo Source: Denver Water

Appropriate Landscape Maintenance

“There’s More to It than Just Water”

(Xeriscape Principle 7)

- Check, adjust and repair irrigation system
- Develop/Follow Site Water Budget
- Reset irrigation controller
- Aerate turf
- Replenish mulch
- Apply fertilizer, as needed
- Properly prune
- Pesticide/herbicide as needed, following label
- Mow at proper height
- Maintain equipment
- Monitor & keep records

Additional BMP Topics

- Herbaceous and Woody Plant Care
- Turf Management
- Mowing, Lawn Waste Disposal & Composting
- Fertilizer, Pesticide and Herbicide Application, Handling & Disposal
- IPM/PHC
- Material Safety Data Sheets (MSDS)
- Role of Landscaping in Engineered Drainageways
- Riparian Buffer Zone Preservation
- Parks, Golf Courses and Other Large Landscapes

Regulatory Awareness and Compliance

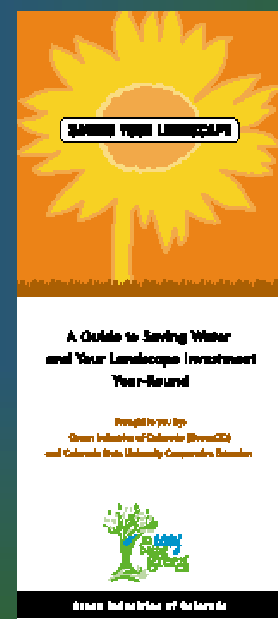
- Pesticides
- Riparian (streamside) setbacks
- Wetlands
- Stormwater management
- Erosion/sediment control
- Groundwater
- Noxious Weeds
- Water rights
- Landscape ordinances
- Back-flow prevention
- Cross-connection controls
- Fire
- Wildlife
- Utilities

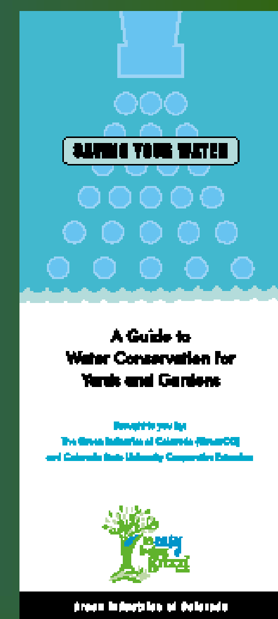
Appendices of GreenCO BMP Manual

- Erosion and Sediment Control BMPs
- Permanent Stormwater BMPs
- Regulatory Matrix
- Water Budget Calculator (also on website)

Educate the Public!

- <u>You</u> set the example!
- GreenCO website brochures
- Educate public on topics such as:
  - Irrigation system maintenance
  - Appropriate turf water use
  - Pesticide/fertilizer application
  - Ground preparation
  - Xeriscape
  - Water budgeting





Education of Employees

- Provide educational materials (field use, bilingual)
- Maintain professional credentials
- Make water conservation a priority
- Emphasize following labels
- Require compliance with relevant permits, local ordinances and regulations

Certification Programs to Consider

- Associated Landscape Contractors of CO
  - Certified Landscape Technician (CLT)
  - Certified Irrigation Technician (CIT)
  - Certified Landscape Professional (CLP)
- Colorado Nursery Association: CO. Certified Nursery Professional
- Colorado Greenhouse Growers Association: Certified Greenhouse Professional
- International Society of Arboriculture: Certified Arborist
- Irrigation Association: Certified Irrigation Auditor (among others)
- Colorado Department of Agriculture: Licensed Commercial Pesticide Applicator
- Green School Certificate
- Professional Gardener

GreenCO BMP Training Course

- – Offered in English and Spanish
- – 1½ hour BMP overview
- – Class based on GreenCO BMP Manual
- – Test on manual (100 questions, open book with 2-hour time limit, 75% passing score)
- – Certificate of completion – “Seal of Knowledge”
- – Recognition on GreenCO website with links to municipalities and others

Colorado WaterWise Council (CWWC)

- The "Voice" of the Colorado's water efficiency community
- Shares information, technical resources, and water management strategies.

COLORADO
WaterWise Council

- Water Providers, Cities, and Municipalities
- Green Industry
- Water Advocacy Groups

Town of Castle Rock

"Creating a community culture that embraces water conservation and smart landscaping techniques, saving the Town and ratepayers millions of dollars in infrastructure, stabilizing rates, protecting property investments, and extending the life of the Town's aquifers."

Be Water Wise

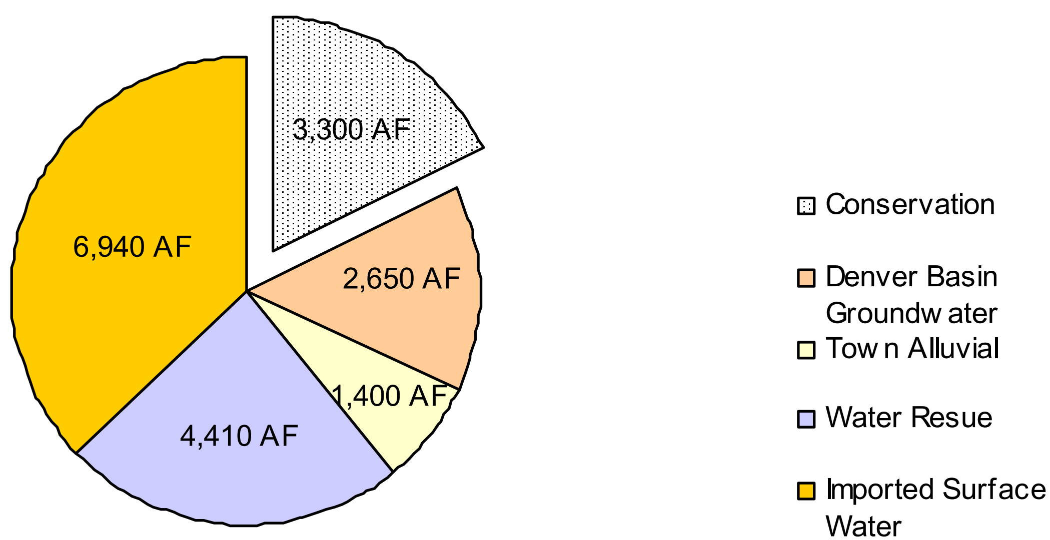
TOWN OF CASTLE ROCK COLORADO

Town of Castle Rock

- Long Term Water Program Over View
  - Achieve a 75% renewable water program
  - Implement a proactive Water Conservation Program
  - Capital Program
  - Program Cost - $400 million

Capital Program Overview

Distribution of 2055 Water Supply



Conservation Program Overview

- Reduce average water consumption by 18%
  - 165 to 135 gallons per capita per day
  - For a single family resident the equates to:
    - 117 to 102 gallons per day
    - Summer months – 17,000 to 14,000 gallons per day
    - Winter months – 5,000 to 4,000 gallons per month
- Preserve/enhance Castle Rock landscape architecture
- Water rates for promoting conservation

Town of Castle Rock Colorado

Conservation Program Overview

- Landscape Professionals Registration
- Rebate Program
- Water Conservation Seminars

Landscape Professionals Registration

- In order to facilitate expeditious plan review, permitting and inspections of landscaping and irrigation systems
  - Landscape designers
  - Irrigation designers
  - Installation and Maintenance Professionals
- Registration is by *individual* not by company
- Must be registered to work within the Town of Castle Rock

Town of Castle Rock Colorado

Landscape Professionals Class

- Attend an annual seminar
- Participate in and pass a test on the Water Use Management Plan and the Town of Castle Rock Landscape Regulations and Principles

TOWN OF
CASTLE ROCK
COLORADO

Landscape Professionals Class

- The seminar curriculum includes at a minimum:
  - Program intent and objectives
  - Designation of large irrigated areas
  - Large irrigated schedule parameters
  - Acquire submittal requirements
  - Enforcement parameters
  - Demand management tools and
  - Related Landscape Regulation and Principles components

TOWN OF CASTLE ROCK COLORADO

Landscape Professionals Class

- Nine classes held in 2006
- 300 Registered Landscape Professionals
- Incorporated GreenCO BMP Training and Certificate Program

WATER WISER

TOWN OF CASTLE ROCK COLORADO

www.crgov.com

Partners in Education

- In late 2005, GreenCO pitches a BMP Training Roadshow to CWWC.
- Cities' support and host training sessions in 2005/06
- Town of Castle Rock takes the BMP Training Program to another level:
  - The City adopts GreenCO's BMPs
  - *Mandates* that before performing work in the town, you *must* be registered with the City, attend BMP training and pass the exam.

The Town of Castle Rock is the BMP Implementation Pioneer!

Brenda O'Brien, GreenCO

Accomplishments

- 420+ "Seal of Knowledge" recipients to date
  - field professionals from green industry businesses, municipalities, metro districts, utilities, parks, towns, schools, correctional facilities, churches, hospitals, and home builders have attended.
- Delivered annually at ProGreen EXPO (www.progreenexpo.com)
- Nine sessions held in 2006
- Partnered with CWWC members to sponsor sessions
- GreenCO BMPs incorporated into various city landscape ordinances and Metro Mayors Caucus outdoor BMPs
- BMP certificate required to work in the Town of Castle Rock

View recipients at www.greenco.org

BMP Testimonials

"Water Conservation in Colorado must become a way of life, all the time, not just in times of drought."

- Green Industries of Colorado (GreenCO) Board of Directors

"We developed short-term and long-term BMP improvements such as, replacing worn heads, using proper pressure, fixing leaks, and hydrozoning for our nursery. When we save on water, we pass the savings on to our customers."

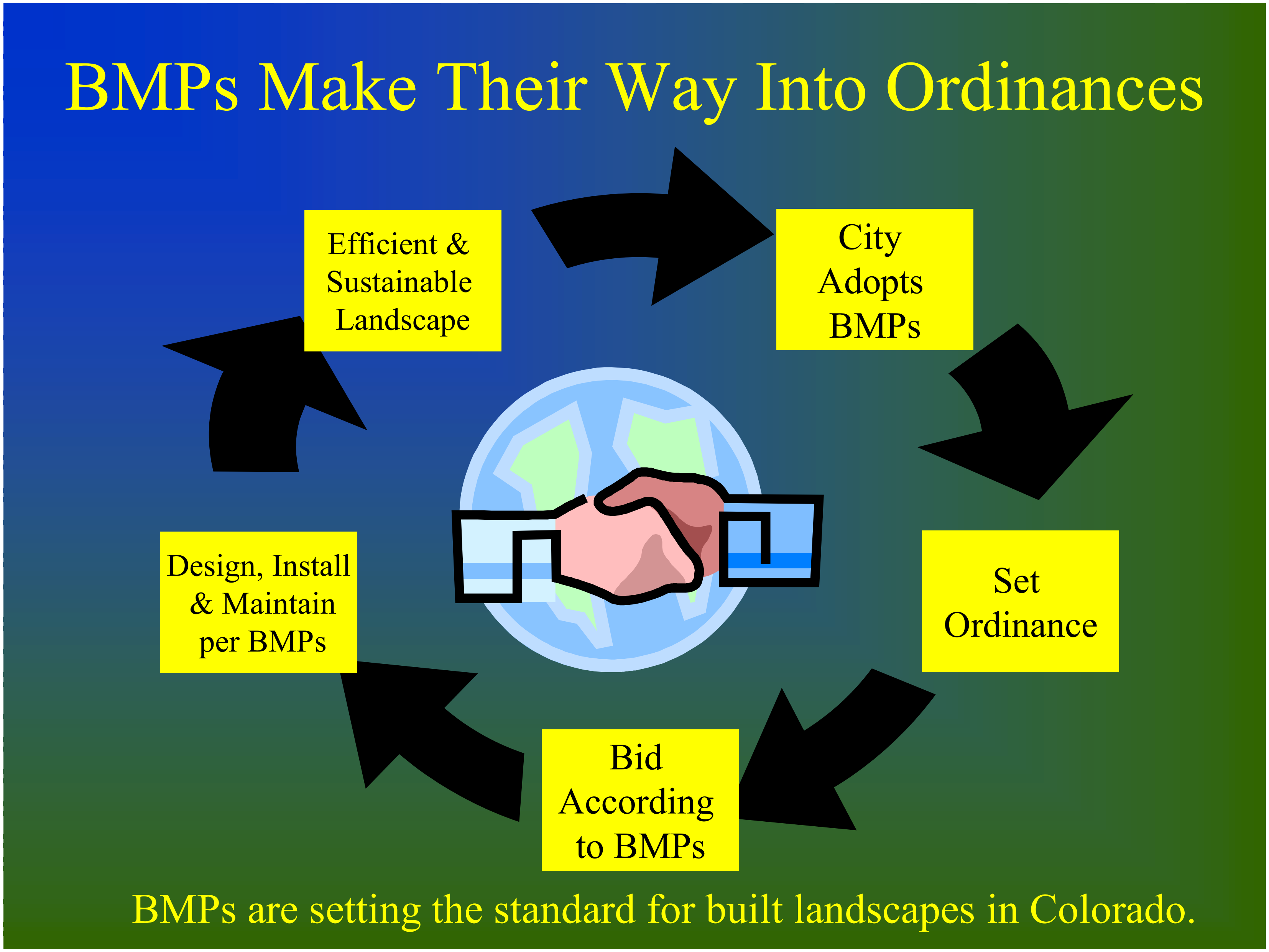
- John Pinder, Little Valley Wholesale Nursery, Brighton, Colorado

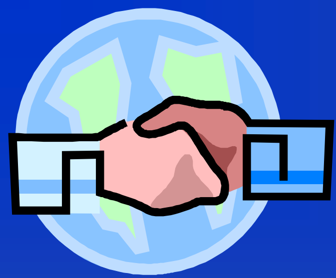
"The cities' intent in reaching out to GreenCO is to establish the BMPs as the standard for built landscapes in their communities."

- Stu Feinglas, City of Westminster, Colorado

"The BMPs are a powerful instrument for the industry to follow. The manual puts all the information under one umbrella and keeps us on the same page."

- Todd Williams, American Civil Constructors, Littleton, Colorado


BMPs Make Their Way Into Ordinances
Efficient & Sustainable Landscape
City Adopts BMPs
Set Ordinance
Bid According to BMPs
Design, Install & Maintain per BMPs
BMPs are setting the standard for built landscapes in Colorado.



Is Your Green Industry Working with Water Suppliers' on Conservation Programs?

As the <u>most visible user of outdoor water</u>, the goal is to:

- **<u>Partner with local organizations</u> to develop outdoor water conservation plans.**
- **<u>Utilize BMPs</u> in conservation planning/ordinances.**
- **<u>Provide industry-driven leadership</u> to help address water issues.**
- **<u>Proactively identify solutions</u> to landscape water waste and pollution.**
- **<u>Supply expertise</u> on green industry related matters.**
- **<u>Act as a resource</u> for scientific research.**

Questions?

Brenda O'Brien

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www.crgov.com

Socialization of Weather-Based Irrigation Technology

Bruce Cardinal, CEO, ET Water Systems, LLC, 100 Tamal Plaza, Suite 250, Corte Madera, CA 94925

Water agencies and government entities are pushing Weather-Based Irrigation Controllers (WBIC's), but are concerned about obstacles to adoption. The obstacles include a lack of widespread understanding of ET and the potential benefits of WBIC's, fears regarding being an early adopter of a “new” technology, worries about purchasing products from fledging companies, apprehensiveness over installing “self-adjusting” controllers, and perceived difficulty in initial programming of WBIC's. The session will include lessons learned from ETwater's sales and marketing experience as well as insights from water agencies, landscape contractors and others on the “front line” regarding how to overcome these obstacles.

ETwater was the first company to complete the SWAT/CIT WBIC test protocol and publish results. Founded in 2002, ETWS has experience in California selling direct to landscape contractors, municipalities, and homebuilders, participating in rebate programs, and selling through distributors in 6 other states.

IRRIGATION INDUSTRY REPONSE TO DROUGHT IN SEVERAL SOUTHWEST STATES

Laurence Budd, Allison Irrigation, CLT, CLIA

Introduction:

Hello, I'm Laurence Budd, owner of Allison Irrigation in Ft Collins, Colorado, and the inspiration of Water Efficiency Magazine, published by Forester Communications out of Santa Barbara. I am a CLT in Irrigation and a CLIA. My main business focus is water efficiency, water management and conservation. My website is www.urban-water-conservation.com.

In 1992 I had come back into the irrigation world, working as a contractor in the Albuquerque area. A combination of population growth and low snow pack were resulting in a drought situation. I found my business shifting quickly to xeriscape and vast drip systems, moving quickly away from large turf installations.
In 1998 I was hired by a large design/build office complex firm in the Boulder area, and in 2002 I noticed that Colorado was going into the same scenario as New Mexico, and for the same reasons. I became known as the boy who cried "drought" among the Colorado water districts. The same forces were acting upon them as in New Mexico, but there was a strong resistance to admit that mother nature had any effect on the water supply.
Now, the same movie is playing in the North Texas region, with cities like Plano in stage 3 drought, while Dallas, 20 miles away, is mysteriously in a no drought mode.

All of these regions had several of the same forces acting on them- an increase in population, no real surplus in water storage, and a drought.

Having been in all three of these markets during their droughts, I noticed consistent trends among the water providers and the landscape industry. In all 3 markets, The water providers were very reluctant to set watering restrictions or landscaping guidelines- at first. There was a great concern that the residents would become angry with the providers, whereas in actual experience the reverse has been true. Homeowners in each market were quick to realise the importance of conserving, although many were misdirected as to where their biggest water uses were. On the same day a water provider would tell me they could not possibly enact restrictions, a homeowner would be telling me we must have restrictions. In New Mexico and

Colorado smaller high end residential contractors began quickly responding to customer desires for less turf, more beds and other features.

Large landscape companies specialising in ICI type new landscape installs did not react well to the quickly changing water situation. This was largely because the designs has been done and approved well before the drought hit, the job was bid on that design, and, (as we all know), there was no extra money in the budget to revise anything. I noticed that large ICI type installs based on the "turn the desert into Kentucky" theme continued for about 2 years after the drought hit in each area. This caused a lot of concern among the public- "Why is my HOA installing 20 acres of decorative irrigated turf, and why are we paying for it?" This large scale landscape portion of the industry did not respond well, simply because of lag time between design and installation, and- money.

So, the public was becoming educated about xeriscape and water conservation more quickly than our industry, and was a major factor in driving the industry to more xeric designs. The smaller contractors, dealing with residential, reacted much more quickly, since there is no lag time between design and install. The proof in the pudding- Denver Water has just announced rate hikes due to low water sales, caused by continuing residential conservation.

New Mexico:

Since Albuquerque region was the first in this drought cycle, you will notice as you drive through the city that it is now largely xeric. New subdivisions in the Albuquerque area have almost no turf, many have gone beyond xeriscape to zeroscapes. Santa Fe has had three years of no outdoor water, which has had a strong effect on the local landscapers. New subdivisions in Santa Fe are allowing irrigation only within the small courtyard area. A few large properties, such as the U of New Mexico in ALbuquerque, are still fighting the trend, but now find themselves the object of scorn by the community. I asked John Seaver, of Just Sprinklers in Albq., how the drought affected his business-

John says he saw a change in customers needs- he began doing more drip, now doing as much drip as turf. Consumers were becoming more educated. The city water conservation program helped a lot on this- several companies jumped on this xeric approach. He notes that he started charging more for his services as the cost of water went up. So, going xeric was profitable for his business.

I also spoke to Bob Englund, a long time high end residential landscape contractor. He feels he was well before the trend, focusing on native plants and drip long before they became buzz words. He feels it is very important to install sustainable landscapes, and to create hydrozones within the landscape. He feels that native type landscapes are the only way to go, and I will bet you that in 20 years we will know he is exactly right.

Colorado:

On to Colorado, 2002. The concept of xeriscape was already well known in the area, but ICI type new installs were still going for the Kentucky look. The largest water agencies were in a full state of denial when the drought hit, which slowed down the response by the industry. Once again, I saw a two year lag in ICI installs becoming more xeric. To make it a bit more confusing, the water agencies have been going back and forth on the water situation, when they should stick to conservation consistently. They are doing this because their budgets are too tight to allow for low water sales. This has been confusing for the public and the contractors. In August this year Denver water announced a rate increase because of low sales, caused by residential conservation efforts.

The large landscape install companies in Colorado did not want to hear about conservation, budgets and audits. There was no room in their budget for it. There persisted a "get it in, get it green, get gone" mentality. As water prices start to creep up in Colorado, the market for upgrading irrigation and xeric conversions is now becoming established. Once again, the smaller contractors are quicker to respond to the desires of the market. I was working in this market during this drought, and asked Paul Harrington of rocky Mtn Landscapes how his business changed. Paul is the premier landscape contractor in the Winter Park/ Vail area.

Paul points out that he is in a different climate zone than the Colorado front range, with more precipitation and lower temperatures. He has noticed a shift to more native trees and plants.

I also spoke to Dale Morehouse , the CID at EDAW Fort Collins. Dale notes that compared to five years ago, their designs are becoming more xeric, far less turf, more beds, and a focus on native plant types that have a high survival rate.

Currently in Colorado, the market for xeriscape on all types of properties is still emerging. The primary interest comes from high end residential. This is a market going xeric for aesthetics and water costs, because they want to, not because they have to. Water is still so cheap in Colorado- $1.50 per thousand gal., that there is virtually no attraction from the property management sector. Most have stated bluntly that when the city arrives at their door with a fine for overwatering, they will do something- not before. The main ICI sectors that are thinking about water management are multifamily and HOA type properties. The reason is simple- their residents have watering restrictions on their own lawns, they pay for the common areas, and want the common areas to obey the same rules. This is the market that I work in, and it is very similar to Southern California. HOA and multifamily properties are still a little hesitant to take the leap of faith and hire a water manager for $10,000, and critical decisions still often die in committee.

Dallas and Northeast Texas

Starting in late 2005, this region began going into a drought. Lack of precip was not the only factor in this. The DFW area had doubled in population over 20 years, from three to six million. This area is one of the largest spots of irrigated turf in the SW U.S.

Storage capacity and distribution were already at limit in numerous areas. The drought brought this into sharp focus. While City of Dallas had enough reserves to avoid any restrictions, the smaller cities around them went into stage 3 in early Summer, now going into stage 4- no outdoor water use. Historically, this area has never had to think about water use levels. This is well illustrated by Highalnd Park's website, which mentions a GPCD level of 360 gal. The website states they hope to reduce that by 2%. What a sharp contrast to the efforts in Austin and San Antonio.

Landscape contractors in the area are at this moment learning about xeriscape design, BMPs for irrigation, and so on. Gene Reagan in Austin notes that there is a strong need to start certifying contractors locally to ensure BMP practices. He also says that water management of ICI and large residential needs to become a reality. He feels that water base prices are too low, a comment heard around the region.

Tony Rizo, president of the Dallas Irrigation Assoc., says there has been a little bit of progress pushing conservation. Homeowners are becoming aware of ET, drip, water budgets, etc. Homeowners are learning to use their controllers better, actually looking at their systems for the first time. It is fascinating to look at the city websites for the DFW area. Some cities have full blown conservation advice, while others never mention it.

Tony feels scheduling and budgets awareness is starting. The drought has done a lot to make homeowners think about their systems- heads straightening, stopping runoff, adding heads, etc. This has been a positive move from homeowners, and of course is driving the contractors. Local distributors are saying more about BMPs for irrigation. Printed material from the city on scheduling is helping. A lot has happened in a short period. The DFW area still has a lot of bad installers, who need to be brought up to speed on conservation. Tony is now using low volume nozzles, smart controllers, much more drip systems vs. turf.

Los Angeles Area:

I spoke to Nick Mrvos in Irvine Ranch, and Bob Galbreath in Santa Monica. Both feel that their public landscapes are doing very well on water management, thanks to lots of attention and central control systems. Mr. Galbreath says residential and ICI properties have not been looked into by the city. In the San Fernando Valley, I found many HOA and institutional properties that are very concerned about landscape water use levels and runoff, but unaware of existing programs. I noticed that xeriscape is being promoted in the press, but it is so easy to grow tropicals in the area, most residents are not looking for a desert/native landscape. I see a market for tropical xeriscape- a contradiction of terms, but a viable alternative to turf.
John Weidman of the Southern Cal metro water district says water management is a critical need, but the controllers will have to be firmly locked to ensure no tampering with the schedules. Southern California is a major year round market for ICI water management.

Manufacturers

The irrigation equipment manufacturers did not seem to notice the drought in New Mexico, maybe just too small of a market, and no one knew the drought would become so wide spread. The drought in Southern Cal really got everyone's attention, and by the time the Colorado drought hit, there was a major focus from the manufacturers for smart controllers, better drip components, etc. The situation in Los Angeles seemed to be the turning point for the industry. Now, with the state of California focused, and the EPA ramping up the watersense program, water efficiency is finally becoming a major market. Several manufacturers who saw this early on and invested are now seeing good results, such as Weathermatic, Calsense, and Walla Walla.

Summary:
The xeriscape remodel theme and efficient water turf market is already well established in NM, is now growing in Colorado, and will really emerge in Texas one or two years from now. It might not emerge in the Los Angeles area.

All of these markets are in different levels of water conserving landscaping, with NM ahead of the others. All of these markets need to encourage the practice of water management of large landscapes. This will take a shift in thinking from the property owners, who have relied on the mowing service to manage their water, and a shift within the landscape maintenance contractors, to switch from "green at all costs" to a water budget mentality.

As water prices rise in Colorado and California, this service will become seen as a necessity, and ICI property owners will respond.
We have seen a consistent disconnect on commercial properties- often the water bills for a property in Denver are paid in New York- they have no idea if their water use levels are correct, they just pay it. There is a steep learning curve for many ICI property managers re water conservation. In 2005 approximately half of all Boulder commercial customers went into their 4th tier- $10 per thousand gal.- most without noticing. Boulder goes to mandatory water budgets for all properties in 2007, but at this moment the ICI market there seems completely unconcerned about reducing use levels. The good news is our industry is already tooling up for this market, with the IA offering certification in water management.

There is a caveat here regarding water management- There has to be ongoing stewardship. A new mowing crew or sprinkler tech might be tempted- perish the thought- to turn the water up again to speed up turf growth. Therefore, initial savings could vanish without ongoing supervision.

Paying for water management as a new line item is a new and expensive proposition for ICI properties.
One novel approach is to offer the ICI property water management services in exchange for the realised savings for one or two years. This prevents the property from paying for services up front. The water manager spends $5000 up front, saving the property $20,000 per year, which is his pay for two years. After that the property goes on saving the same amounts. Sounds good on paper, but it is a path strewn with ball bearings- call backs, tampering, etc.

Some cities in the region are being very proactive, such as Albuquerque, San Antonio, Westminster Colorado and Austin. These cities use their monies to pay for toilets, audits, and so on. Other cities, such as Boulder, are very proactive, but relying on the property owners to pay for conservation upgrades. In these cities, the residential market has responded well, but the ICI sector has not. This is bad, since the ICI segment uses far more water per property than residential. The cities are torn between using a club or sugar cubes to get the properties moving.

So, large ICI type new install contractors are still lagging in xeric or water efficient designs, whereas the high end residential market is moving quickly towards sustainable low water landscapes.

I have not seen any of these cities really targeting the local contractors to enlist their help, but Gene Reagan in Austin, and the CLCA in Claifornia are working on this now. In my classes for contractor BMPs I stress to them that it is time to stop being an irrigation installer, and become an irrigation conservation consultant. I notice that currently about 30% of the contractors in Colorado are very concerned about conservation, uniformity, and runoff. About 5% in the Dallas area. The IA and CLCA water management cert. Programs will help this immensely, bringing the concept to the forefront.

The market for water efficient landscapes and water management will continue to grow throughout the southwest, and will even spread into the wetter parts of the country, as treated water costs rise and the need to conserve treated water and energy.

Water management has been a focus for a handful of us for several years, it's great to see the movement take off now, providing growth for our industry.

Don't be a drip---be a WWIP!

Karen Stewart, Water Conservation Specialist, Sr.
Austin Water Utility, Water Conservation Program
Austin, Texas

In Texas, landscape irrigation is regulated by the state agency, Texas Commission for Environmental Quality (TCEQ). Licensed irrigators are often involved with determining much of the commercial and multi-family irrigation use, as well as some residential water use. This water consumption drives the summer peak-day water use. In an effort to communicate the need for water conservation, the City of Austin Water Conservation Program, now with the Austin Water Utility, instituted an annual training for licensed irrigators. The WaterWise Irrigation Seminar provides licensed irrigators with the 8 hours CEU's needed for their license renewal. By completing the course and agreeing to support the City's programs, irrigators may also apply to be a WaterWise Irrigation Professional (WWIP). WWIP's are then put on a list to provide services to homeowners who need repairs. The City's irrigation auditors may hand out the list, or it maybe found on our website.

The annual WaterWise Irrigation training includes water conservation topics such as peak-day information, water availability, City of Austin ordinances on water waste and peak-day water restrictions, and water conservation programs such as irrigation evaluations and rebates. Other topics that have been covered include information about weather patterns presented by a meteorologist, backflow prevention and requirements, a turfgrass drought study, rainwater harvesting and alternate water sources, electrical troubleshooting, irrigation BMP's, Smart Controllers and ET controllers, and plant water requirements.

In order to publicize the training, a statewide list of licensed irrigators is obtained from TCEQ. Out of this list, a mailing is sent to the five county Austin metro area. Caldwell, Bastrop, Hays, Travis and Williamson counties all have irrigators that work in the Austin area. This is approximately 400 irrigators. The mail-out includes registration for the class, WWIP materials that list the qualifications, and an agreement to sign. (<u>See attached forms and sample registration</u>.) Some years we have more than one class, and sometimes we offer an 8 hour or 4 hour class. Up to 150 irrigators typically sign up for our classes. About half of those sign up to be WWIP's. One of the requirements is that the individual does business with Austin Water Customers. This criterion does not apply to all who attend. This annual class has earned a reputation for providing valuable information, and is anticipated by local irrigators.

While the author is the primary instructor, a large portion of the class presentations are made by guess speakers who are professionals in that area.

Field trips to see Central Control systems, weather stations, and location of the seminar such as the Lady Bird Johnson Wildflower Center and Umlauf Sculpture garden make the class interesting.

Water Conservation charges $50 for an 8 hour class. This class would be approximately $150 in the private sector which adds to its popularity. The cost of the class pays for the venue, breakfast, snacks and lunch or expenses of the speakers.

The class attendees are provided with handouts, plant guides for the Austin area, and other materials related to water conservation. Irrigation vendors and proprietary information is prohibited by TCEQ for CEU presentations. Therefore, at times we have invited vendors that pertain to the topic such as drip irrigation or ET controllers. At the end of the seminar, participants are given an evaluation form. The form asks not only about the quality of the seminar, but what topics would be interesting for future presentations. This is very helpful when planning the next year's topics. The evaluations are quite favorable.

At the close of the day, the participants receive their certificate of completion required by TCEQ, and the WWIP's receive a framed certificate every year to hang in their office, similar to yearly BBB (Better Business Bureau) stickers.

Requirements for City of Austin WaterWise Irrigation Professional (WWIP)

"It is declared that, because safe high quality drinking water is a precious resource, the general welfare requires that the water resources available to the city be put to the maximum beneficial use to the extent to which they are capable, and the waste, or unreasonable use, or unreasonable method of use of water be prevented, and the conservation of water is to be extended with a view to its reasonable and beneficial use in the interests of the people of the city and for the public health and welfare."
City of Austin Policy 4-21-55

1. Be a licensed irrigator that works for or owns a company that installs irrigation systems for City of Austin or Austin wholesale (MUD districts) water customers.

2. Attend a City of Austin WaterWise Irrigation Program (WWIP) Seminar (8 hours) yearly.

3. Fill out agreement form and return to COA Water Conservation office yearly.

   - Use MPR heads and nozzles
   - Promote City of Austin Efficient Irrigation rebates and auditing programs
   - Install systems at proper operating pressure
   - Promote the once every five-day watering calendar
   - Install rain shut-off devices and other water conservation equipment

4. Irrigator will receive a certificate at the seminar.

5. Remain a member in good standing by following the agreement, attend the required educational seminar and sign the agreement each year.

6. Companies that are certified are responsible for all employees and are responsible for training those employees. It is recommended that individual employees become Certified WaterWise Professionals.

7. Three or more valid complaints by customers about an individual or company will be grounds for removal from the WaterWise Professionals list.

For more information call Karen Stewart, Water Conservation Specialist at (512) 974-2978.

WaterWise Irrigation

Professional

WaterWise Professional Certification Application
(For Licensed Irrigators only within the Austin ETJ)
Must be filled out each year. Not for seminar registration

City of Austin Water Conservation

Please print clearly:

Applicant's Name____

Job Title____ Irrigator's License Number____________

Business name____

☐ Commercial installations ☐ Residential installations

Business address____

City________________________ Zip_________________

Business phone number_____________________________ pager or mobile_________________

E-mail Address____

WaterWise Certified Professional last year? ☐ yes ☐ no

Please check all that apply:

☐ Landscape maintenance ☐ Landscape Contractor ☐ Irrigation installation ☐ Irrigation repairs

☐ Other ___________________________________

☐ Accepting new clients ☐ Not accepting new clients

The City of Austin will provide water customers with a list of WaterWise Professionals to choose from for repairs or installations. You will receive a certificate to display at your business.

WaterWise Irrigation Professional

WaterWise Irrigation Program Agreement

I___________________________, a licensed irrigator, agree to comply with the City of Austin's water conservation WaterWise Irrigation Program, by assisting customers with reducing peak day water demand in the summer months. I agree to adhere to the COA Ordinance Article II, Chapter 4-2 of the City Code Stage 1 and Stage II Water Use Management Criteria, and the water waste** provisions:

Systems may not be operated that have broken sprinkler heads, or with leaking valves. Permanently installed irrigation systems with broken heads, with a head that is out of adjustment and spraying more than 10% of the spray on a street or parking lot, or that mist are a violation of the water waste ordinance. Irrigation systems must not allow a substantial amount of irrigation water to run off a property or to pond in the street or parking lot to a depth greater than 1/4 of an inch.

If the City of Austin reaches Stage II Water Use Management Criteria, I will assist my customers in following the mandatory water conservation schedule.

To the best of my ability:

- I will maintain and install systems that limit watering hard surfaces and waste of water.**
- I will install water conservation devices: MPR heads, drip irrigation, check valves, rain shut-off devices and manual flow control valves.
- I will install and maintain systems at proper operating pressure.
- I will recommend City of Austin Water Conservation Programs when appropriate.
- I will follow manufacturer's recommendations for head spacing (head-to-head).
- I will install controllers that have multiple programs, multiple start times, and are 5-day programmable and promote the five-day watering calendar.
- I will help the customer develop a water budget, for that property, based on irrigated area.

Signed

____Irrigator's License Number______

____Date ___________
Printed name

(For City of Austin Use Only)
Date Received _________________
Approved (date) By ____

WaterWise Irrigation Seminar, Thursday, February 26, 2004

LBJ Wildflower Center
4801 LaCrosse Ave 8 am – 5 pm

SEMINAR REGISTRATION ONLY   PLEASE PRINT CLEARLY
RETURN THIS SLIP WITH REGISTRATION FEE. FILL OUT ONE PER PERSON
NO REGISTRATIONS OR FEES WILL BE ACCEPTED AT THE DOOR!

Sign up early space is limited! Deadline February 20, 2004

Make the Check out to City of Austin, there will be no refunds.

Applicant's Name___________________________________Irrigator's License Number____________

Business name_____________________________________JobTitle____________________________

Business address____City_______________ Zip________

Please send my registration confirmation to this address (if different than above):

____

Business phone number__________________________pager or mobile__________________________

Email address: ____

____ I install/repair irrigation systems in the City of Austin, I have included my WWIP certification application and signed agreement so that my company can be listed on the WWIP list.

____ I have included $50 check or money order for 8 CEU's.

Lunch will be assorted sandwiches with vegetarian option.

I have special dietary needs: (please explain) ______________

____

Mail checks or money orders City of Austin Water Conservation   PO Box 1088, Austin Tx 78767

Or to our office at 625 E 10th Suite 615
Questions? 974-2978

Water Conservation Education using Children's Water Festivals: experiential learning and quality of retention

Mahbub Alam[1]

ABSTRACT:

Children's Water Festival in Colorado followed the model developed by the Groundwater Foundation in Nebraska. The first event in Colorado was held in Greeley, Colorado. The following year in 1992, Children's Water Festival was introduced in Delta-Montrose area in western Colorado. The very first event was a grand success. The school district, community intellectuals, and government agencies cooperated and subsequently adopted Children's Festival as an annual educational event for school children of the wider community. The program provided an experiential learning opportunity to fourth and fifth graders. The children enjoyed the outdoors and learned from fun filled activities related to water resources, conservation, pollution prevention, and aquatic habitat of wild life, fisheries and other organisms. A survey was conducted on the tenth anniversary of the program in 2001 to evaluate the quality of retention of this out of class education on water by students and the degree of commitment of the organizers and teachers. It also aimed at finding how this knowledge has impacted the youth in implementing conservation practices in their daily life. The results are presented.

INTRODUCTION:

Water is life. Life on earth as we know it would not have existed without water. Three fourths of the earth's surface is water, yet supply of fresh sweet water is becoming scarcer every day as the demand for growing food, manufacturing industrial goods and every day domestic use increases with the increase in population. At the same time the incidence of degradation of water quality is also rising from improper human activities. It is therefore essential to conserve water in daily uses and curb unnecessary waste. At the same time, it is also imperative that the water bodies, both surface and ground waters be protected from pollution and contamination. Over use of irrigation and fertilizer for crop production in the Central Platte River Basin within High Plains of Nebraska raised the nitrate level of groundwater above allowable Maximum Contaminant Level (MCL) of 10 ppm. Susan Seacrest, Director of the National Arbor Day Foundation created The Groundwater Foundation in 1985 (www.groundwater.org) in response to the situation that threatened public health. One of the key programs of the Groundwater Foundation was Children's Water Festival. The daylong event is targeted to children of grades 4-5 for to instill in their mind the importance of water conservation and water quality protection in a fun filled experiential

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learning setting. This event was introduced in other states. The author attended such a program in Greeley, Colorado, at Aims Community College. In turn, he introduced the same in Delta and Montrose Counties, Colorado, in 1992 with the help of local School District, government and non-government agencies of the locality. A list of presented materials is appended to the report.

METHODS:

In 2001, during the 10th annual presentation of the Children's Water Festival event, the author of this report decided to attend the Children's Water Festival program in Delta, Colorado, the place he left in 1996. The idea of surveying the participants came about at the site and survey instruments were developed on short notice. The survey forms were distributed to the presenters, teachers, attending parents, and volunteers at the site of event. Student evaluation forms for the current year participants were distributed in classes the following day with the help of the class teachers. The current participants were grouped according to ages, which ranged from 10-12. Questionnaires were also developed to obtain feed back from past participant students now in upper grade levels (5-12). The questions were simple and were geared to assess their level of satisfaction towards the program, impact on behavioral change, desire for continuation of the program. Questions were also asked to assess what were the short comings and suggestions were solicited for improving the program.

RESULTS AND DISCUSSION:

Class Teacher response: Eleven teachers from three elementary schools currently participating in the program responded. One of the teachers present at this event of 2001 was involved in the program for last nine years and four of them have participated before. The remaining five responded that this was their first direct involvement. All of them indicated that they do discuss and prepare the students prior to the event and carry on a follow up session after the water festival event. They ranked Children's Water Festival as an excellent experiential learning tool and recommended that this program be continued. Most of them have included this event as a part of class curriculum knowing that the School Board has approved the same. Four of the respondents did not know if this was an approved program from the School Board (details appended).

Response from Presenters: Eighteen presenters responded and ranked the Children's Water Festival as an excellent (10) or good (8) educational event for the school children. All of them look forward for participating in coming years. Eight of the presenters were new and some of the remaining presenters have been involved for past nine years. Their response to the question what keep them motivated to return, they all answered; it was the children – their excitement, curiosity and interest, and the new perspective they bring. All responded that the energy emanated by the children keeps them energized and motivated. The suggestion for future improvement offered by the presenters was the need for readily available plenty of cool drinking water. They also suggested that the event may be spread out to two days with presentations lasting for half a day period. Students become exhausted by the afternoon, especially on a hot day.

Student participants of past events: In this group students from 5th to 12th grade were targeted. It was difficult to distribute these forms to all schools within the district. The number of returns was variable, abruptly falling for 12th grade. It was already the month of May and senior students were busy finishing up their program in the school. It was heartening to find that they remembered the event very clearly and that it has affected how they feel about water. The twelfth graders responded that they do practice conservation by taking shorter showers, using less water in irrigating lawns and washing dishes. The overwhelming number of response came from the 7th graders from all three middle schools. Seventy-six students returned a completed survey form. Forty-five of this group who has attended Children's Water Festival three years ago responded that the memory of what they learned affects how they feel and take care of water. About the same number responded that they practice conservation in their daily life, which is encouraging. The practices adopted for conservation according to the seventh graders extended beyond taking short showers, turning off the faucet while brushing teeth or washing face and hands, having full load in the washing machine etc. to conserving electricity, recycling, checking Grandma's well for pollution, and installing special low volume faucets. The question on whether the students will "always" remember the Children's Water Festival was far reaching. Understanding or interpreting the word "always" can bring different response. Even though the intent of the question was to find out if they will remember the event or what they learned the students may interpret it as whether they will constantly remember the events. As result the answer falls to twenty-nine against forty-five who say that the memory of that day affects their feeling and how they take care of water. Question phrasing is important and care is needed when developing questionnaire. As mentioned earlier, these instruments were developed in a hurry while the event was in progress.

CONCLUDING REMARKS:

It is the opinion of the author that the Children's Water Festival stands out as a highly successful experiential educational program for school children who will become future leaders. It is desirable that this program be expanded nationally and internationally. The author acknowledges the support of the school districts, fellow co-workers in state and federal agencies, community leaders and businesses, and most of all, teachers and parents. Due to space limitation, it was not possible to mention them individually (acknowledgement appended).

REFERENCES:

Masters & Associates. 2002. Follow-up Behavioral Impact Study on Groundwater Foundation Student Education Programs: Final Report

Miller, J. 2003. The History of the Children's Groundwater Festival. http://www.groundwater.org/pe/festival_history1.html

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Appendices

Programs presented over the years:

– Water Safety is no Accident: Learning the basics for being safe around water. Learn the Reach, Throw, Go for water rescue and toss ring buoys at floating targets. Learn hypothermia affects body.

- How High is the River, Smarty: Learn the importance of knowing stream and river flow. Hands on flow measurement.

Children learning about stream flow measurement by using simple float device like bath tub toy ducks. The results were compared with electronic flow measuring device.

- The Water Wizard: Challenge the wizard in a water knowledge contest.
- Pondering at the Pond: Examine the tiny organisms that live in local ponds using the microscope.

- Selenium Plinko: The game illustrates how a drop of water moves through high selenium ground and takes selenium to lakes and rivers. Discuss negative impact of selenium and other salts they may dissolve and move to water.
- Watershed Wonders: Review Water Cycle and understand protecting watershed.
- Would you share your water? A visual lesson on the amount of water in the world.
- There is salt in river: Learn how salt loading of the Colorado River and tributaries occurs as water passes through Mancos Shale – the source of salt in our soil and underground rocks.
- Snowpillows: Learn how snow turns into water, and how to measure how much water is in that snow.
- Go with the flow: learn about the history of the irrigation water distribution system and how we keep track of how much water is used. Learn how to set siphon tubes and also how to be safe around canals.
- A River Runs Through it: Learn how groundwater and river interacts using groundwater model and learn about benefits river provide including how it functions.

Children dressed up as a snowflake-water drop and beneficial worm to provide fun and joy to fellow students during the fun filled experiential learning day.

Children learning about water quality, how salinity is measured, and discuss its effect in agriculture, industry, and domestic water use.

Children learning how to protect watershed

Water Festival Survey Answers from Presenters

1. **Since when did you start to present at Children's Water Festival?**
   1st year – 8 2nd year – 5 3rd year – 1 5th year – 2
   6th year – 1 9th year – 2

2. **Have you participated every year since then?**
   Yes – 15 No - 4

3. **How did you get volunteered to do the presentation?**
   - I choose to volunteer as I think this program is good.
   – I had someone "volunteer" me, my zeal for relaying info
   – You have to like this type of situation to effectively be able to do this outreach.
   - I am the park interpreter.
   - Biology teacher selected me because I am his best student.
   - It's part of my plan of work.
   - I did it last year.
   - Solicitation through Master Gardener's.
   - My own accord.
   - Part of our yearly schedule is to participate.
   - I feel it is an agencies and professional responsibility.
   - It was my first day as a ranger and I was volunteered for it.
   - I do not do the presentations, but I make sure the presenters are there and have supplies.

4. **Do you enjoy making presentations to the children?**
   Very much – 9 Much – 9 Not so much – 0

5. **Working with children is tiring. What keeps you motivated?**
   - The kids, they always have a new perspective.
   - Working with kids is energizing and always motivates me.
   - My love for teaching. The children's excitement.
   - Children's curiosity & interest.
   - It's only one day. It's fun.
   - It's a worthwhile subject matter. The a.m. when it is still a little cool and the kids are fresh! Especially when they already know the stuff!
   - The crawdads!
   - The ice water at our station. The kids really responded to what it was like feel ice water. (Part of hypothermia safety.)
   - Working with the children is not tiring; otherwise I don't think the adults who are presenting would be presenting – It pains me to see the sheer exhaustion of the face of these kids who have to endure 12 stations. (And it was not just my station!!)
   - Diet Pepsi, and the joy in their faces.
   - I like to see their reactions to various information.
   - We make a viable safety message for the kids.
   - Lots of coffee.
   - Friends

6. **Write something to express your heartfelt feeling about Children's Water Festival.**
   - This was great. I look forward for next year.
   - The children make it worth while to spend my time being involved at the festival.
   - Working with kids.
   - I think it's a good fun way for the kids to learn.
   - I think it's a great venue to reach out to the kids – the different presenters & the different aspects of water & its effect on the different interests, it is important for the kids to understand. I think you should continue with it. Continue to ask for input from presenters.
   - I love water and it loves me.
   - The coordinated efforts of everyone involved is to be applauded – and congratulated –

especially Terri Monroe – Good Job!
- I got a tan.
- Fun and rewarding.
- The programs deal with one of our most valuable resources.
- Good event that kids enjoy and also learn.
- I believe that all of the students took home some new knowledge with them.
- Could be better.
- Good experience for all.

7. How do you rank the Children's Water Festival as an educational event for the children?

Excellent – 10   Good – 8   Fair – 0 Poor – 0

8. List some suggestions to improve Children's Water Festival.

- Nothing. It was GREAT!
- Some events are very loud and active and this can be distracting.
- Water at every station (to drink). Louder horn (we were too far away).
- Keep it the same but have circus clowns come with water balloons in the shape of puppies.
- Allow a little more time for each station.
- More activities – water balloons.
- Better grass
- More water.
- By the afternoon children are exhausted. The children are over-stimulated, and no longer have the ability to retain presented materials – My recommendation would be to have 2 half day sessions, so as to accommodate all of the schools – and to somehow utilize a space where children are not drained by the elements, i.e. heat, sun wind, and rain. To expect 2 people to present 12, 20 minute presentations is unrealistic – the quality of the information disintegrates over time, especially by afternoon! Let us think of the kids and not our own inconveniences!!
- Consider doing 2, ½ days – half the kids one morning and the other half the next day. We really loose them in the afternoon – too hot and tired. Speakers get tired too!

Water Festival Survey Answers from School Teachers

1. How many years have you participated in Children's Water Festival?

1 year – 6   2 years – 1   3 years – 1   6 years – 1   7 years – 1   8-9 years – 1

2. Do you prepare the students before the festival date about what they will learn?

Yes – 11   No - 0

3. Do you have a follow-up session to evaluate what the students have learned?

Yes – 11   No - 0

4. Is Children's Water Festival a part of class curriculum?

Yes – 9   No – 2

5. Has this program been approved by school board?

Yes – 7 No – 0   Don't know – 4

6. Tell us why you like Children's Water Festival program?

- I like Children's Water Festival because it is a fabulous hands-on experience.
- Hands-on way to learn about how water affects our lives.
- The kids hear about the things we've read and talked about in another format.
- The combination of the science, history, and technology was great.
- There were many hands-on science reinforcement activities.
- Hands-on activities help children appreciate the importance of water and the complexity of some issues surrounding it.

- Because we live in a semi-arid climate water conservation & education affects everyone.
- The main reason would be for the water safety.
- It is an extended experience in Science. I have especially appreciated the conservation kits and Water Wise Program in the class and how interrelated they are.
- Offers students new ways of learning about water and its importance. It's an application of information to the real world.
- The students loved learning about water. They love learning new concepts in different ways.

7. In your opinion, does this program help children to think about conservation of water or other resources?

- Yes, it does help children become aware of water issues.
- Definitely.
- Absolutely! This program got children and parents involved in the conservation of water at school as well as in the home.
- Yes, most of the stations relate to their level.
- Yes, my students have discussed at length. They even told me how concerned they were about the janitor cleaning our sidewalks with an open hose.
- Yes, some don't realize all the different ways to conserve.
- Yes, because this typically is not a high education priority until droughts impact our community.
- Yes, especially the models and the stations where the kids were involved.

8. Would you like this program to be continued?

Yes – 11 No – 0

9. How do you rank Children's Water Festival as an experiential learning tool?

Excellent – 7 Good - 4

Water Festival Survey Answers from Students Who Have Attended Children's Water Festival in the Past.

Grade 5

1. What one thing do you remember most about the Children's Water Festival?

- I remember the game.
- Learning about how different salmon live and how difficult it is.
- Water Wizard
- Salmon swim up stream and there is not a lot of fresh water on earth.
- That most fish swim up stream to lay their eggs.
- The one thing I remembered is that we have 3% fresh water and the rest is salt water.
- Learning how to conserve more water.
- Learning about water and having fun.
- How the salt gets in the water.
- Stuff cows are used for.

2. Do you think you will always remember the Children's Water Festival?

Yes – 8 No – 8

3. Does this memory affect how you feel or take care of water?

Yes – 13 No – 2 Sometimes – 1

4. Do you practice conservation?

Yes – 8 No – 8

If yes, what are the things you do for conservation?

- Turn off water while brushing teeth.
- Take quick showers.
- Don't waste water that I drink.
- Use the shower head, etc., that was provided.
- Water the lawn in the evening
- Don't water the lawn in the afternoon.
- Use one inch of water on the lawn.
- Take showers instead of baths.
- Wash the car with a bucket.
- Don't leave the hose on.
- Take 10 minute showers.
- Use water conservation stuff.
- Don't leave glasses of water unattended.
- Don't use so much water in the bath.

<u>Grade 6</u>

1. What one thing do you remember most about the Children's Water Festival?

- When we answered questions wrong and got squirted.
- The Wizard Game.
- There was water.
- I remember trying to throw the life saver
- Water and its uses.
- How to conserve water.
- The Plinko game.
- Watching the creatures squirm around under the microscopes.
- The water in the trailer.
- The bath toys floating in the ditch.

2. Do you think you will always remember the Children's Water Festival?

Yes – 5 No – 11

3. Does the memory affect how you feel or take care of water?

Yes – 7 No – 9

4. Do you practice conservation?

Yes – 4 No. – 11 Sometimes – 1

If yes, what are the things you do for conservation?

- Take quick showers.
- Help fix drains.
- Water lawn for ½ an hour.
- Turn off the water when brushing teeth.

<u>Grade 7</u>

1. What one thing do you remember most about the Children's Water Festival?

- Throwing the lifesavers to save a drowning person.
- The Water Wizard
- It had to do with water.
- Don't Know
- When they showed us that gum is made from cow fat and then we had to eat it.
- It was kind of fun.
- The fake river demonstrating erosion.
- I remember all of the germs and organisms in the water.

- How to save water.
- Getting to eat M&M's if you answer questions right.
- All kinds of kids got together to do a whole day of water activities.
- Erosion
- The water in the dirt.
- Getting squirted during the game.
- The activities.
- How to clean water.
- We had water geography questions.
- It was boring
- Measuring snowfall.
- Learning how bottled water is produced.
- Water fights
- The casting practice in the lake.
- Setting the tube for the irrigation thing.
- Blowing bubbles in the big pool.
- There isn't as much water in the world as there used to be because of wasteful people.
- Teachers yelling at us to get away from the pond.
- The test
- You waste lots of gallons if you leave the water on while brushing your teeth.
- Water safety

2. Do you think you will always remember the Children's Water Festival?

Yes – 29 No – 47

3. Does the memory affect how you feel or take care of water?

Yes – 42 No – 31 Kind of – 3

4. Do you practice conservation?

Yes – 42 No – 34

If yes, what are the things you do for conservation?

- I don't use a lot of water for showers
- I turn off water when I'm brushing my teeth.
- Have a full load in the washing machine.
- Make sure the faucets are off.
- Have a full load in the dishwasher.
- I don't pollute water.
- Recycle
- I drink all the water that I pour.
- I don't leave the light on.
- Water
- I don't use a lot of bath water.
- I don't leave water on all the time.
- Take showers, not baths.
- Turn off the water while washing my face.
- We have special faucets for our sinks.
- I don't have water fights.
- Electricity
- Food
- I turn off the water when I'm done using it.
- I collect cans and recycle them.
- I try not to flush the toilet every 2 seconds.
- I don't wait for water to get cold.
- Throw away trash
- Use less water every day
- Water lawn late in the day
- I check my Grandmas well for pollution.

- Don't use that much water to wash your hands.
- Don't let the toilet run.
- Don't run the water bull blast when I rinse dishes.

Grade 8

1. What one thing do you remember most about the Children's Water Festival?

- Lot's of games and cool activities.
- Looking through microscopes at bugs.
- Talking about the birds of the lake and of Colorado.

2. Do you think you will always remember the Children's Water Festival?

Yes – 2 No – 3

3. Does the memory affect how you feel or take care of water?

Yes – 1 No – 3 Sort of – 1

4. Do you practice conservation?

Yes – 4 No – 1

If yes, what are the things you do for conservation?

- Don't leave water on.
- Recycle cans.
- Have water-saving faucet things from my 5th grade sister.
- Turn off faucet while brushing my teeth.
- Bottle water for future use.
- Don't use as much water for taking baths and showers.

Grade 9

1. What one thing do you remember most about the Children's Water Festival?

- The big model of the river and erosion.
- There were many people and different stations.
- Irrigation, water flow, currents and racing toy boats.
- Irrigation and habitat
- Learning how to siphon water

2. Do you think you will always remember the Children's Water Festival?

Yes – 3 No – 7

3. Does the memory affect how you feel or take care of water?

Yes – 5 No – 5

4. Do you practice conservation?

Yes – 4 No – 5 Sometimes - 1

If yes, what are the things you do for conservation?

- I use sparingly.
- Hunting, hunters were the first conservationists.
- Planting trees.
- Take shorter showers
- Turn off faucets.

Grade 10

1. What one thing do you remember most about the Children's Water Festival?

- Looking through the microscopes.
- Getting out of school.

- Working with the children.
- The model of the water and erosion.
- Learning how to start the irrigation pipes.
- Installing new shower heads to conserve water.
- It was interesting.
- The water cycle exhibit.
- Learning not to waste water.

2. Do you think you will always remember the Children's Water Festival?
Yes – 5 No – 7

3. Does the memory affect how you feel or take care of water?
Yes – 6 No – 5 Yes & No – 1

4. Do you practice conservation?
Yes – 2 No – 9 Yes & No – 1

If yes, what are the things you do for conservation?
- Don't over water fields.
- Don't waste water.

<u>Grade 11</u>

1. What one thing do you remember most about the Children's Water Festival?
- Being on T.V.
- How many kids and interesting things there were.

2. Do you think you will always remember the Children's Water Festival?
Yes – 4 No – 0

3. Does the memory affect how you feel or take care of water?
Yes – 1 No – 3

4. Do you practice conservation?
Yes – 3 No – 1

If yes, what are the things you do for conservation?
- Conserve electricity
- Don't use a lot of water
- Turn water off when shaving my legs.

<u>Grade 12</u>

1. What one thing do you remember most about the Children's Water Festival?
- The lady who gave us jelly beans for telling her she took too many showers, washed her car too much and watered her lawn.

2. Do you think you will always remember the Children's Water Festival?
Yes – 0 No – 1

3. Does the memory affect how you feel or take care of water?
Yes – 1 No – 0

4. Do you practice conservation?
Yes – 1 No – 0

If yes, what are the things you do for conservation?
- Shorter showers. - Water the lawn less. - Use less dish water.

Water Festival Survey Answers

Students Attending - Age 10

1. I enjoyed the Water Festival (mark below how you feel).

Very Much – 26 So Much – 12 Not So Much – 5 Not At All – 0

2. What are three things that you will remember?

- Water Wizard
- The water cycle
- Crawdads
- The River
- Reach, Throw, Go
- Salmon go through a hard life.
- Selenium is harmful to fish and birds.
- 10 inches of snow is 1 inch of water.
- Some of the things that are made from cows.
- Topsoil, subsoil
- Hypothermia
- We use the same water as the dinosaurs did.
- Water picks up suet.
- I learned that shale is everywhere under the ground.
- H-O-M-E-S
- I always have a buddy.
- Looking at some of the creatures that live in a pond.
- We use the river today for what people used it for 100 years ago.
- Make-up is made of fat.
- Glue is made from hooves.
- Plinko
- How much salt is the river
- Always go swimming with a buddy.
- Never try to swim across the river.
- The one about the sand
- Saving water is better than wasting.
- 98% of the water is salt water

3. What are three things you did not like so much?

- It got boring after awhile.
- I don't think you should change a thing.
- The heat
- Learning what things are made from cows.
- Water Wizard
- The wind
- Keeping our arm in ice water.
- Walking around.
- We had no breaks.
- Snow Pillows
- Plinkos
- Some centers repeated everything over & over.
- I learned more at stations that had activities.
- Planning would have helped.
- We didn't get to catch animals
- We didn't get to see the fish or crawdads
- We didn't get to look in the telescopes.
- Some stations were boring.
- The Heat
- The guy with the sand

- Short lunch
- I did not like the very aggressive teacher
- The water cycle

4. What are your suggestions to make the festival better?

- Play more games.
- Have it in the shade.
- Let us swim.
- Have it indoors.
- Don't change a thing.
- Let us fish.
- Have different themes.
- Explain more
- Have more breaks
- Get people wet more often.
- Some stations could have been longer.
- Don't tell us what comes from cows.
- Next time I want to catch animals.
- I wanted to throw rocks in the river.
- Have a longer lunch.
- We needed a recess
- Have more Water Wizard questions.

5. Would you recommend the Water Festival to your friends?

Yes – 43 No – 1 No answer - 1

Students Attending - Age 11

1. I enjoyed the Water Festival (mark below how you feel).

Very Much – 60 So Much – 54 Not So Much – 13 Not At All – 3

2. What are three things that you will remember?

- Water Wizard
- The salmon activity.
- Sticking my arm in the cold water and learning of hypothermia
- Water safety
- Selenium is metal
- The water cycle.
- That all of the cow is used.
- Defining soil
- Not to waste water.
- The water river trailer.
- All of the different games.
- Looking at the crawdad.
- How much salt is in the water.
- How much snow weighs.
- Salt can be rocks.
- Water runs off dirt faster than grass.
- Not to dump oil on the ground
- Hooks and Ladders
- Looking in the microscope
- To not pollute water.
- Why water is important

- The wildlife habitat group
- I will remember that HOMES will help me remember the 5 great lakes.
- Not to take long showers.
- The Water Plenko
- Recycle when I can.
- I will remember all the fun that was provided.
- I will remember all the information I learned.
- That all kinds of pop have salt in them.
- Not to litter.
- Bullfrogs eat about anything smaller than themselves.
- You can save a drowning person with a stick.
- H2O is the molecular formula for water.
- How much water is in the ocean.
- The san box.
- What non-point source pollution means.
- I will remember not to put too much fertilizer on the lawn.
- Hydroelectricity
- That 97% of the earth is water.
- I learned that 55% of your body is water.
- I learned that 24 million people drink Colorado water.
- I will remember that it is important to take care of the environment.
- I will remember the faucets you gave us.

3. What are three things you did not like so much?

- The heat.
- The cow station.
- Putting our hands in the freezing water.
- The dirt station.
- The pond section because fish were dead or dieing.
- Having to listen with no activity.
- Water safety
- The River stand.
- I didn't like "Could you share your water?"
- The Water Wizard station.
- To have to sit and not do anything.
- I didn't like the snow station.
- The CD rom game.
- Not all the stations were fun.
- Having to walk.
- I didn't like the Watershed wonders station.
- The loud noise that came from the horn.
- The microscopes. The pictures were gross!
- Sitting on the ground.
- Not enough water to drink or water breaks.
- I didn't like the water cycle.
- I didn't like the salt station.
- I did not like that we only had a little bit of time at each station.
- There were too many stations.
- The crawdads.
- I didn't like my apple, it was rotten.
- Too long of a break between stations.
- Not having a very long lunch break.
- Not having any shade.

- Having to eat a cold lunch.
- I whish there weren’t so many sit down and learn stations and more hands-on activities.
- I didn’t like how my classmates didn’t pay attention.
- The shell thing
- The fact of not having much water to drink.
- I had a terrible headache all day.
- When they talked about something else other than water.
- Not being able to participate at every station.
- Some stations didn’t give enough detail.
- Being in a sort of dirty area.
- I didn’t like the recycle station.
- I didn’t like the smell of the lake.
- Having to wait for lunch.
- Some of the people did not talk very loud.
- I didn’t like that we couldn’t go swimming.
- I did not enjoy the immature helpers.
- Each station lasted too long.

4. What are your suggestions to make the festival better?

- I have no suggestions; I enjoyed it the way it was.
- More activities
- More shade.
- Make every station active.
- Let us swim or get wet.
- More hands-on activities.
- WATER – Get some water.
- Have a longer lunch.
- More water and bathroom breaks.
- Have this on a cooler day.
- Make it all day long.
- Having it inside.
- Having seats set out for the kids.
- You should have a water balloon throwing contest.
- Talk more about water.
- Don’t have as many stations.
- Let people visit the station they want.
- Having it for less time.
- Have more live animals.
- Tents at every station even during lunch.
- Talk louder.
- Practice safety more.
- No loud air horn.
- Let us go down to the pond.
- Leave the trees and bugs alone.
- I would like to have the rubber ducky race.
- Having more chances to participate in activities.
- Have less kids at each station.
- Have better things.
- Have a snack bar.
- Give oranges not apples.
- Eliminate the dirt station.
- Ditch the crawdads.
- Break up our class into smaller groups.
- Be more prepared.

5. Would you recommend the Water Festival to your friends?

Yes – 120 No – 10

Students Attending - Age 12

1. I enjoyed the Water Festival (mark below how you feel).

Very Much – 9 So Much – 6 Not So Much – 2 Not At All – 0

2. What are three things that you will remember?

- Save water.
- The Water Wizard.
- The games.
- The water safety station.
- Learning about the water cycle.
- How hot it was.
- Don't pour oil on the ground.
- Don't pollute the water.
- The wild life and water animal station.
- I will remember what I learned about fish.
- You can't drink salt water.
- Don't build houses next to rivers.
- Dams make energy.
- How much water is in me.
- The ice boxes
- The river model.
- I will remember how much fun I had with my friends.
- Our lunch was very good.
- All the fun stations.
- I learned that water is valuable.
- Water is good for you.
- How much snow weighs and all the facts at the snow station.
- I will remember the salmon game.
- I will remember the buzzer.
- Hypothermia.

3. What are three things you did not like so much?

- It was too hot.
- No shade.
- Some centers are boring.
- There were too many stations.
- Us not getting very wet.
- Salt station
- The air horn
- All the talking
- That now I know that gum is made out of cow.
- I didn't like the pond.
- I didn't like putting my hand in the cold water.
- I didn't like to sit and not have anything to drink.
- I didn't like to see the kids chew tobacco.
- I didn't like that we had to sit on the bus with other people.

4. What are your suggestions to make the festival better?

- Have more stations.
- Make the centers not so boring.
- Let us swim or get wet.
- Make it in a shady place.
- Let us use the bathrooms and get drinks more often.
- Make the centers last longer.
- Have a water balloon activity.
- Do it when it is not so hot outside.
- Get rid of the air horn.

- I have no suggestions, I liked it just the way it is.
- Make the stations closer together so we don't have to walk very far.
- Don't make us stand all day long.

5. Would you recommend the Water Festival to your friends?

Yes – 415 No – 2

ACKNOWLEDGEMENTS

Children's Water Festival Committee:

- Mahbub Alam, Organizing Chair, Colorado State University Cooperative Extension Salinity Control Project, Delta
- John Almy, USFS, Delta
- Bob Balerio, Montrose Co. Joint School District #RE-1J
- Richard Antonio, CSUCE Salinity Control Project, Montrose
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- Jerry Thrush, DOWR, Montrose
- Jone Wright, US Bureau of Reclaim, Grand Junctin
- Carl Zimmerman, Colorado State Soil Conservation Board, Grand Junction

Presenting Organizations:

- Bill Heddles Recreation Center, City of Delta
- Colorado Division of Water Resources
- Colorado Division of Wildlife
- Colorado Soil Conservation District
- Colorado State Soil Conservation Board
- Colorado State University Cooperative Extension, Salinity Control Project
- Delta High School
- Montrose Recreation District
- U.S.D.I. Bureau of Land Management
- U.S.D.I. Bureau of Reclamation
- U.S.D.A. Forest Service
- U.S.D.A. Soil Conservation Service
- Uncompahgre Valley Water Users Association

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- Water Education Foundation, Sacramento, CA

How Water Budgets Can Increase Flexibility for Irrigation Professionals

Leslie Martien and William B. DeOreo. Engineer, Aquacraft, Inc., Boulder, CO 80302

Water budgets have been a water management tool for golf courses, parks, and large commercial properties for some time now, particularly in the drought-stressed western regions. As the tools and information needed to manage residential irrigation are becoming readily available, some utilities are beginning to adopt residential water budgets as a viable conservation measure. The authors of this paper will discuss:

•What is a water budget •How a water budget works •The necessary tools and information needed to develop a water budget •The benefits to the irrigation industry of using water budgets •How a water budget will help your clients •Ways in which a water budget provides you with more flexibility

As more utilities adopt water budgets it is incumbent upon irrigation professionals to develop a thorough understanding of this excellent water management tool.

A Formula for Success: Save Water, Increase Business, Advance Industry Professionalism, Achieve Community Goals

Dana Nichols and Patricia T. Garza. Water Conservation Planner, San Antonio Water System, P.O. Box 2449, San Antonio, TX 78298

Communities around the country are grappling with how best to manage their water resources, and San Antonio is no different. Through extensive community and stakeholder cooperation San Antonio has continued to reduce both its per capita water use and over all water use even as population continues to increase. With a 9 to 12 month growing season, and intermittent drought conditions, landscape irrigation continues to account for a significant portion of water use. Within this framework the local irrigation industry, water utility and city have found a formula for success that neither compromises industry standards, community goals for water reductions or landscape quality. It's resulting in more business too. Come learn about this formula for success and get ideas on how you can implement this formula in your own backyards.

Author Index

A

B

J

K

L

M

N

O

P

T