TECHNICAL SESSION PROCEEDINGS

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Enhancing Adoption of Site-Specific Variable Rate Sprinkler Systems

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Abstract: Existing irrigation technologies are well advanced and would conserve large amounts of water if fully implemented. Adoption of site-specific technologies could potentially extend these water savings even more. However, more than twenty years of private and public research on site-specific variable-rate sprinkler irrigation (SS-VRI), also called zone control, has resulted in limited commercial adoption of the technology. Competing patents, liability and proprietary software have affected industry's willingness to move into a new technology area, but sales of these machines are increasing. Documented and proven water conservation strategies using site-specific irrigation are quite limited, and its cost-effectiveness has not been demonstrated. Marginal costs associated with site-specific technologies are high. Thus, SS-VRI is primarily being used for eliminating irrigation and chemigation on non-cropped areas of a field or for land application of liquid agricultural and municipal wastes. Various SS-VRI technologies for general crop production are to beginning to slowly gain widespread acceptance; however, they are operated considerably below their potential capabilities, which is expected to continue. Currently, these systems are largely focused on addressing symptoms of poor water and nutrient management. This relatively low level of management is where the technology is expected to stay in the future unless much higher costs for water and the implementation of substantial economic incentives for compliance with environmental and other regulations become significant factors. Research on SS-VRI technologies could also enhance management of uniform irrigation technologies. In the short term, attention must be given to addressing equipment deficiencies and developing basic criteria for defining management zones and locations of various sensor systems for both arid and humid regions. Training adequate personnel to help write prescriptions in humid and arid areas and to assist growers with the decision making process is also a high priority. This paper discusses some of the research and training needed to focus on developing and documenting cost-effective site-specific water conservation strategies in order to develop markets for these advanced irrigation technologies for general crop production.

Key Words: water resources, water management, irrigation, precision agriculture, decision support, adaptive control systems, automation, irrigation controls, sprinkler irrigation, wireless networks, sensors

Introduction*

Demands on the world's finite water supplies for uses other than agriculture are increasing at a rapid rate. Population growth is also reducing the land available for food production. Consequently, there is a pressing need for agriculture to significantly improve production on less land and less water. Thus, it is to the advantage of all to be able to utilize all available tools including various aspects of precision agriculture (PA) to their maximum potential to address these issues.

Recent innovations in low-voltage sensor and wireless RF technologies combined with advances in Internet technologies offer tremendous opportunities for development and application of real-time management systems for agriculture. These have enabled implementation of advanced state-of-the-art water conservation measures such as site-specific variable-rate sprinkler irrigation (SS-VRI) for economically viable, broad scale crop production with full or limited water supplies. SS-VRI technologies uses many of the same management tools as other precision agriculture technologies, and make it possible to vary water and agrochemical (chemigation) applications to meet the specific needs of a crop in each unique zone within a field.

Existing irrigation technologies are well advanced and would conserve large amounts of water if fully implemented to their capacity, but this is not happening. Adoption of site-specific irrigation technologies could potentially extend these water savings even more. However, in more than 20 years of public and private research pertaining to SS-VRI, demonstrated proof of any definitive economic benefits has failed to materialize. Consequently, there has been limited commercial availability of SS-VRI systems and relatively little use of site-specific sprinkler irrigation technologies as a management tool for general crop production. To put this in perspective, it is estimated that there are about 175,000 center pivot and linear move sprinkler systems in the USA (USDA, NASS, 2009); but the authors estimate that less than 200 of these machines currently have SS-VRI capabilities other than speed control, end gun and corner system controls, and it is not known how many are actually using SS-VRI capabilities for irrigated crop management.

Severely limited water supplies for irrigation and environmental issues in various areas in the western United States and around the world are driving renewed interest in SS-VRI by growers and policy makers. Several new SS-VRI systems have been purchased and installed around the world in the past couple of years, and the technology will likely continue to show moderate gains in the marketplace. Most of this growth will likely occur with speed control systems.

However, current uses of SS-VRI technologies for agricultural fields are generally on a fairly coarse scale and are often limited to site-specific treatment of non-cropped areas based on physical features such as water ways, ponds, or rocky outcrops where some interior sprinkler heads are turned off in these areas (either 0% or 100% applications). Their use for general crop production is still limited and is mostly directed toward treating symptoms of localized overirrigation, underirrigation, runoff, ponding, nutrient management and related issues under maximum ET scenarios, which often do not produce measureable savings in water or energy use although total field yields may increase. The current management levels are considerably below the potential achievable benefits of SS-VRI and even well below the potential for

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* Mention of trade names, companies or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture

conventional non-site specific systems. Unfortunately, this relatively low management level is where SS-VRI technology is likely to stay in the future until cost effectiveness can be increased by higher costs for water, the implementation of economic incentives for compliance with environmental and other regulations, and the development of research results on how to manage these systems and demonstrating the extent that economic returns can be increased using SS-VRI.

This paper discusses the historical development of SS-VRI technology (zone control) and some barriers to adoption. Various short-term and some long-term research needs are also suggested to focus on developing and documenting cost-effective site-specific water conservation strategies for self-propelled sprinkler systems in order to develop markets for these advanced irrigation technologies for general crop production.

Site-Specific Variable Rate Sprinkler Irrigation

SS-VRI can be defined as the ability to spatially vary water application depths across a field to address specific soil, crop and/or other conditions and treatments in ways that optimize plant responses for each unit of water. SS-VRI has its' roots in the location control of end guns and sequencing sprinkler heads on center pivot corner-arm systems. Advances in technologies including computers, electronics, communications, geographic information systems (GIS) and global positioning systems (GPS) have provided the tools for SS-VRI management to move to the next level.

Center pivots and linear move sprinkler systems are designed and generally operated so as to replace the average water used by the crop over the past few days as uniformly as possible across the field. Irrigations are frequent and apply relatively low amounts of water so that soil water is ideally maintained at relatively constant levels. The high frequency of the irrigations under these machines potentially reduces the magnitude of variability in soil water contents in the field. However, stochastic spatial and temporal variability of a number of factors across a field can still affect crop growth during the growing season and from one season to the next. These factors can influence management decisions over time, which may also introduce additional in-field variability to crop production. Consequently, the center pivot industry is beginning to market irrigation systems that can adjust for at least some of this spatial variability by zone control or speed control, both of which are often referred to as site-specific irrigation or variable rate irrigation. Kranz (2009) has summarized characteristics of some of the various commercial site-specific control systems.

Maximum application depths on self-propelled center pivots and linear move sprinkler systems are generally controlled by the speed of the machine. Some center pivots can change speed in as little as 2 degree increments as the machine moves around the field to effectively change application depths in each radial sector of the field. This is sometimes referred to as sector control. However, field variability seldom occurs in triangle-shaped parcels and adjusting machine speed may not be a sufficient level of control resolution as soil and crop conditions often vary substantially in the radial direction.

Zone control involves spatially defining management areas or zones following specific guidelines. Water is then applied to each management area (zone) by controlling water output from small groups of sprinkler heads along the length of the machine depending on location in the field. Zone control has the largest potential for achieving more efficient and economically viable management of water and energy, and is the general topic of this paper.

Simulation studies comparing conventional and site-specific irrigation have reported water savings of 0 to 26%. Ironically for well-watered crop production, water savings from site-specific irrigation maybe greatest in humid climates by spatially maximizing utilization of growing season precipitation (Evans and King, 2010). However, these water saving benefits have not been verified by field-based research.

Historical Development of SS-VRI

Many individuals, groups of researchers and companies have been developing SS-VRI technologies for at least the last 20 years. Almost all of the SS-VRI research done to date has been directed toward development and improvement of hardware and basic control software. As a result, several innovative technologies have been developed to variably apply irrigation water to meet anticipated whole field management needs in precision irrigation, primarily with self-propelled center pivot and linear move irrigation systems. Little research has been done on the economics or the management of these systems for greatest agronomic or resource conservation benefits. These efforts have been reviewed by Evans and King (2010), Evans et al. (2010) and others.

Commercial Adoption of SS-VRI

A program to extend SS-VRI technology was developed in 2005 by the University of Georgia to promote SS-VRI in the Flint River basin of Georgia using the FarmScan VRI system (only commercially available SS-VRI system at the time). The USDA-NRCS Environmental Quality Incentives Program (EQIP) provided 75%-25% cost-share funding for about 40 systems. Four additional SS-VRI systems were also purchased by growers without cost-share assistance. These systems were installed on peanut, cotton, and corn fields plus some turf farms. A companion USDA NRCS Conservation Innovation Grant also provided funds to demonstrate the benefits of SS-VRI for irrigation management, water conservation, and optimal application efficiency through a series of workshops and field days as well as some research efforts (Perry and Milton, 2007).

In 2006, an Australian company (Computronics) began selling SS-VRI controls for center pivots in the USA through a company in southeastern USA (Holder and Hobbs). In 2008, the marketing of Computronics was shifted to FarmScan. Starting in 2010, Valmont Industries (a major manufacturer of self-propelled sprinkler irrigation machines) began offering the FarmScan site-specific variable rate package through their dealer network based on a licensing agreement. Also, based on the licensing agreement, Valmont began developing a two different VRI packages based on their irrigation system control system. In 2010 Valmont began selling on a limited basis some zone control units, which was expanded in 2011 to offer both speed and zone control.

Some other center pivot manufacturers and related companies are also beginning to integrate various site-specific control options with their systems. For example, Lindsay Manufacturing started working with Precision Irrigation of New Zealand in 2011 and began to offer zone control in some countries. In 2009, AgSense began offering speed control as part of their add-on telemetry package. Integrating soil moisture monitoring with center pivot controls is also beginning to receive commercial attention by center pivot manufacturers.

In early 2011, it was estimated that over a 100 FarmScan VRI systems were installed (Rick Heard, 2011, personal communication). However, very few of these systems (estimated at 25% or less based on conversations) are using the full features of site-specific irrigation.

In the past several years, various commercial manufacturers of self-propelled sprinkler systems have been offering limited site-specific capabilities for center pivot and linear move sprinkler systems for tertiary treatment of agricultural processing and municipal wastewaters using soil biota and crop uptake for disposal. These systems are used to periodically apply water to specified areas within a field based on approved regulatory plans primarily for management of nitrogen, phosphorous and various potential biological contaminants in the effluent. These systems generally have static application maps that do not change from year to year and feedback mechanisms often consist of periodic soil water measurements and annual soil sampling to measure levels of various chemical and biological parameters. More recently, a few irrigation system manufacturers have begun offering VRI as an option on new center pivot installations.

Potential Barriers to Adoption

Generally, adoption of the various PA technologies including SS-VRI has been limited and its' use by early adopters has not always been sustained. Equipment has not generally been a restraining factor with regard to the adoption of SS-VRI and other PA technologies. For SS-VRI at least, this has been partially because the only choices for SS-VRI equipment and controls were third party sources until recently.

Barriers for SS-VRI

One potential barrier is that full implementation of SS-VRI generally has the most difficult requirements and the most complicated and costly control systems of all PA technologies because of complex spatial and temporal interrelationships of the soil-plant-atmosphere-irrigation systems. SS-VRI is also the most expensive in terms of management because of the much higher frequency of treatments compared to other PA technologies.

An additional reason for non-adoption is that government regulatory and action agencies generally do not support SS-VRI technologies for cost-share and other farm programs, especially at the local level, which may be partially due to a lack of understanding the technology and a shortage of regional research demonstrating benefits. In addition, manufacturer's distribution networks and dealers are sometimes cautious to embrace new technologies until they see opportunities for profit and have the resources and training to support the product.

Some of the slow rate of adoption problems have also been partially due to patent issues and high capital cost per hectare for the equipment. However, equipment costs are coming down due to technological advances.

Adoption Needs for SS-VRI

Some of the most common reasons for growers to invest in advanced irrigation technologies are to: 1) reduce labor costs, 2) minimize water costs due to pumping (higher irrigation efficiencies), 3) improve field scale yields with better application uniformities, and 4) use the "saved water on other fields (often referred to as water spreading). However, acquisition of an advanced irrigation technology does not always result in improved levels of management, which is often due to a lack of time by the operator to devote to better management or a shortage of appropriate scientific agronomic and irrigation knowledge by the operator. At the same time, the increasing complexity of implementing advanced irrigation strategies and other cultural activities place even greater demands on management, which is primarily addressed with the help of consultants.

Experience of the authors indicates that new agricultural technologies must overcome several stumbling blocks or expectations, all of which must be individually addressed in order to be accepted by producers. To be successfully adopted growers expect that the new technology will met the following criteria, which are: 1) to do what they are designed (and promised to do); 2) to be flexible to meet grower expectations; 3) to be easy to use, adjust and adapt to fit their perceived needs; 4) to be scalable to meet a wide variety of applications; 5) to be robust and durable with low hardware and software maintenance requirements; 6) to be easy to retrofit the system and to upgrade all components; 7) to be intuitive to operate for the end user; 8) to have good data management and interpretation capabilities and for future evaluations and analyses of the results; and, 9) to be affordable, reduce production costs and increase net returns (evident positive benefit cost ratio for producer); and 10) high quality technical support and educational efforts by the industry and extension are readily available. These ten factors as well as wide spread availability of the technology may also be affected by the manufacturer's assessment of the industrial effort (e.g., retooling), materials and fabrication costs. However, it's probably safe to say that most of these conditions for the adoption and sustainable use of SS-VRI have not been met and remain to be addressed by researchers and industry, and coordinated research programs addressing these issues must be conducted before the full potential of these technologies can be commercially realized (Evans and King, 2010).

RESEARCH NEEDS

Existing irrigation technologies are capable of conserving large amounts of water if implemented to their full capability. Adoption of site-specific irrigation technologies could potentially extend these water savings even more. SS-VRI could play a major role in maximizing net returns when implementing limited or deficit irrigation strategies in water short areas and in the optimal use of precipitation in humid regions. However, the high potentials of these technologies are not close to being realized because the necessary incentives and the supporting research base are both severely limited.

Sound decision making consists of defining the scale of the problem and how much is to be gained from solving the problem. However, SS-VRI has not followed this process. Almost all of the SS-VRI research done to date has been directed toward development and improvement of hardware and basic control software to implement SS-VRI. The net result of this earlier work is that SS-VRI has essentially become a solution looking for a problem. Unless the problems to be addressed can be precisely defined and quantified for research and education, SS-VRI will basically remain a novelty and research aimed at developing more complex SS-VRI technology will remain fragmented and a general waste of resources.

By definition "site-specific" means that such prescriptions will be climate, crop and region specific. Thus, it should be noted that transferability or SS-VRI research results to other regions will often not be appropriate, and this type of research will have to occur regionally where ever SS-VRI is practiced.

One of the major reasons attributed to the low adoption rates of SS-VRI has been the shortage of research by public and private groups demonstrating that this technology will better manage water and/or increase net returns. Past SS-VRI agronomic research was generally directed toward meeting full crop ET and maximizing yields per unit area with no concern for limited water availability scenarios.

Limited grower experiences over the past few years with new SS-VRI systems are providing some direction to the manufacturers, but verifying research is way behind. Documented and proven water conservation strategies using site-specific sprinkler irrigation for crop production are quite limited and its cost-effectiveness has not been adequately demonstrated regionally. This type of research is high priority for the adoption of SS-VRI. These critical research requirements have short term and long term considerations as well as critical technology transfer aspects, which are further discussed below.

Short Term Research Needs

Some general topics that need to be addressed to further encourage adoption in the short term are briefly discussed below. These include both commercial development and scientific research by public and private groups that addresses equipment, management and economic issues.

Equipment Needs

General operational criteria for grower acceptance of advanced SS-VRI systems include: 1) easy to retrofit to existing commercial center pivots, 2) maintain good water application uniformity within and between treatment areas, 3) robust electronics, 4) compatible with existing center pivot equipment, 5) bi-directional digital communications, and 6) expandability for future development and operational requirements. Any hardware and control limitations in this regard will need to be addressed by the manufacturers to facilitate successful marketing of the technology.

One constraint has been the limited availability of low- cost, reliable variable frequency drives (VFD) for large irrigation pumps to match variable irrigation system demands associated with SS-VRI, especially with multiple irrigation systems using a single pump. In addition, the highly variable flow requirements of SS-VRI systems used for chemigation may also require smaller VFD drives for injection pumps to maintain appropriate chemical concentrations.

Commercially available SS-VRI systems generally rely on some form of pulse modulation to control application depths. Thus, one area for improvement is the development of reliable valves at an economically viable cost that can cycle millions of times before failure. Some variable rate application methods may require more reliable, cost-effective flow-modulating sprinkler heads. However, equipment needs are relatively minor and are evolving much more rapidly in comparison to the development of management tools for growers and consultants for the optimal operation of these systems and maximization of benefits.

There is a concurrent need to develop improved control systems for site-specifically applying crop amendments (e.g., nutrients, pesticides) to improve profit margins and reduce environmental impacts with little additional cost (Watkins et al., 1998; King et al., 2009). These features add value to SS-VRI systems that help offset high initial capital costs and management expenses.

Defining Water Requirements

More than fifty years of research has been conducted to enable prediction of water requirements for well water crops that are actively growing free of pest or nutrient stress. Little is known about how pest or nutrient stress affects water requirements. Likewise, how evapotranspiration varies with yield potential is unknown. Crop water use is a combination of soil evaporation and plant transpiration. Stresses that inhibit plant development would be expected to decrease transpiration due to a reduction in leaf area. However, soil evaporation will likely increase due to more solar radiation reaching the soil surface. Water requirements for a well water crop under pest or nutrient stress may not change in proportion to yield potential.

Determining Economic Returns

Probably the most critical research needed to encourage adoption of SS-VRI is the development of guidelines and criteria for defining prescriptions for how a SS-VRI system can be used to increase economic return and achieve environmental benefits. Appropriate guidelines for economical management of SS-VRI systems that quantify the monetary value of various management alternatives have not been developed. Likewise, little research has been done on the economics of the number of zones or sectors or management of these systems for greatest agronomic benefit.

Use of SS-VRI to avoid irrigating non-cropped areas may be economical in terms of water and nutrient savings as well as avoidance of environmental and regulatory penalties. However, economics of SS-VRI for general crop production is a major concern because the water savings are typically only on the order of 5%-10% over more conventional management in arid areas, but may be as high as 26% in humid regions (Evans et al., 1996; Hedley and Yule, 2009; Evans and King, 2010). Thus, the marginal costs for the relatively small water savings are relatively high, which often makes purchasing and managing site-specific irrigation equipment difficult to justify economically.

Higher net returns to the grower may be needed to economically justify the capital costs of implementing site-specific irrigation management with center pivots (about \$200- \$550 ha^{-1}) additional depending on size and options over SS-VRI systems) plus extra mapping (commonly about \$15-\$20 ha^{-1}) and management costs. Reliable estimates of ongoing maintenance costs for SS-VRI are not known because of the low adoption rates. Operating costs will be higher as well because of added maintenance of sensors stations, communications, software maintenance, and consultant fees.

Anecdotal information from growers on fields with rolling topography using speed control (\$10-\$125 ha^{-1} depending on system) during the 2011 crop season indicates they believe payback for the SS-VRI aspects can be achieved in as little as one year due to the ability to reduce runoff in fields with rolling topography. Those using zone control SS-VRI attribute the observed benefits to a significant reduction of yield variability and higher overall productivity, which are largely due to minimizing areas of overirrigation and the associated reductions in runoff. In non-limiting water situations, savings in water or energy use have not been generally observed or cited as a benefit by growers. These practices also reduced leaching and soil erosion, and the reduced yield variability was probably more of a response to uniform access to applied fertilizers than to water However, these benefits have not been independently verified across different regions.

Development of Tools for Growers and Consultants

The short term research must also transfer the technology by producing tools for the industry to utilize in building prescriptions and managing SS-VRI systems. Some specific, identified tools for continued commercial development that will be required for sustained adoption of SS-VRI technologies include:

1) A need to develop guidelines and tools to assist consultants and growers in predefining rule bases or guidelines for management scenarios that are used for defining broad management areas that can be used to write general prescriptions. This information can also be used to define the requirements for the type and level of SS-VRI hardware for a field.
2) A need to develop tools that determine how to best locate various combinations of wireless sensors for maximum benefit across a management area or field and their use. Defined management zones will guide the placement of some sensor systems, but not all. In the short term, this goal would also apply to the improved management of conventional irrigation systems.
3) A need for the development and testing of easy-to-use integrated decision support systems for adaptive control starting with simple static scenarios for both humid and arid areas and build to include more complex dynamic conditions over the long term.

4) A critical, immediate need exists to define and implement specialized training on the hardware, software and advanced agronomic principles for growers, consultants, dealers, technicians, and other personnel on how to define management areas, write prescriptions and develop management guidelines.

These critical tools and management guidelines are further discussed below.

Tools for Defining Management Zones

Application of water with site-specific irrigation systems generally involves some type of variable rate application method in combination with geo-referenced maps or tables defining the various management zones. Management zones (sometimes also called management areas or productivity zones) are areas within a field that are relatively homogeneous with regard to at least one characteristic or factor (e.g., similar soils, topography, microclimate, harvested yields, pest pressures or plant response). These zones can also vary depending on the issue being addressed (e.g., irrigation, fertilizer, pests). Management zones for SS-VRI can be used to treat a whole field or to treat small areas of a field with simple on/off sprinkler controls in single span-wide treatment areas.

Because of large sizes of modern farm equipment, growers cannot usually manage PA on areas less than 0.4 ha (1 ac), which generally deal with relatively broad areas that account for topography, major soil texture changes or physical constraints. One manufacturer of SS-VRI self-propelled sprinkler systems (Valmont) offers the capacity to define up to 5400 management zones in a single field (about 0.01 ha/zone) based on various criteria, data sources and grower input. Even though most center pivot irrigators will typically have less than 10 management zones in a field, the capacity to have a large number of small zones allows for the composite definition of large zones with convoluted shapes. Basic and applied research is needed to provide guidance on how to best define the most appropriate agronomic management zones for SS-VRI.

Commercially, assistance in defining management zones or management areas and building suitable prescriptions is in its' infancy. Companies such as CropMetrics™ (http://cropmetrics.com/) have developed and are marketing a basic sets of tools and provide limited agronomic guidance to assist growers in defining static management areas, which are generally based on changes in soil texture or electrical conductivity (as a surrogate to water holding capacity) and topographic features. General guidelines may also be provided on irrigation management in the various zones. While a step in the right direction, management zones based on only one or two parameters are generally inadequate for optimal management because many of the other parameters affecting the crop can also vary independently throughout the season.

There is a critical need to develop basic rules or guidelines and tools for defining management zones, determining the best locations for sensor stations, and writing prescriptions for irrigation applications in different zones for both humid and arid regions. These agronomic and engineering tools would be used by consultants and growers and must allow for grower preferences, pest management issues and some economic considerations.

Tools for Optimal Placement of Various Sensor Systems

Recent innovations in low-voltage sensor and wireless radio frequency technologies combined with advances in Internet technologies offer tremendous opportunities for optimal management of SS-VRI systems. Sensors can be at fixed locations or mounted on the irrigation system, farm equipment or other mobile platforms depending on data needs and requirements.

Properly defined management zones will guide the placement of some sensor systems, but not all. There remains a critical need to develop tools that help define which sensors are needed and to determine how to best locate various combinations of wireless sensors for maximum benefit across a field. The integration of various sensor types that provides measurements at different temporal and spatial scales make it potentially possible to extend the range of point measurements and more accurately estimate the variability of other sensors and field data sets.

It is not possible to know the exact conditions in all areas of a field in real time. Therefore various estimating procedures or predefined management zones can potentially be used to account for this variability. Distributed in-field plant and soil sensors in combination with agro-weather stations can be used to measure climatic, soil water and other types of variability and assist in the development and implementation of optimal site-specific irrigation management strategies.

All sensor systems have their own particular limitations and scales and there is no perfect sensor or sensor system for managing SS-VRI systems. Thus, there is a need to continue the development and testing of a range of low-cost, wireless and non-intrusive sensors for spatially-distributed measurement of soil moisture and various crop response indicators for management of site-specific systems.

Decision Support

Most current irrigation decision support software (often called scientific irrigation scheduling programs) deigned to basically address temporal variability. They calculate timing and duration of water applications using algorithms that forecast irrigations based on historical weather patterns and predicted crop water use over a relatively short period (e.g., 3-14 days). Feedback to the process is usually made by spot measurements (e.g., soil water) and other data after the operation is completed and adjustments are made to the program for the following irrigation event. The next step is to include spatial variability in the process.

General, broad-based and easily modified software (decision support) for implementation of prescriptions for SS-VRI systems is not available for a multitude of crops, climatic conditions, topography, and soil textures. In the short term (e.g., next 5 years), development of basic decision support systems should focus on generalized regional-type prescriptions for humid and arid areas if SS-VRI is to become economically viable. There is a need to develop and market basic decision support programs with simple closed-loop feedback systems so that easy on-the-go corrections can be made to VRI irrigation systems and provide real time status information to the operator for other necessary adjustments.

Training for Technical Assistance for SS-VRI

Adjusting water application depths to account for spatial and temporal variability to fine-tune the water management can be a significant challenge and most producers will require agronomic and other types of assistance from multiple sources to successfully implement these technologies.

However, this is complicated by the acute shortage of available agronomic expertise to set up and maintain decision support software for each field (English, 2010). Growers generally do not have the interest, knowledge or the time to adjust and play for software; thus, dealers or consultants would likely have to provide this service. Thus, there is a critical need for trained personnel, who will often be independent from the equipment dealers, to assist growers in using these tools to write prescriptions, best locations for sensor stations.

The need for advanced training is immediate. However, training programs may be ineffective until results from the above list of short term research areas can properly define the scope and criteria for the training curricula and sufficient numbers of people are trained. Plans are being developed to produce this information, but much of these results may not be available for another 5 years or so, which may delay the progress of SS-VRI adoption. .

Conclusions

The potential to save water at the farm scale depends on the capabilities of the irrigation system and the operator to implement water-saving practices and technologies. Conventional irrigation technologies are well advanced and would conserve large amounts of water if implemented to the full extent of their capabilities. The resulting less-than-optimal levels of current irrigation management are primarily due to the lack of appropriate economic and social incentives to adopt the improved practices. Adoption of site-specific technologies could potentially extend these water savings even more; however, these same issues also apply to SS-VRI as the potential economic and water conservation benefits of these advanced systems have not been independently defined and quantified.

There have been over 20 years of government and private research on SS-VRI and the technology has been commercially available since the mid-1990s. However, adoption rates of SS-VRI have been quite low for a number of reasons. Almost all of the SS-VRI research done to date has been directed toward development and improvement of hardware and basic control software. Little research has been done on the economics, determination of the number of zones or sectors or the management of these systems for greatest agronomic or resource conservation benefits. Past research was generally directed toward meeting full crop ET and maximizing yields per unit area with no concern for limited water availability scenarios. Thus, the current state of the technology is essentially a solution looking for a problem.

Current uses of SS-VRI technologies for agricultural fields are generally on a fairly coarse scale and are often limited to site-specific treatment of non-cropped areas. Their use for general crop production is still limited and is mostly directed toward treating symptoms of poor water management under full ET conditions. Site-specific irrigation is basically used to provide water conservation benefits in cases of overirrigation, underirrigation, runoff, erroneous irrigation scheduling, in-season precipitation harvesting, or inefficiencies associated with particular crop production practices. In actuality, use of this site-specific technology today is basically for uniform nutrient management rather than water management.

The full potential of SS-VRI as well as conventional uniform irrigation systems are considerably higher that current practices. Unfortunately, this relatively low level of management is where SS-VRI technology is likely to stay in the future until cost effectiveness can be increased, which will be the result of several external factors.

In the short term, several equipment and research deficiencies need to be addressed to encourage further adoption. Equipment issues include the use of variable frequency pump motor controls for both irrigation and chemigation, and more reliable valves to control individual sprinkler heads. From a research standpoint, the foremost need is the development of guidelines and tools to assist consultants and growers in predefining rule bases for management scenarios that are used for writing dynamic prescriptions for defining management areas. Secondly, there is a need to develop tools that determine how to best locate various combinations of wireless sensors for maximum benefit across a field and their use. Thirdly, there is a critical need for the development and testing of easy-to-use basic, generalized decision support systems for SS-VRI starting with simple static scenarios for both humid and arid areas.

In addition, specialized, continual training on the hardware, software and advanced agronomic principles will be needed for growers, consultants, dealers, technicians and other personnel on how to define management zones (areas), write prescriptions and develop management guidelines. However, criteria for training individuals to develop management zones, write prescriptions and assist with the decision making processes has not been defined.

Ultimately, it is expected that higher costs for irrigation water, water scarcity and the implementation of economic incentives for compliance with environmental and other regulations will potentially provide the necessary incentives for much greater adoption of various advanced irrigation technologies. However, this must be supported by basic short-term and long-term research demonstrating how and the extent that net economic returns can be increased using both conventional and SS-VRI systems. These research priorities must be addressed for both humid and arid climates because the strategies and procedures may be quite different. It should be noted that this research on advanced SS-VRI irrigation management strategies, sensor systems and decision support would also improve our capacity to better manage conventional irrigation systems.

Various forms or aspects of SS-VRI are becoming commonly available and are probably here to stay at a low level. These marketing efforts are helping customers consider the future and how to position their farming operations including center pivot irrigation to take advantage of rapid changes in technology. However, the research effort needed to successfully and economically apply SS-VRI is substantial and will take several decades to address. With adequate funding, such field research will likely take 5 to 10 years to obtain measureable results. Maintaining the current levels of inadequate funding for field research on SS-VRI technology means that the time table to accomplish these goals will be substantially increased.

A suitable research and education program to adequately address the barriers to adoption and to practically achieve the potential benefits of SS-VRI will require considerable investment in these areas at a time the nation is attempting to reduce spending on domestic programs, such as public agricultural research. This means that bulk of research and education funding will have to come from SS-VRI equipment manufacturers and commodity groups. However, without a clear definition of the problem to be addressed and value to be derived, funding cannot be expected to available.

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Infiltration Model for Center Pivot Sprinkler Irrigation

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Abstract. *The marked reduction in infiltration rate caused by formation of a soil surface seal due to water droplet impact on bare soil is a well known phenomenon but is rarely considered in infiltration models, especially under center pivot irrigation. The objective of this study was to develop a soil infiltration model for center pivot sprinkler irrigation that incorporates the transient reduction in soil surface seal hydraulic conductivity as affected by soil and sprinkler characteristics. A sealing soil infiltration model was developed using an explicit finite difference solution scheme with a transient soil seal formation model, which is unique from other studies in that it explicitly uses droplet specific power as the driving factor for formation of a soil surface seal. The model was calibrated to a specific soil using published runoff data from a rainfall simulation study with varying droplet kinetic energies and application rates. The model was then applied to center pivot irrigation for five common sprinklers to evaluate the effect sprinkler selection has on infiltration. Due to the high susceptibility of the soil to surface sealing from water drop impact and low satiated hydraulic conductivity, the sprinkler with the largest wetted diameter was predicted to maximize infiltration. The infiltration model predicted an average difference of 3.2 mm between protected and bare soil infiltration for a 25.4 mm application depth. Sprinkler kinetic energy had minimal impact on infiltrated depth because all the sprinklers used in this study caused a surface seal.*

Keywords. Sprinkler irrigation, Center pivot, Infiltration, Runoff, Soil surface seal, Droplet kinetic energy.

Introduction

The marked reduction in water infiltration rate of bare soils caused by raindrop impact has been recognized for over a century and has been extensively documented and studied over the past 70 years. The decrease in water infiltration rate of soils under droplet impact was first investigated by Duley (1939), Borst and Woodburn (1942), and Ellison (1945). McIntyre (1958) was the first to measure saturated hydraulic conductivity of soil surface seals created by raindrop impact. He found that the saturated hydraulic conductivity of the formed seals was a function of the soil, applied water depth and application rate. Seal saturated hydraulic conductivity was found to be 2 to 3 orders of magnitude less than for the underlying soil. Moldenhauer and Long (1964) found that infiltration rate was a function of soil properties, kinetic energy of the water drops and application intensity. They found that time for runoff to begin was a function of cumulative kinetic energy applied to the soil. Studies of Edwards (1967), Mannering (1967), Sharma (1980), Baumhardt (1985), Mahamad (1985), Thompson and James (1985), Betzalel et al. (1995) have demonstrated the influence droplet kinetic energy and water application rate has on infiltration rate into bare soils.

Studies' documenting the significant effect water droplet impact has on the infiltration rate of bare soils led to the development of empirical models representing the transient nature of the saturated hydraulic conductivity of soil surface seals during a rainfall event. In general, these models expressed hydraulic resistance or saturated conductivity of the seal layer as an exponential decay function of time or applied droplet kinetic energy (Farrell and Larsen (1972); van Doren and Allmaras (1978); Linden (1979); Moore, et al. (1981); Brakensiek and Rawls (1983); Bosch and Onstad (1988); Baumhardt et al. (1990)). The models all include 3 or more parameters that need to be estimated from simulated rainfall infiltration experiments. These parameters have not been related to bulk soil properties to expand the models to other soils in general with the exception of Brakesiek and Rawls (1983) who developed a crust factor to account for crusted soil infiltration with the Green and Ampt (1911) infiltration model.

Nearly all of the research related to soil surface sealing has focused on rainfall conditions, but the same processes occur under sprinkler irrigation (von Bernuth and Gilley, 1985; Ben-Hur et al., 1995; Silva, 2006). Soil surface seal formation in combination with high water application rates under center pivot sprinkler irrigation exacerbates potential runoff and erosion hazard. Runoff under center pivot sprinkler irrigation is a well recognized problem (Undersander et al., 1985; DeBoer et al., 1992; Hasheminia, 1994; Ben-Hur et al., 1995, Silva, 2006), but is normally unseen because runoff often infiltrates before exiting the field boundary as only a small fraction of the field is irrigated (saturated) at a given time and/or runoff collects in low spots within the field.

The operational characteristics of center pivot sprinklers such as wetted diameter, application rate pattern shape and drop size distribution have been studied (e.g. Kincaid et al., 1996; Faci et al., 2001; DeBoer, 2001; Sourell et al., 2003; Playan et al., 2004; Kincaid, 2005;). However, studies evaluating the effect operating characteristics of a particular sprinkler have on infiltration, runoff, and erosion of specific soil types are limited (Undersander et al. 1985; DeBoer et al. 1992; Silva, 2006; King and Bjorneberg, 2011). Area weighted kinetic energy per unit volume of common sprinklers has been modeled by Kincaid (1996). King and Bjorneberg (2010) found that area weighted kinetic area does not represent the actual kinetic energy applied to the soil under center pivot sprinkler irrigation. They developed a methodology to calculate actual kinetic energy applied by center pivot sprinklers. With the wide range in operating characteristics of center pivot sprinklers currently available, the potential to select sprinklers that minimize runoff and erosion exist (King and Bjorneberg, 2011). However, data or models relating sprinkler operating characteristics to runoff and erosion for specific soil types are limited. Models relating potential runoff to sprinkler peak application rate have been developed by Dillion et al. (1972), Slack (1980), Gilley (1984), DeBoer et al. (1988), Allen (1990) and Wilmes et al. (1993), Martin et al. (2010). Based on the work of Gilley (1984), von Bernuth and Gilley (1985) developed a methodology for estimating center pivot sprinkler irrigation runoff which considered infiltration rate reduction due to water drop impact on bare soil. Models currently available for estimating runoff under center pivot irrigation do not account for the effect of soil surface sealing on infiltration. Thus, such runoff estimations are of limited value under actual field conditions of arid regions where center pivot sprinkler irrigation on bare soil is generally required for crop germination and establishment.

The objective of this study was to develop a soil infiltration model for center pivot sprinkler irrigation that incorporates the transient reduction in soil surface seal hydraulic conductivity as affected by soil and sprinkler characteristics.

Model Development

Soil and Infiltration Data

Data used to develop and evaluate sealing soil infiltration model were obtained from Baumhardt (1985). Baumhardt (1985) measured runoff from laboratory soil columns measuring 0.3 m tall and 0.35 m in diameter over a range of application rates and droplet kinetic energies per unit volume. The soil was an Atwood silty clay loam with 12% sand, 60% silt and 28% clay. The soil was air dried, sieved and packed into the soil column to a density of 1.4 Mg m^{-3}. The columns were placed on a ramp with a 9% slope during rainfall simulation. The rainfall simulator produced droplets with kinetic energies of 20.0 and 27.5 J m^{-2} mm^{-1} with a range of application rates from 20 to 90 mm hr^{-1}. Rainfall simulation duration ranged from 60 to 120 min.

Soil water retention characteristics of the soil used in this study was estimated based on soil texture using the pedotransfer functions of Saxton and Rawls (2006). The Brook and Corey (1964) relationships were used to model soil hydraulic properties as a function of soil water potential. Parameters for the Brooks and Corey (1964) soil water relationships were estimated by fitting them to values of soil water potential versus soil water content estimated by the Saxton and Rawls (2006) pedotransfer functions. Satiated water content was taken as 80% of pedotransfer function predicted porosity. Other infiltration studies have estimated satiated water content as 62 to 92% of saturated water content (Mein and Larson, 1973; Slack, 1980; Moore, 1981; Römkens et al., 1985; Eisenhauer et al., 1992). Water entry pressure head for soil wetting was estimated as one-third the air entry pressure predicted by the Saxton and Rawls (2006) pedotransfer function. Satiated hydraulic conductivity was determined by fitting the infiltration model absent soil surface sealing to infiltration data with the surface protected from droplet impact. Values used to characterize soil water retention properties of the soil are given in Table 1.

Infiltration Model

Infiltration was modeled using a one dimensional fully implicit finite difference numerical solution to Richard's equation (Rathfelder and Abriola 1994; Shahraiyni and Ashtiani, 2009). The Thomas Algorithm (Thomas, 1949) was used to solve the tridiagonal matrix of simultaneous equations. The model was written in Microsoft Visual Basic. Soil profile depth increments were 1 mm and time increments were 0.01 min for the first 3 min of infiltration then 0.1 min thereafter. Convergence criteria for each time step was less than 0.2 mm of head change between subsequent iterations for any node in the soil profile. Developing soil surface seal hydraulic properties were assumed to be uniform over a 5 mm depth below the soil surface. The soil profile was assumed to be infinitely uniform below the surface seal with constant hydraulic properties equivalent to the soil surface layer prior to infiltration.

Soil Surface Sealing Model

Specific power (W m^{-2}) also termed kinetic energy flux density (Thompson and James, 1985) can be calculated for a rainfall simulator with constant application rate and drop kinetic energy as:

$$SP = \frac{KE_d \cdot R}{3600} \tag{1}$$

where KE_d is droplet kinetic energy per unit volume (J m^{-2} mm^{-1}) and R is application rate (mm hr^{-1}). Cumulative kinetic energy applied to a soil surface can then be calculated as specific power multiplied by time in sec.

Transient soil surface seal development has traditionally been modeled using an exponential decay function of cumulative kinetic energy ((Farrell and Larsen (1972); van Doren and Allmaras (1978); Linden (1979); Moore, et al. (1981); Brakensiek and Rawls (1983); Bosch and Onstad (1988); Baumhardt et al. (1990)) of the general form:

$$K(t) = K_f + (K_i - K_f) \cdot e^{-c \cdot E} \tag{2}$$

where K is satiated hydraulic conductivity (mm hr^{-1}), K_f is final hydraulic conductivity (mm hr^{-1}) of the soil surface seal after an extended period of droplet impact absent the effect of seal erosion, K_i is

Table 1. Infiltration model parameters used to characterize the hydraulic properties of the soil used in this study.

Model Parameter	Atwood Silty Clay Loam
Porosity	0.48
Residual Moisture Content, % volume	0.1
Satiated Moisture Content, % volume	39.7
Initial Soil Water Potential, mm	-5000
Water Entry Head, mm	-300
Brooks-Corey Exponent (λ)	0.158
Satiated Hydraulic Conductivity*, mm hr^{-1}	6.0

*Equals K_i in equations 2 and 3.

initial satiated hydraulic conductivity of the surface soil (mm hr^{-1}), c is an empirical parameter (m^2 J^{-1}) and E is some representation of cumulative droplet energy (J m^{-2}).

Through trial and error analysis of fitting the infiltration model using transient soil surface sealing described by equation 2 to the infiltration data, improved results were obtained using the transient soil surface sealing model:

$$K(t) = K_f + \frac{(K_i - K_f)}{1 + S_f\left(\int_0^T SP(t) \cdot dt\right)^{1.2}} \quad (3)$$

where S_f is an empirical soil factor that represents resistance to surface seal formation, t is time (seconds) and T (seconds) is the time of the rainfall event. Using this transient soil surface sealing model provided a better fit to the infiltration data under low levels of specific power (i.e. low rainfall intensity and/or low droplet kinetic energy). Consequently, this empirical transient soil surface seal model was used in this study.

Model Fit Criteria

Infiltration model goodness of fit was quantified by examining the sum of squared difference between model predicted value and data relative to the sum of squared difference between data and mean data value which is termed model efficiency (ME). Model efficiency (Nash and Sutcliffe 1970; Bjorneberg et al. 1999) is defined as:

$$ME = 1 - \frac{\sum \left(y_i - y_{pred}\right)^2}{\sum \left(y_i - y_{ave}\right)^2} \quad (4)$$

where y_i is the ith data value, y_{pred} is model predicted value for y_i and y_{ave} is the mean of the data values. Model efficiency was used to optimize model parameter and quantify goodness of fit. Model efficiency is similar to the correlation coefficient associated with linear regression in that its value ranges from -∞ to 1. A value of 1 means the model is a perfect fit to the data but a negative ME value signifies that the data mean is a better estimate of the data than the model. Use of ME alone can be misleading as it does not take into account other factors that enter into determining model goodness of fit. For example with infiltration models, reliable estimate of time to ponding is important but is not quantified by using ME alone. Model parameters were determined based on maximizing ME but adjusted when there was considerable variability in the data to provide an improved estimate of mean time to ponding with little quantitative decrease in the value of ME.

Sprinkler Characteristics

Sprinklers used in this study and corresponding operating pressures, nozzle sizes and flow rates are listed in Table 2. The R3000[1] sprinklers (Nelson Irrigation Corp., Walla Walla, WA) used rotating plates with grooves to breakup the nozzle jet and create discrete streams of water leaving the plate edge. The R3000 sprinkler with the brown plate had ten grooves with multiple trajectories angles and widths. The R3000 sprinkler with the red plate had six grooves of equal trajectory angle (12°) and width. R3000 sprinkler with the orange plate had eight grooves with multiple trajectories angles and widths. The R3000 sprinklers had plate rotational speeds of 2 to 4 revolutions per minute. The S3000 sprinkler (Nelson Irrigation Corp., Walla Walla, WA) used a rotating purple plate with grooves to breakup the nozzle jet. The rotating plate had six grooves with trajectories from 12 to 20° and a rotational speed of 400 to 500 revolutions per minute. The D3000 sprinkler (Nelson Irrigation Corp., Walla Walla, WA) had a fixed flat plate to breakup the nozzle jet into discrete water drops. Sprinkler operating pressures were selected to be representative of field installations on center pivot sprinkler irrigation systems in southern Idaho. Sprinkler nozzle sizes were selected to provide nearly equal flow rates at the given operating pressures based on manufacturer data. Sprinkler flow rate was representative of that found near the end of the lateral on 390 m long center pivot sprinkler irrigation systems in southern Idaho.

Table 2. Operating characteristics for the five sprinklers used in this study.

	Sprinkler				
Parameter	D3000	S3000	R3000 Red Plate	R3000 Brown Plate	R3000 Orange Plate
Nozzle Diameter, mm	8.14	8.14	7.54	7.54	7.54
Operating Pressure, kPa	103	103	138	138	138
Flow Rate*, L min^{-1}	43.4	43.4	42.7	42.7	42.7
Average Application Rate, mm hr^{-1}	104.0	61.8	51.0	47.6	28.6
Peak Application, Rate, mm hr^{-1}	165.3	97.4	84.6	88.5	47.3
Kinetic Energy, J m^{-2} mm^{-1}	11.8	10.9	12.1	9.7	13.2
Average Specific Power, W m^{-2}	0.340	0.188	0.171	0.129	0.109
Peak Specific Power, W m^{-2}	0.602	0.263	0.233	0.191	0.149

*Based on Manufacturer's data.

[1] Mention of trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the authors or their institutions and does not imply approval of product to the exclusion of others that may be suitable.

Center pivot composite application rate and specific power profiles for sprinklers spaced 3m along the lateral were determined using the methodology described by King and Bjorneberg (2010). Briefly, sprinkler drop size and velocity were measured at 1 m radial increments from the sprinkler in the laboratory using a laser disdrometer (King et al., 2010). Sprinkler radial application rate profiles were also measured in the laboratory. These data were used to compute sprinkler radial specific power and droplet kinetic energy profiles. A sprinkler pattern overlap model was used to compute no wind composite water application rate and specific power profiles from sprinklers spaced 3m along a single lateral using the laboratory determined sprinkler radial water application and specific power profiles. The average composite water application rate profile between sprinklers was used to determine the travel time of a center pivot lateral to apply 25.4 mm of water. Kinetic energy applied per unit application water depth was determined by integrating the average composite specific power profile profile between sprinklers over the time interval required to apply 25.4 mm of water and dividing the value by 25.4 mm. The resulting composite water application rate and specific power profiles for each sprinkler are shown in figures 1 and 2, respectively. Peak and average water application rate and specific power and droplet kinetic energy per mm water application for each sprinkler when spaced 3m along the center pivot lateral are given in Table 2.

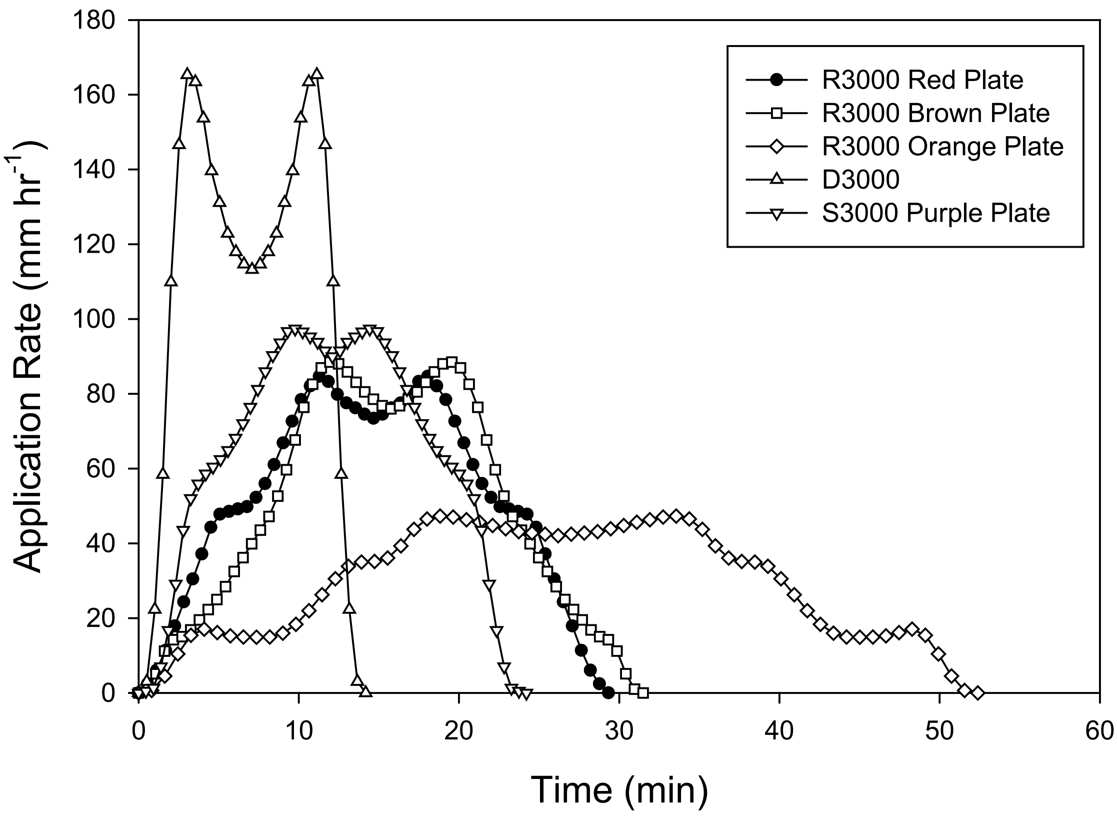

Figure 1. Average composite application rate profile for five sprinklers used in this study spaced 3m along a center pivot lateral.

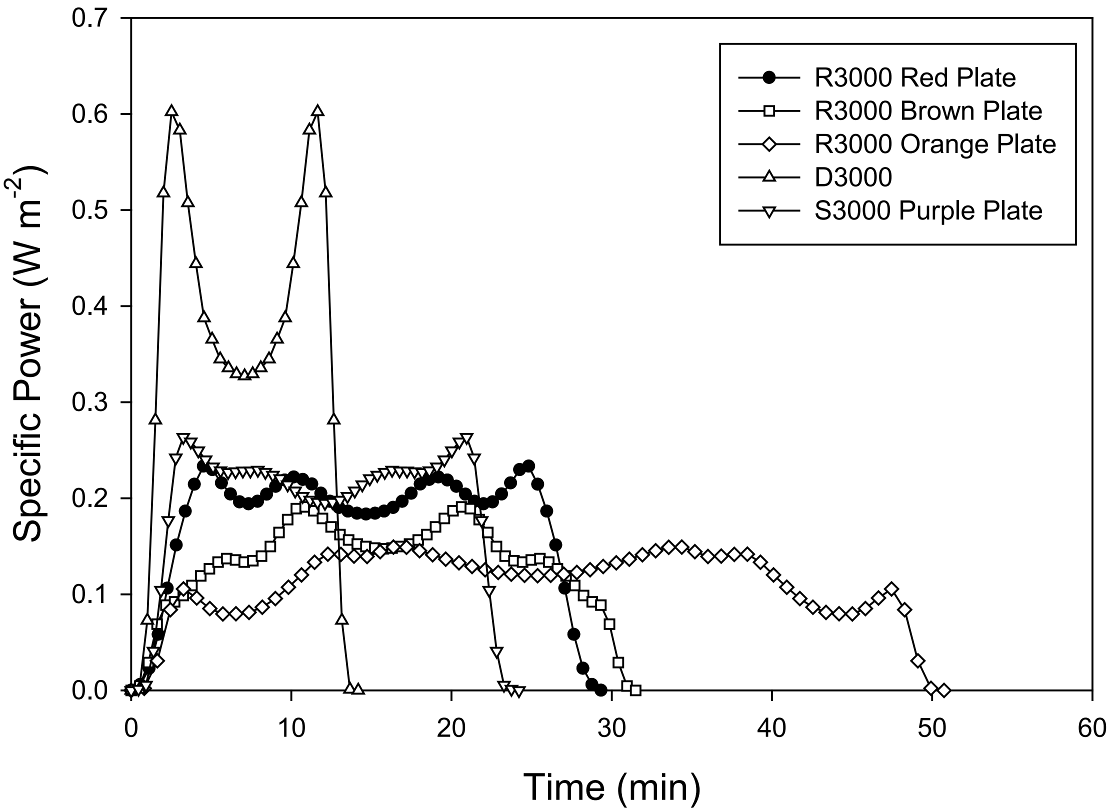

Figure 2. Average composite specific power profile for the five sprinklers used in this study spaced 3m along a center pivot lateral.

Results and Discussion

The sealing soil infiltration model was fit to infiltration rate data for the soil when the soil surface was protected from droplet impact (Baumhardt, 1985) to determine the value of satiated hydraulic conductivity. The value obtained for satiated hydraulic conductivity was held constant for all model simulations under transient soil seal development due to varying kinetic energy levels and application intensities. The infiltration model without surface sealing provided good fit to the infiltration data based on the values of ME obtained for each application rate (fig. 3) and prediction of time of ponding. The lower value for ME for the 41 mm hr^{-1} application rate tests is an artifact of the ME parameter and scatter in the infiltration data rather than poor model fit to the infiltration data. For the Atwood soil, an average of the infiltration data provides a reasonable representation of infiltration rate, which is the basis for the denominator in equation 3. The infiltration model provides an improved fit to the data compared to an average value, but the improvement over an average is relatively small, hence the value of ME is between 0 and 1. A value of 6.0 mm hr^{-1} for satiated hydraulic conductivity was found to provide a good overall fit to the infiltration data.

The sealing soil infiltration model provided a good fit to the laboratory infiltration data of Baumhardt (1985) for the Atwood silty clay loam soil. The results at four levels of specific power are shown in fig. 4. The value for S_f (eqn. 3) was held constant at 0.02 and the value of K_f (eqn. 3) ranged from 0.005 to 0.04 mm hr^{-1}. The fit of the model was slightly reduced at higher levels of specific power due to an apparent increase in final infiltration rates with specific power. Assouline and Ben-Hur (2006) found

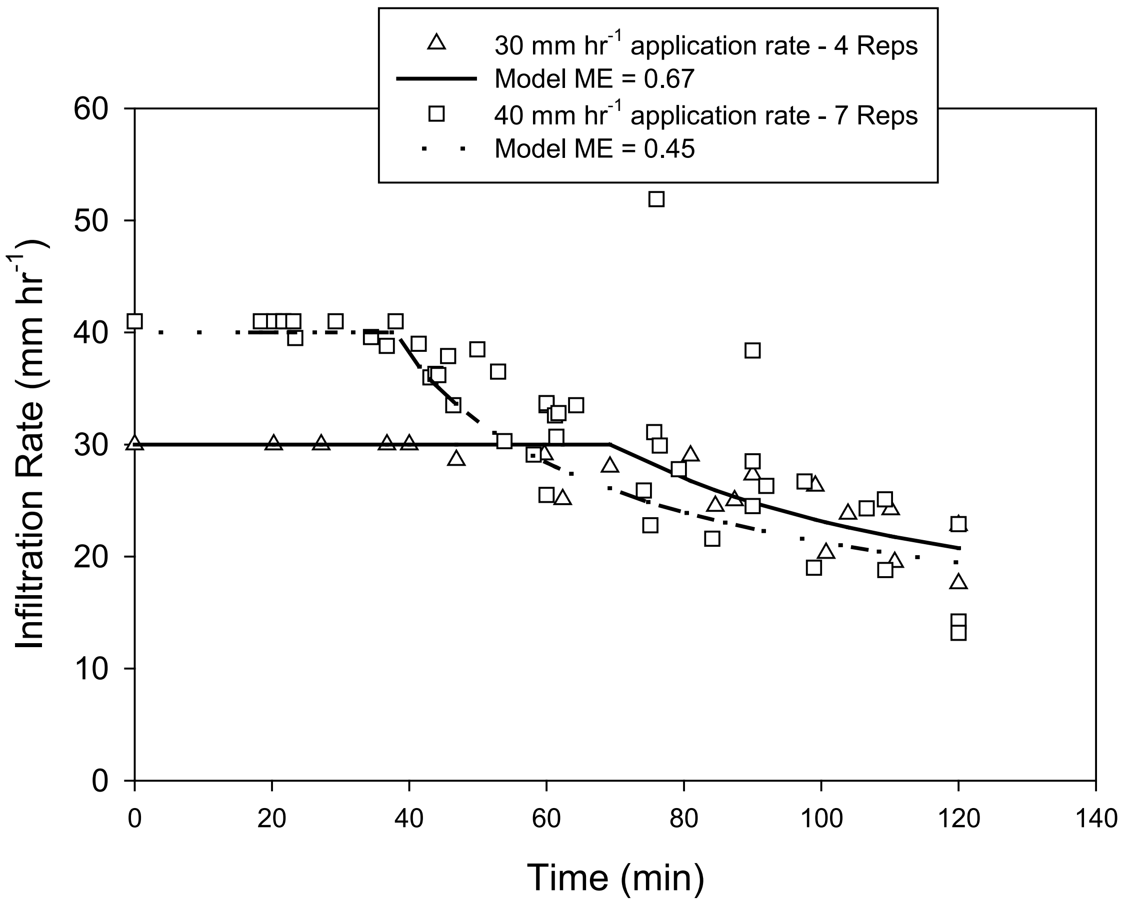

Figure 3. Model prediction of infiltration into the Atwood silty clay loam soil reported by Baumhardt (1985) when the soil surface is protected from droplet impact under two simulated rainfall intensities.

that final infiltration rate and soil loss increased with rainfall intensity (specific power) and became more prominent with slope steepness, consistent with several other study results (Assouline and Ben-Hur, 2006). The increase in final infiltration rate (seal conductivity) with increasing rainfall intensity can be due to a thinner and less compacted seal layer resulting from higher erosion of the soil surface and lower normal component of drop impact force (Assouline and Ben-Hur, 2006). Another possibility is that as slope increases, more fine particles susceptible to be washed-in and clog pores below the surface are transported by overland flow, thus reducing the probability of pore clogging within the seal layer and, consequently, thickness and final infiltration rate (Assouline and Ben-Hur, 2006). The surface seal model used in this study (eqn. 3) does not account for erosion of the seal layer, potentially the cause for the reduced fit to the infiltration data of Baumhardt (1985) at higher specific powers.

Final infiltration rate (K_f, eqn. 3) was found to decrease with increasing specific power, figure 5. This can be due to a thicker soil surface seal and an increase in surface seal density with greater specific power applied to the soil surface. The finite difference model used a constant 5 mm soil surface seal thickness. Thus, any change in surface seal thickness is modeled as a change in final hydraulic conductivity. For the Atwood soil, a power relationship between K_f and specific power provides a good fit to the data (fig. 5). It may be possible to develop a relationship between K_f, specific power and soil texture in general, but more infiltration data is needed to determine if such a relationship exists. The effect of specific power on K_f is consistent with the results of Shainberg and Singer

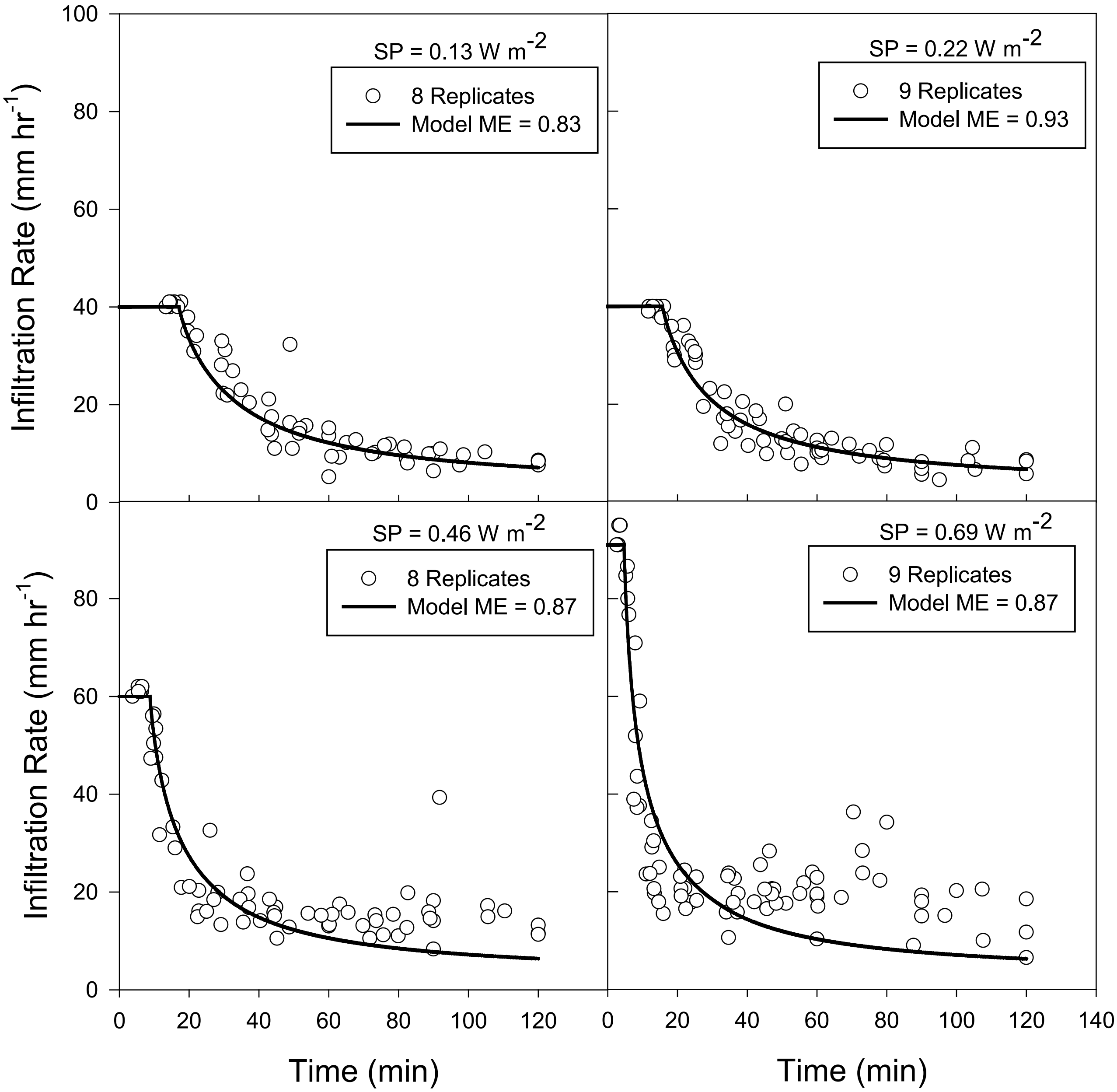

Figure 4. Infiltration model fit to runoff from soil columns of Atwood silty clay loam soil reported by Baumhardt (1985) under four levels of specific power applied by simulated rainfall.

(1988) who found that final infiltration rate decreased with increasing droplet fall height for an application rate of 40 mm hr^{-1}.

The surface sealing infiltration model calibrated to rainfall simulator data (fig. 4) was used to evaluate the effect of sprinkler selection on infiltration for the Atwood silty clay loam soil. Sprinkler composite application rate (fig.1) and specific power (fig. 2) profiles as a function of time were used in the model rather than constant application rate and specific power of a rainfall simulator. The power relationship between specific power and K_f shown in figure 5 was used in the model. With center pivot irrigation, specific power is a function of time rather than a constant with a rainfall simulator. To

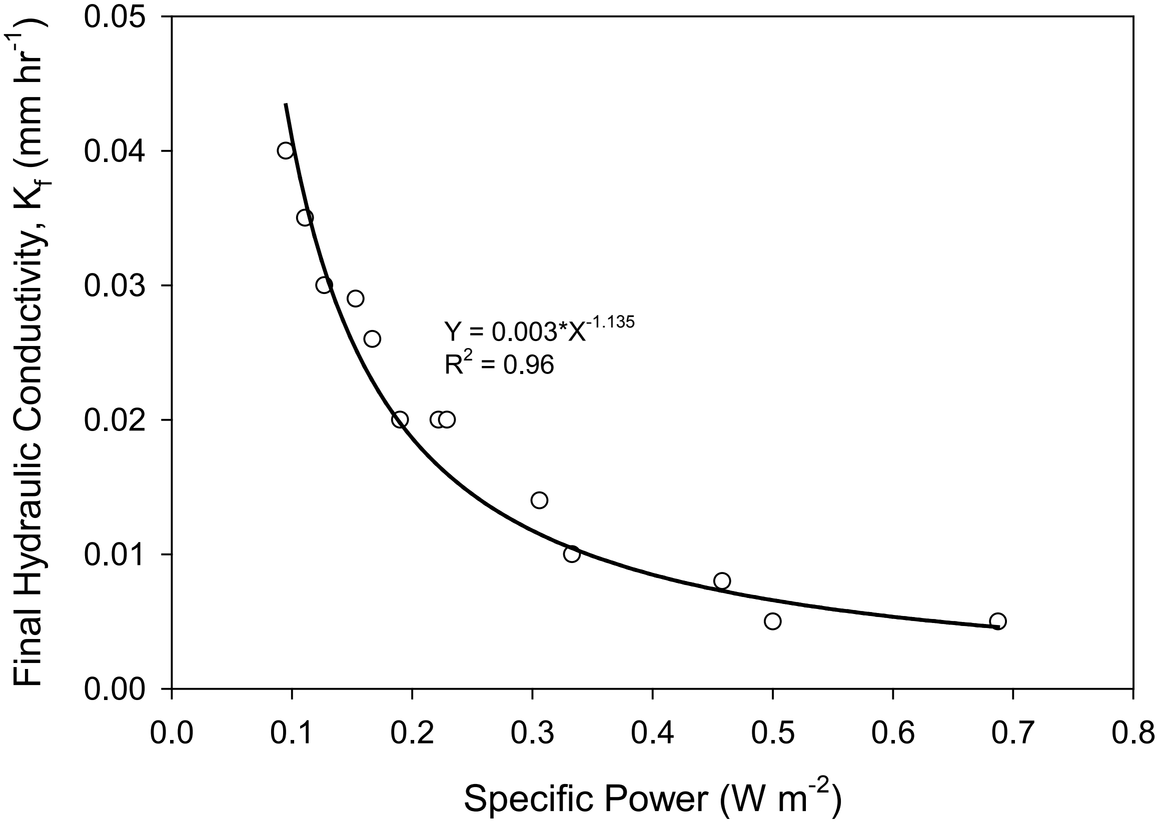

Figure 5. Relationship between final hydraulic conductivity of surface seal and specific power for the Atwood silty clay loam soil used in this study.

adapt the model to this feature of center pivot sprinkler irrigation, K_f was allowed to decrease with time (increasing specific power) to a minimum value (maximum specific power) and held constant for the remainder of the irrigation event. This implicitly assumes that peak specific power determines K_f for the soil under transient conditions.

The effect surface sealing has on predicted infiltration rate for the R3000 red plate sprinkler is shown in figure 6 for both a 25.4 mm and 15.0 mm irrigation water application event. Predicted infiltration with soil surface sealing is 3.6 mm less for the 25.4 mm application and 2 mm for the 15.0 mm application than predicted for no surface seal, Table 3. Potential runoff exists with or without surface seal formation due to the low satiated hydraulic conductivity of the Atwood silty clay loam soil. Predicted potential runoff is 43% for the 25.4 mm application and 27% for the 15.0 mm application with the effect of surface sealing and 29% and 13%, respectively, without surface sealing. Decreasing irrigation application depth decreases potential runoff and potentially increases irrigation water application efficiency with or without surface sealing.

The effect sprinkler wetted radius has on infiltration both with and without surface sealing is shown in figure 7 where the D3000 sprinkler is contrasted with the R3000 orange plate sprinkler. Predicted infiltration is 9.8 mm for the D3000 sprinkler and 19.2 mm for the R3000 orange plate sprinkler (Table 3) for a 25.4 mm application event with the effect of surface sealing, a 96% difference in infiltration and hence potential runoff. Conventional sprinkler irrigation wisdom suggests that a sprinkler with small drops (minimum droplet kinetic energy) should be used on a sealing soil such as the Atwood silty clay loam, to maximize infiltration and minimize runoff. However, the infiltration model does not

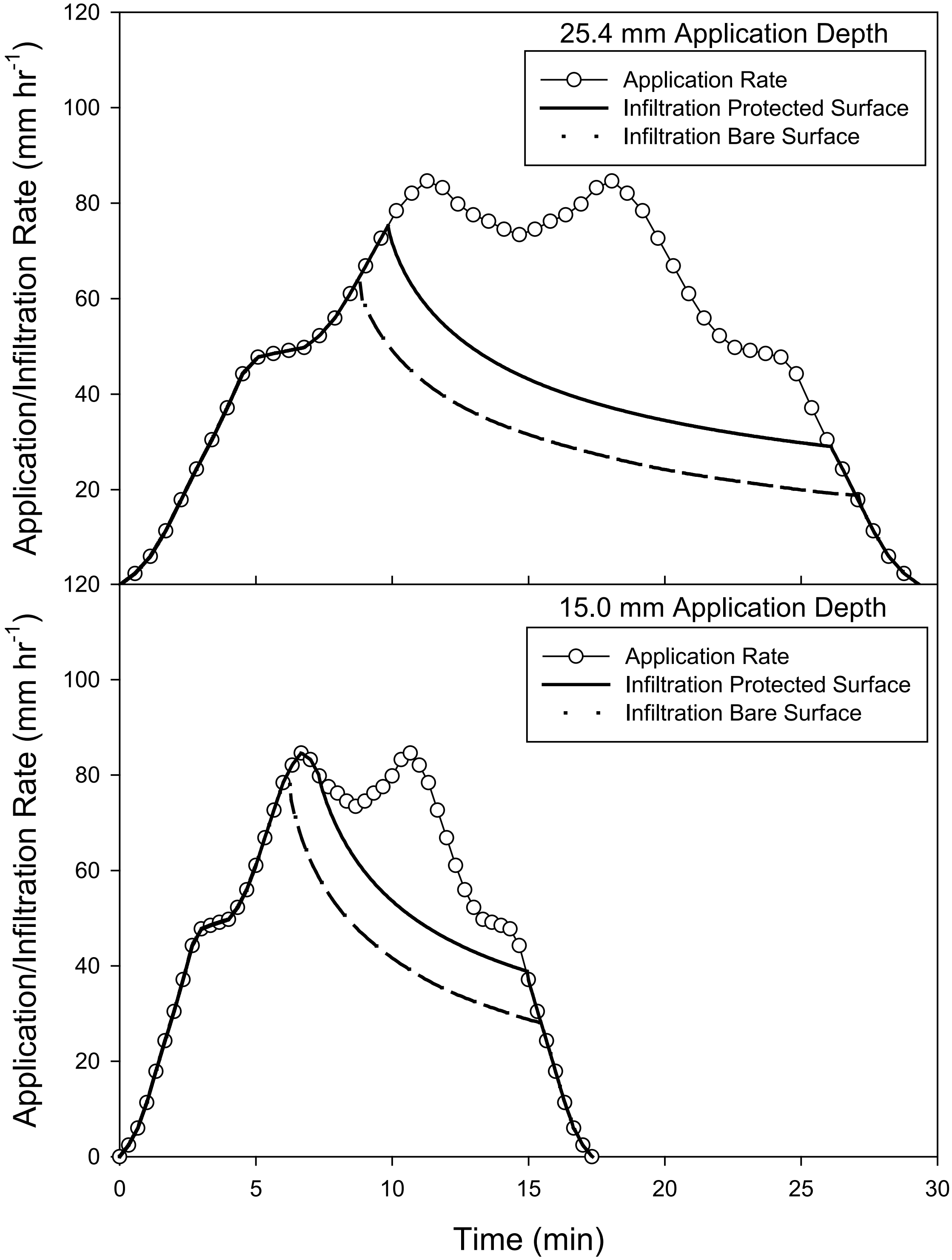

Figure 6. Model predicted infiltration rate for the Atwood silty clay loam soil under center pivot irrigation with the R3000 red plate sprinkler for protected and bare soil surface conditions and application depths of 25.4 and 15.0 mm.

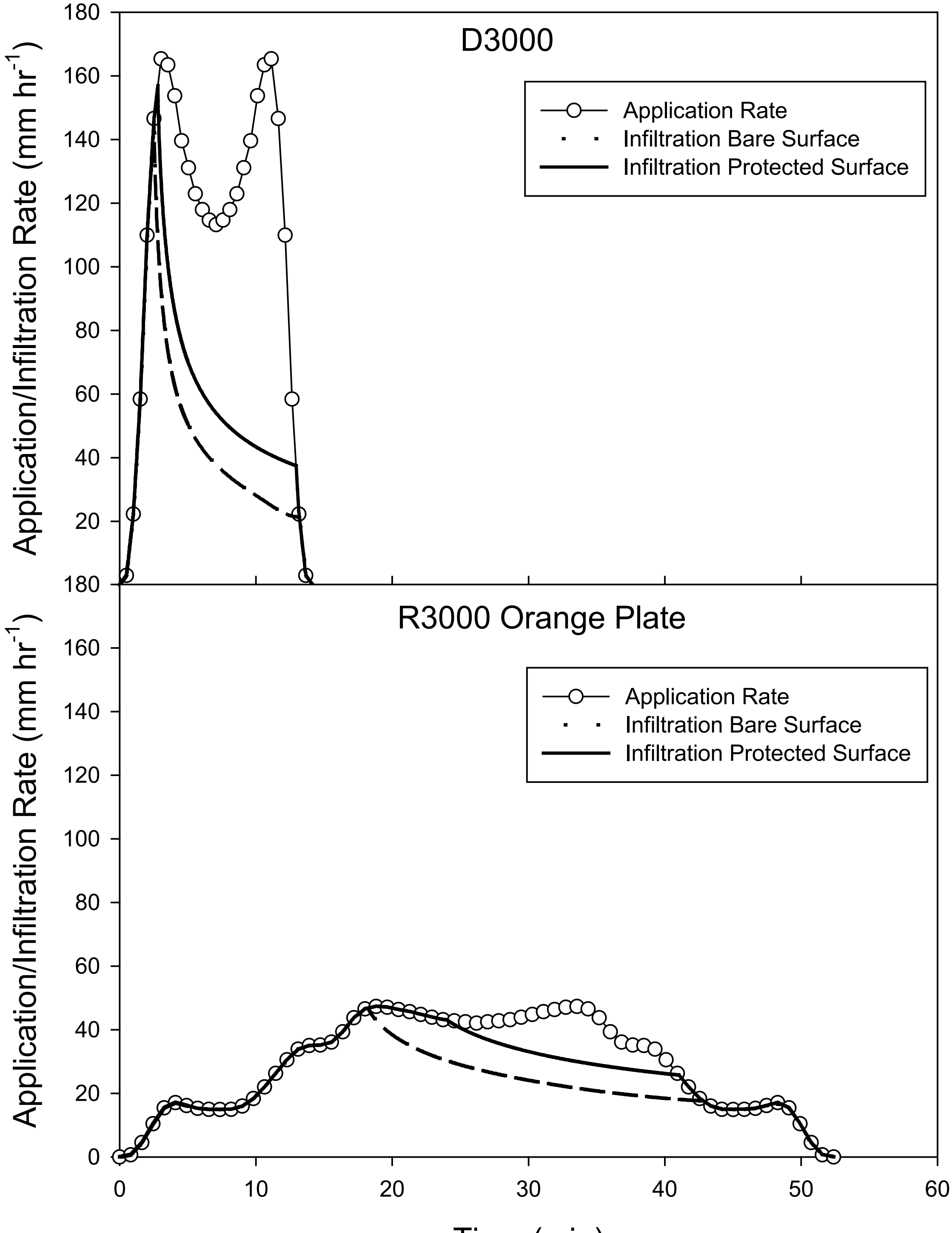

Figure 7. Model predicted infiltration rate for the Atwood silty clay loam soil under center pivot irrigation with the D3000 and R3000 orange plate sprinkler for protected and bare soil surface conditions and an application depth of 25.4 mm.

predict this to be the case. The Atwood silty clay loam soil is highly susceptible to surface sealing as hydraulic conductivity of the seal decreases by two orders of magnitude with as little and 0.1 W m^{-2} of applied specific power, figure 5. All the sprinklers used in this study have greater specific power and consequently form a soil surface seal. Given that a surface seal is going to form, spreading out the irrigation event over time and minimizing application rate maximizes infiltration, which is what the model predicts, regardless of kinetic energy. Thus, the R3000 orange plate sprinkler with 13.2 J m^{-2} mm^{-1} of applied kinetic energy (Table 2), which is 12% greater than the D3000 sprinkler, results in the greatest predicted infiltration for the Atwood silty clay loam soil. For the sprinklers used in this study, the infiltration model predicted an average difference of 3.2 mm between protected and bare soil infiltration for a 25.4 mm application depth.

Summary

A sealing soil infiltration model was developed using an explicit finite difference solution scheme with a transient soil seal formation model, which is unique from other studies in that it explicitly uses specific power as the driving factor for formation of a soil surface seal. The form of the transient seal formation model is also unique in that it is expressed as a rational function of specific power rather than an exponential decay function of cumulative droplet kinetic energy, water applied or time. The advantage of using specific power is that application rate as well as droplet kinetic energy are implicitly incorporated into soil surface seal formation. The utility of using specific power as the driving factor is demonstrated by application and performance of the sealing soil infiltration model across for both rainfall simulation and center pivot sprinkler irrigation.

The transient soil seal formation model uses three parameters; initial satiated hydraulic conductivity of the soil, final saturated hydraulic conductivity of the soil surface seal, and an empirical soil factor that represents the susceptibility of the soil to aggregate breakdown under droplet impact. Final saturated hydraulic conductivity of the soil surface seal was found to be well correlated with specific power for the soil used in this study. The soil factor was found to depend upon soil only. Predetermined estimation of the three model parameters is difficult, but could potentially be achieved by the development of correlations with soil physical parameters.

The infiltration model was used to predict infiltrated depth for five common center pivot sprinklers on the soil used in this study. Due to the high susceptibility of the soil to surface sealing from water drop impact and low satiated hydraulic conductivity, the sprinkler with the largest wetted diameter was predicted to maximize infiltration. The infiltration model predicted an average difference of 3.2 mm between protected and bare soil infiltration for a 25.4 mm application depth. Sprinkler kinetic energy had minimal impact on infiltrated depth because all the sprinklers used in this study caused a surface seal.

ACKNOWLEDGEMENTS

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Update on Variable Rate Irrigation Performance

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Abstract *The paper will discuss the processes, data and results in the work being conducted to validate the performance of variable rate zone control irrigation. Information from two years of data collection and analysis will be presented. A brief review of the status of commercially available variable rate products in the USA will begin the paper. Information on the processes used to validate performance will be presented. Then the discussion will move to specific information on fields' characteristics and VRI irrigation equipment. The data will be presented that has been collected through the 2010 and 2011 growing seasons in the USA. The data will include but not be limited to catch can, soil moisture, aerial imagery and crop performance. The paper will close with the conclusions and recommendations for future work in evaluating VRI performance.*

Keywords Irrigation, variable rate irrigation, center pivot, precision irrigation

Introduction

Since the introduction of the center pivot in the mid-1950s, the mechanical move industry has continued to improve and develop products to better meet the needs of production agriculture. The overall goal has been to provide cost-effective, uniform irrigation across the field with a specific application depth.

With the introduction and acceptance of precision agriculture, suddenly more information has become available for a particular field and areas in the field, including yield, EC maps, soil and grid sampled fertility maps. Farmers now have data indicating the variability across the field, which was already suspected but not proven. The challenge then becomes how to use this data and how to make changes that would impact different areas of the field.

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, Ft. Collins, CO and Sidney, MT (King 2005, Marek 2004). The first commercial, marketed variable rate irrigation package in the USA was jointly developed by the University of Georgia, FarmScan and Hobbs and Holder (Hobbs & Holder 2006). This package 'broke' the center pivot into sections and had the ability to apply different depths in different areas along the pivot and in the direction of travel. These units have primarily been installed in the southeastern United States. AgSense (AgSense 2011) introduced a commercial add-on unit for center pivots in 2009 that would change the speed at various locations around the field based on a specific field prescription in six degree increments. Valmont Industries introduced the Valley VRI Zone Control in 2010 and in 2011 the Valley VRI Speed Control packages.

Objective

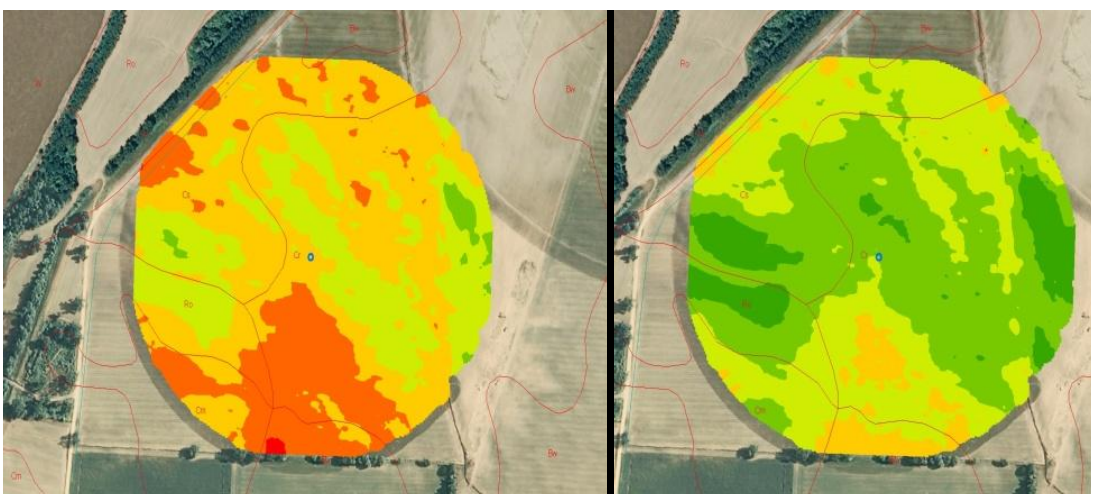
The goal of this project was to collect and analysis field data on commercial center pivots using zone control packages to characterize the performance of variable rate irrigation.

Discussion

The zone control packages reviewed were all Valley VRI Zone Control consisting of a Valley Pro2 control panel, VRI tower boxes, sprinkler control valves and sprinkler package. Below is a conceptual drawing of the Valley VRI Zone Control package components.

A prescription that is specific for the field is created with the Valley VRI Prescription Software or CropMetrics Virtual Agronomist. The prescription is then loaded into the Pro2 control panel. The VRI Prescription Software allows prescriptions to have up to 30 zones and 180 sectors around the field, each sector as small as two degrees.

In the spring of 2010, Valmont Irrigation began to validate the lab and field testing that had been done with the Valley VRI Zone Control package on a field near Dyersburg, Tennessee. The machine's configuration was a total length of 350m (1,148 ft) and six drive units. The flow rate was 51lps (800gpm) with fixed-pad sprinklers with a medium groove pad and regulator. The field challenge was parts of the field were either being overwatered or under watered, and uniform crop production was not being achieved across the field. In conversations with Dr. Earl Vories of USDA-ARS about VRI and how to determine the layout of Management Zones, it was suggested by Dr. Vories that apparent electrical conductivity (EC_a) of the soil profile be used (Vories 2008). EC_a is a sensor-based measurement that provides an indirect indicator of important soil physical and chemical properties.



Deep EC_a Figure 2 Shallow EC_a

Results

In 2010 the problem of characterizing performance was approached in three ways:

- Visual observation management zones – particularly those with the lightest textured soils receiving the full depth and those with the heaviest soils receiving a reduced depth.

- Soil moisture monitoring in one of the areas with the light textured soils where the prescription always called for 100% of the base application depth, and in heavy soils area where the base depth was reduced by 40%.
- Aerial imagery– infrared to compare ground cover and growth of the crop and visually look for areas where the crop appeared to be under stress.

One of the first observations was the cycle time was too long when a Pivot Zone was operating in an area where there was to be a reduction in the application depth. It was observed the drive unit was moving too far during a pulse and sufficient overlap of the sprinkler package in the direction of travel was not being achieved. To correct this, the cycle time was changed in the constants at the control panel.

The soil moisture data was tracked remotely; it looked for drying trends in the area where the prescription called for a reduced application depth. Below is an example of the soil moisture data sets for a sample time period (Figure 4a and 4b).

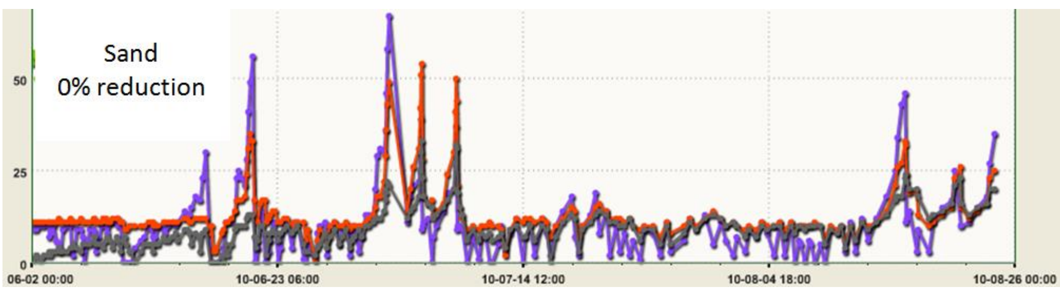


Figure 4a

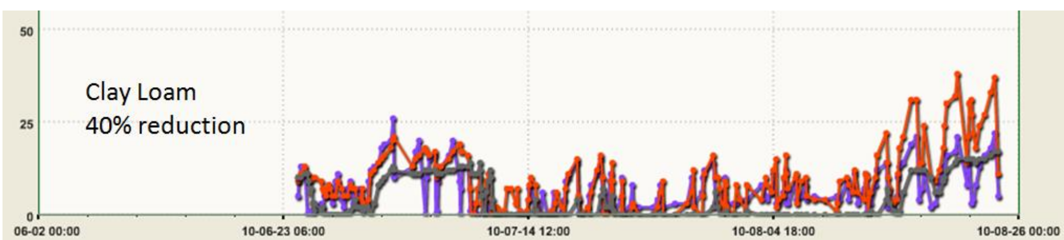
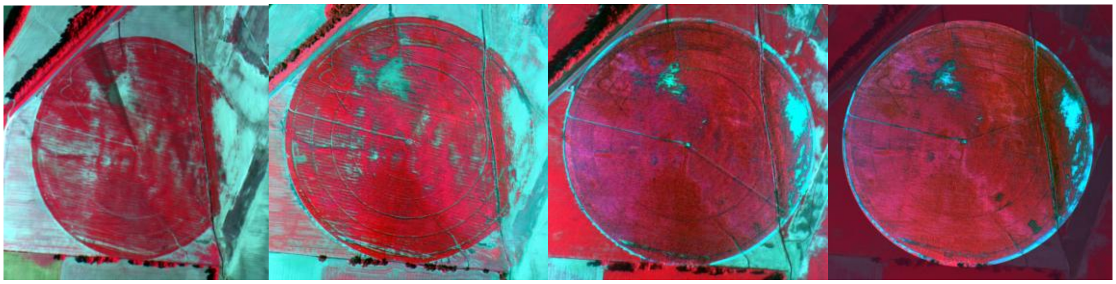


Figure 4b

Figure 4a is an area with clay loam soil that received 60% (40% reduction) of the base application depth. Figure 4b is an area of fine sand that always received 100% of the base depth. Each area received the same number of irrigations. Most important from this data is that over time, the clay loam with the reduced application depth did not show a drying trend; for most of the crop season it paralleled the soil moisture status of the area that received 100% of the base application depth.

The following were a series of infrared images taken during the growing season



June 16th June 30th July 23rd August 6th

Figure 5

In the images above, there was gradual improvement in the ground cover and, in general, the crop appeared "good" across the field with no particular weak areas except for the areas where the crop was blown out by wind in the early season.

For the 2011 crop season several VRI zone control packages were followed to characterize performance in southwest Kansas, western Nebraska, eastern Nebraska and central Illinois. Plans to continue work with the Tennessee pivot were discontinued due to flooding along the Mississippi and no crop was planted. The plans to characterize these VRI zone control packages included:

- Sprinkler uniformity by catch can testing
  - Along the center pivot – 3m (10ft) spacing
  - In the direction of travel – in a grid of three lines (3 x 30) under a particular zone (usually the next to the last) in a 3m (10ft) spacing
- Soil moisture grid sampling
  - Watermark sensors were spaced roughly 10m (30ft) apart at 15cm (6in) deep in an array of six in two areas – one group of six where full application depth was applied and another group where the application was reduced
- Aerial imagery
  - Used combination of chlorophyll, ground cover and NDVI at 5m resolution

Unfortunately due to resource constraints, weather and other situations not all of the center pivots had all of the characterizations done.

Southwest Kansas

Figure 6

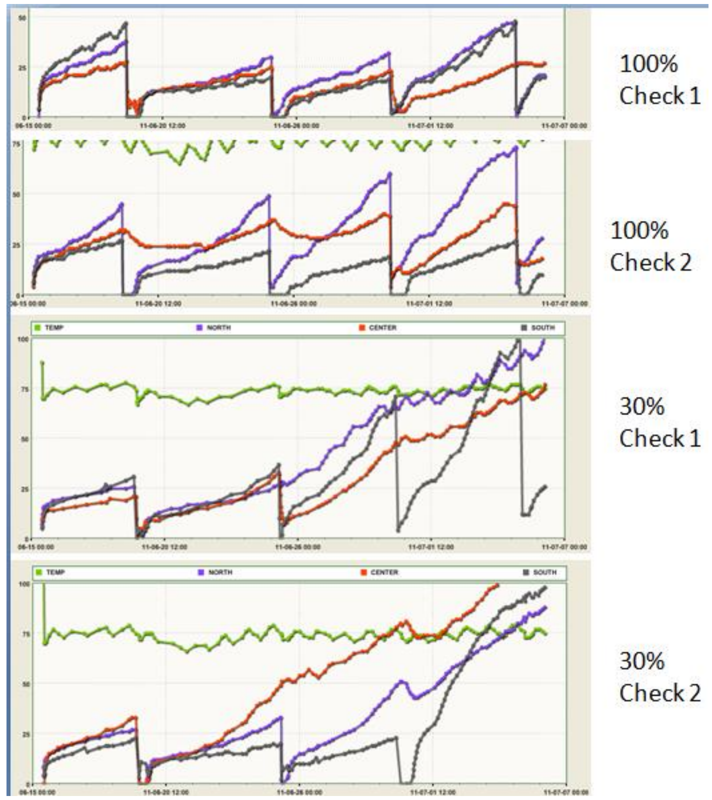


Figure 7

Figure 6 is an aerial shot of the center pivot and figure 7 presents the soil moisture grid data. All sensors were positioned 15 cm (6in) deep in a grid pattern. The 100% shows irrigations and the soil profile being refilled. The 30% gradually shows a drying and after irrigation and the soil profile not being refilled. No other data was collected from this center pivot

Western Nebraska

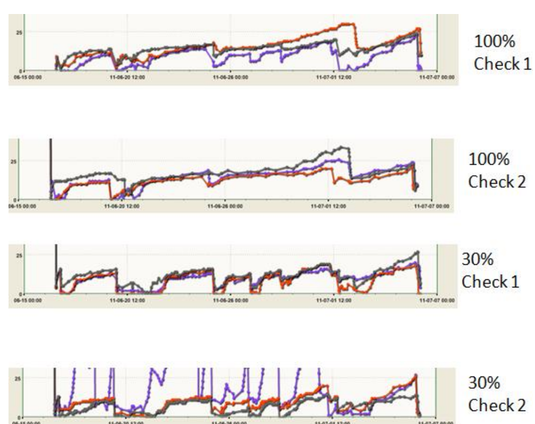


Figure 9

Figure 9 shows the soil moisture grid the same layout as for figure 7. However rainfall 'masked' any signs of soil moisture differences.

Figure 10 shows a catch can layout during a test. The cans are in three lines in an arc under a specific zone. The center pivot is operated ahead of the catch can arc to ensure everything is operating okay and then started into the catch can area. After the center pivot moves across 1/3 to ½ of the catch cans then the prescription is changed and then later changed back.

Figure 10

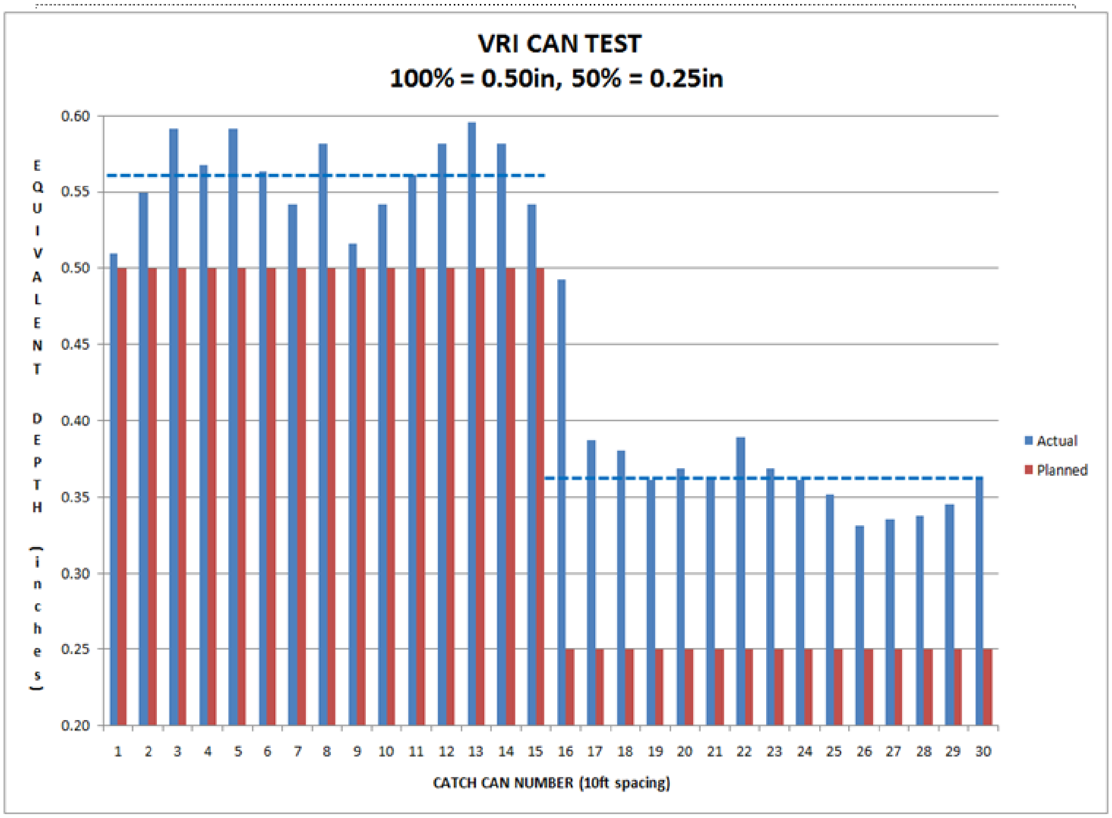
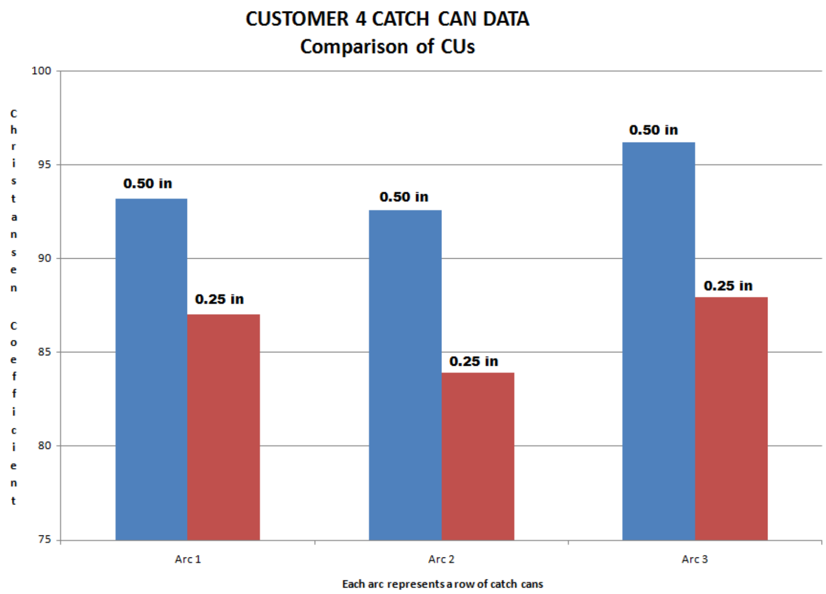


Figure 12

Figure 12 represents one of the passes and the data of the catch can test. The red bars represent the application depth that was planned to be applied and the blue bars the actual average of the three catch cans that are side by side. This center pivot had a rotating sprinkler package mounted on drops about 2.5m (8ft) off of the ground.

Figure 13 shows the Christiansen Coefficient for each segment of the arc. The blue bars are each arc for the area of 12mm (0.50in) application depth. The red bars represent the lines when applying 6mm (0.25in).



F
igure 13

Figure 14 shows three examples of aerial imagery that was collected on July 12th.

Again due to the rainfall no trends were observed during the growing season when comparing one image to the next taken three to four weeks later.

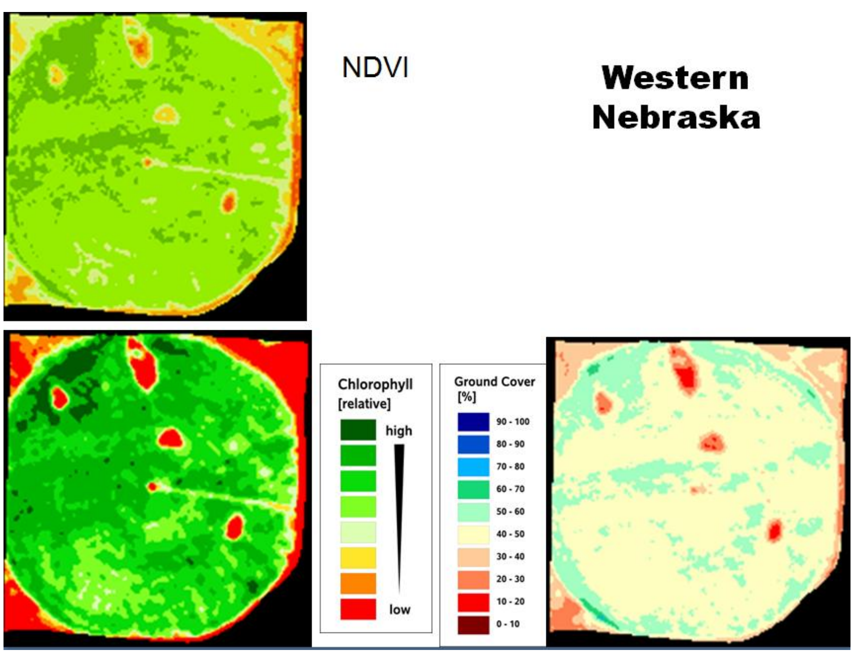


Figure 14

Eastern Nebraska

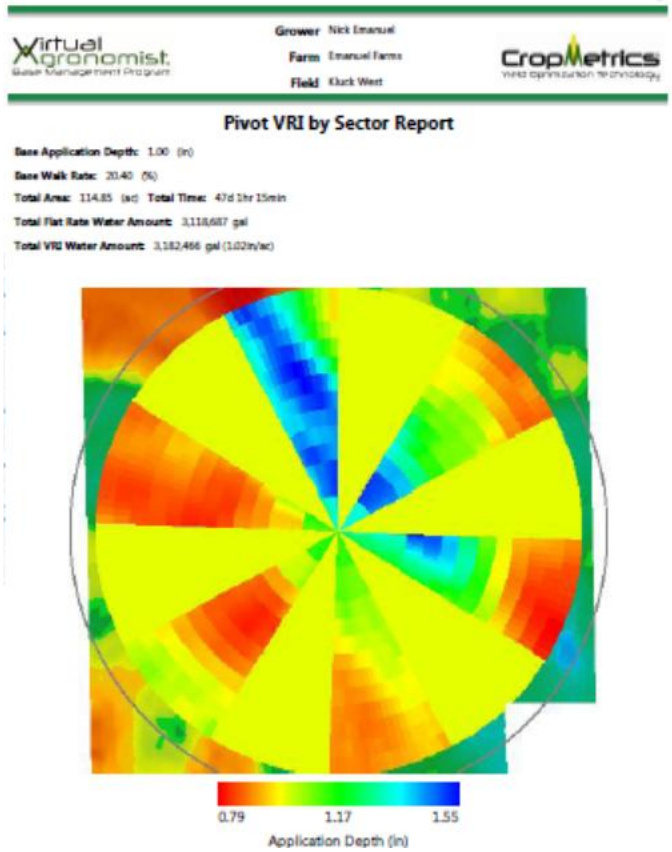


Figure 15

Figure 15 represents the prescription used for the center pivot in eastern Nebraksa. The owner working with CropMetrics wanted to do some testing of prescriptions vs. no prescriptions.

A soil moisture sensor grid was setup for this site similar to what was used at the other sites. Again due to the rainfall no specific trends could be seen.

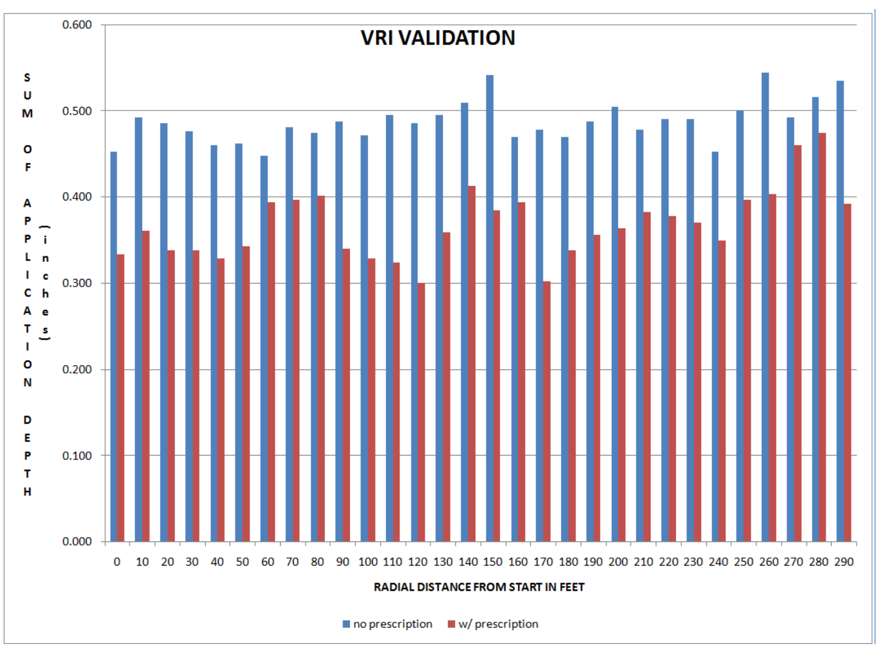


Figure 16

Catch can data is shown in figure 16. The blue bars represent the average of the three catch cans operating with no prescription and the red bars with a prescription of 100% - 50%. The sprinkler package used rotating pads on top of the pipeline.

Central Illinois

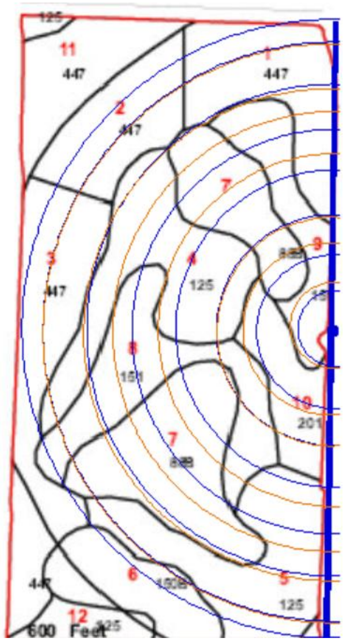


Figure 17 is an aerial image of the field used for initial planning purposes.

Figure 18 shows the soils map in relationship to the center pivot drive units and the VRI zones.

Figure 17 Figure 18

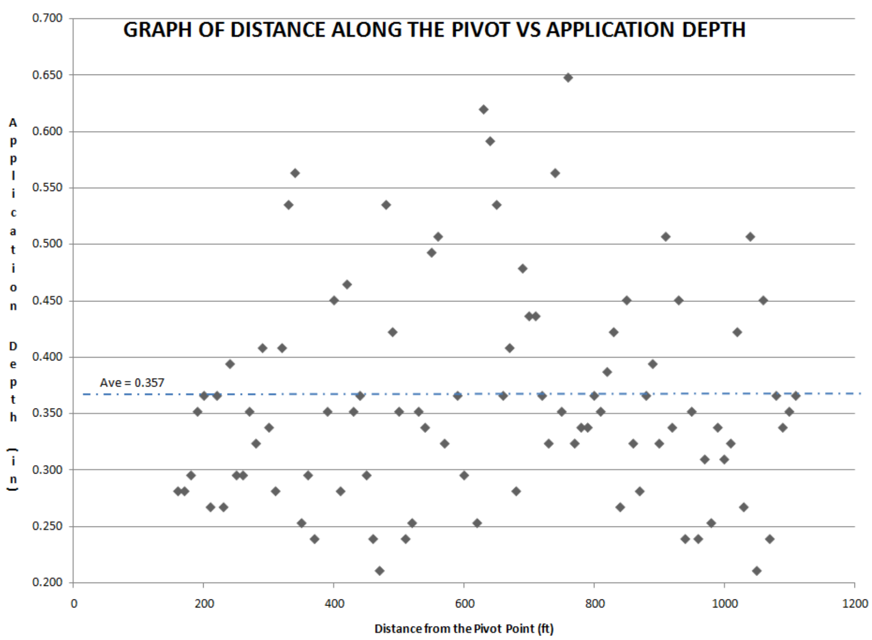


Figure 19

Figure 19 above illustrates a catch can test where the cans were set in a line 3m (10ft) apart parallel to the center pivot and the pivot run across the catch cans applying 12mm (0.50in) without a prescription running.

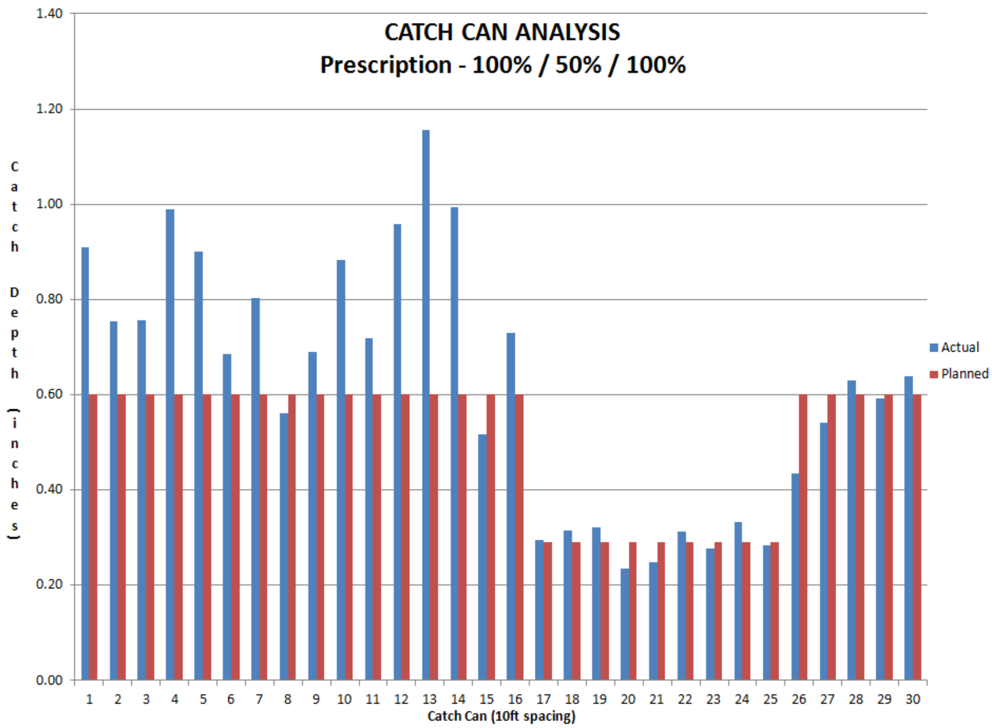


Figure 20 shows the average volume collected. The red line show planned and the blue the actual depth.

The sprinklers were fixed head sprays at 2m (6ft) ground clearance.

Started applying 15mm (0.60in) , switched to 4.5mm (0.30in) and then back to 15mm (0.60in)

Figure 20

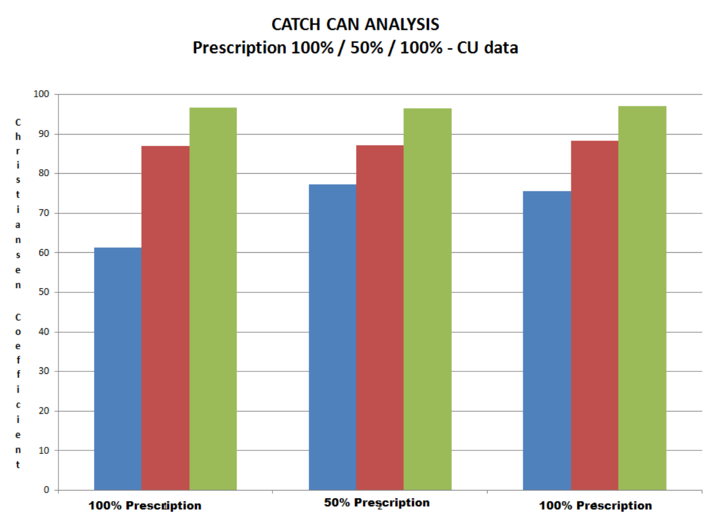


Figure 21 shows the Christiansen coefficient for each of the catch can segments at the various prescriptions

Figure 21

Conclusion

Historically, center pivot irrigation has treated the entire irrigated field the same and the goal has been to make uniform applications across the field. With variable rate irrigation, the farmer now has the ability to apply specific amounts of water to specific locations within the field. Preliminary work with validation of the performance in 2010 and 2011 indicate that while in general terms the zone control works as expected there are items that are not completely understood.

Sprinkler uniformity by catch can testing – along the center pivot. Only one good test was able to be run as shown in figure 19. This data indicated more scatter than we expected and a Heerman and Hein coefficient of 88.

Sprinkler performance in the direction of travel also was a challenge due to wind, crop growth and resources. Figures 12, 16 and 20 are the best examples of what happened in the direction of travel.

In figure 12 there are a couple of points to note:

- The transition between prescriptions appears to occur in about 6m (20ft)
- Both at 100% and 50% prescriptions applied a depth greater than expected
    - At the 100% it was determined there was an error in the panel constants which explains the difference
    - At the 50% setting even with the panel constant adjustment the difference is not totally understood. As soon as the crop is harvested additional tests will be run with more catch can tests to characterize the performance.
- The Christiansen coefficient shown in figure 13 shows good uniformity but a definite difference with higher values at 100% prescription and lower values when the nozzles are being pulsed on and off to achieve the 50% prescription which seems to make sense.

In figure 16 there is primary point to note:

- Due to the wide patterns of the rotating pad sprinklers on top of the pipe the transition is not visible between prescriptions and for tests to be meaningful need to run characterization with much larger zones.
- With vs. without prescription showed different application depths which is not completely understood and again needs more testing as the wind was at a higher speed then we would have liked for the without prescription and suspect the drift would account for the differences.

In figure 20 there are a couple of points to note:

- The transition between prescriptions appears to occur in about 6m (20ft) switch from 100% to 50% but 9m (30ft) when switching back to 100%. Again this was the best run due to wind and anticipate more testing this fall.
- Both at 100% and 50% prescriptions applied a depth close to expected

- The Christiansen coefficient shown in figure 21 indicates a difference between the lines which may be more related to the position in relation to the sprinkler head than anything. When pulsing, at 50% did not show significantly lower uniformity than at 100%.

Soil moisture grid sampling from figure 7 showed what was expected. At a reduced application depth the soil gradually dried out. As shown in figure 9 no trends were see which was true at the other sites due to rainfall refilling the profile.

Aerial imagery was not very informative as no trends were noted on the fields where a series of images were collected.

Based on the information collected in 2010 and 2011, there are a number of areas requiring additional work and evaluation:

- Validation and characterization of VRI zone control performance
    - Catch can tests
        - Show promise in providing information for specific units but require considerable resources to do and timing with crop and weather are critical in commercial fields
        - Considering possible ways to simulate
    - Grid soil moisture sensing shows promise and for 2012 want to continue with this same basic plan
    - Aerial imagery may not offer much to help evaluate and understand performance but also may have not gotten a fair opportunity in 2011.
- Need to explore more about sprinklers and how they relates to VRI performance.

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Application Uniformity of a Commercial Center Pivot Variable Rate Irrigation System[1]

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Abstract. With the advent of commercial variable rate irrigation (VRI) systems, there is a great interest in using them to improve water use efficiency, implement deficit irrigation strategies in water limited regions and manage water applications for many other important objectives. Multiple catch can trials were performed to determine the application uniformity of a commercial VRI system for a 3-span center pivot. Catch cans were used in radial transects and grid patterns to test the uniformity in multiple zones along the pivot lateral at different watering rates (100%, 80%, 70%, 50%, and 30% of nozzle "ON" time), and in an arc-wise pattern to test the circumferential uniformity and sector-wise resolution of the system. Results showed that the Heerman and Hein coefficient of uniformity (CU_{HH}) and the lower-quarter distribution uniformity (DU_{lq}) were significantly lower when the watering rate was 30%; but there were no significant differences in uniformity for the higher watering levels or among span locations. With respect to circumferential uniformity, the mean CU_{HH} and DU_{lq} values were 88.1% and 0.82; these values were not significantly different from those obtained when catch cans were arranged in a transect pattern. The mean evaporation and drift loss for the transect-type trials was 10.8%.

[1] The U.S. Department of Agriculture (USDA) is an equal opportunity provider and employer.

Keywords: center pivot system, uniformity of application, variable rate irrigation

INTRODUCTION

Due to increasing competition for quality water and limited water resources, improving irrigation efficiency is a continuing goal for production agriculture. Site-specific or precision irrigation using VRI equipment is one method of improving control of the depth and timing of irrigations. Application uniformity and irrigation control are especially critical for the success of site-specific irrigation.

Commercially available VRI equipment enables a moving sprinkler system to adjust the depth of water applied along the lateral. The commercial VRI software enables a field to be divided into management zones that range in width from 2º to 180º sector angles, while the minimum radial length of a zone is dependent on the number of drop hoses in a sprinkler bank controlled by one valve and the distance between the drops. Sprinkler banks are configurable and controlled by a single solenoid valve that activates hydraulic valves on drops in a bank. Quantifying the uniformity of the depth of water applied within a management zone and determining the resolution of control in an arc-wise

direction is critical for assessing VRI system capabilities and for interpreting experimental results (Stone et al., 2006).
The objectives of this study were to evaluate the application uniformity and practical management zone resolution for a 3-span center pivot irrigation system retrofitted with a commercial variable rate irrigation system.

METHODS AND MATERIALS

Experimental site and existing irrigation system

Experiments took place at the Conservation and Production Research Laboratory, Bushland, Texas (35° 11' N, 102° 06' W, 1170 m above mean sea level) using a three span center pivot system with pivot lateral length of 131-m and drop hoses spaced 1.52-m apart. Catch can trials were performed during the months of April and May 2011 during daylight hours. Meteorological data was collected from a nearby weather station located less than 30 m from the pivot field (Evett et al., 2011).

Variable Rate Irrigation Equipment

An existing three-span center pivot system with a Pro-panel 2[2] was retrofitted with a variable rate irrigation (VRI) system that is commercially available from Valmont Industries Inc., Valley, NE. The major VRI components included a programmable logic controller (PLC) that actuates electronic solenoid valves for sprinkler bank control; hydraulic valves plumbed between the pivot lateral and each drop hose (Fig. 1) and arranged in banks, each of which was controlled by a separate electronic solenoid valve; a geographical positioning system (GPS) receiver; and variable rate irrigation prescription firmware and software. Watering application rates were enabled by ON/OFF pulsing of the hydraulic valves; and the sprinkler bank duty-cycle was prescribed through the VRI software. Each of the sprinkler banks was configured to include six drop hoses; and 12 banks were established along the pivot lateral. An electronic solenoid valve controlled each bank and the number of drop hoses within the bank defined the radial dimensions of a management zone.

Flexible drop hoses 19-mm (¾") in diameter where made of polyethylene and equipped with a pressure regulator rated at 41.37-kPa (6-psi), and a low drift nozzle system (LDN) with a single concave pad (Senninger, Clermont, FL). Drop hoses were approximately 1.8 m above the ground and spaced 1.5 m apart. Nozzle design flows were between 0.027 and 0.316 L s^{-1} (0.43 – 5.0 gpm) and the sprinkler operated at an average pressure of 172.4 kPa (25 psi) and the maximum throw diameters ranged from 2.6-m to 4.9-m.

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[2] The mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

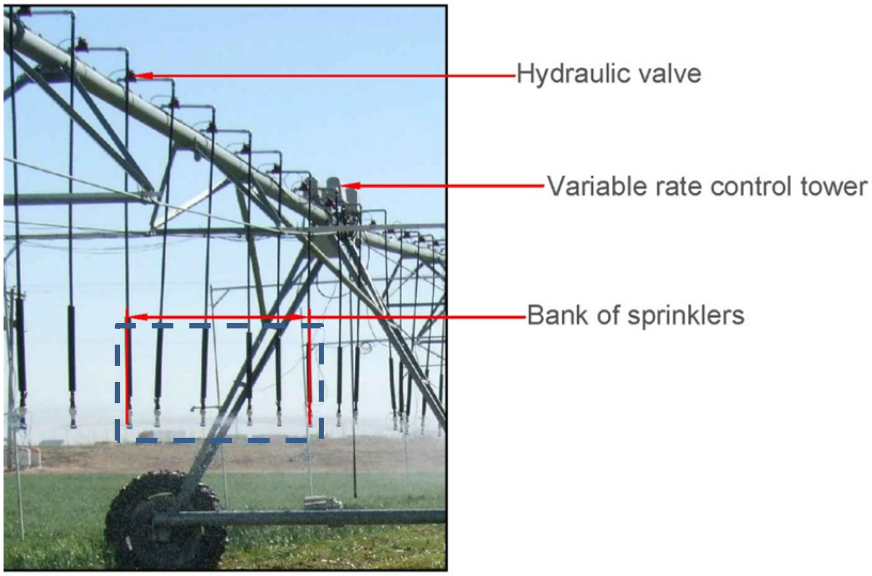


Figure 1. Section of center pivot showing hydraulic valves on each drop hose, variable rate control towers located near the regular tower box, and bank of sprinklers (6 drop hoses) which comprise a zone.

Catch can specifications

Catch cans (15.2 cm ht. × 15.4 cm dia.) were constructed of white rigid polyvinyl chloride (PVC), Schedule-40 (Fig. 2). The top portion of each can was beveled to define the catch area precisely. Can height was chosen to help reduce droplet splashout. The cans were placed over mowed wheat, each on a three-legged wire stand. The top of the stand was approximately 7 cm above the ground and was leveled by adjusting the penetration into the soil. Prior to each trial, dirt and insects were cleaned from the collectors and vegetable oil was sprayed inside the collector to decrease evaporative losses.

Figure 2. Typical positioning of catch can in the pivot field for uniformity testing.

Trials

To evaluate application uniformity of the VRI system, we aligned the catch cans in three patterns: (1) transect; (2) grid; and (3) arc-wise (Fig. 3). The transect- and grid-type patterns were combined during the first five trials. The pivot travel speed was set at 9%

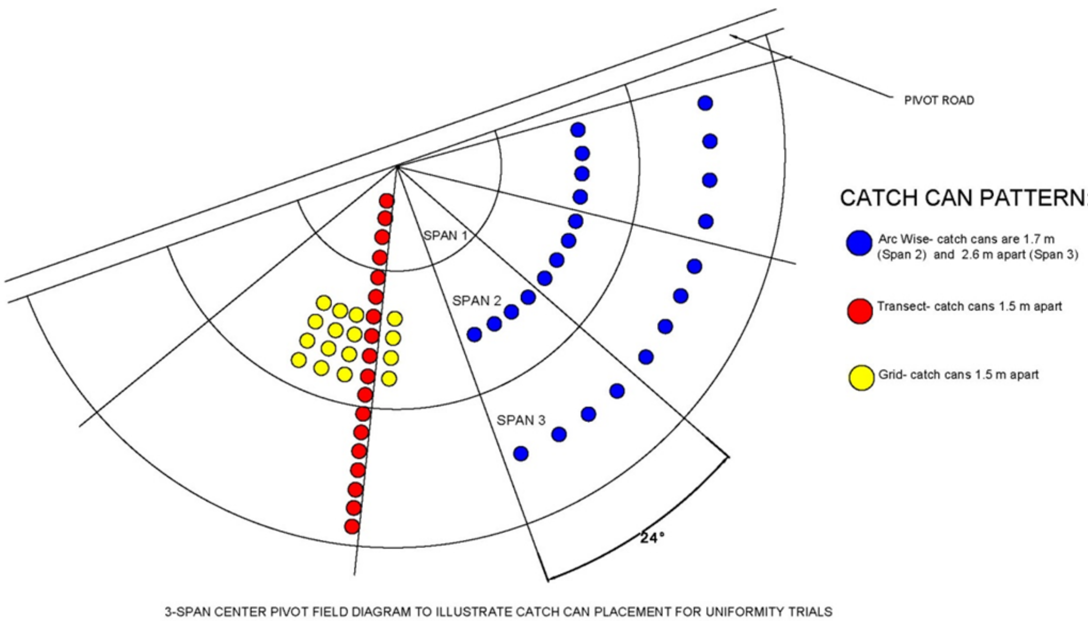


Figure 3. Catch can layout patterns for uniformity testing of variable rate irrigation system over a 3-span center pivot.

for Trials 1-4 and Trials 6-10; and at 4% for Trial 5 (Table 1). Seventy catch cans were placed in a transect the length of the pivot lateral, and an additional 20 were placed to form a 5 x 5 grid within a single zone. During the trials, 12 sprinkler banks were actuated, and every two banks were programmed to deliver water at the same rate; thereby 6 zones were established. The order of the watering rates was randomized along the lateral for Trials 1-5. The minimum collector distance to the pivot point was 21.8-m .

Twelve collectors were placed in each zone for Trials 1-5; a 2 × 14 grid was established in each of the three zones for Trial 6; 10 collectors were placed in each of the 12º sectors for Trial 7;sector length was 13-m. Sixteen collectors were located in each of the 24º sectors for Trials 8-10. Collectors were spaced 1.5-m apart for Trials 1-6; 1.3-m for Trial 7; and 1.7-m in the second span and 2.6-m in the third span for Trials 8-10. The length of the sector between transitions was 26.3-m in span 2 and 99.4-m in span 3. The level of watering rates was chosen to evaluate the pulsing response between rate changes of low-to-medium, low-to-high, and medium-to- high, as well as the converse.

Table 1. Trials, collector patterns, and watering rates per zone for uniformity testing

Trial	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Travel speed
1: Transect/grid	50	30	50	30	80	100 (grid)	9%
2: Transect/grid	30	80	50	100	30	100 (grid)	9%
3: Transect/grid	50	100	80 (grid)	30	50	30	9%
4: Transect/grid	100	30 (grid)	50	80	30	50	9%
5: Transect/grid	100	30 (grid)	50	80	30	50	4%
6: Grid	30	-	50	-	80	-	9%
7: Arc-wise, 12º	-	-	80, 30, 100, 50, 80, 100, 30, 50, 100, 30	-	-	-	9%
8: Arc-wise, 24º	-	30,70, 100	-	-	70, 100, 30	-	9%
9: Arc-wise, 24º	-	70,100 ,30	-	-	30, 70, 100	-	9%
10: Arc-wise, 24º	-	70,30, 100	-	-	100, 70, 30	-	9%

Standard methods for center pivot evaluation of application uniformity were followed (S436.1, ASABE *Standards*, 2004). The pivot was started approximately 10º before the approach of the transect line to allow adequate time for the pulsing action of the valves to synchronize. The volume of water collected in each catch can was measured using a funnel and a 1 L capacity graduated cylinder marked every10-ml. Measurements were made after the pivot moved beyond the target collector(s) and as soon as the spray from the sprinklers was no longer striking the collector.

Calculations

Uniformity of application was evaluated using two approaches. The Heerman and Hein (1968) uniformity coefficient (CU_{HH}) is:

$$CU_{HH} = 100\left[1 - \frac{\sum_{i=1}^{n} S_i \left|V_i - \overline{V}_p\right|}{\sum_{i=1}^{n} V_i S_i}\right]$$

where n is the number of collectors, *i* is the ith collector, V_i is the volume of water collected in the ith collector, S_i is the distance of the ith collector from the pivot point, and $\overline{V}_p$ is the weighted average of the volume of collected water and is calculated as:

$$\overline{V}_p = \frac{\sum_{i=1}^{n} V_i S_i}{\sum_{i=1}^{n} S_i}$$

Lower quarter distribution uniformity (DU_{lq}) for each zone was calculated as (Duke and Perry, 2006):

$$DU_{lq} = \frac{\overline{V}_{lq}}{\overline{V}_{tot}}$$

where $\overline{V}_{lq}$ is the average of the lowest one-fourth of the measurements in the zone, $\overline{V}_{\text{tot}}$ is the average depth of all applications in the zone. This coefficient represents the spatial uniformity across and within a field (Howell, 2002), and is not a measure of efficiency.

The mean absolute error (MAE) was calculated to compare how close the measured collector volumes were to the expected design volumes:

$$\text{MAE} = \frac{1}{n}\sum_{j=1}^{n}\left|\hat{P} - O\right|$$

where $\hat{P}$ is the predicted value and O is the observed value, n is the number of catch cans used in zone j.

Standard error (SE) calculations were used to judge differences in measurements within a management zone:

$$\text{SE} = \frac{s}{\sqrt{n}}$$

where s is the sample standard deviation and n is the number of collector measurements within a zone. An analysis of variance (ANOVA) of the coefficients of uniformity was performed using SAS (SAS Institute, Inc., Cary, N.C.).

The calculated evaporation and drift losses were based on the equation (Faci et al., 2001):

$$EDL = \left(\frac{V_c - V_m}{V_c}\right)100$$

where V_{c} was the total volume of water discharged (calculated using the speed of the pivot for the particular trial run, 9% = 0.575 m min^{-1}, and actual nozzle flow rates from previous flow tests); and V_{m} was the total measured volume of water collected in the catch cans.

RESULTS AND DISCUSSION

During the first six trials, the average air temperature remained relatively cool and the humidity was relatively low. Air temperature did warm up later in May for Trials 7, 9, and 10. The average wind speed was higher than recommended by Standard S436.1 throughout all the trials; however, we did our best to perform the catch can trials on days when the wind was not gusting for the short window of time that was available for the testing. During several of the trials, 4, 5, 7, and 10, there was a change in wind direction; and wind gusts were particularly high during Trials 5, 8 and 10 (Table 2). High and gusting winds are common at Bushland, Texas.

Table 2. Average meteorological data during the catch can trials and calculated evaporation and drift loss. Losses were not calculated (NC) for the arc-wise runs.

DOY	Trial No. (Time of day performed, CST)	Average RH (%)	Average Wind Speed ($m\ s^{-1}$)	Wind Gusts ($m\ s^{-1}$)	Wind Direction	Average Air Temperature [ºC]	EDLs (%)
118 (Apr 28)	1: (930-1130)	35	5.6	6.6	NW	16	8.6
	2: (1330-1500)	17	4.4	4.9	WSW	22	13.7
123 (May 3)	3: (1000-1100)	21	5.7	6.9	NW	15	12.8
	4: (1400-1530)	14	5.5	5.9	N, NW	21	8.9
126 (May 6)	5: (930-1100)	22	9.4	11.9	S,SE, SW	24	9.8
132 (May 12)	6: (1300-1500)	25	4.3	4.9	SE	21	NC
143 (May 23)	7: (830-1840)	15	4.0	6.5	NNE, NW	29	NC
146 (May 26)	8: (830-1500)	31	5.1	10.3	NE,E,S,SE	23	NC
147 (May 27)	9: (830-1500)	19	5.0	7.9	NW,NE	28	NC
152 (June 1)	10: (830-1500)	42	8.2	12.2	S, SE	30	NC

An ANOVA indicated that the CU_{HH} and DU_{lq} were significantly influenced by watering rate and configuration of the catch cans, but not by span location (Table 3). The grid pattern resulted in significantly higher CU_{HH} and DU_{lq} values than transect and arc-wise patterns. Zones with a watering rate of 30% had a significantly lower CU_{HH}. Their average CU_{HH} and DU_{lq} values were 85.1% and 0.80, respectively. The MAE of the collected volumes was positively correlated with watering rate ($F = 11.9$, $\alpha = 0.001$). The SE was inversely correlated ($F = 6.3$, $\alpha = 0.014$) to the distance of the span from the pivot point, i.e. the farther away the bank of collectors from the pivot, the smaller the SE. Although not significantly greater, application uniformity tended to increase from the inner span to the outer span. Overall, the CU_{HH} ranged from a low of 69.6% during Trials 7 and 10 (arc-wise pattern), in zone 2 of span 1 with a watering rate of 30%, to a high of 96.8% during Trial 3 (transect pattern) in zone 3 of span 2 with a watering rate of 80%. For Trials 1-5 and 8-10, the mean absolute application error was 4.4% of the 100% applied amount. Trial 6 results were not included because the 100% watering rate was not utilized, and for Trial 7, the mean absolute application error was 10.9%. The 30% watering rate had the highest mean absolute error (6%) and was typically affected by wind speed and wind direction, especially during Trials 4 and 10.

Analyzing data grouped by transect-type trials indicated that the average CU_{HH} and DU_{lq} were 87.9% and 0.82, respectively. The application uniformity was greatest in zones 2 and 3 for Trial 3 (Fig. 4a). During this trial, the wind blew out of the Northwest (NW) and the average wind speed was $5.5 \pm 0.4\ m\ s^{-1}$. In the majority of these five trials, it was typical that the first two collectors within a watering zone had a greater volume (Fig. 4a and 4b) than the mean volume for the zone, if the zone had a lower watering rate and was distal to the adjacent zone with a higher watering rate. Variations in depth were likely caused by spray overlap and drift from neighboring nozzles. The drift was likely due to variable wind speed, and the change in wind direction. These uniformity values for the transect trials are higher than average values (CU_{HH} = 81.3% and DU_{lq} = 0.70) reported

Table 3. Test results indicating mean coefficient of uniformity ($\overline{CU}_{HH}$) and mean distribution uniformity ($\overline{DU}_{lq}$) from catch-can trials on 3-span center pivot system for all collectors placed. Letters of the same value in each column indicate no significant difference. The number of samples of each uniformity coefficient is represented by n.

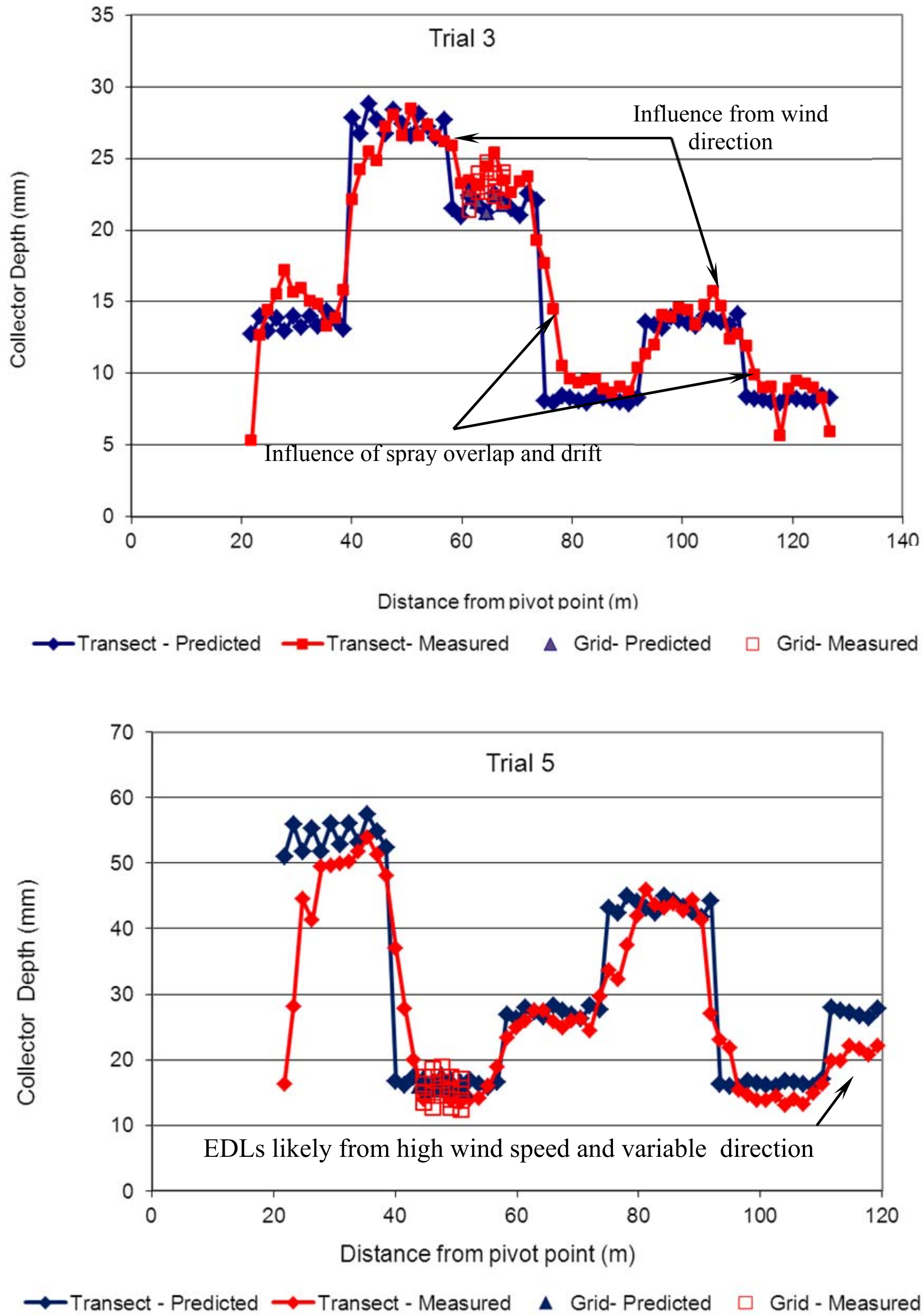
	$\overline{CU}_{HH}$	$\overline{DU}_{lq}$	n
Catch-can Location			
Span 1	86.8a	0.81a	12
Span 2	88.0a	0.83a	32
Span 3	89.8a	0.85a	22
Watering Rates (%)			
30	85.1b	0.81b	22
50	89.3a	0.86a	14
70	91.7a	0.86a	6
80	89.8a	0.85a	9
100	90.1a	0.83a	15
Catch-can Configuration			
Transect	87.9ab	0.82ab	28
Grid	91.1a	0.90a	8
Arc-wise	88.1b	0.82b	30

by Dukes and Perry (2006) for a variable rate center pivot system with LDN nozzles tested in Georgia at a travel speed of 11%, and collectors under spans 3 and 4. Han et al. (2009) reported decreased coefficient of uniformity values for a 25% watering rate for a linear move with a VRI system. The percent EDL for our trials fell within the range (7% – 20%) simulated by Faci et al. (2001) for fixed spray plates at 1-m and 2.5-m; and those measured by Ortiz et al. (2009) for fixed spray plates of 9.2% at a height of 1-m and 13.6% at 2.5-m.

During Trial 5, the average wind speed was 9.4 m s^{-1} with wind gusts up to 11. 9 m s^{-1}, and the wind direction was from the S, SW, and SE directions. These influences likely caused the losses in the cans at the end of span 3 (Fig 4b), as the pivot moved against the wind for the majority of the trial.

An analysis of the collected depths from the grid-pattern trials indicated that the mean CU_{HH} and DU_{lq} were 91.1% and 0.90, respectively, neglecting the edges of the zone and the variations near the edges. This level of uniformity is not surprising since the grid patterns were placed within a zone. Neither the span location nor the watering rate significantly influenced the application or distribution uniformity during the trials.

In the case of the arc-wise trials, when the management zones were prescribed as 24º sectors, the average CU_{HH} and DU_{lq} were 90% and 0.85, respectively; and the minimum



(a)

(b)

Figure 4. Collector depth for transect and grid type configurations for: (a) Trial 3 with a wind direction out of the NW; and (b) for Trial 5 with winds blowing from the SW, S, and SE.

values were 69.6% and 0.71, respectively (Fig. 5). The lowest CU_{HH} occurred during Trial 10 (on DOY 152) from collectors located in zone 3 of span 2, with a watering rate of 30% (Fig. 5c). During this time, the average wind speed was 6.6 m s^{-1} with gusts up to

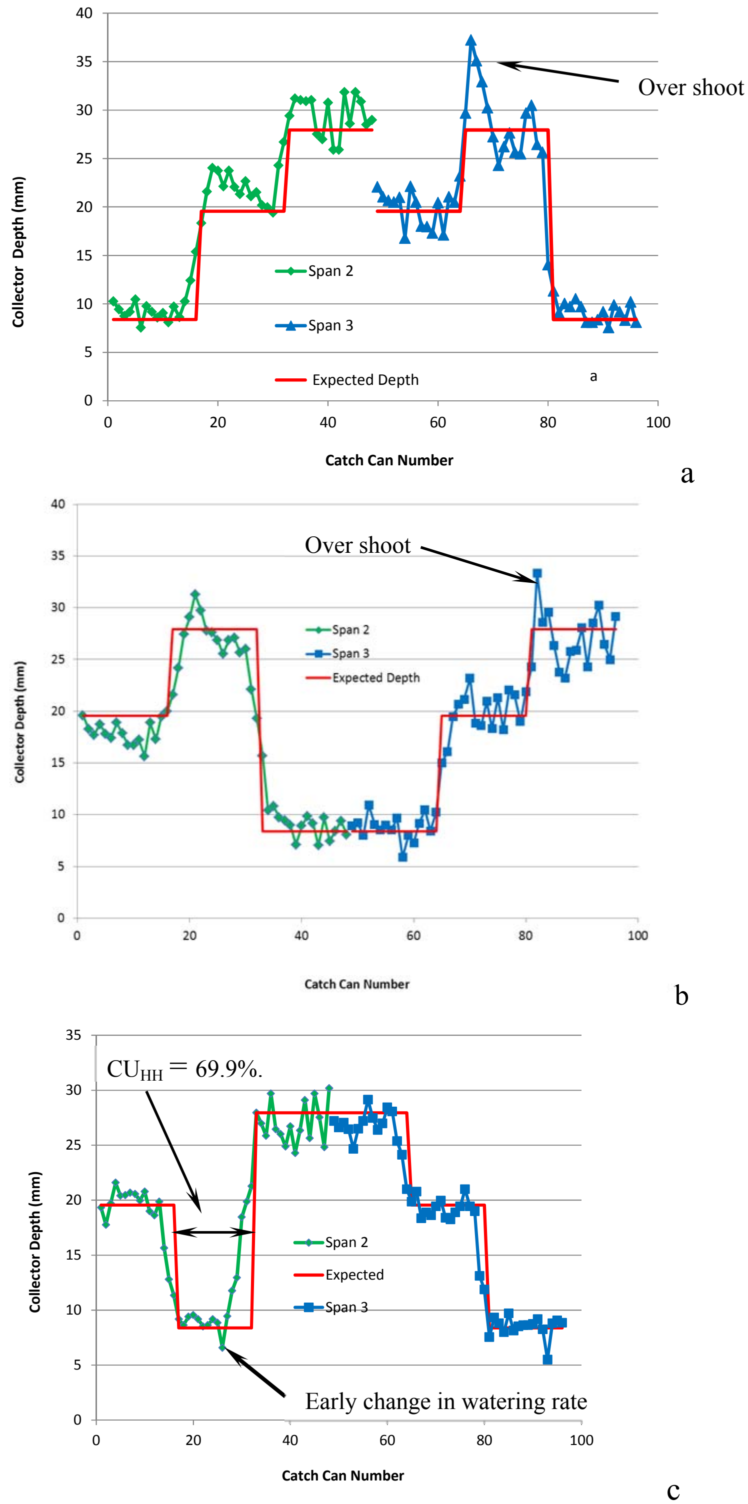


Figure 5. Catch cans 1-48 were located in the middle of span 2 and 49-96 were located in the middle of span 3. Measured and expected collector depth for Trials (a) 8; (b) 9; and (c) 10 using an arc-wise pattern with watering rates changing between 30%, 70% and 100% after the pivot traversed a 24º sector.

8.7 m s^{-1},the wind direction was SE to SW while the pivot end-tower was pointed in the SE direction moving SE to SW (Fig. 6). The graphs also show where the collected

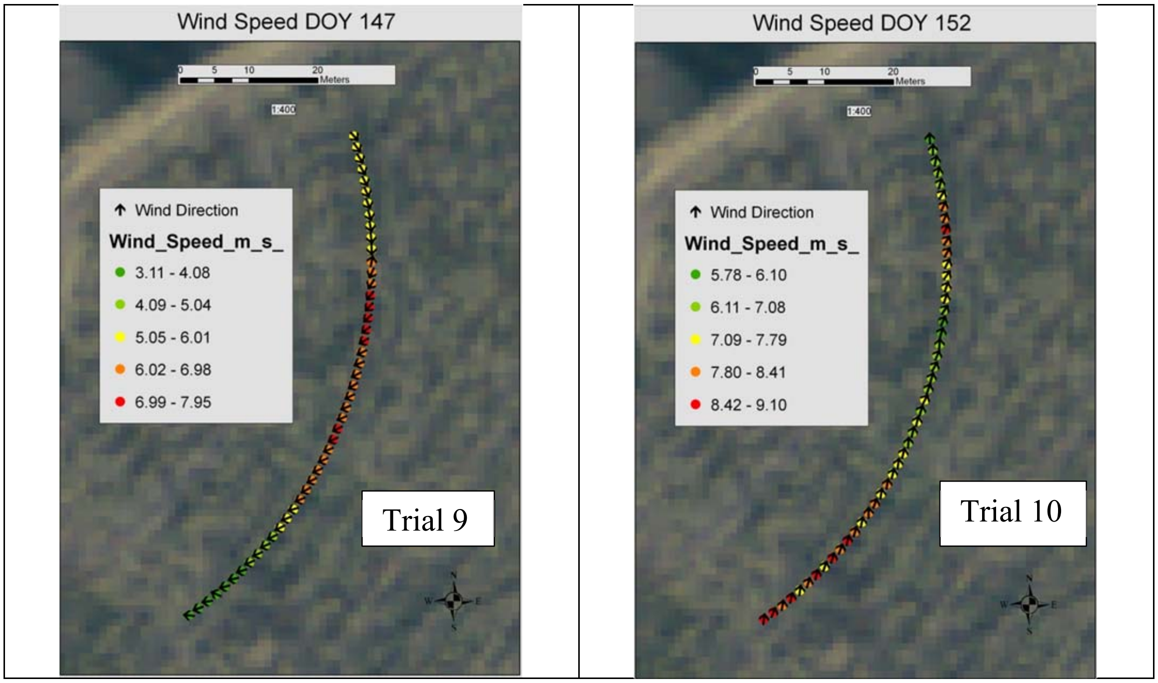


Figure 6. Data showing wind speed and wind direction during: Trial 9 (left) and Trial 10 (right). In both trials, the pivot is moving SE to SW.

volumes over-shot the expected volume when the watering level changed from a lower to a higher rate (Fig. 5a and 5b). This higher than expected values can be a result of the high wind speed and its direction in relation to the movement of the pivot. However, the mean collected depth of the catch cans during the 30% and 70% applications was within 1-2% of the mean collected depth for the 100% watering rate in that same span with the exception of Trial 10, span 2 for a watering rate of 30%.

Trial 7 also had collectors configured in an arc-wise pattern, however, for this trial the management zones were prescribed with sector angles of 12º. During this trial run, the MAE was consistently higher than for previous runs (data not shown). The average CU_{HH} and DU_{lq} were 76% and 0.76; and the average wind speed was 4.0 ± 1.0 m s^{-1} with a shift in direction from NNE to NNW, and then from W to SW. In comparison to the other arc-wise pattern trials (8-10), the uniformity of application for Trial 7was much lower. This occurred even though the average wind speed for Trial 7 was also much lower. The low uniformity values were caused by consistent undershoot and overshoot in water delivery rates as the VRI system changed delivery rates while transitioning between the narrower 12º sectors (Fig. 7). Future catch can trials with similar sector angles will be performed to help determine the causes of these results.

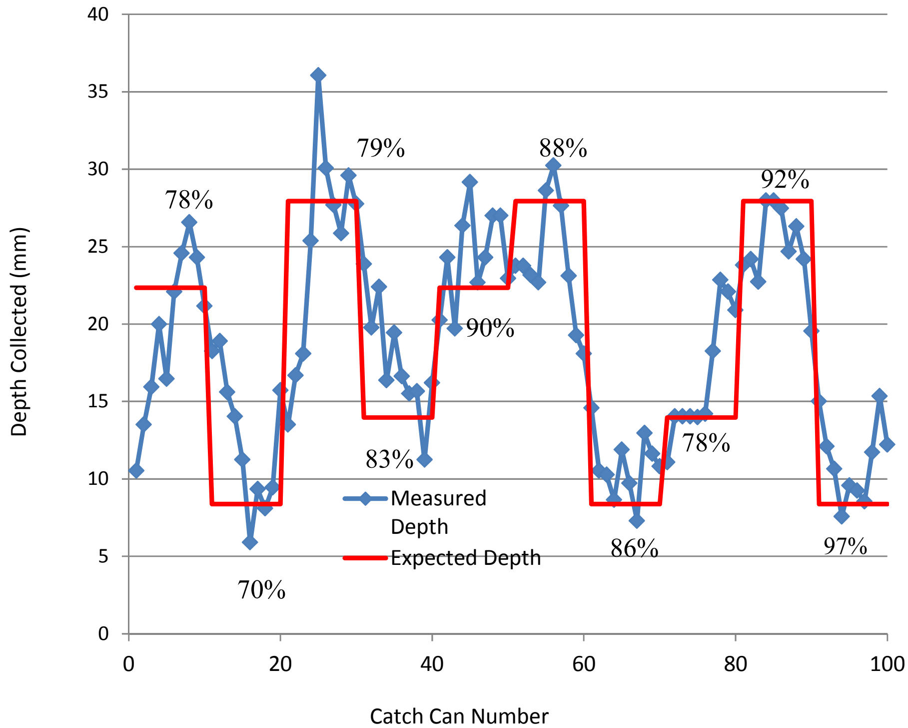


Figure 7. Trial 7 where 100 catch cans were placed in an arc-wise pattern at the same distance from the pivot point in the middle of span 2. The percent coefficient of uniformity is shown for each watering rate.

CONCLUSIONS

Multiple catch can tests were performed to test the application and distribution uniformity of a commercial VRI system along the length of a 3-span lateral and in arc-wise directions in the two outer spans. The CU_{HH} and DU_{lq} were relatively high (> 87% and 0.82) for an 18-m wide management zone, each comprised of 12 drop hoses, spaced 1.5-m apart in spans 1-3. The uniformity of application was significantly lower when the watering rate was 30%, which may have been caused by high wind speed and changes in wind direction.

The application uniformity measured in an arc-wise direction was also relatively high when the management zones were prescribed with a sector angle width of 24º. Variability in uniformity when the collectors were placed in the 12 º sectors may have been affected by wind speed and direction, and a problematic GPS system. The problem has since been corrected and future trial runs will be conducted to test the uniformity of application over smaller sector angles.

The application depth for the different zones compared well to the depth of application that was applied at the 100% watering rate in that same span. The mean application error < 5% in the management zones for transect trials and arc-wise trials where the management zone was 24º. Future work is needed to determine the circumferential resolution of the VRI system. Upcoming work will include mechanically addressing the speed of valve closure and catch can tests on a six-span center pivot VRI system.

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Peanut Canopy Temperature and NDVI Response to Varying Irrigation Rates

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Abstract: *Variable rate irrigation (VRI) systems have the potential to conserve water by spatially allocating limited water resources. In this study, peanut was grown under a VRI system to evaluate the impact of differential irrigation rates on peanut yield. Additionally, we evaluated the impact of differential irrigation rates on crop canopy temperatures and vegetative indices. Canopy temperatures and vegetative indicies may be potential tools for VRI system management. The study consisted of four experiments with two planting dates (early and late plant). For each planting date there were two periods of imposed plant stress (early and late stress). Within of these four experiments there were four irrigation treatments (0, 33, 66, and 100% of the calculated crop evapotranspiration). The overall peanut yields for the study averaged approximately 4300 kg/ha with individual treatment means ranging from 3380 to 4958 kg/ha. Peanut yields across irrigation treatments were not significantly different. The peanut NDVI measurements were significant across irrigation treatments in only one experiment. In this experiment (#1) with significant differences across irrigation treatments, the non-irrigated treatment NDVI measurements began to indicate potential water stress. However, water stress based on NDVI measurements occurred several days after both canopy temperatures and soil water potentials began to indicate potential water stress. The crop canopy temperatures in experiments 1 and 3 were significantly different across irrigation treatments and did indicate potential water stress. In contrast to NDVI measurements, the crop temperature measurements were able to quickly differentiate among the irrigation treatments and could provide a tool that could be used for spatial irrigation management using variable rate irrigation systems.*

Keywords: Variable-rate Irrigation, Canopy Temperature, NDVI, Peanut

INTRODUCTION

Variable rate irrigation systems provide a tool to spatially allocate limited water resources while potentially increasing profits. Spatial water applications attempt to overcome site-specific problems that include spatial variability in topography, soil type, soil water availability, and landscape features. Although technology for spatial water application is available and it has high grower interest, farmers that have retrofitted their center pivot systems to precision apply water are basing spatial applications on their past experience and historical knowledge of variability in their fields. Science-based information is needed on how to precision-apply water with these systems. Sadler et al. (2005) identified critical needs for site-specific irrigation research that included decision support systems for spatial water application and improved real time monitoring of field conditions with feedback to

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irrigation systems. To address the issues of real time monitoring of field conditions, variable rate irrigation experiments were conducted on peanuts to evaluate methods of obtaining spatial irrigation management data. In this research, peanut was grown under a variable-rate irrigation system with different irrigation treatments to impose water stress during two parts of the growing season. The crop response to the irrigation treatments were monitored using both NDVI and infrared thermometers. These responses need to be quantified and assessed as potential measurements needed to spatially manage variable-rate irrigation systems. The objectives of this research were to: 1) Determine the yield response of peanut to varying irrigation water treatments; and 2) Determine the impact of varying irrigation water treatments on peanut canopy temperature and reflectance.

MATERIALS AND METHODS

Peanut (*Arachis hypogaea*) was grown under conservation tillage on a 6-ha site of uniform Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) near Florence, South Carolina. Four individual experiments were conducted to evaluate peanut response to water stress at different stages of production and with different irrigation levels (Figure 1).

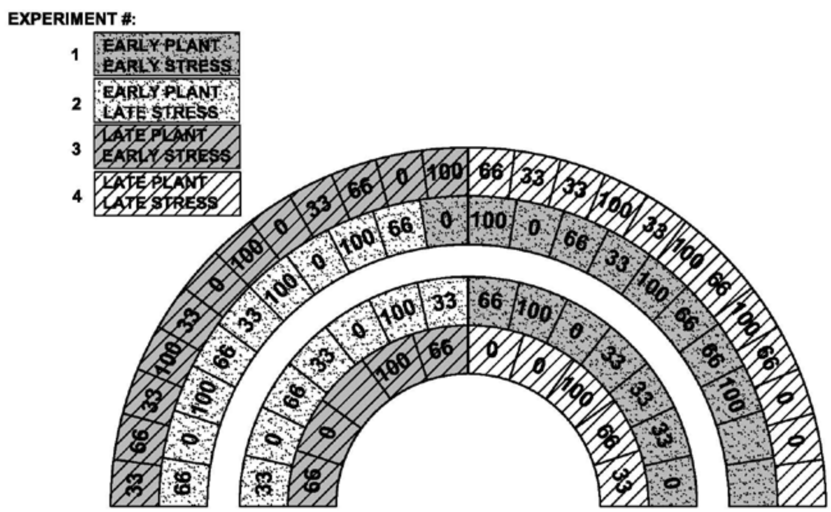

Figure 1. Diagram of the peanut experimental plot layout for the four irrigation treatments and four experiments.

Experiments one and two were planted on May 25, 2006 and experiments three and four were planted two weeks later on June 8, 2006. The two planting dates were selected to provide potential differences in natural rainfall patterns during various parts of the peanut growing season. Experiments one and three had water stress imposed (using differential irrigation levels) on the peanut crop during the first half of the growing season (early stress) and extended throughout remainder of the growing season. Experiments two and four had full irrigation throughout the first half of the growing season and then had water stress imposed (using differential irrigation levels) on the peanut crop during the second half of the growing season (late stress). The first growth stage was defined as 0 to 10 weeks after planting (doy 145 to 215 for experiments 1 and 2; doy 159 to 229 for experiments 3 and 4) and the second growth stage was defined as 11-20 weeks after planting (doy 216 to 285 for experiments 1 and 2; doy 230 to 299 for experiments 3 and 4). For each experiment, the irrigation treatments included 4 irrigation rates of 0, 33, 66, and 100% of calculated ET_{crop}.

The four experiments and irrigation treatments were arranged in randomized complete blocks with 4 reps of each treatment under the variable rate center pivot irrigation system.

The irrigation system utilized was a center pivot irrigation system modified to permit variable applications to individual areas 9.1 x 9.1 m in size. The center pivot length was divided into 13 segments, each 9.1 m in length. Variable-rate water applications were accomplished by using three manifolds in each segment, each with nozzles sized to deliver 1x, 2x, or 4x of a base application depth at that location along the center pivot length. A more detailed description of the water delivery system may be found in Omary et al. (1997) and for the control system in Camp et al. (1998).

ET and Irrigation Details
Reference evapotranspiration (ET_{os}) was calculated using the ASCE standard methods for grass or short surfaces (Walter et al. 2000). Weather data used in these calculations were obtained from an on-site weather station. ET_{crop} was calculated using the single crop coefficient method of Allen et al. (1998) and was obtained by multiplying the reference ET_{os} by the crop coefficient representing the peanut crop and growth stage. The crop coefficients used in the calculations were $K_{c\ ini} = 0.4$, $K_{c\ mid} = 1.15$, and $K_{c\ end} = 0.6$. A simple water balance for the preceding seven days was used to schedule irrigations. Irrigation and rainfall for the preceding seven days was subtracted from the accumulated ET_{crop}. Irrigation was initiated when the difference between accumulated ET_{crop} exceeded accumulated rainfall and irrigation by more than 12.5 mm. When the deficit exceeded 12.5 mm an irrigation of 12.5 mm was applied to the 100% irrigation treatments and the other treatments were irrigated with 8.25 for the 66% and 4.125 for the 33% irrigation rates. To evaluate how well the irrigation treatments were performing, soil water potentials (SWP) were measured using tensiometers at two depths (0.30 and 0.60 m) in each irrigation treatment. Measurements were recorded at least three times each week.

Canopy Temperature and NDVI
Within-season measures of canopy temperature and normalized difference vegetative index (NDVI) were made throughout the growing season and intensively during periods with little to no rainfall (days 199-200, and 212-216). The NDVI was measured using a Holland Scientific Crop Circle model ACS 210 canopy sensor (Holland Scientific, Lincoln, NE) mounted on a toolbar in front of a tractor at a height of approximately 1 m above the canopy.
The canopy temperature was measured using Infrared Thermometers (IRT) mounted on a toolbar in front of a tractor. The IRT's used were Exergen IRT/c .3X with a 3:1 field of view and type K thermocouple leads (Exergen Corp., Newton, Mass.) with a published accuracy of ±2%. These sensors were mounted on the front of a tractor at a height of approximately 0.4 m and adjusted to minimize the soil surface in the IRT's field of view. A global positioning system (GPS) unit mounted on the front of the tractor allowed for the data to be geo-referenced to the individual plots.

Harvest Details
Peanut digging was accomplished using a KMC 2-row peanut digger. The peanuts were dug October 10-11, 2006 for experiments one and two and October 20, 2006 for experiments three and four. A two row KMC peanut combine retrofitted with a peanut yield monitor system developed by the University of Georgia (Vellidis, et al., 2001) was used to

harvest the peanut crops for the entire field. Small sub-plot areas were harvested separately to compare with the yield monitoring system and were used for all analyses.

Statistical Analyses

The four experiments and irrigation treatments were arranged in randomized complete blocks with 4 reps each treatment under the variable rate center pivot irrigation system (Figure 1). The data were analyzed using the Statistical Analysis Software (SAS) version 9.2, (SAS Institute, Cary, NC). Regressions analyses were performed using Proc REG. Comparison of slopes for the different irrigation treatment was performed using Proc GLM.

RESULTS and DISCUSSION

Rainfall and Soil Water Potentials

Rainfall for the growing season was generally adequate. However, there was an extended period from days 180 to 220 (~40 days) that no significant daily rainfall (< 5 mm and cumulative rainfall of 19 mm) occurred. Rainfall totals for the experiments were 391 mm (experiments 1 and 2) and 378 mm (experiments 3 and 4). The rainfall totals accounted for 68 and 71% of the seasonal ET_{crop} respectively. The long term historical rainfall from May-September was 559 mm (SC State Climatologist, 2010). For experiments 1 and 2, rainfall was sufficient until the sixth week (~doy 184) after planting, at that time, irrigation was required to meet ET_{crop} through the thirteenth week (~doy 220) after planting. The majority (65%) of the irrigation applied for experiments 1 and 2 occurred during the first 10 weeks (until ~ doy216) of the growing season. Likewise, for experiments 3 and 4 the majority of the irrigation applied occurred during the first 8 weeks of the growing season. The simple weekly water balance irrigation scheduling method kept the soil water potentials generally below -40 kPa for the 100% and 66% irrigated treatments throughout most of the growing season for each experiment except for the extended drought period from days 180 and 220. In experiments 1 and 3 with early stress, soil water potentials for the non-irrigated and 33% irrigation treatments often exceeded -40 kPa, particularly during the extended drought period between days 180 to 220 and several times during the remainder of the season. During this drought period, even the 66 and 100% irrigation treatments had soil water potentials exceeding -40 kPa for a few days across all experiments. During this time, all treatments reached their highest soil water potentials levels for the entire season.

Peanut Yields

The peanut yields ranged from 3,380 to 4,958 kg/ha across the four individual experiments and exceeded the 2006 South Carolina state wide average yield of 3360 kg/ha (USDA-NASS, 2010). The irrigation treatment mean yields over all four experiments ranged from 4,130 to 4,464 kg/ha and were not significantly different (Table 1). The mean yield for each of the individual experiments ranged from 3,875 to 4,643 kg/ha over all irrigation treatments and were significantly different. The mean yields for the individual experiments were not significantly different for experiments 2, 3 and 4. For experiments 1 and 3 (early stress), the yields were not significantly different from each other, but experiment 1 was significantly different than experiments 2 and 4. These differences were most likely due to the water stress imposed during the early part of the growing season and the lower total water received particularly for the treatments irrigated at less than 100% of ET_{crop}. Overall, there did not appear to be a significant statistical relationship between peanut yield and irrigation treatment for this year, probably due the generally adequate rainfall during the latter part of the growing season. With the adequate rainfall during the latter part of the season, the lack of significant differences across irrigation treatments and experiments was somewhat

Table 1. Mean peanut yields and standard deviations for the four irrigated treatments and four experiments

	Peanut Yield (kg/ha)				
	Experiment				Irrigation Mean
	1	2	3	4	
Irrigation					
0%	3515 ±1443a*	4186 ±950 a	4046 ±733 a	4771 ±394ab	4130 ±974 a
33%	4721 ±909 a	4173 ±1911 a	3844 ±982 a	4167 ±920 b	4226 ±1168a
66%	3380 ±1788a	5422 ±915 a	4360 ±1372a	4678 ±328ab	4460 ±1333a
100%	3883 ±1804a	4601 ±151 a	4416 ±512 a	4958 ±135 a	4464 ±934 a
Experiment Mean	3875 ±1470b**	4596 ±1165a	4167 ±887 ab	4643 ±563 a	

* Column means followed by the same letter are not significantly different at the 5% level.
** Row means followed by the same letter are not significantly different at the 5% level.

expected. In previous studies, Chapin et al. (2010) reported that peanut was capable of recovering from early drought stress with adequate late season rainfall. Also, Pallas ea al. (1979) found midseason droughts, imposed with rainfall shelters, did not impact yields as great as drought stress during the latter part of the growing season.

Canopy NDVI Measurements

Characteristics of the peanut vegetation (NDVI and canopy temperatures) were analyzed for eight days during the growing season (Figure 2). The NDVI measurements for each irrigation level were compared across irrigation levels in each experiment. Initially on doy 199, there were no significant differences for the irrigation treatments or for any of the experiments. On doy 200, the non-irrigated treatment in experiment 3 had a significantly lower NDVI measurement than any of the irrigated treatments. Experiments 1, 2, and 4 had no significant difference in NDVI measurements. Throughout the other NDVI sampling days, only experiment 1 had significant NDVI differences across the irrigation treatments. These differences were typically between the non-irrigated treatment and the irrigated treatments. However, on the last observation day (doy 216), the 33% irrigation rate was significantly different from the non-irrigated and from the 66% and 100% irrigation treatments as well. For experiment 1 and the 0% irrigation treatment, decreasing NDVI measurements were observed for both measurement periods (doys 199-202, and 212-216; Figure 2). During the second sampling period (doy 212-216), the NDVI measurements for the 33% irrigation treatment also begin to separate from the other irrigation treatments. For experiment 3, the NDVI measurements were not as well separated over time as in experiment 1, particularly during the second half of the sampling period. However, the NDVI measurements were more scattered than those from experiments 2 and 4 (Figure 2). NDVI measurements for experiments 2 and 4 were not significantly different and the NDVI readings were

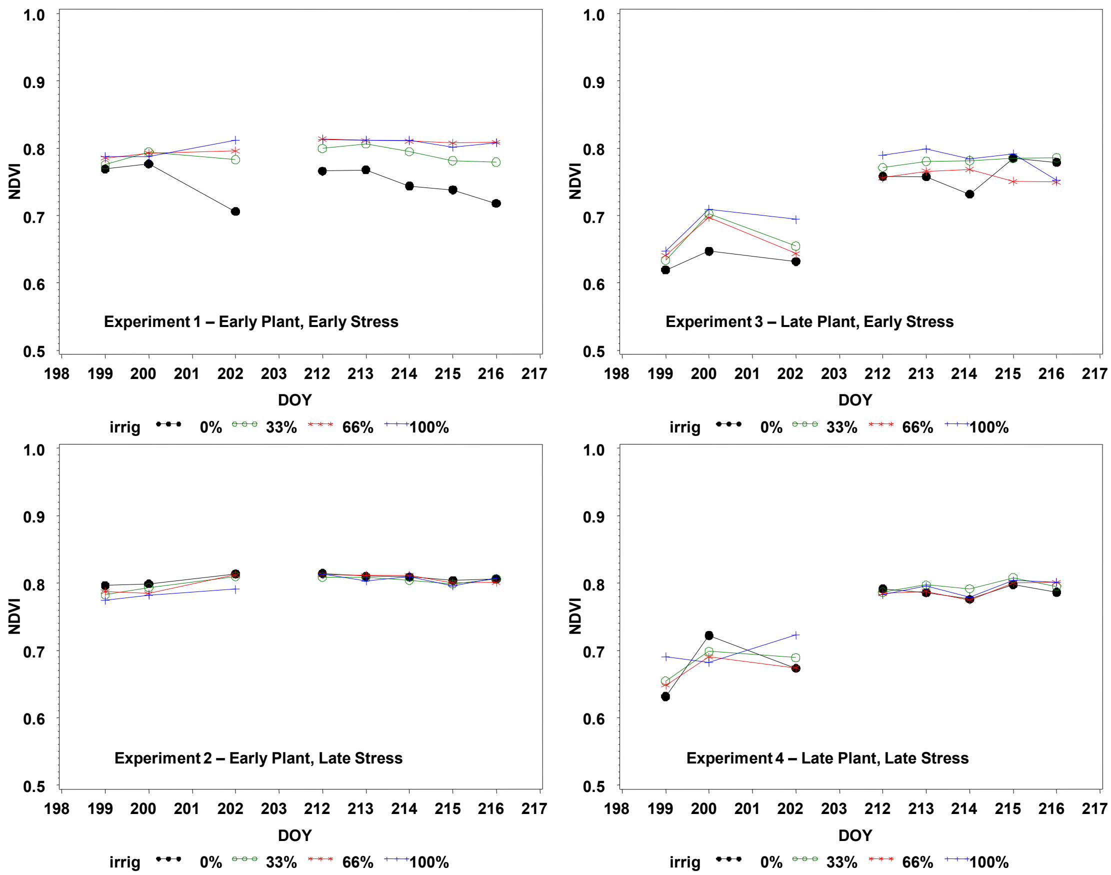

Figure 2. Peanut NDVI measurements for the DOY 199-201 and 212-216 sampling periods for the four irrigation treatments and four experiments.

almost identical for each irrigation treatment (Figure 2). It appears that from these results that the early water stress (experiments 1) did have some impact on the NDVI readings. These initial results indicated that NDVI measurements may be able to detect water stress, particularly in experiment 1.

Canopy Temperature Measurements

Crop canopy temperatures were collected simultaneously with the NDVI measurements (Figure 3). Rainfall during the sampling period was minimal. For the 10 days prior to day 199, rainfall occurred on day 196 (1.1 mm). During the sampling period, rainfall occurred on day 201 (2.9 mm), 203 (2.6mm), 204 (1.0 mm), 205 (4.8 mm), 206 (1.2 mm), 207 (2.8 mm), and 210 (0.7mm) for a total of 16 mm over 18 days which was much lower that the calculated ET_{crop} requirement of 105 mm.

The canopy temperatures above air temperature were compared across irrigation treatments for each experiment. Experiments 1 and 3 had the most differences in canopy temperatures across the irrigation treatments. In experiment 1 with the early imposed stress, the canopy temperature for the 0% irrigation treatments was significantly higher than the other irrigated treatments throughout the sampling period. As time passed without rainfall (days 212-216), the canopy temperatures for the other irrigation treatments also began to separate themselves. The 33% irrigation treatment became significantly different from the 66% and 100% treatments. The canopy temperatures for the 66% and

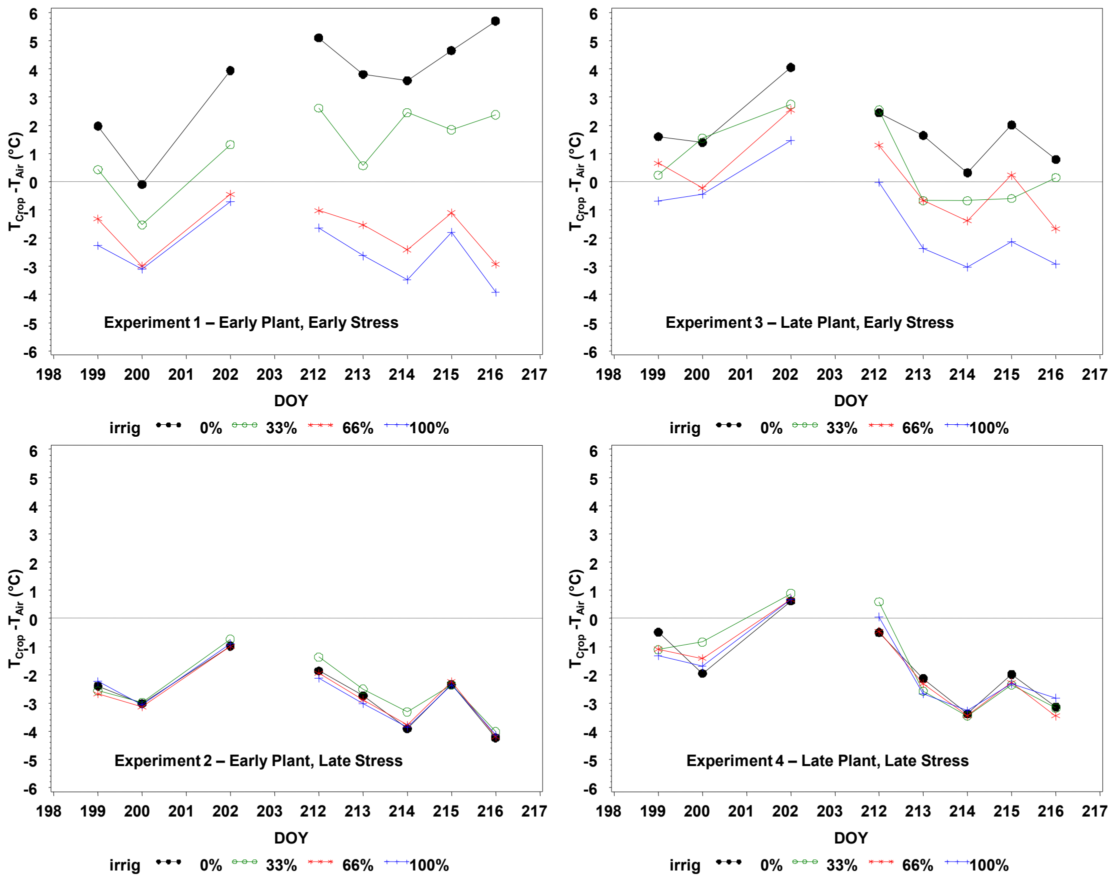

Figure 3. Peanut Crop canopy temperature above air temperature measurements for the DOY 199-201 and 212-216 sampling periods for the four irrigation treatments and four experiments.

100% treatments remained below the air temperature throughout the sampling period, whereas the temperatures for the 0% irrigation treatment were much higher than the air temperature which generally indicates water stress (Aston and Van Bavel, 1972; Sadler et al. 2002). In experiment 3, also with the early imposed stress, the canopy temperature for the 0% irrigation was above air temperature for all sampling dates. Experiment 3 also had several days where there were significant canopy temperature differences among the irrigation treatments. The 0% irrigation treatment was generally had a higher temperature and was significantly difference from the 100% treatment throughout the sampling period.

The canopy temperature results along with the NDVI measurements indicated that the irrigation treatments that had differential irrigation rates applied during the first 10 weeks experienced water stress. However, the water stress was not enough to significantly impact yields during this growing season. The irrigation treatments that had differential irrigation rates applied during the last 10 weeks of the growing season did not experience any observed water stress. Overall, it appears that NDVI measurements responded to water stress; however, it may not be able to be used as an indicator to initiate irrigations. The canopy temperature measurements were able to differentiate among the irrigation treatments and could provide a tool that could be used for spatial irrigation management using variable rate irrigation systems.

CONCLUSIONS

Experiments were conducted under a variable rate center pivot irrigation system to determine the impact that varying irrigation rates would have on crop canopy temperatures and vegetative indices for potential use in site-specific irrigation management. Rainfall for the growing seasons accounted for approximately 70% of the seasonal ET_{crop}. However, there were periods during the growing season with little to no rainfall when irrigation was required. The overall peanut yields across irrigation treatments were not significantly different. However, the experiments that had differential irrigation rates applied throughout the season (early water stress) had lower yields than treatments only differentially irrigated during the last half of the growing season (late stress). The peanut NDVI measurements were significant across irrigation treatments in experiment 1 only, and did show an indication of potential water stress for the non-irrigated treatment. However, it may not be able to be used as an indicator for irrigation management. The crop temperatures were significant in experiments 1 and 3 (early water stress) across the irrigation treatments. Overall, the crop temperature measurements were able to differentiate among the irrigation treatments and could provide a tool that could be used for spatial irrigation management using variable rate irrigation systems. Additional research is needed to investigate the use of canopy reflectance and temperature measurements for irrigation scheduling in humid regions.

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No-Till Cropping Systems with Limited Irrigation

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Abstract. *Research was initiated in 2001 and conducted through 2010 under sprinkler irrigation in western Kansas to evaluate limited irrigation in several no-till crop rotations on grain yield, water use, and profitability. Crop rotations were 1) continuous corn, 2) corn-winter wheat, 3) corn-wheat-grain sorghum, and 4) corn-wheat-grain sorghum-soybean. Irrigation was limited to 10 inches annually with 5 inches applied to wheat, 15 inches to corn (when in rotation with wheat), and 10 inches to grain sorghum, soybean, and continuous corn. Crop water productivity and yield of corn was greater when grown in rotation than with continuous corn. The length of the rotation did not affect grain yield or crop water productivity of grain sorghum or winter wheat. Continuous corn was generally the most profitable cropping system. However, relatively small changes in prices or yields could result in multi-crop rotations being more profitable, indicating the potential for alternate crop rotations to reduce risk under limited irrigation.*

Keywords. No-till, crop rotations, limited irrigation

Introduction

Irrigated crop production is an important component of agriculture in western Kansas. However, with declining water levels in the Ogallala Aquifer and high energy costs, optimal utilization of limited irrigation water is required. Precipitation is limited and sporadic in the region with annual precipitation supplying about 60-90% of the seasonal water requirement for grain sorghum and only 50-75% for corn (Doorenbos and Kassam, 1979). 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]) with 57% 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. 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 1990s has been towards increasing acreage of irrigated corn (665,000 acres in 1990 compared with 1.2 million acres in 2000) with corresponding reductions in grain sorghum (326,000 acres in 1990 compared with 71,000 acres in 2000) and winter wheat (692,000 acres in 1990 compared with 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 with 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.

Materials and Methods

A field study was conducted at the Kansas State University Southwest Research-Extension Center near Tribune, KS from 2001 to 2010 on a deep silt loam soil (Ulysses silt loam [fine-silty, mixed, superactive, mesic Aridic Haplustolls]). Only data collected beginning in 2003 are presented to allow time for establishment of the crop rotations. The region is semi arid with a summer precipitation pattern and an average annual precipitation of 440 mm. The study consisted of four crop rotations; continuous corn (CC), corn-winter wheat (CW), corn-winter wheat-grain sorghum (CWS), and corn-winter wheat-grain-sorghum-soybean (CWSB). Each phase of each rotation was present each year and replicated four times. The plots were approximately 60 ft wide and 120 ft long. Irrigations were scheduled to supply water at the most critical stress periods (near flowering) for the specific crop and were limited to 1.5 inches per week. If precipitation was sufficient within a week, then irrigation was postponed. In some years, the maximum amount of irrigation was not applied because of above normal precipitation. The average first irrigation was 14 June for corn in rotation, 23 June for continuous corn, and 4 July for sorghum and soybean. The final irrigation averaged 28 August for corn in rotation, 15 August for continuous corn, and 22 August for sorghum and soybean. If needed to aid emergence of wheat, irrigation was initiated in the fall (four years) otherwise irrigation was reserved for spring application with average final irrigation on 6 June.

Average plantings dates were 3 May for corn, 20 May for soybean, and 27 May for grain sorghum. Winter wheat was planted after corn harvest (average of 1 October). Cultural practices (e.g., pesticides, tillage, and fertilization) typical for the region were used in all years of the study. The center portion of all plots was machine harvested with grain yields adjusted to 15.5% moisture (wet basis) for corn, 13% for soybean, and 12.5% for sorghum and wheat. Plant densities were determined along with the other yield components (kernels/ear and kernel mass).

The plots were irrigated with a linear move sprinkler irrigation system which had been modified to allow for water application from different span sections as needed to accomplish the randomization of plots. Soil water measurements (8-ft depth in 1-ft increments) were taken throughout the growing season using neutron attenuation. Available soil water was calculated by subtracting unavailable water from measured soil water. All water inputs, precipitation and irrigation, were measured. Crop water use was calculated by summing soil water depletion (soil water near emergence less soil water at harvest) plus in-season irrigation and precipitation. Non-growing season soil water accumulation was the increase in soil water from harvest to the amount at emergence the following year. Precipitation storage efficiency was calculated as non-growing season soil water accumulation divided by non-growing season precipitation. Crop water productivity (WP) was calculated as grain yield (bu acre^{-1}) divided by crop water use (inches).

Statistical analyses were performed using the GLM procedure from SAS version 9.1 (SAS Institute, Cary, North Carolina).

Local crop prices and input costs were used to perform an economic analysis to determine net return to land, management, and irrigation equipment for each treatment. Custom rates were used for all machine operations. Harvest prices and input costs were kept uniform for all years based on 2010 prices.

The objectives of this research were to determine the effect of limited irrigation on crop yield, water use, and profitability in several crop rotations.

Results and Discussion

All rotations were limited to an average of 10 inches of irrigation annually; however, corn following wheat received 15 inches because the wheat received only 5 inches. This extra 5 inches of irrigation water increased the level of irrigation to nearly full and increased corn yields about 40 bu acre^{-1} compared with continuous corn (Table 1). Thus, limited irrigated corn yielded about 80% of full irrigation. Klocke et al. (2007) reported that limited irrigation (no more than 6 in water) yields were 80 to 90% of fully irrigated yields. Corn yields in the multi-crop rotations were similar regardless of length of rotation. Wheat and grain sorghum yields were similar in all rotations.

Table 1. Average grain yields of four crops as affected by crop rotation, KSU Southwest Research-Extension Center, Tribune, KS, 2003-2010.

Crop	Crop rotation†			
	CC	CW	CWS	CWSB
	bu $acre^{-1}$			
Corn	163 b‡	203 a	202 a	203 a
Wheat	—	35 a	36 a	37 a
Sorghum	—	—	134 a	138 a
Soybean	—	—	—	43

† CC = continuous corn; CW = corn-wheat; CWS = corn-wheat-grain sorghum; CWSB = corn-wheat-grain sorghum-soybean.
‡ Means within a row with different letters are significantly different (P≤0.05).

Crop water productivity was in the order of corn>sorghum>wheat=soybean (Table 2). Crop water productivity of corn was increased when irrigation was increased to 15 inches and grown in rotation with other crops. Grain sorghum grown in 4-yr rotations had slightly greater crop water productivity than grown in 3-yr rotations. The length of rotation had no effect on crop water productivity of wheat.

Table 2. Average crop water productivity of four crops as affected by crop rotation, KSU Southwest Research-Extension Center, Tribune, KS, 2003-2010.

Crop	Crop rotation†			
	CC	CW	CWGS	CWSB
	lb $acre\text{-}inch^{-1}$			
Corn	377 b‡	411 a	398 a	410 a
Wheat	—	115 a	125 a	122 a
Sorghum	—	—	314 b	326 a
Soybean	—	—	—	110

† CC = continuous corn; CW = corn-wheat; CWS = corn-wheat-grain sorghum; CWSB = corn-wheat-grain sorghum-soybean.
‡ Means within a row with different letters are significantly different (P≤0.05).

An economic analysis (based on grain prices and input costs in 2010 with average crop yields) found that the most profitable crop was corn in rotation followed by continuous corn (Table 3). Profitability was similar for grain sorghum and soybean in the 3- and 4-yr rotations. The least profitable crop was wheat, primarily because of reduced yields caused by hail and spring freeze injury in about 50% of the years. However, the most profitable crop rotation was continuous corn. All multi-crop rotations had net returns of \$12-24 $acre^{-1}$ less than CC. Lower returns in the multi-crop rotations were due to low returns from wheat.

Table 3. Net return to land, irrigation equipment, and management from four crop rotations, KSU Southwest Research-Extension Center, Tribune, KS, 2003-2010.

	Crop rotation†			
Crop	CC	CW	CWS	CWSB
	---------------------------- $ $acre^{-1}$ --------------------------			
Corn	237	332	326	321
Wheat	—	4	1	5
Sorghum	—	—	189	198
Soybean	—	—	—	198
Net for rotation	192	168	172	180

† CC = continuous corn; CW = corn-wheat; CWS = corn-wheat-grain sorghum; CWSB = corn-wheat-grain sorghum-soybean.

Conclusions

With limited irrigation (10 inches annually), continuous corn has been more profitable than multi-crop rotations including wheat, sorghum, and soybean primarily because of spring freeze and hail damage to wheat in the multi-crop rotations. In multi-crop rotations, relatively poor results with one crop (in this case wheat) can reduce profitability compared with a monoculture, especially when the monoculture crop does well. However, the multi-crop rotation can reduce economic risk when the monoculture crop does not perform as well. All multi-crop rotations had net returns only \$12-24 $acre^{-1}$ less than continuous corn. Therefore, relatively small changes in prices or yields could result in any of the rotations being more profitable than continuous corn, indicating the potential for alternate crop rotations under limited irrigation.

Acknowledgements

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IMPROVED WATER RESOURCE MANAGEMENT USING AN ACOUSTIC PULSED DOPPLER SENSOR IN A SHALLOW OPEN CHANNEL

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Abstract. *Over the years acoustic Doppler profilers (ADP) have become a standard for flow measurement in large open channels. In most cases, pulsed Doppler systems measure the water velocity profile either from the side of the channel or from a bottom mounted system. Having a velocity profile is critical in providing accurate flow measurements and provides important information about the structure of the velocities in the flow. A SonTek IQ flow meter uses multiple beams to measure water velocity and applies a vertical beam and pressure senor to measure water level – these two types of data are used to calculate flow. In addition to the new design, the flow meter provides improved performance for theoretical flow calculations, which are important in smaller channels, such as ditches and turnouts where an index calibration may not be practical when considering cost.*

Keywords. Doppler profiler, water management, flow rate, total volume, water velocity, agricultural flow monitoring

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INTRODUCTION

Traditional flow monitoring in open channels has been done by monitoring water level as a surrogate. For this method, a rating curve is developed by comparing various water levels to the corresponding flows, which are determined by discharge measurements or gagings over the range of water levels and time at the site. Using this method, periodic discharge measurements are required to validate the stage-discharge relationship. For some sites, such as tidal rivers, locations with variable backwater like irrigation gate control systems, no reliable stage-discharge relationship is developed. At these sites, a velocity index relationship is typically used. For a velocity index, a channel cross-section survey provides a relationship between stage and cross sectional area. A velocity sensor is installed and a relationship is developed between the velocity of the permanently installed sensor and the mean measured velocity in the channel (via gaging). The combination of the stage-area and measured-mean velocity relationships provides the ability to continuously monitor discharge. Like the stage-discharge method, this velocity indexing also requires periodic discharge measurements at the site in order to maintain a viable index, however complex hydrologic conditions are more accurately monitored.

Side-looking Doppler velocity sensors (such as the SonTek Argonaut-SL) have become a preferred method for monitoring velocity at index rated sites in larger channels. The sensor is mounted on a vertical structure and measures a horizontal velocity profile and a programmable cell some distance into the river. Simple installation, low maintenance requirements and the ability to monitor velocity away from flow interference generated by underwater structures are advantages of these sensors. Side-looking instruments do have some limitations; for instance, the relationship between Doppler velocity (measured at one depth) and mean channel velocity can be difficult to determine in situations of highly variable water level. In addition, sites with highly stratified flow can require permanent installations at more than one depth. Lastly, from a resource standpoint, it is not always practical to make the measurements required to develop an index rating. For side-looking systems, this theoretical relationship is less robust since velocity is measured only at a single depth and stratification of flow in open channels is vertical.

Considering this, the Argonaut-SW (SW for "Shallow Water") was developed. The Argonaut-SW is a bottom-mounted system that is intended for complex index velocity sites (those with large stage variation or stratified flow) and for sites where purely theoretical discharge calculations are desired. Although very accurate and precise in regular open channels, the SW requires 1-foot (30 cm) of water to measure flow. Thus small channels and irrigation turnouts are limited to determining discharge with techniques that are not accurate or repeatable (measure flow based on water level or determine flow using low cost continuous wave Doppler instruments that do not have a high degree of accuracy or precision).

Considering the increasing demand for freshwater resources and the affects of climate change there is an increased need to quantify flow in smaller and smaller channels, such as irrigations turnouts. In 2007, SonTek was awarded a Small Business Innovation Research (SBIR) grant from the USDA. The aim of the project was to develop a Doppler-based instrument that would measure in small channels (such as irrigation turnouts with a minimum depth of 3-inches or 8-cm) with a high degree of accuracy – thus end-users are not required to perform a velocity index or calibrate the instrument to the site and still provide an accurate and reliable measurement.

MATERIALS AND METHODS

Preliminary flow comparison study was conducted at the Irrigation training and Research Center (ITRC) at the California Polytechnic State University, San Luis Obispo (Cal Poly). Figure 1 displays an aerial photo of the testing facility. The testing facility has a 280 ft long hydraulic flume with dimensions of 4.0 ft × 4.0 ft. A variable speed pump, capable of delivering up to 30 cfs, delivers water through a pipeline to a buffer pond at the upstream end of the flume. A magnetic meter (magmeter) is located in the pipeline, with large air vents located upstream of the magnetic meter. Since a constant flow rate was desired, the pump was set at a constant speed and the water passed into and out of the buffer pond with no change in position of any of the downstream control structures over time. Measurements were taken after the flow rate stabilized in the flume test section, typically after 30 minutes. Water depths in the flume were controlled by flashboards or gates at the downstream end of the flume for the three tests presented here; water level was varied for each flow rate.

Figure 1. California Polytechnic State University - Irrigation and Training and Research Center

Reference measurements were made using a McCrometer® UltraMag model #UM06-30, 76 cm (30”) meter (magmeter) which samples data multiple times per second and averages over a 2 second period. The magnetic meter’s data is output using the meter’s standard 4-20ma signal converter. A Control MicroSystems SCADAPack32 was used to convert the analog data to a digital number and recorded every 2 seconds. The SonTek IQ was installed approximately 180 ft from the inlet of the flume in order to avoid turbulence and to allow flow to homogenize. The IQ was installed in the bottom of the flume using two 5/16” stainless steel screws with the power and communications cable point downstream. Figure 2 displays a picture of the IQ installation at ITRC.

Figure 2. SonTek IQ installation at ITRC flume

The SonTek IQ was designed to provide highly accurate and precise flow measurement in shallow channels. A built in pressure sensor and vertical acoustic beam are used in tandem to determine water level, while four velocity profiling transducers, two that measure velocities along the channel flow axis while two skew beams. The skew profiling beams measure velocities at 60° off the vertical axis and 60° center axis of flow, while the along axis profiling beams are 25° off of the vertical axis. A rendering of the instrument is presented in Figure 3. The housing of the sensor has screws pre-set in the mounting brackets all of which were designed for an easy install. The instrument was configured to collect data every 30 seconds and average data for 30 seconds – effectively measuring flow continuously. Flow is determined by using a combination of the water level data that are converted into cross-sectional area using – cross sectional area rating. Cross-sectional area is multiplied by average velocity (taken from the averaging interval) to determine flow.

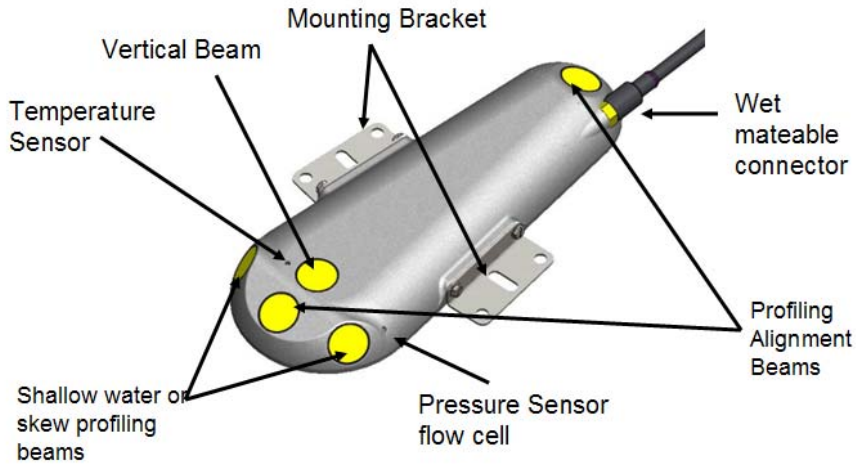

Figure 3. Drawing highlighting the attributes of the SonTek IQ

Figure 4 presents the configuration of the SonTek IQ for data collection. In order to calculate flow the use has to enter the channel cross-section. System elevation, or the elevation of the vertical beam referenced to channel bottom, was 0.09 ft (effectively the height of the instrument). Figure 4 presents how the instrument was configured using the IQ software.

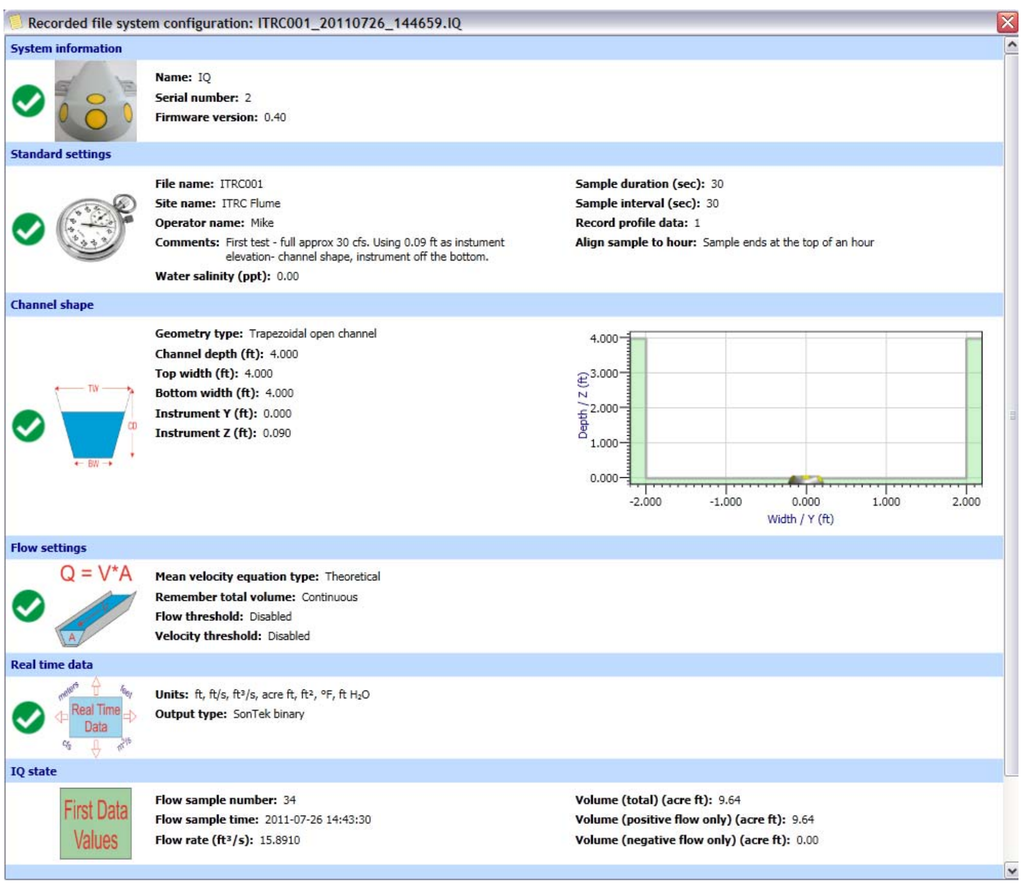

Figure 4. SonTek IQ configuration for ITRC testing

RESULTS

The results from three tests at the site are presented in Figures 5-7. The blue line displays a trace for the flow measured by the magnetic meter, while the red line represents data from the IQ. Since the flow meters are not installed in the same place flow rates were allowed to stabilize for 30 minutes in order to make data comparisons and the pumping rate and hydraulic head were maintained the same throughout the tests. All tests we performed for approximately 30 minutes.

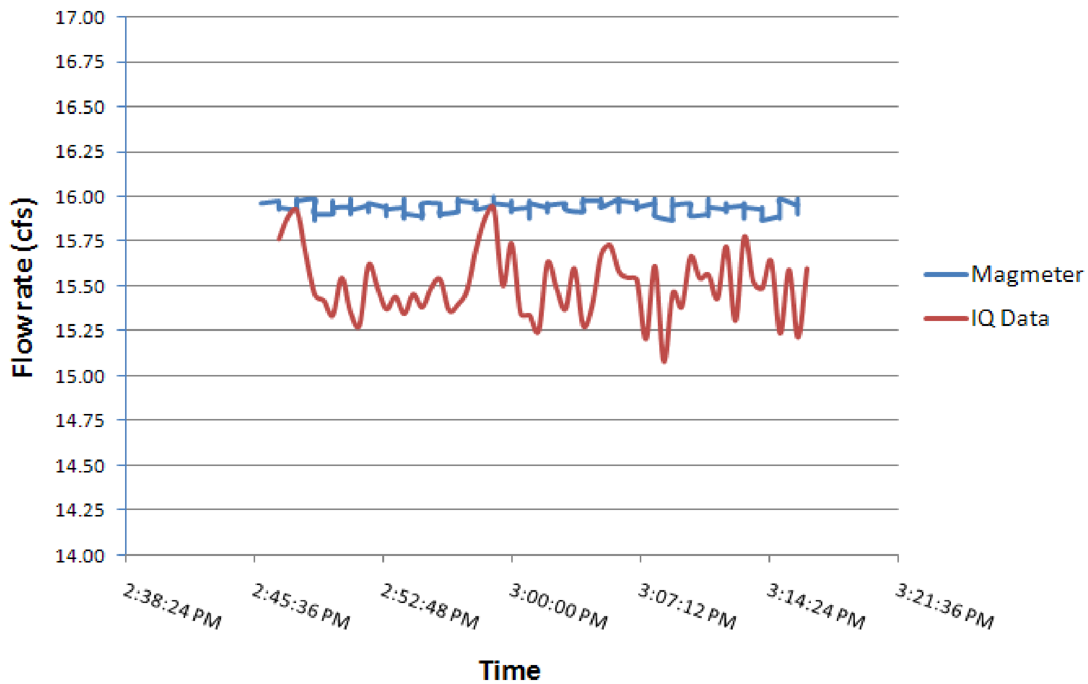

Figure 5. Flow data comparison at a reference flow of 15.94 cfs

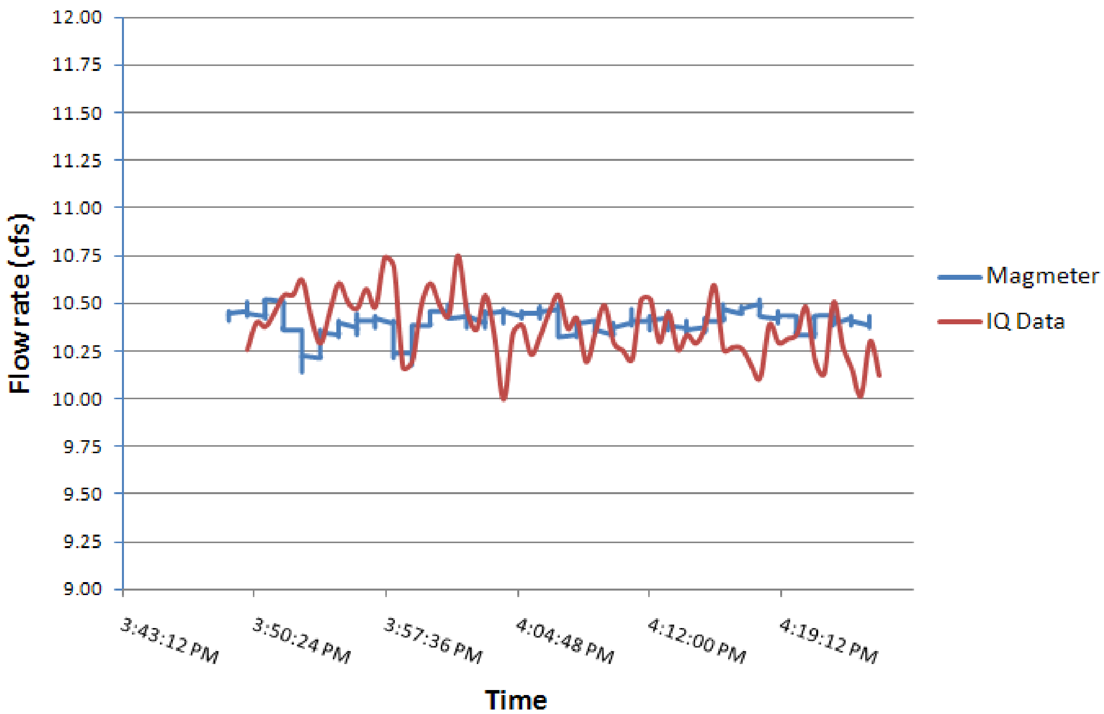

Figure 6. Flow data comparison at a reference flow of 10.42 cfs

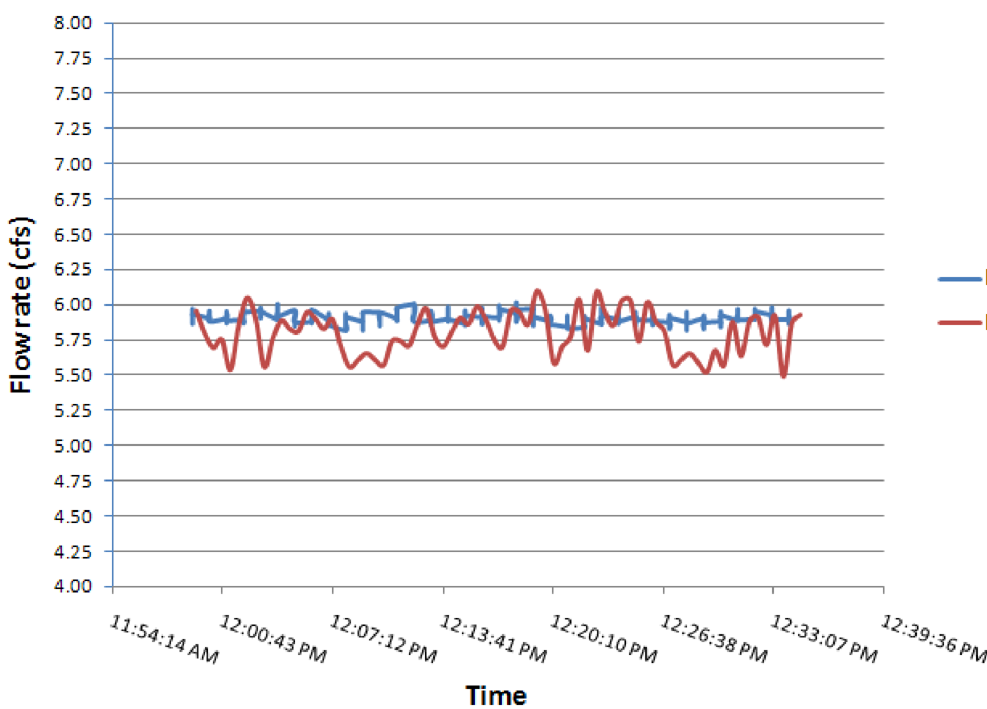

Figure 7. Flow data comparison at a reference flow of 5.80 cfs

Table 2 summarizes the results from the flow testing. The simple data analysis compares flow rate from the Magmeter and SonTek IQ. In general, there is good agreement between technologies with the average difference -1.68% for flow rate.

Table 2. Summary of the flow data comparing Magmeter and SonTek IQ

	MAGMETER (CFS)	SONTEK IQ (CFS)	% Diff. Flow Rate (cfs)
Test 1	15.94	15.51	-2.69%
Test 2	10.42	10.38	-0.36%
Test 3	5.92	5.80	-2.00%

Over the period of the tests, the SonTek IQ collects additional data at the site. Table 3 presents average values for flow (cfs), velocity (ft/s) and stage (ft).

Table 3. Summary of average values collected by SonTek IQ

	FLOW RATE(CFS)	VELOCITY (FT/S)	STAGE (FT)
Test 1	15.51	1.67	2.32
Test 2	10.38	1.80	1.43
Test 3	5.80	0.84	1.73

CONCLUSIONS

Based on the preliminary tests the SonTek IQ compares on average 1.68% lower than the reference measurement done using a magmeter. Graph indicate that the variability of the data from the SonTek IQ is greater than the magmeter, however the measurement devices are installed in two different environments – the magmeter in a pipe and the SonTek IQ in an open channel. The open channel environment for measuring flow is much more complex as flow patterns or velocity fields can be highly variable, where as in pipe conditions flow lines are streamlined and thus easier to measure. For accurate flow monitoring in open channels, it is necessary to sample a large portion of the water column as flow can be distributed unevenly, as such the SonTek IQ measures velocity horizontally and vertically by using the along axis beams as well as the skew beams. The SonTek IQ configuration and the corresponding algorithms have been specifically designed using data from agricultural canals to more accurately monitor flow in open channel.

Preliminary results are encouraging when considering the flow ranges evaluated (5.8 - 15.5 cfs) as well as velocities (0.84 -1.80 ft/s) and stage (1.43 ft – 2.32 ft), however additional tests should be conducted to verify the performance of the instrument in a wider range of flow conditions. Future tests will incorporate not only variations in water-level, velocity and the corresponding flow rate but field testing as well. Field testing for flow rate will be verified by comparing flow rates to reference flows or by making spot measurements using instruments in the field.

Acknowledgments

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Filter Efficiency Translates to Water and Energy Savings

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Abstract. *Criteria for optimum filtration systems should include a focus on performance, price and pressure/water loss. Add maintenance/replacement costs to that criteria and the filtration specifier/buyer takes greater control of the selection process, maximizing the potential payback value. Today's technology provides options for operating at lower pressures, resulting in significant cost savings in terms of pump horsepower and total kilowatt consumption. A review of filter options and the keys to energy cost improvements reveal savings beyond the obvious. Determine the needs of your water system and the contaminants that need to be removed. Compare filters based on your needed criteria. Maximize the value by knowing the pressure and water loss requirements of your filter options. A simple application-based calculation reveals the potential savings. Examples show the potential savings in both water and energy costs.*

Keywords. *filtration systems, irrigation filtration, water separator, sediment filter, prevent drip clogging, reduced backflushing, water well pump protection, prevent sand damage*

It's always a matter of efficiency

Competition, at the manufacturer, dealer and grower levels, fuels a never-ending drive to improve everything possible in an irrigation system. The design, materials and flow/pressure requirements are all part of the mix to improve yield with less water and pressure and more economical equipment costs. Pumps, too, have become a significant focal point for water and energy savings, with many agencies providing financial stimulus to re-build or replace inefficient pumps. And moisture-sensing technology has become both prolific and more sophisticated than ever before. To be sure, saving more water continues to be a powerful theme as both the weather and political environments increase the pressure to find even more ways to reduce loss and maximize every drop.

Water quality makes an impact

When a water source has been chosen (water well, canal, reservoir, etc.), know what potential contaminants are in that water source and plan accordingly. If you suspect bacteria or corrosive potential, a water analysis can help you properly select the downstream equipment best suited to withstand such issues.

If large debris or aquatic life must be considered, examine your options and budget accordingly. Unless the water is crystal clear (which is rarely the case), determine if the contaminants are settleable (sand, grit, scale, etc.) or suspended (algae, organics, bugs, etc.).

Compare the contaminants to the chosen irrigation technique (drip, sprinkler, etc.) and know what that irrigation technique can tolerate. This will help you select the proper filtration system. Be prepared that multiple contaminant issues may suggest multiple filter solutions, rather than forcing one type of filter to handle every situation. Such a practice often leads to greater maintenance as well as water loss.

Make intelligent filter choices

There are many filtration options available to protect irrigation systems from clogging and abrasive wear. Knowing what each filter can and can't do is important. Adopting an appropriate list of criteria for each application gives the specifier/buyer greater control and focus for making the right selection. Here are the industry's most common options:

- ***Pump protection sand separators –*** If coarse sand is grinding away at the impellers and bowls of a submersible or turbine pump, pump protection sand separators can keep that sand from causing excessive damage and help dramatically extend pump life. Limited by flow range and sizes that fit into the well for select flows, these units are maintenance-free and easy to install onto the pump for in-well installation. Surprisingly, separated/purged sand from the pump protection separator does not fill up the well, given the underground aquifer's natural flow that helps minimize sand build-up in the well.

- ***Pump intake screens –*** Generally, these devices are for open water applications only and are meant to remove only somewhat larger debris or keep aquatic life from being drawn into pumps and irrigation systems. Some are simple strainers, requiring manual cleaning routines. Others are self-cleaning, employing continuous spray nozzles to clean/backwash the screens. If you choose a self-cleaning screen that deposits the contaminants into a vessel out of the water source, be prepared to routinely deal with that material. If you expect long periods of inactivity, consider techniques for pulling the device from the water in order to prevent unwanted organic growth onto the screen. See Figure 1 for example of a pump intake screen.

Figure 1: Pump intake screen
This design removes particle matter while in the water and therefore does not require methods for collection or disposal of the filtered debris from the water.

- ***Filter screens –*** Installed after the pump, screen filters are best suited for light-to-moderate loads of inorganic particle matter. Excessive loading would mean greater cleaning/maintenance routines. Choose the screen mesh wisely; fine enough to protect the irrigation system, but not so fine as to create unnecessarily excessive pressure loss and/or maintenance routines. Good for variable flow rates. Not recommended for organics, algae, etc. Some with automatic self-cleaning options.

- ***Disc filters –*** For lighter contaminant loads and predominantly inorganic particle matter, these largely automated filters are compact and effective. Requires minimum flow/pressure for proper self-cleaning. Be cautious about combinations of sand/silt/organics, which can clog these filters and become difficult to self-clean.

- ***Sand separators –*** Meant only for settleable sand and inorganics, these centrifugal-action filters are flow-sensitive, operating effectively only within specified flow ranges. Pressure loss is predictable, based only on flow (separated sand does not increase pressure loss). Easily automated for maintenance-free operation.

- ***Sand media filters –*** Best suited for the removal of organics & suspended solids. Typically automated and triggered to clean by rising pressure differential. Not recommended for sand, which could cause residual build-up of pressure loss and increased backwash routines and excessive water loss. Minimum flow and pressure requirements vary by maker for effective backwashing.

Combine filters for reduced maintenance & water loss

Applications where multiple issues and/or two or more types of particle matter are present may suggest the need for more than one filter. It is not recommended, for example, to employ a pump intake screen for fine particle removal. Choosing too fine of a screen on the pump intake can make it more difficult to clean and restricts effective flow to the pump; the potential for excessive vacuum on the screen could result in screen collapse and permanent damage. Instead, use the pump intake screen for larger debris and install a filter downstream of the pump to achieve finer filtration.

When two or more contaminants are in the water, consider employing filtration best suited for those contaminants. A good example is when both sand and organics are involved. Yes, a sand media filter can remove both types of contaminants, but heavy sand is difficult (if not impossible) to backwash effectively from the sand filter, resulting in residual build-up, higher pressure loss, more frequent backwashing and greater water loss. See Figure 2 for a graphic example of the problem.

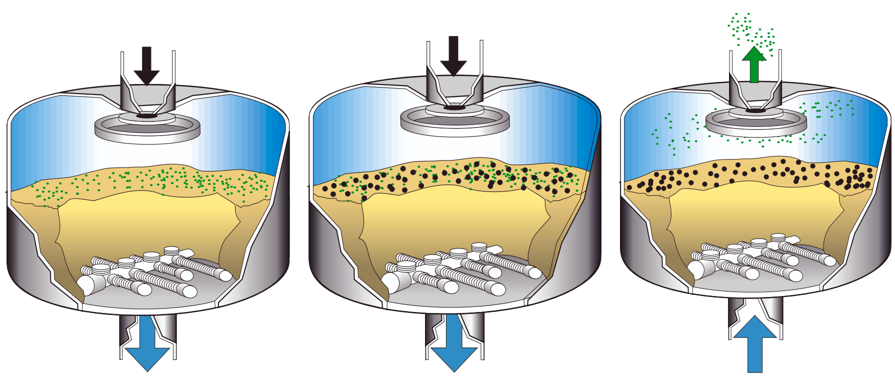

Figure 2: Organic vs. Sand Removal in a Sand Media Filter
At left, the organics are trapped on the sand media surface layer. Center, note the heavier sand particles, also trapped on the media sand. Right, the organics easily backwash, but the sand remains, adding pressure loss and causing increased backwash frequency and water loss.

If, instead, both a sand separator and a sand media filter were employed for removing the combination of sand & organics, the sand separator --- installed prior to the sand media filter --- can effectively remove the sand (and not be clogged by the organics), while the sand media filter easily removes the organics (and is not burdened by the increasing build-up of sand). See Table 1 for an example of the potential water savings.

Table 1: Sand in a sand filter

Application conditions: 650 gpm system flow; Backwashing every 15 minutes
Backwash conditions: 860 gallons per cycle; 3,440 gallons per hour
Add a sand separator as a pre-filter …

- *Backwashing reduced to every 4 hours*
- *94% reduction of backwash water*
- *Savings of 1 acre-foot of water per month*

If coarse sand is causing premature pump wear and fine sand is a problem for sprinklers, a pump protection sand separator can only protect the pump and remove only some of the fine sand. For greater protection, a filter after the pump is best for keeping the fine sand from clogging/abrading the sprinklers.

Selection criteria for filtration

Consider the following list of criteria for evaluating and comparing filters for any given application. Select those criteria which are important only to that specific application. Take control of the process for determining the best filtration for your needs.

- **Particle removal performance:**
  What is the filter capable of removing? Can the manufacturer/supplier provide test results (third party preferred) to validate the claims?
- **Pressure loss and requirements:**
  What's the expected maximum pressure loss? Will pressure loss vary or remain constant? What is the minimum required pressure to operate the filter?
- **Water loss:**
  How much water is needed for flushing/purging/backwashing? How often will flushing/purging/backwashing be necessary?
- **Replacement parts/media:**
  Which parts, if any, will be necessary to repair/replace? At what intervals? At what costs?
- **Downtime/maintenance:**
  What downtime and maintenance routines are required? Special tools or skills? Expected time requirement for servicing routines?

Challenge traditional filter logic for improved energy savings

The manufacturers of drip and micro-spray irrigation systems have developed very low pressure requirements for operating their systems. Yet, the pressure requirement for the pump to feed water and operate such systems has remained largely unchanged at 35-40 psi for many, many years. The issue is not the irrigation system, but rather the required filtration system, which demands both flow and pressure to properly operate and efficiently flush/backwash the filtered contaminants from the filter. Research and testing have shown that the popularly-known "constant" of 35-40 psi CAN and SHOULD be not only evaluated, but also challenged … and that the energy savings can be significant.

If, for example, a sand media filter can be operated at a lower pressure, it is possible that the pump requirement can be reduced, saving not only on the initial cost of the pump, but also the long-term cost of energy to run that pump for years to come. See Table 2 for examples of such savings.

Table 2: Reduced filter system pressure requirements & related energy savings

EXAMPLE 1 – Application conditions:
Central California Almond Grower; 500 acres; 850 gpm filter
Changing from 35psi to 25psi saves $3,980 annually in pump energy

EXAMPLE 2 – Application conditions:
Imperial Valley Tomato/Pepper Grower (double-crop); 1,000 Acres; 1500 gpm filter
Changing from 35psi to 25psi saves $5,660 annually in pump energy

EXAMPLE3 – Application conditions:
Northern California Grape Grower; 750 Acres; 1200 gpm Filter
Changing from 40psi to 25psi save $1,593 annually in pump energy

Sand media filters require pressure to engage the backwash valve into the backwash position. That same pressure feeds the filter's underdrain to uplift the sand media and release the suspended organics from the sand in order to be flushed away. The design of the backwash valve (more specifically, the size of the plate connected to the shaft that moves to change the backwash valve from the "run position" to the "backwash position") dictates the valve's minimum pressure requirement. A bigger plate helps operate at a lower pressure loss. In addition, the more extensive the open area of the underdrain, the more it can effectively function with less pressure, providing adequate and consistent flow to evenly lift and clean the media sand surface layer. To be sure, not all filter systems are alike. Look for these features in order to capitalize on the ability to operate at lower pressures and save on energy costs. See Figure 3 for an underdrain design comparison.

Figure 3: Underdrains are different; performance varies
Shown are two of the many designs employed by sand filter manufacturers. Note the differences in pattern, coverage and total open area. These features affect the pressure requirement and the efficiency of the backwash flow.

Conclusion

Know the water source and its potential contaminants. Use that information and your application requirements to compare filter options according to your needs. Examine every opportunity to save water and energy for reduced waste and expense. Challenge traditional thinking and pay attention to the subtle differences in products like sand media filters, which can greatly affect efficiencies. You may be pleasantly surprised at the potential savings in both upfront equipment costs and long-term operating costs.

Selenium Incorporation and Partitioning in "Jose" Tall Wheatgrass (*Thinopyrum ponticum*) Irrigated with Saline Drainage Water

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Abstract: In the western San Joaquin Valley (SJV) of California, saline drainage water (DW) has been utilized for irrigation primarily to extend irrigation water supplies and to dispose of these saline waters. High levels of selenium (Se) in this DW, however, requires that measures be taken to minimize the exposure of wildlife to this selenium. 'Jose' tall wheatgrass (TWG) (*Thinopyrum ponticum* var. 'Jose'), a highly salt tolerant forage which can be grown in soils of even 20 dS/m ECe and with high Se has accumulated up to 10 mg Se/kg in the dry matter. Conversely, in the eastern SJV, soils are low in Se and dairy cattle producers often supplement their animals with inorganic sodium selenate. A greenhouse study was initiated in 2009 at California State University, Fresno to assess the selenium accumulation in TWG with irrigation waters of two salinities (EC 3 and 12 dSm^{-1}) and two selenium concentrations (350 and 1000 ppb), along with three cutting heights (20, 40, 60 cm) arranged in a split-plot design. Initial results showed significant effects of irrigation water combination and cutting heights on forage Se accumulation which was as high as 15 mg/kg for the 60 cm cuts.

Keywords: Reuse, drainage water, selenium, "Jose" tall wheatgrass

Introduction

The San Joaquin Valley (SJV) which is the southern half of the Central Valley of California extends approximately 402 km from the San Joaquin-Sacramento River Delta on the north to the Tehachapi Mountains to the south. The valley often called the food basket of the world, contributes about 12.8% of United States agricultural production (2009) and includes the top five counties of United States in terms of agricultural production (Fresno, Tulare, Kern, Merced, Monterey). This enormous production which is brought about by irrigated agriculture has also brought the problem of salinity in the western part of the valley.

The western side of the SJV is mostly made of sedimentary deposits enriched in trace elements such as selenium (Se), molybdenum (Mo), and boron (B). Fine-textured soils along with shallow water tables in wet years contribute to these salinity problems. Conversely, soils on the east side of the valley which are granitic in origin and mostly coarse-textured, contain few native salts and much lower concentrations of selenium and boron. Interestingly, besides being an environmental hazard, Se is an essential element required for livestock, humans and cattle. It is the essential component of glutathione peroxidase and thyroid oxidase in mammals which are enzymes responsible for regulating reproductive health and immunity. Consequently, in the eastern SJV where selenium is often deficient in the soils, dairy farmers commonly supplement their animals with sodium selenate for proper animal nutrition. This area has some of the nation's largest dairy industries thus the importation of Se in the form of these dietary supplements represents a significant import of Se into the valley.

Drainage water (DW) management to cope with salinity has been approached in the past by the use of sub-surface drains. Reuse of saline DW to produce salt tolerant forages has emerged as an attractive option to reduce drainage volumes and produce high quality forage for the large beef and dairy cattle industry in the Central Valley of California. In areas of the western SJV where soils contain high levels of Se, forages enriched in Se due to DW irrigation have potential to be processed into organic Se supplements to replace the sodium selenate currently used by producers in Se-deficient areas (Suyama et al, 2007b, Grattan and Diaz, 2009, Robinson et al, 2004). As the problem of salinity in the WSJV is inseparably associated with the presence of Se, any salinity management approaches must address the issue of Se. The objectives of this study were to evaluate the effects of salinity and Se levels in the irrigation water and cutting height on Se accumulation in 'Jose' tall wheatgrass (TWG) (*Thinopyrum ponticum* var. 'Jose') in order to assess its potential as a local, organic source of dietary Se for dairy cattle.

Methodology

Experimental set-up and design

The study was conducted in a greenhouse at California State University, Fresno. Soils were collected from Red Rock Ranch in Five Points in western Fresno County, CA and passed through a screen. The soil thus screened was mixed with sand in a 60:40 (soil:sand) ratio to ensure better drainage in the pots while maintaining the cracking clay characteristics common to soils in the western SJV. Four irrigation water combinations consisting of two levels of salinity (3 and 12 dS/m) representing low (LS) and high (HS) salinity levels and two levels of Se (350 - 400 and 1000 ppb) as low (LSe) and high (HSe) selenium levels were utilized as the main plot factor. The LSe treatment level could not be set more precisely because the lowest level was determined by the amount of source water that had to be added to reach the HS (high salinity) level. Cutting heights of 20cm, 40cm, and 60cm were used as sub-plot factor which resulted in a split-plot design (Fig. 1).

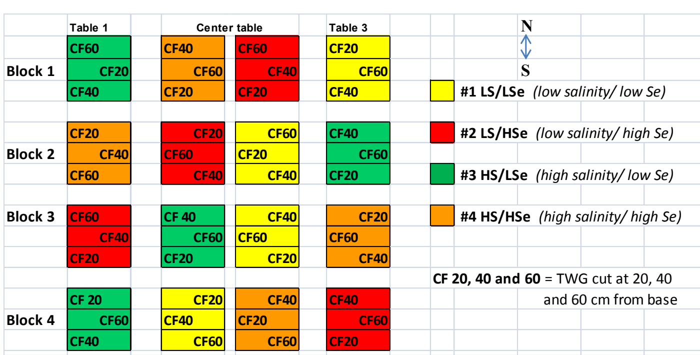

Fig. 1: split-plot design for arrangement of pots in the greenhouse.

Plant establishment, salinization, and irrigation

The pots used in the study (25.5 cm diameter x 30 cm deep= 15.3 L volume) were seeded directly and thinned to 12 plants per pot once the seedlings were several inches tall. The tall wheatgrass variety used was "Westside Wheatgrass" from S&W Seed, Five Points, CA. For the first several weeks all the plants were irrigated with non-saline tap water supplemented with basic nutrients (3 mmol/L of KNO_3, 0.5 mmol/L of KH_2PO_4 and 20μmol/L of Fe-DTPA). Concentrated DW from Panoche Water District, CA was collected from a drainage sump and used as the saline water source. To reach the target salinities, this saline water was introduced weekly in step-wise increments (¼, ½, full strength). From laboratory analysis, the Se input from the DW was determined for each irrigation water treatment and then supplementary Se in the form of sodium selenate was added to reach target Se levels. Once desired salinity, selenium and nutrient levels (as listed above) were reached, irrigation water samples were taken for complete chemical analysis.

Large plastic irrigation tanks (378.5 L) were used in a re-circulating system in which all the drainage water from the pots returned to the source tank. Tap water was used to replenish the water lost to evapotranspiration when the water level in the tank fell below 90%. Irrigation water salinity and nitrate concentrations were measured weekly and the targets levels were maintained. Irrigation tank waters were changed bi-monthly and fresh nutrients were added. The pots were irrigated 3-4 times a week initially and then daily or twice daily during the peak of summer to maintain a sufficient leaching fraction to maintain soil salinities in the pots close to the irrigation water salinities. To calculate the leaching fraction (LF), drainage was collected from selected pots and the LF calculated as the ratio of the drainage volume to the volume of irrigation water. An LF of approximately 20-30 % was maintained to keep salinity in the high salinity treatment at or below 15 dS/m.

Water and soil sampling

Irrigation tank waters were changed bi-monthly with samples collected one day after mixing and at the end of the tank mix. These water samples were analyzed for EC, pH, B, Se, Cl-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and NO_3-N. Beginning with the second tank mix, it was observed that Se levels in the irrigation water were depleting substantially over the two month period between mixes. Thus beginning with tank mix 2, Se spikes (50 ppb for LSe and 150 ppb for HSe treatments) in the form of Na selenate were added to the irrigation tanks every two weeks. At the end of the experiment soil samples representing the entire depth of the pot were taken from each pot and saturated soil pastes were prepared. Salinity (EC_e), pH, B, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, and Na^+ were measured on the saturated paste extracts and total Se and NO_3^- were measured on dry soil samples using established procedures.

Forage Sampling

Forage samples were harvested when the plants grew to 20cm, 40cm, and 60cm height. A complete harvest was considered to be completed when the 60 cm plants reached their full height. Samples thus obtained were rinsed three times in deionized water to remove surface salts and dust. Samples were then air-dried in forced air oven at 60ºC for 48 hours and weighed. The dried tissue was then ground to pass a 1 mm sieve using a Wiley mill. The samples were analyzed individually for total Se, but for the analysis of other mineral nutrients (Cu, Zn, B, S, Ca, Mg, total N and crude protein) samples from multiple cuts within a harvest period, as occurred for the 20 cm plants, were composited.

Data and statistical analysis

Total plant Se concentrations (mg/kg) and mineral nutrient concentrations were statistically analyzed using a general linear model with irrigation treatment (salinity/Se level), cutting height, and the interaction (irrigation treatment x cutting height) as fixed factors and block as a random factor using SPSS 17 (SPSS, Inc., Chicago, Illinois). The data sets were tested to see if they meet the assumptions of the analysis of variance (ANOVA), but no transformation was required. Since the 2-way ANOVA indicated significant differences at the 0.05 significance level amongst irrigation water treatments and cutting heights, Tukey's HSD test was used for mean separation.

Results and Discussion

Irrigation water composition

The average salinity (EC_w), pH and ionic composition (other than Se) of the water used to irrigate the pots are shown in Table 1. Low salinity (LS) treatments had salinities of 3.3 to 3.4 dS/m EC_w, boron concentrations of 4.2 mg/L, and SAR of 10.3. In contrast, the high salinity (HS) treatments had an EC_w.of 10.7 dS/m, boron concentrations of 17-18 mg/L and SAR of 27. Nitrate (NO_3-N) levels were 36-40 mg/L for the LS and 41-47 mg/L for the HS irrigation waters.

Table 1: Irrigation water composition (averages for six tank mixes and for samples taken at the beginning and end of each mix). Selenium data are shown in Table 2.

Irrigation treatment	EC_w (dS/m)	pH	Se (ug/L)	B (mg/L)	NO_3-N (mg/L)	Cl^-	SO_4^{2-}	Na^+ (meq/l)	Ca^{2+}	Mg^{2+}	SAR
LS/LSe	3.3	7.9	313	4.2	39.9	12.4	15.6	23.0	5.1	5.9	10.2
LS/HSe	3.4	8.0	761	4.2	36.1	13.0	16.1	23.5	5.4	5.9	10.4
HS/LSe	11.5	8.0	369	17.8	47.5	59.2	70.7	103.2	14.1	13.5	27.8
HS/HSe	11.1	8.2	787	18.3	41.3	56.5	67.7	98.2	13.2	12.8	27.3

Selenium levels in the irrigation waters (initial and final concentrations for each of the six tank water mixes) are shown in Table 2. It can be observed that for tank mix 1, Se levels in the irrigation water depleted during the two month period prior to re-mixing. For tank mixes 2 to 7, there was less depletion of Se because beginning with tank mix 2, Se spikes were added to the irrigation tanks, initially every month and then every two weeks from tank mix four onward.

Table 2: Selenium levels (ug/L) in the irrigation water with initial and final values shown for each tank mix

Irrigation	Mix 1		Mix 2		Mix 3		Mix 4		Mix 5		Mix 6		Mix 7	
treatment	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
LS/LSe	271	108	310	154	420	321	371	320	337	392	385	462	428	255
LS/HSe	.	627	800	305	971	455	990	916	835	1420	943	1150	783	172
HS/LSe	362	218	360	177	315	184	347	244	317	453	963	795	368	690
HS/HSe	891	323	877	177	883	655	995	856	914	1140	1090	1100	946	174

**Spiking of Se was done monthly from Mix 2 onward with 50 and 200 mg/L sodium selenate for LSe and HSe treatments, respectively. From Mix 4 onward spiking was done every 2 weeks with 50 and 150 mg/L sodium selenate for LSe and HSe.*

Soil chemical composition

Soil salinities at the end of season for the LS treatments were 4.5 to 4.7 dS/m EC_e. For the high salinity treatments the values were 12.8 to 13.3 dS/m. The ratio of soil salinity to irrigation water salinity (EC_e/EC_w) was 1.26 for the LS treatments and 1.22 for the HS treatments which indicates a leaching fraction of about 20% (Ayers and Wescot, 1986). Measured leaching fraction (volume of drainage from pots/volume of water applied) was 20-30%. This range in measured LF values was likely due to differences in water use between the 20, 40, and 60 cm plants. LF values were higher for the 20 cm plants, lower for 40 cm and lowest for 60 cm plants.

Table 2: Soil chemical composition (samples taken at end of experiment)

Irrigation Treatment	EC_e (dS/m)	pH	Soluble Se (ug/L)	B	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}
				.... mg/L				
LS/LSe	4.7 ± 0.4	7.7 ± 0.03	100 ± 10	6.2 ± 0.2	561 ± 23	1362 ± 223	140 ± 25	53 ± 8
LS/HSe	4.5 ± 0.2	7.9 ± 0.1	110 ± 3	6.4 ± 0.7	611 ± 97	1125 ± 186	134 ± 9	53 ± 5
HS/LSe	13.3 ± 1.8	7.6 ± 0.1	100 ± 5	19.8 ± 1.9	1980 ± 359	4160 ± 620	342 ± 42	174 ± 25
HS/HSe	12.8 ± 0.1	7.7 ± 0.1	100 ± 10	18.1 ± 1.3	1847 ± 98	3699 ± 311	305 ± 23	153 ± 1

Boron concentrations were high (17-18 mg/L) in the irrigation water for the HS treatments and accordingly, soluble B was high in the soil at the end of the experiment (Table 3) being nearly 20 mg/L. In both the irrigation water and the soil, SO_4^{2-} was more predominant than was Cl^-. High levels of sulfur in soil and irrigation water are of particular importance because sulfate has been shown to inhibit Se uptake by plants (Grieve et al., 2001; Bañuelos et al., 2003) and high levels of sulfate in forage tissue can be detrimental to ruminant health (Grattan et al., 2004). Soluble Se concentrations were very low in the soil (100 to 110 ug/L soil paste extract) and they were similar amongst LSe and HSe treatments. Total Se concentrations are a better indicator of Se potentially available for plant uptake, but these data are not yet available.

Forage Selenium accumulation

Irrigation water composition (salinity/selenium level) had a significant effect on Se accumulation in TWG forage ($P \leq 0.0001$). For plants cut at 40 and 60 cm, Se accumulation in the herbage was greatest under HSe irrigation (10.1 to 12.1 mg/kg = ppm, average for six harvests), but not significantly different for low and high salinity conditions. For the 20 cm plants, the effect of salinity on Se accumulation was more significant as the LS/HSe plants had higher Se in the herbage (10.8 ± 0.51 mg/kg, average of six harvests) as compared to the HS/LSe (8.3 ± 0.51 mg/kg). Overall, it appeared high sulfate levels in the irrigation did not substantially inhibit Se accumulation in the HS/HSe plants, with the possible exception of the plants cut at 20 cm at T2, T3, and T4 (Fig. 1d). However, it cannot be determined if reduced Se accumulation under high salinity at these harvests was due to sulfate inhibition of Se uptake or an effect of salinity on evapotranspiration (ET) which in turn could have reduced Se uptake. Irrigation with low Se irrigation water resulted in lower Se accumulation in the forage, averaging from 3.8 to 5.8 mg/kg Se, averages for six harvests) under both low and high salinity conditions.

Cutting height also had a statistically significant effect on Se accumulation in the TWG herbage ($P \leq 0.003$). Differences in Se accumulation in response to cutting height were greatest for the HS/HSe treatment (Fig. 1d) and for this treatment, Se accumulation was lowest for plants cut at 20 cm suggesting that the osmotic effect of salinity may have impacted water and Se uptake to a greater extent in these frequently cut plants with younger tissue. For the T3 and T4 cuts, plants irrigated with low salinity and high selenium (LS/HSe) irrigation water and cut at 40 cm and 60 cm accumulated the most Se (12.1 ± 1.4 and 15.5 ± 1.0 mg/kg, respectively) which was significantly higher than for the 20cm cuts. At the T5 cut, Se accumulation was highest for 60 cm plants under both HS/HSe and LS/HSe irrigation which were not significantly different from one another. The final harvest (T6) produced highest Se accumulation for LS/HSe treatments which was not statistically different within cutting heights, nor from the 60cm plants in the HS/HSe treatment (Fig. 1c,d).

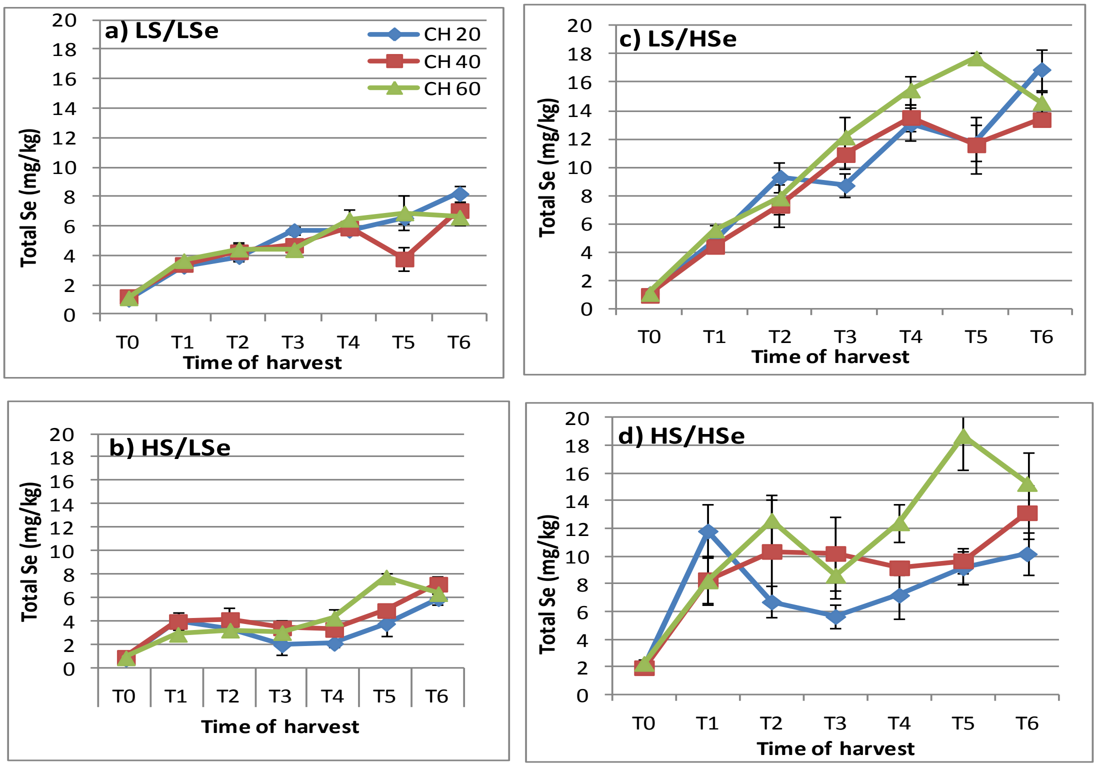

Fig.1. Total Se accumulation (mg/kg) in “Jose” tall wheat grass irrigated under irrigation with a) low salinity, low selenium (LS/LSe), b) low salinity, high selenium (LS/HSe) c) high salinity, low selenium (HS/LSe) and d) high salinity, high selenium (HS/HSe) water for plants cut at 20, 40 or 60 cm heights. Six cuts of the forage were made over the one year period.

For the plants cut at 40 and 60 cm, Se concentrations in the herbage generally increased over time likely due to the increased exposure to the selenium enriched irrigation waters. Interestingly, there was little difference in final concentrations of Se in the herbage of plants cut at 40 vs. 60 cm which could mean that as the tissue started to age the uptake and accumulation of Se slowed down. It is important to note that with 20 cm plants, frequent cuttings resulted in low biomass production per pot and the death of a number of plants initially. With frequent cutting these plants became fewer and finer. With the overall objective of harvesting tall wheatgrass as an organic Se supplement for dairy cows, the greater biomass production obtained from the plants cut at 40 and 60 cm would be desirable.

Conclusion

The highest Se accumulation was obtained for tall wheatgrass plants cut at 60 cm under LS/HSe (17.7 ± 0.4 mg/kg) and HS/HSe (18.7 ± 2.4 mg/kg) irrigation and these plants also had the greatest biomass production (data not shown). These data suggest that there is potential to use high Se drainage waters of high or low salinity to produce Se-enriched ‘Jose’ tall wheat grass in salt- and drainage-affected areas of the western SJV. The Se enrichment achieved in the TWG forage under DW irrigation (up to 18 mg/kg = ppm dry matter) would be sufficient to provide adequate Se to meet the nutritional requirement of dairy cattle (0.05 mg Se/ kg of ration) (Minson, 1990) when added to the diet at low percentages (< 5%). Utilization of Se-enriched tall wheatgrass forage in place of sodium selenate supplements currently used by the industry would have the environmental benefit of reducing Se imports into the SJV in the form of dietary supplements for cattle.

Acknowledgements

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Agricultural/Urban/Environmental Water Sharing: Innovative Strategies for the Colorado River Basin and the West

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ABSTRACT

Increasingly, agricultural water is being considered the likely source of water to meet unmet urban and environmental demands. Are there strategies for water sharing between sectors which meet multiple purposes while avoiding unilateral transfer of water from agriculture? This session will describe the results of an initiative funded by the Walton Family Foundation in 2010 to explore that question. The Family Farm Alliance, Western Urban Water Coalition, The Nature Conservancy, and others convened a workshop of western water leaders from all three sectors to develop recommendations for the Western Governors' Association. Those recommendations, and a dozen strategies being employed around the West will be discussed. The Colorado Water Institute (CWI) at Colorado State University facilitated the workshop and the report. CWI policy and collaboration specialist, MaryLou Smith, will present this session.

KEY WORDS

Water sharing, agricultural water transfers, water shortages. Cooperative water sharing strategies.

SECURE WATER FOR AGRICULTURE BY SHARING?

Across the west, the writing is on the wall: we do not have enough water for projected population growth and to keep our rivers whole. More and more, farms are being purchased and dried up so that water can be transferred for other uses, mostly urban. Nicknamed “buy and dry”, almost no one thinks it is a good idea.

The target is on agriculture when it comes to looking for water to reallocate. But we count on the food and fiber, the rural communities, the wildlife habitat, and the open space agriculture gives us. Are there creative ways we can share water for agricultural, urban, and environmental purposes, without relying on unilateral transfers of water from agriculture?

WATER LEADERS TACKLE THE ISSUE

In the summer of 2010, a group of agricultural, urban and environmental water leaders retreated to a ranch in the Rocky Mountains of Colorado to look at water sharing strategies across the west that are working and consider how to remove obstacles that keep such strategies from being employed more widely. They believe if we set aside differences in how we have traditionally viewed things, we can figure out ways to share water without harming agriculture or rivers—and without pulling the rug out from under private property rights.

RECOMMENDATIONS

The convened leaders, from perspectives as diverse as the Family Farm Alliance, The Nature Conservancy, the Western Urban Water Coalition and two dozen others, came to consensus on a set of recommendations—action steps for governors and policy makers. Their recommendations, along with creative water sharing strategies being employed across the West, are contained in the report *"Agricultural/Urban/Environmental Water Sharing: Innovative Strategies for the Colorado River Basin and the West"* available at www.cwi.colostate.edu/watersharing. Basically, these leaders agreed we need to:

- Look at things whole instead of as separate jurisdictional pieces to find ways to share infrastructure, utilize advanced technology and manage more flexibly.
- Go beyond lip service to meaningfully engage all affected stakeholder groups, all the time, from the beginning, not after proposals are already developed.
- Work toward a regulatory process that's better integrated, with less redundant action by multiple agencies, that aims to facilitate sustainable solutions that meet multiple needs.
- Identify incentives for market driven solutions.
- Identify laws and institutions that might be modified to provide more flexibility and effectively promote water sharing, while respecting and preserving water rights.
- Find ways to reduce high transaction costs that discourage temporary transfers.
- Encourage western governors and other policy makers to address the overarching obstacles that stand in the way of creative water sharing strategies.

WATER SHARING STRATEGIES

This project included interviewing 50 individuals across the West who are actively employing or investigating creative water sharing strategies, to determine from their experiences what works, what doesn't work, and what are the challenges that stand in the way. Eleven of those strategies are detailed in the report. A sampling of the strategies includes:

• Farmers and cities in Arizona trading use of surface water and groundwater to mutual advantage
• Ranchers in Oregon paid by environmentalists to forego a third cutting of hay to leave water in the stream for late summer fish flows;

• A ditch company in New Mexico willing to sell shares of water to New Mexico Audubon for bird habitat on the same terms offered to farmers who grow cotton or pecans;
• A California flood control and water supply project creatively managed to meet multiple goals of restoring groundwater, maintaining instream flows for wild salmon and steelhead, and providing water for cities and farms;
• Seven ditch companies cooperating in Colorado in a "Super Ditch" scheme to pool part of their water through rotational fallowing, for lease to cities, while maintaining agricultural ownership of the water rights.

"While these strategies sound like good common sense, they all faced sizable obstacles," says Reagan Waskom, director of the Colorado Water Institute. "If we want to share water for the benefit of all, we need a lot more flexibility." The group's recommendations were developed to provide that flexibility, Waskom said.

WHAT'S NEXT?

Western States Water Council, the water policy arm of the Western Governors' Association received the group's report in the spring of 2011. They have formed a committee to consider ways these strategies might be adapted and adopted throughout the West.

The Walton Family Foundation that funded the 2010 initiative recently funded two field trips to the Pacific Northwest so that agricultural and environmental stakeholders from the Colorado River Basin in Arizona and Colorado could learn about unique water sharing strategies being employed there. Water leaders from both the environmental and agricultural sectors had the opportunity to spend a week together touring various projects in the Deschutes Basin, in the Yakima Basin, and on the John Day River in Oregon. In addition to hearing about how Oregon stakeholders overcame obstacles to achieve water sharing, the Colorado and Arizona stakeholders benefitted from the relationship building afforded from the trips.

Colorado State University has recently been awarded a planning grant from the USDA to explore further how agricultural water security can be strengthened by relieving water shortage pressures on other sectors through cooperative management agreements.

Funding Urban Landscape Water Efficiency Programs with Adjusted Agriculture Water Offsets

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Abstract. *Does it make sense to continue to deliver water to Southern California urban landscape systems despite great economic, social and environmental consequences over the last 40 years? What isn't discussed is the irrigation efficiency rating is well below 50% at many urban parks and schools. Water agencies have used "efficiency grants and rebate" paid by the water user to assist with urban landscape retrofit programs reducing the water demand immensely.*

Economic conditions in southern California forced retrofit programs to be cut sharply making each gallon of water sourced to be less efficient. So the question is asked; is it inappropriate for urban rate-payers to support out-of-region corporate farms in exchange for their water to be used ineffectively?

This presentation looks at what a $50 million per year investment in schools and parks can do to increase efficiency and improve the social welfare locally and across the globe.

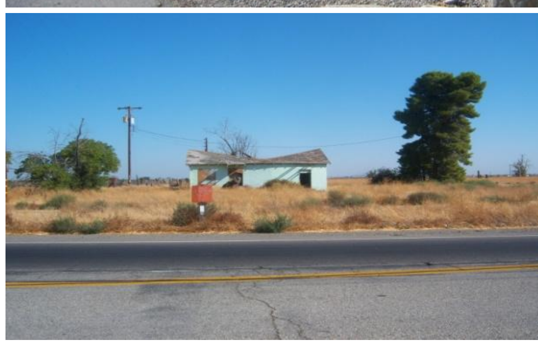
Key Words. Water, Irrigation, efficiency, sustainable, landscape upgrades, agriculture, water transfers, energy, employment, obesity, social justice, climate change, food shortages.

A Model for Change

1. Energy is deeply imbedded in southern California water.
    - Water must be pumped multiple times for a +2,300 foot elevation gain.[1]
    - Four pumps, each being large enough to run a battleship.[2]

2. Inefficient water use in urban areas can be linked to Social issues in the agriculture regions of the San Joaquin Valley.
    - Unemployment[3]
        - US @ 10%
        - CA @ 12%+
        - Kern @ 18%

3. Urban schools and parks are unable to fund and maintain parks
    - Retrofit rebate dollars have shrunk; from $50million to less than $15million in 3 years.[4]
    - Irrigation systems at <50% DU[4]
    - Obesity is a major California problem.[5]



Sustainable Supplies and the California Community

1. **Environmental**

- Energy costs are rising equal to water cost increases.[6, 8]
- 20% of all energy utilized in California goes to acquiring, pumping, moving and treating water.[7, 13]
- California must acquire 33% of its power from renewable methods by 2020 and AB-32 is a legislative bill that stands to tax all methods of energy use to offset CO_2 releases.[8]

2. **Economic**

- Easy to deliver and measurable retrofit programs are funded by the rate payer but the money is handled by the water agency.[4]
- Urban Irrigation accounts for a significant amount of sourced water from agriculture regions where water is transferred or “offset”.[6]

3. **Social**

    1. New landscape promotions and requirements called "Water Wise Landscapes" account for substantial savings in water use in urban areas. [9]

    2. Better funded retrofits programs equals increased urban employment, especially when workforce partnerships are involved where job skills are learned making for a ready-to-work workforce.
        a. "Infrastructure (upgrades) could be the way out of job-starved (situation) we find ourselves in". [10]
    3. Improved landscapes represent a healthier community.

    4. Reduction in green house gases can be achieved with smart landscapes that assist in lowering the demand of industrial pumping. [6]

Sustainable Supplies and the California Community

Political Stakeholders Have Messages

Community Stakeholders (local, region, national and international)

Social Justice is a subject not normally covered in the science and engineering arena, but it is a critical part of sustainability

The 3 Orbs of Sustainability

ECONOMIC **SOCIAL**

ENVIRONMENTAL

In the public and media sector, too often sustainability is connected to a political viewpoint, generally called SOCIAL Justice.[8]

From a business point of view, ECONOMIC stands to get a majority share of attention. [8]

And there is also the ENVIRONMENTAL voice that tends to look at things in a modeled view.[8]

The Best Stuff on Earth

High Commodity Prices

Lessons to be learned, California agriculture is connected to the world

Substituting Offset Water for Local Retrofits

It is estimated that over $50,000,000 is annually paid by an urban water agency to out of region growers to for their water[6].

If twenty percent or $10,000,000 was diverted to urban landscape efficiency irrigation retrofit programs over five years, 400 schools could have their play grounds upgraded, installed or retrofitted to natural turf.

The goal is to have the lowest efficient schools or mini-parks (DU 20%?) upgraded to a minimum of 65% DU.

These 400 schools or parks in communities that are unable to find adequate funding are normally in underserved and disadvantaged communities where the outdoor experience is lacking and obesity is chronic.

A single school district in southern California serves 700,000 students at 700 schools.[11]

Some schools have not had an irrigation upgrade since the 1970's.

Using a conservative number of 1.5 acres of natural turf per school campus.

Target 35% water savings with at the poorest DU campuses.

5 year target based on meter rates of $1,200 AF for years 2012 to 2017.

$50,000,000 available to fix school sites with diverted "offset" money and grants provided via Workforce Partnership programs.

Not factored is many sites actually may need a booster pump system installed to meet the expectations of an institutional irrigation system.

Landscape upgrades can contribute to a healthier agriculture marketplace with respect to jobs.

And help feed countries around the globe.[12]

- Arab Spring lesson

Landscape retrofits will continue to contribute to higher employment rates;[6]

- Irrigation consultants
- Manufacturers
- Distributors
- Contractor Firms

Landscape retrofits will lead the fight against poor health conditions in the region

- Obesity in young adults in California is a matter of national security.[5]

- More than 50% of California elementary schools do not meet the 200 minutes of physical activity required every 10 days.[5]

The Facts from Costs to Directives

California Potato

Results from an inefficient irrigation system at an urban school

To farm or to fallow – selling water to urban areas without accounting for where the water will be used.

It is difficult to resource current figures listing the amount of water offset in Kern County for urban areas. *Call that the hidden fact*[x].

Water transfers from the Imperial Valley to the Southland exceed 100,000 AF.[14]

Millions of dollars are going into regional water collection, diversion, spreading and other long term strategies. But what is missing is the long-term savings if low performing irrigation systems become upgraded to last another 4 decades. [7]

Urban water costs are expected to rise, doubling for the second time by 2015.[4]

Electricity costs, Legislation and environmental conditions report that if a local region reduced its water demands by 100,000 AF over a period of time, enough electricity would be saved to power 25% of all the homes in the same region.[13]

Running the faucet for 5 minutes equals the power to run a 60 watt bulb for 14 hours.[15]

Pre-Conclusion; Efficiency vs. Cost

The cost to be efficient will never match the direct outcome.

Solar Power / Wind Power vs. Fossil Fuels

Electric Vehicle vs. Internal Combustion

However, consider the indirect costs associated with pumping water in such a spectacular fashion, water that could have been used to grow commodity crops keeping the farming community vibrant.

And then the attributes of fixing what needs to be fixed post-haste; jobs are created and urban irrigation systems (finally) get upgraded.

California Pima Cotton, Kern County CA, pre-harvest 2011

Conclusion

Sustainability works best in a balance. "Social" considerations are normally excluded when it comes to the water saving discussion, but it is just as important as the "Economic and Environmental" orbs of sustainability[16].

Smart, effective and efficient retrofit programs equate to long-term savings. Agricultural water transfers are a short-term fix and 20% of the money provided to offset could be kept within the Southland region for a five year retrofit program.

Water agencies could put this retrofit program into action immediately if their Integrated Water Management Plan is amended to keep rate payers fees local and economic job stimulus on the water-use side is targeted.

Jobs will be created in the urban areas and re-created in the farming districts.

Commodity food prices could become more stable resulting in a more stable global arena.

Children would become active participants in outdoor activities helping to turn back the tide of increased long-term chronic health concerns.

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The Metropolitan Water District of Southern California 2010 Integrated Water Resources Plan.

G2 Workforce Partnership on Creating "Green Industry" Manufacturing and Construction Jobs to Battle Unemployment and Reduce Water Use in the Counties of Ventura, Los Angeles and Orange. Sponsored by MWD and the State of California Workforce Partnership Grant.

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Subsurface Drip Irrigation of Alfalfa

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Abstract. Alfalfa, a forage crop, has relatively large crop water needs and, thus, can benefit from highly efficient irrigation systems such as subsurface drip irrigation (SDI). A field study was conducted from 2005 through 2007 at the KSU Northwest Research-Extension Center, Colby, Kansas to examine alfalfa production at three perpendicular distances from the dripline (0, 15 and 30 inches) for 60-inch spaced driplines under three irrigation regimes (treatments designed to replace 100, 85 or 70% of ETc minus precipitation). No statistically significant differences in dry matter yields were attributable to irrigation level, but a tendency for slightly reduced yields was observed with less irrigation as the season progressed through the 4 to 5 harvests annually. Also, yields tended to decrease with distance from the dripline during a dry season.

Keywords. microirrigation, alfalfa, forage, irrigation management, drip irrigation, Great Plains.

Introduction

Alfalfa (*Medicago sativa* L.), a forage crop, has relatively large crop water needs and, thus, can benefit from highly efficient irrigation systems such as subsurface drip irrigation (SDI). In some regions, the water allocation for irrigation is limited by geohydrological or institutional constraints, so SDI can effectively increase alfalfa production by increasing the crop transpiration while reducing or eliminating irrigation runoff, deep percolation and soil water evaporation. Since alfalfa is such a large water user and has a very long growing season, irrigation labor requirements with SDI can be reduced relative to less-efficient, alternative irrigation systems that would require more irrigation events (Hengeller, 1995).

A major advantage of SDI on alfalfa is the ability to continue irrigating immediately prior, during and immediately after the multiple seasonal harvests. Continuation of irrigation reduces the amount of water stress on the alfalfa and thus can increase forage production which is generally linearly related to transpiration. Transpiration on SDI plots that did not require cessation of irrigation was 36% higher during this period than plots where irrigation was stopped for the normal harvest interval (Hutmacher et al., 1992). Yields with SDI were approximately 22% higher than surface flood-irrigated fields while still reducing irrigation requirements by approximately 6%. Water productivity (WP), the alfalfa yield divided by the water use, was increased mainly due to increased yield, not due to less water use (Ayars et al. 1999). When irrigation can continue, plant crowns have less physiological stress, and this can help suppress weed competition. On some soils with some SDI designs, irrigation with SDI may need to be reduced during the harvest interval to avoid wet spots and compaction by heavy harvesting equipment. Possible solutions to these problems might be deeper SDI installations or closer dripline and emitter spacings, thus resulting in more uniform water distribution (McGill, 1993; Hengeller, 1995).

On some soils under good irrigation management, it may be possible to use a relatively wide dripline spacing for alfalfa because of its extensive and deep root system. In arid California on a silty clay loam, yields from driplines spaced at 80 inches were nearly equal to that obtained by a narrower, 40-inch spacing after the first year of operation. Yield for the wider spacing was reduced approximately 17% during the first year when the root system was not well established. In semi-arid Kansas on a sandy loam soil, yields were 18% lower for a 60-inch spacing as compared to the narrower 40-inch spacing for the second and third years of production (Alam et al., 2002 a and b). It was concluded in this study that it was more economical to use the 40-inch spacing. However, it may be possible that irrigation applications with SDI on this soil type were too marginal to allow the alfalfa to fully develop under the wider 60-inch spacing. SDI applications were only approximately 50% of the average reference evapotranspiration due to study constraints imposed on this producer-owned field.

A field study was conducted from 2005 through 2007 at the KSU Northwest Research-Extension Center, Colby, Kansas to examine alfalfa production at three perpendicular distances from the dripline (0, 15 and 30 inches) for 60-inch spaced driplines under three irrigation regimes (treatments designed to replace 100, 85 or 70% of crop evapotranspiration (ETc) minus precipitation).

Methodology and Procedures

This experiment was conducted at the Kansas State University Northwest Research-Extension Center at Colby, Kansas, USA, during the period 2005 through 2007. The deep silt loam soil as described in more detail by Bidwell et al. (1980), can supply about 17.5 inches of plant available soil water from an 8-ft. soil profile. The climate can be described as semi-arid with a summer precipitation pattern and a long term average annual rainfall of approximately 19 inches. Average precipitation is approximately 15.75 inches during April through October, the typical alfalfa active-growing period. The latitude is 39.39 degrees north and the longitude is 101.07 degrees west with an elevation of 3159 ft above sea level.

The field site was approximately 390 ft wide and 80 ft long, consisting of 13 field plots approximately 30 x 80 ft in dimension. The two most northern and southern plots were not used in the field study and served as crop buffers. The area was thoroughly disked with a tandem disk and firmed with a spring tooth cultivator prior to planting of the inoculated alfalfa seed. The alfalfa (Pioneer HiBred brand 54Q25) at the field site was planted on September 12, 2003 with a disk drill at an approximate seeding rate of 12 lbs/a. Stand establishment was insufficient with the fall 2003 planting, so on April 20, 2004, the established alfalfa stand was interseeded at an approximate seeding rate of 12 lbs/a using the same disk drill at an approximately 15 degree angle to the original drill rows. Hand-set sprinkler lines were used to apply approximately 1 inch of irrigation after both seeding attempts to improve germination. Stand establishment after this second seeding was sufficient for good alfalfa production. The SDI system was not used for stand establishment for either planting due to the deep SDI installation depth of 20 inches. Although the crop was harvested three times during the summer and irrigated using the SDI system, no irrigation treatments were imposed or harvest data was collected during 2004 while the alfalfa was becoming more fully established. During 2004, the crop was irrigated as needed with a water-budget irrigation schedule designed to apply approximating 100% of the alfalfa evapotranspiration not replaced by precipitation for a total seasonal irrigation amount of approximately 14.75 inches.

The subsurface drip irrigation (SDI) system was installed in the fall of 2003 before planting of the alfalfa. Low-flow (0.6 L/h-emitter) dripline with a 12-inch emitter spacing and 0.875 inch inside diameter (Roberts Ro-Drip XL 12-15) was installed with a 60-inch dripline spacing using a shank-type injector at a depth of 20 inches. The emitter exponent for this dripline as measured in the laboratory was 0.59 which was slightly greater than the manufacturer's specified value of 0.57. There were six driplines in each plot running from east to west for a length of approximately 80 ft. Each plot was instrumented with a municipal-type flowmeter to record accumulated flow. The water source for the study was fresh groundwater pumped from the Ogallala aquifer with a water temperature of approximately 57° F.

Cultural Practices and Harvest Procedures

No fertilizer was applied to the field site during the course of the study, but small amounts of nitrogen and sulfur were applied through the dripline in the form of Urea-Sulfuric Acid (N-pHuric 15/49, 15% nitrogen and 49% sulfuric acid by weight). The Urea-Sulfuric Acid was injected annually in the late fall at an approximate rate of 3.75 gal/a to help maintain emitter performance and to help prevent alfalfa root intrusion. The amounts of N and S provided annually in this maintenance treatment were approximately 7 lbs/a and 7.5 lbs/a, respectively. Sodium hypochlorite (7.5% concentration) was also applied as a dripline maintenance treatment twice a year (early spring and late fall) at an approximate rate of 2.5 gal/a.

Five harvests occurred each year with the first harvest occurring near the end of May, approximately 54 days from the beginning of spring green-up which typically began around April 1. During each harvest, plot samples were obtained from each replicated treatment plot at three horizontal distances from the dripline (0, 15 and 30 inches) to examine the effect of the 60-inch dripline spacing on alfalfa yield. This self-propelled plot harvester utilized a flail chopper 36 inches in width to cut and blow the harvested material into a container mounted on load cells on the harvester for mass determination. Samples centered at the fixed horizontal distances (0, 15 and 30 inches) from the dripline were obtained from the second, third, and fourth driplines of the 6-dripline plots, respectively, to avoid overlap of the harvester which had width greater than the sampling distance interval. The plot area and wet mass were recorded and a grab-sample of approximately 2.5 lb of the wet mass was used for water content determination. Harvested wet forage yields were corrected to dry matter yield for each horizontal distance from the dripline. A composite plot yield was calculated as the average of the combined sum of the measured yield at horizontal distance 0 and at 30 inches and twice the measured yield at 15 inches (i.e., 4 yield terms divided by 4 to accurately mirror samples around the distance 0 sample and to fully represent the 60-inch dripline spacing).

Irrigation Water Management

The irrigation treatments were three levels of irrigation (replicated three times in a randomized complete block design) that were designed to apply 100, 85 or 70% of the calculated evapotranspiration that was not replaced by precipitation.

Irrigation was scheduled using a weather-based water budget constructed using data collected from a NOAA weather station located approximately 1500 ft northeast of the study site. The schedules were started each year on April 1 and continued thorough the end of October or the first killing frost, whichever came first. The reference evapotranspiration (ETr) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heermann (1974). The specifics of the ETr calculations used in this study are fully described by Lamm et al. (1987). Daily crop coefficients (single Kc) were generated using FAO-56 (Allen et al., 1998) as a guide with periods adjusted to northwest Kansas growing period lengths. Specifically, Kc values for the initial 40-d period beginning April 1 were allowed to increase linearly from 0.2 to a maximum of 1.0 and remain at 1.0 until harvest. For subsequent harvests in a given year, Kc values were allowed to increase linearly from 0.2 to a maximum of 1.0 in a 17-d period. Crop evapotranspiration (ETc) was calculated as the product of Kc and ETr. In constructing the irrigation schedules, no attempt was made to modify ETc with respect to soil evaporation losses or soil water availability as outlined by Kincaid and Heermann (1974). Typically, weekly or twice-weekly irrigations were scheduled whenever the calculated soil water depletion in the profile exceeded approximately 2 inches. The few exceptions to this scheduling frequency were related to the unavailability of the pumping water source due to its concurrent use on another study site. Irrigation amounts ranged from approximately 0.25 to 1 inch for each event, depending on availability of pumping system for the given event.

In the late fall of each year following the dormancy of the alfalfa top growth, an irrigation amount of 5 inches was applied with the SDI system. This large irrigation event was conducted to reduce the chance for root intrusion and/or rodent damage during the long overwinter period. This large irrigation amount would affect the year-to-year sustainability of the alfalfa under the more deficit-irrigated treatments, but should not greatly affect the in-season differential responses of the various irrigation treatments.

Weather and Water-related Experimental Data and Calculated Parameters

Additional study data collected during the growing season included irrigation and precipitation amounts, weather data, and soil water data. Volumetric soil water content was measured weekly or biweekly with a neutron attenuation moisture meter in 12-inch increments to a depth of 10 ft at a distance of 30 inches horizontally from the dripline. Calculated values from the collected data included water use and water productivity. Crop water use was calculated as the sum of soil water depletion between the initial and final soil water measurements, and precipitation and irrigation between the initial and final soil water measurements. Calculating crop water use in this manner would inadvertently include any deep percolation and rainfall runoff and is sometimes termed as the field water supply. Water productivity (WP) was calculated as dry matter alfalfa yield divided by the total crop water use.

Statistical Treatment

The experimental data were analyzed as mixed models using the PROC MIXED procedure with repeated measures of the SAS statistical package (SAS Institute, 1996. SAS systems for mixed models. SAS Institute, Inc. Cary, NC, USA. 633 pp.). Year, harvests, irrigation level, distance from the dripline, and their interactions were considered fixed effects while replication was the random effect. Year and harvests were used as the repeated measures in the models. Main effects and their interactions were considered to be significant at the $P<0.05$ level. Mean separations at the $P<0.05$ level were conducted within significant effects using the LSMEANS and PDIFF options of the MIXED procedure.

Results and Discussion

Weather Conditions and Irrigation Requirements

Weather conditions during the three years of the study were generally favorable for alfalfa production. Two weather events that were less than favorable to production were a hail storm that occurred midway (June 16) between the first and second harvest in 2006 and a hard freeze (April 12) that occurred approximately two weeks after the initiation of spring green-up in 2007. There was very little difference in seasonal calculated ETc for the three years of the study, but a difference of nearly 5 inches occurred in seasonal precipitation between the wettest year (2005) and the driest year (2006). Weather patterns differed between the years with greater calculated ETr and greater average air temperature during May and June of 2006 as compared to the other two years, while the latter part of the 2006 season generally had less ETr and milder air temperatures. Precipitation was above the long-term average in three of the five months in 2005 (May, June and August) and for only June and September in 2006. Although May through mid-July of 2007 was very dry, precipitation during the latter part of the season was well above normal. Irrigation requirements were somewhat similar among the three years, with the seasonal amount for the fully irrigated treatment being 22.6, 25.0 and 21.7 inches for 2005, 2006 and 2007, respectively. Overall, the years provided a relatively good variety of seasonal weather conditions and the varying conditions were typical of the Central Great Plains.

Effect of Irrigation Level on Annual Alfalfa Yields, Water Use and Water Productivity

Alfalfa yields were excellent compared to regional norms of approximately 6.5 tons/a for all 3 years (Table 1 and Figure 1). There were no statistically significant differences in dry matter yields attributable to irrigation level, but yields differed by year with the greatest dry matter yield the first year of the study in 2005 and the smallest yield in 2006. Yields for the second harvest in 2006 were reduced by a hail storm on June 16, and an early final harvest on September 13 contributed further to lower total 2006 yield. The first-harvest yields in 2007 may have been suppressed by a hard freeze on April 12 with a temperature of 20°F. The average dry matter yields from this study were approximately 10% greater than those reported by Alam et al. (2002a) for alfalfa grown on a sandy loam in southwest Kansas. The annual yields also compare well with the maximum yields from several western U.S. states summarized by Grismer (2001) which ranged from approximately 7.5 to 9.8 tons/a.

The lack of significant differences in total seasonal alfalfa dry matter yield as affected by irrigation level is probably related to the extensive root system of the alfalfa being able to sufficiently and effectively mine the plant available soil water from the deep silt loam soil without experiencing severe water stress. Although available soil water decreased throughout the season and more so as the irrigation level became more deficit (data not shown), the decreasing late summer crop growth and less crop water use during the latter part of the season (fall) would tend to buffer yield differences between the treatments. Plant available soil water started each year at a relatively high level because of overwinter precipitation and because of the 5 inches of late fall irrigation applied to minimize overwinter root intrusion and rodent damage of the SDI system. Seasonal water use within a given year was significantly different and increased with increasing irrigation level (Table 1), averaging approximately 11% greater for the fully irrigated (100% of ETc) compared to the most deficit irrigation level (70% of ETc). Seasonal water use was also significantly different between years with greater water use in 2005 and the smallest water use in 2006.

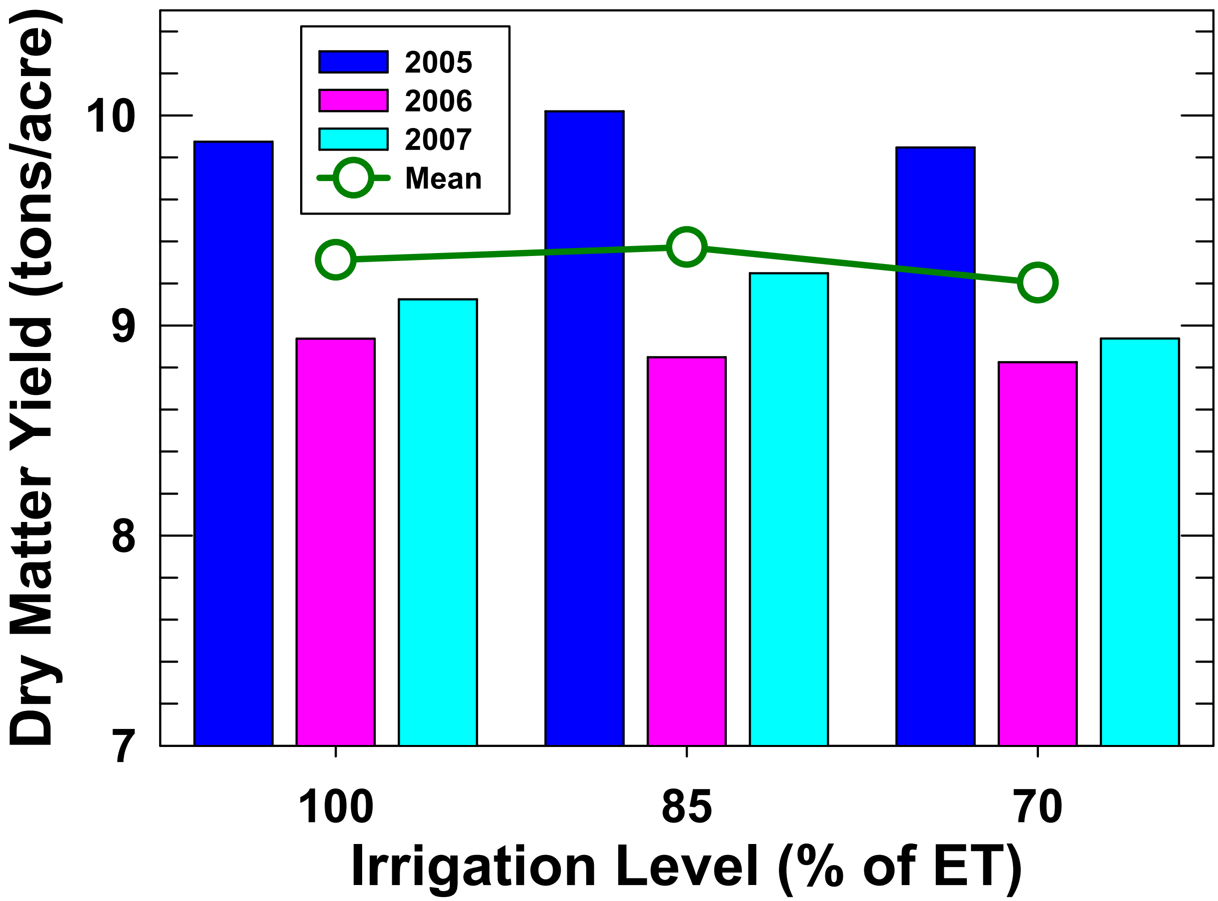

Figure 1 Annual dry matter yields for alfalfa as affected by irrigation level for 2005 through 2007 in a subsurface drip irrigation study, KSU Northwest Research-Extension Center, Colby, Kansas.

Water productivity tended to be greater for the deficit-irrigated treatments and was significantly greater in both 2006 and 2007 for the 70% of ETc treatment as compared to the fully-irrigated treatment (Table 1). Although the greatest dry matter yield occurred in 2005, that year had a significantly lower WP and the greatest WP occurred in 2006 which had the smallest annual dry matter yield. Water productivities in this study were somewhat greater than values of 0.18 to 0.19 tons/acre-inch that was reported by Grismer (2001) and also greater than the 0.20 tons/acre-inch value by Hengeller (1995). These greater WP values are probably indicative of reduced soil water evaporation, the E component of ETc, when alfalfa is grown with SDI.

Table 1. Annual alfalfa dry matter yield, seasonal water use, and water productivity as affected by irrigation levels in a subsurface drip irrigation study, 2005 through 2007, KSU Northwest Research-Extension Center, Colby, Kansas.

Dry matter yield (tons/a)

Irrigation level (% of ET)	2005	2006	2007	Mean
100	9.87	8.94	9.12	9.31
85	10.02	8.85	9.25	9.37
70	9.85	8.83	8.94	9.20
Mean	9.91 A	8.87 C	9.10 B	9.30

Seasonal water use (inches)

Irrigation level (% of ET)	2005	2006	2007	Mean
100	42.1 a	37.1 c	41.8 a	40.3 ψ
85	39.9 b	33.5 d	39.8 b	37.7 □
70	38.9 b	29.2 e	36.6 c	34.9 λ
Mean	40.3 A	33.3 C	39.4 B	37.7 □

Water productivity (ton/acre-in)

Irrigation level (% of ET)	2005	2006	2007	Mean
100	0.2347 bc	0.2407 bc	0.2184 d	0.2313
85	0.2510 bc	0.2641 ab	0.2327 cd	0.2493
70	0.2530 bc	0.3021 a	0.2442 bc	0.2664
Mean	0.2462 B	0.2690 A	0.2317 C	0.2490

Table values for a given parameter (dry matter yield, seasonal water use, or water productivity) for the various years and irrigation levels followed by a different lowercase letter are significantly different at $P<0.05$.

Column values for the parameters for the various years followed by a different uppercase letter are significantly different at $P<0.05$.

Row values for the parameters for the various irrigation levels followed by a different Greek symbol are significantly different at $P<0.05$.

Effect of Distance from Dripline on Annual Alfalfa Drymatter Yields

There were generally, no appreciable difference (<0.1 ton/acre) in annual alfalfa drymatter yield as affected by distance from dripline when averaged over all the years (Table 2 and Figure 2), but there were differences between years. Although no statistically significant differences in alfalfa yield as affected by distance from the dripline occurred in 2005 and 2007, yield gradually and significantly decreased as distance from dripline increased in the drier and warmer year of 2006. The small yield differences in 2006 that were related to increased distance from the dripline tended to increase slowly with successive harvests (data not shown). This would be as anticipated as the plant available soil water decreases throughout the season and alfalfa plants further from the dripline would be having increased difficulty scavenging for the limited soil water resources. The general results of no appreciable differences in alfalfa drymatter yield as affected by distance from dripline for this 60-inch dripline spacing would appear to conflict with the results obtained by Alam et al. (2002a) that found an approximately 19% yield increase for driplines spaced at 40 inches as compared to driplines spaced at 60 inches. The sandy loam soil texture of that demonstration study in southwest Kansas may have increased in-season water stress for alfalfa plants in the wider 60-inch spacing, and plant stands were also negatively affected by the wider dripline spacing (Alam et al., 2002a). Additionally, in the current study, 5 inches of dormant-season subsurface drip irrigation was applied to help prevent root intrusion and rodent damage, and this may have increased profile soil water at the further distances from the dripline as compared to the Alam et al. (2002a) study. However, the results of the current study are somewhat similar to the results of Hutmacher et al. (1992) from the arid Imperial Valley of California on a silty clay loam that found that yields from driplines spaced at 80-inches were nearly equal to that obtained by a narrower 40-inch spacing after the first year of operation.

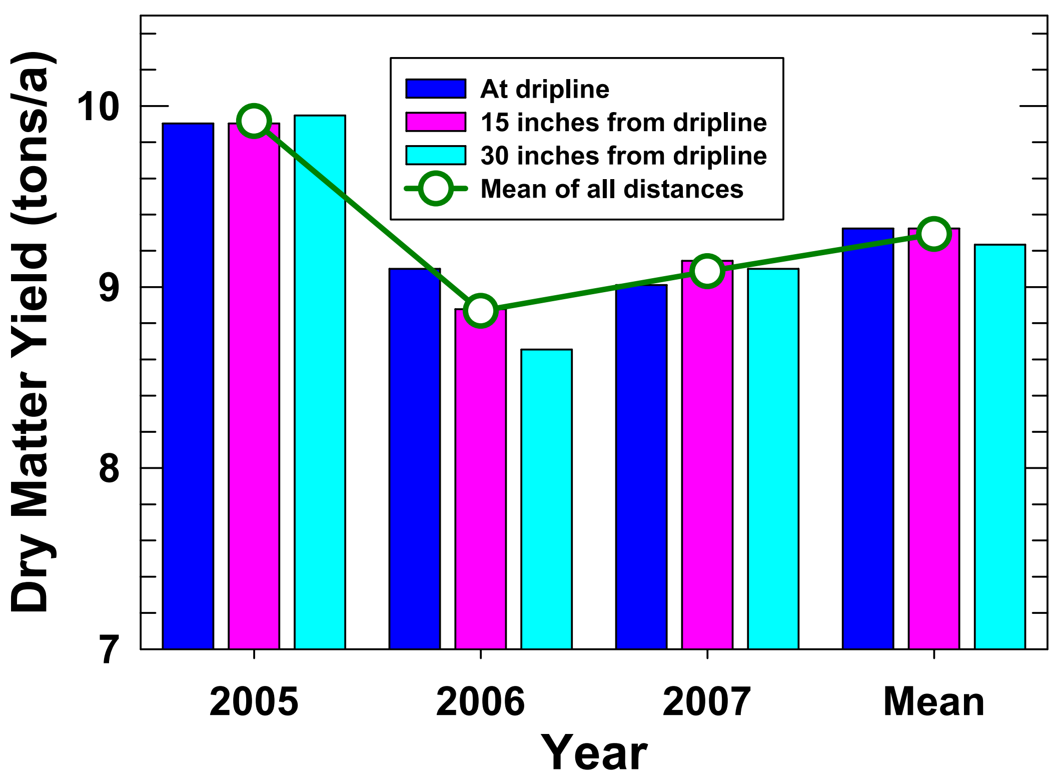

Figure 2 Annual dry matter yields for alfalfa as affected by perpendicular distance from the dripline for 2005 through 2007 in a subsurface drip irrigation study, KSU Northwest Research-Extension Center, Colby, Kansas.

Table 2 Annual alfalfa dry matter yields as affected by distance from dripline and irrigation level, 2005 through 2007, KSU Northwest Research-Extension Center, Colby, Kansas.

Year	Irrigation level (% of ET)	Distance from dripline 0 inches	15 inches	30 inches
2005	100	9.86	9.81	9.95
	85	9.81	10.13	9.99
	70	10.08	9.72	9.81
	Mean	9.90 a	9.90 a	9.95 a
2006	100	9.01	9.06	8.65
	85	8.92	8.79	8.88
	70	9.37	8.79	8.39
	Mean	9.10 b	8.88 bc	8.65 c
2007	100	9.14	9.14	9.10
	85	9.06	9.32	9.28
	70	8.83	9.01	8.92
	Mean	9.01 b	9.14 b	9.10 b
All years	100	9.32	9.32	9.23
	85	9.28	9.41	9.41
	70	9.41	9.19	9.06
	Mean	9.32	9.32	9.23

Alfalfa drymatter yields for the various years and distances from the dripline followed by a different lowercase letter are significantly different at $P<0.05$. No significant differences in drymatter yields for the various distances from the dripline were attributable to irrigation level.

Concluding Statements

Irrigation levels designed to replace between 70 and 100% of the calculated ETc minus precipitation had no appreciable effect on annual alfalfa yields grown using SDI in northwest Kansas on a deep silt loam soil under typical weather conditions. These results may need to be tempered with the fact that 5 inches of irrigation was applied late fall each year to help prevent root intrusion and rodent damage. Also, no large effects of perpendicular distance from the dripline occurred on alfalfa yield. Water productivity tended to be greater for the 70% ET irrigation treatment and was significantly so in some cases. A follow-up study currently underway is examining deficit SDI of alfalfa during specific periods between harvests.

Acknowledgements

[1] Mention of tradenames is for informational purposes only and does not constitute endorsement by the authors or by the institutions they serve.

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Strawberries Transplants: Modifying Irrigation Methods for Establishment

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Chuck Bates

Abstract. *The purpose of the project is to develop an analysis of the current irrigation practices of strawberry growers on the Central Coast of California. The primary research evaluation centers on the time period during the establishment of transplants where sprinklers are used even though drip irrigation is available, often due to salinity concerns. The specific objectives of the project are to: (1) Set up research areas and control plots on a demonstration scale, (2) determine the key factors that affect the problems in early growth of transplanted strawberries, (3) determine relationships between the use of irrigation water and the control of salinity, and (4) provide a multi-year analysis to determine long-term salinity impacts on yields. This project examines the motives, methods, and need for sprinklers on strawberries, and is designed to determine the conditions where growers can conserve water by minimizing or eliminating sprinkler use on strawberries. This project targets drought management and aims to reduce runoff as a potential source of contaminants reaching waterways. The results of this study have demonstrated on a block scale that yields can be increased by up to 10%, water use decreased by 10%, and runoff eliminated by heavily reducing or eliminating sprinkler use.*

Keywords. salinity, drip, irrigation, microirrigation, strawberries, runoff, drought management

Introduction

For the past three growing seasons, the Irrigation Training and Research Center (ITRC), has been conducting research on the water use, salinity levels and various other information related to strawberries. This paper is a summary of work that can be found online at the ITRC website (www.itrc.org/projects.htm).

The project started in the fall of 2009 with a capacity issue on the Pumping Trough Pipeline (PTP), which is managed by the United Water Conservation District and supplies growers in the Oxnard area. At the time, strawberries growers would all plant during the same period in October (using sprinklers on the new transplants) and the demand created by sprinkler irrigation exceeded the pipeline's capacity. Faced with complaints of poor service, the district felt the best course of action was to regulate the practice of using sprinklers in October, and threatened to ban sprinkler irrigations for strawberry growers that month. Local growers requested assistance to determine the best method to move away from sprinkler irrigation towards alternate methods. The simplest option was to use the drip irrigation system that is already installed when the transplants are brought to the field, but growers were concerned about the effects of salinity without sprinklers.

The key objectives of the project are to:

- keep the strawberry transplants healthy
- switch to drip irrigation as soon as possible

Specifically, this involves the following steps:

1. Set up research areas and control plots on a demonstration scale
2. Determine the key factors that affect the problems in early growth of transplanted strawberries
3. Determine relationships between the use of irrigation water and the control of salinity
4. Provide a multi-year analysis to determine long-term salinity impacts on yields

Soil salinity, yield data and water use on the strawberry fields during the first three years of the projects will be discussed in this paper.

Figure 1. California strawberry bed in February, early in the growing season

Irrigation Methods Evaluated
The project continues to use three different irrigation methods. These methods are:

- conventional sprinkler (up to 6 weeks of daily sprinkler application)

- reduced sprinkler
- drip only

In the first two years of the project, the focus was on establishing the project and evaluating initial data. For current and future years, the project focuses on evaluating and applying new techniques that have been discovered through the study. For example, some growers used the method of reduced sprinklers, which allowed the use of sprinklers for special cases such as excessive hot dry wind events (Santa Ana winds), and for frost protection. This was limited to 3-5 events during the season. Growers have noticed an improvement in yields and less water usage with the reduced sprinkler method. The drip only protocol has been successful but may be dependent on other factors such as lighter soils and more rainfall in a given year.

Several blocks of strawberries have been converted from a convenional method (growers performing sprinkler irrigations for 4-6 weeks during transplant establishment) to a reduced sprinkler one. This is partly due to the studies that were conducted on those strawberry fields in the previous years (2008-2011). Once growers have seen the benefits of a new practice, they have opted to change to the new practice. This has caused somewhat of a problem for the study since the control is no longer available. However, it is important to remember that one goal of this project was to demonstrate new techniques.

Salinity

Salinity is a key determinant for the success of the project. Salinity is generally reported in units of electrical conductivity (EC), generally deciSiemens per meter (dS/m). Three common EC measurements are used. EC_w refers to the salinity of the irrigation water. EC_{sw} refers to the salinity of the soil water solution. This is the salinity that the plant actually experiences. EC_e refers to the salinity of the saturated soil extract and is always somewhat lower than EC_{sw} due to the way in which it is determined (Burt and Styles 2007). This project used a new type of sensor that was not widely used prior to 2008 and which allows for the continuous evaluation of the EC_{sw}, allowing for more accurate survey data.

Strawberries are considered to be extremely sensitive to salts, especially compared to other crops. High salt levels have been reported to cause decreased strawberry size and overall yield (Larson, 1994). Bernstein (1965) estimated that an electrical conductivity of saturated soil extract (EC_e) of 1.5 dS/m resulted in a 10% yield loss. Mass and Hoffman (1977) and Mass (1990) report that strawberries have a threshold EC_e of 1.0 dS/m and experience a 33% loss in yield for every 1 dS/m increase beyond this threshold value. For comparison, tomatoes have a threshold EC_e of 2.5 dS/m (1.5 times that of strawberries) and a decrease in yield of only 9.9% for every 1 dS/m past the threshold value (Mass and Hoffman 1977). It must be noted that the salts present in these studies are typically chlorides. Soils and water that are high in calcium tend to “buffer” these values and may lead to an adjustment of up to +3 dS/m. Experience from this project has shown that growers are able to farm on fields with EC_e values of 4-5 dS/m with no reported yield decreases.

Traditional salinity management techniques involve heavy sprinkler irrigations just before and after strawberry transplants are put in to the beds. This leaches salts away from the young sensitive plants and helps compact soil around the roots. The most salt-sensitive growth period for most crops is emergence. Sprinkler irrigation is often preferred over subsurface drip for leaching salts as it removes the tremendous uncertainties associated with how evenly water will move upward from buried emitters (Burt and Styles 2007). The heavy use of sprinklers at this time was to blame for the supply problems in the Pumping Trough Pipeline in 2009. An additional problem is the significant amount of runoff that occurs when sprinkler irrigation is combined with the use of plastic bed covers for weed control and evaporation reduction. Water runoff from strawberry fields has recently been blamed for contaminating local waterways in Oxnard, CA (Krist 2007).

ITRC utilizes two devices for monitoring salinity levels: Decagon Em50 data loggers are used in conjunction with Decagon 5TE soil moisture/EC sensors to constantly monitor salinity and moisture levels at each of the test sites. This setup requires someone to physically go to the onsite data logger to download information. Internet-based systems are available that transmit data from the Decagon 5TE sensor via a radio to a base station where it is posted on a website. These systems allow several 5TE soil moisture sensors, flow meters, and weather station readings to be broadcasted via the internet for real-time monitoring, but have proven to be unreliable (see later discussion).

Procedure and Methods

Test Sites

Table 1 lists the project test sites. One clear conclusion has been that the ease of growing strawberries in Oxnard depends heavily on location. The key differences are that on the east side of the Oxnard plain rainfall is more abundant, water requirements are lower, and the number of wind events is smaller.

Table 1. Strawberry project fields on the Central Coast

Santa Maria	**Oxnard**	**Watsonville**
Manzanita 2 Block I – 2-Tape Drip Only Block II – 2-Tape Drip Only Block A2 – 2-Tape Conventional Block A4 – 2-Tape Conventional Block B2 – 2-Tape Conventional Block B4 – 4-Tape Conventional Manzanita 7 Block A – 2-Tape Conventional Block B – 2-Tape Conventional Block I – Drip Only Block II – Drip Only Rice Block A – 4-Tape Partial Sprinkler Block B – 4-Tape Drip Only Main Block B – 4-Tape Reduced Sprinkler Block B – 4-Tape Reduced Sprinkler	Eclipse Block C – 4-Tape Reduced Sprinkler Block I – 4-Tape Conventional Block II – 4-Tape Conventional Donlon Block A – 4-Tape Partial Sprinkler Block B – 4-Tape Partial Sprinkler Sammis Block A – 4-Tape Drip Only Block B – 4-Tape Partial Sprinkler	Redman Block A – 2-Tape Drip Only Porter Block A – 2-Tape Drip Only Captainich Block A – 2-Tape Conventional Shultz Block A – 2-Tape Drip Only

Soil Texture

As mentioned previously, the ease of salinity management in a block depends largely on soil texture. The blocks used for this project are planted in several different types of soil, as shown in the diagram in Figure 2. The large ovals represent general areas of light, medium and heavy soils, from left to right. This diagram is not meant to cover all of the soil types and textures present in the project fields, but rather gives a broad picture of the terms mentioned in this paper.

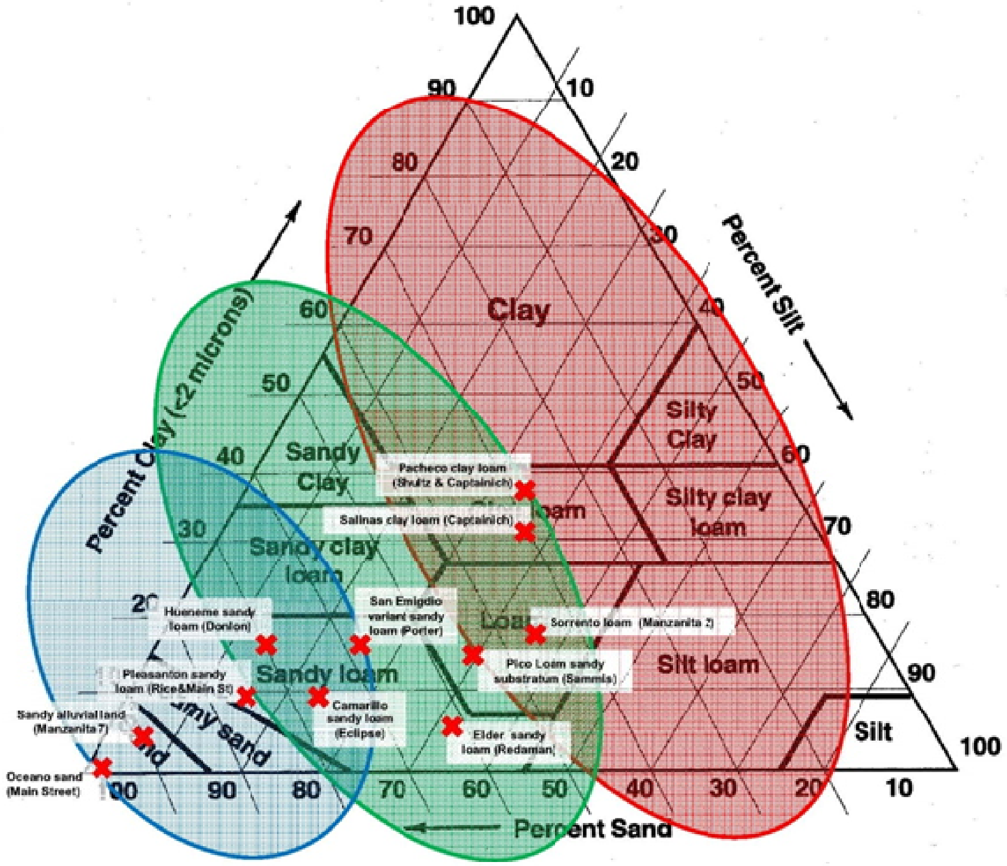


Figure 2. Soil structure triangle showing soil types on project fields

Flow Meters

Magnetic flow meters were chosen for the project as a flow measurement device due to their high reliability, ease of installation, and accuracy. A magnetic flow meter or "magmeter" has no moving parts and does not require the pipe to be full in order to make accurate measurements. It also has the ability to totalize flows and provide an accurate volumetric reading. This was a necessity as all water use numbers would need to be compared volumetrically. Also, magmeters are much less sensitive to turbulent flows than most other flow measurement devices. This allowed the meter to be installed in close proximity to elbows or valves, which made the installation very convenient. Both types of magnetic flow meters used are made by SeaMetrics and have a rated accuracy of ±1%.

Internet Monitoring – Ranch Systems and ClimateMinder

To simplify data acquisition, several growers implemented data monitoring systems from Ranch Systems and ClimateMinder. Ranch Systems offers a variety of products to allow active monitoring of in-field conditions. Generally, this information can be posted on the internet in real-time. The theory was that not only would the data be logged, but valuable irrigation scheduling information would be readily available to the growers.

Base Station. A crucial part of the Ranch Systems setup is a base station that relays all information collected by the nodes to the Ranch Systems network. This allows the information to be presented on the Ranch Systems website and accessed by users.

Nodes. Nodes are the devices that collect field sensor readings and transmit them to the base station. They consist of a solar panel, radio, and in this case soil and pressure sensors. Each node was connected to two Decagon 5TE soil moisture/temperature/EC sensors and one Decagon PS1 pressure switch. The 5TE sensors were run down the strawberry bed and placed at a depth of 3" in each of the two middle plant rows. The PS1 pressure switch was connected using a brass T connection to a nearby sprinkler head in order to monitor the duration and frequency of sprinkler irrigations.

Figure 3. Ranch Systems node

Data Collection. Collecting data from the Ranch Systems sensors required simply accessing the Ranch Systems website, logging on and selecting the node of interest. However, the data from Ranch Systems was extremely unreliable and proved to be of little use. The sensors tended to fail and due to the complexity of the system, it was too difficult to repair/replace them.

ClimateMinder. ClimateMinder was also used by several growers. The internet-based real time monitoring systems were provided by the growers.

Data Loggers
A traditional data logger was placed in each site of interest as a method to constantly monitor field conditions. While the manually downloaded loggers do not have the convenience of Ranch Systems' and ClimateMinder's real-time monitoring, they quickly became very useful as Ranch Systems proved unreliable at times especially with the salinity data.

Data Logger Installation. Decagon Em50 data loggers were installed at every site at the Oxnard, Santa Maria, and Watsonville locations. These small data loggers were placed on the end of a block, near the middle row. Their compact size allowed them to be placed virtually anywhere in the field without the risk of damage from passing equipment. Each data logger was connected to two Decagon 5TE soil moisture/temperature/EC sensors and one Decagon PS1 pressure switch. The 5TE sensors were run down the strawberry bed and placed at a depth of 3" in the middle plant row. To monitor moisture and water movement in the rootzone, additional 5TE sensors were installed at depths of 6 and 12 inches. The PS1 pressure switch was connected using a brass T connection to a nearby sprinkler head in order to monitor the duration and frequency of sprinkler irrigations.

Data Collection. Data collection consisted of simply visiting each site and downloading the logged data onto a laptop. This was done on a weekly basis during the period of transplant establishment. This allowed for frequent analysis of soil salinity levels during the most sensitive growth period. During the later stages of growth, data was collected on a bi-weekly basis as the strawberry plants are much more resistant to salinity during this period. Generally, the data loggers required little maintenance. About once per season, the batteries had to be changed and occasionally a 5TE sensor would fail. These sensors proved to be much more useful than the Ranch Systems.

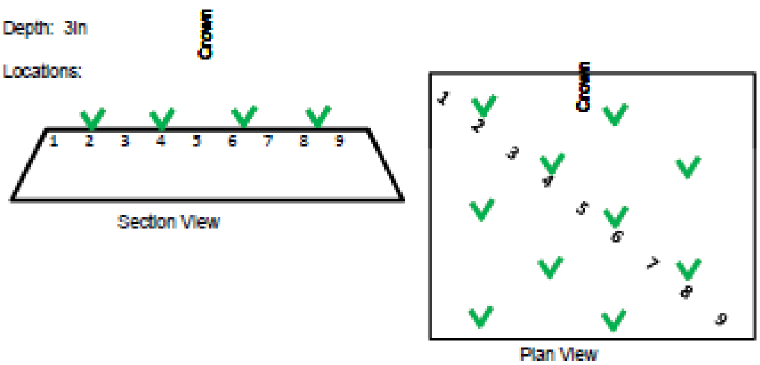
Soil Sample Procedure
Periodically throughout the growing season, soil samples were taken in order to monitor the specific salt concentrations present in the soil. This was done by pulling samples from 0-3", 3-6", and 6-12" from the two middle plant rows. The EC and soil moisture content were also checked at each of the three depths using a handheld Decagon ProCheck device with a 5TE sensor. The samples were taken from near the center of the field close to where the 5TE data logger sensors were located. The locations of the samples vary somewhat between dates but for a given date, each sample was taken from the same spot in each field.

Salinity "Snapshot" Procedure
In an attempt to track the movement of salts, EC measurements were taken across the top of the strawberry bed at a depth of 3 inches on numerous occasions throughout the growing season. This was done using a handheld Decagon ProCheck device with a 5TE sensor. Measurements were taken at the nine locations shown in Figure 4. These measurements were taken near the middle bed at both ends of each block. The locations of the measurements vary somewhat between dates, but for a given date, each measurement was taken from the same spot in each field.

Salinity Across Strawberry Bed
Results from 12-17-09

Testing Depth: 3in

Testing Locations:



Sammis

Block A Drip Only

North Side

Location	1	2	3	4	5	6	7	8	9
EC (ds/m)	6.6	0.7	10	6.9	9.7	2	0.5	5.3	3.6
%VWC	26	25	24	23	25	29	21	22	19

South Side

Location	1	2	3	4	5	6	7	8	9
EC (ds/m)	12.5	3.8	3.8	11.7	13.7	11.1	4	5.4	15.3
%VWC	13	17	28	26	28	24	29	24	15

Figure 4. Salinity snapshot testing locations and data set

Water Sample Procedure

Water samples were taken whenever water was on the site. This gave some idea as to the quality of the irrigation water that was being used at each site. A Eutech waterproof total dissolved solids tester was used to test samples.

Photo Log Procedure

Pictures were taken of each test site during each visit. This allowed the growth process of strawberries at each site to be monitored and later compared. All pictures were taken facing north from the location of the data logger in each field. One of the best methods to determine the health of the transplants during establishment has been the evaluation of the photos.

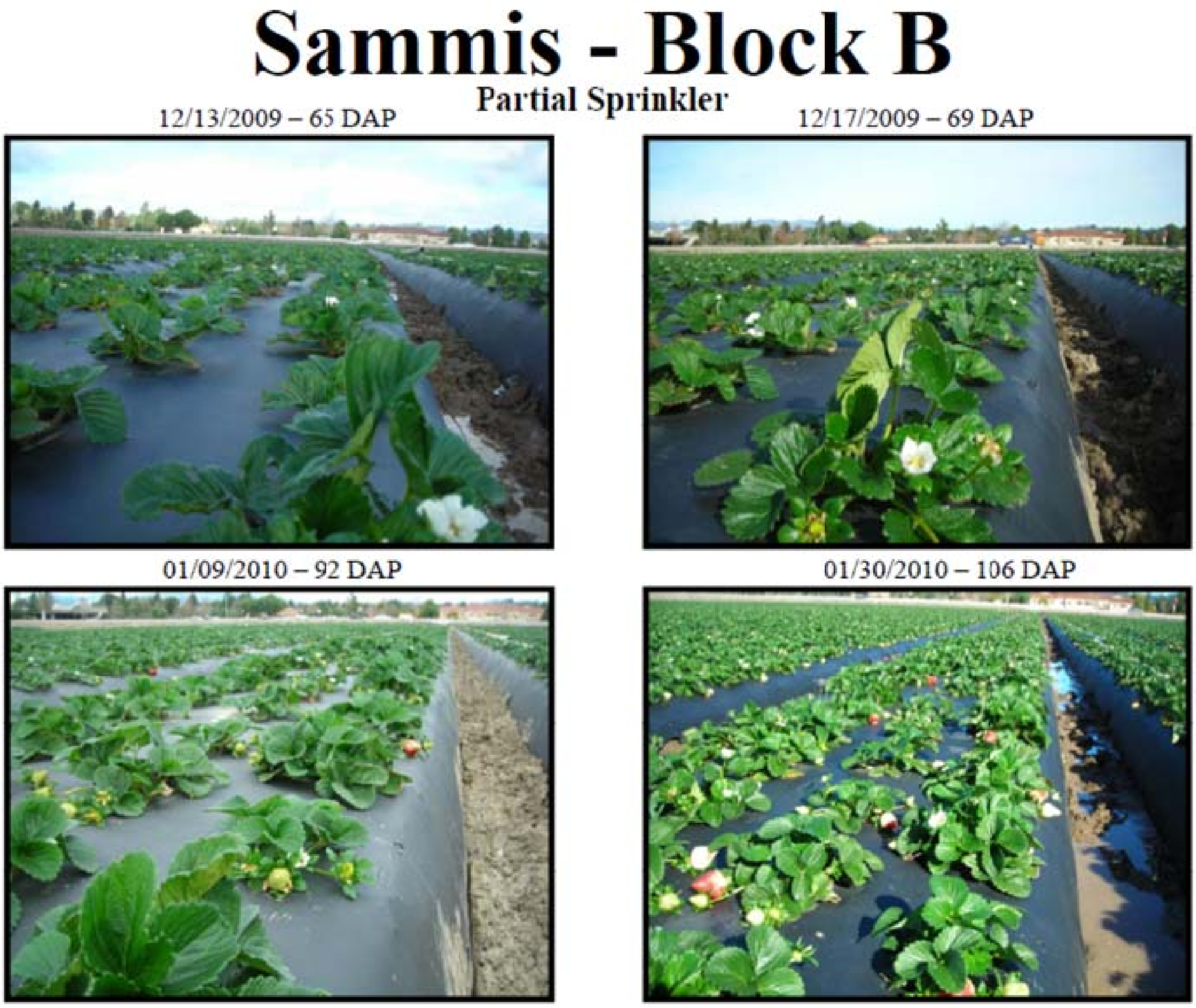


Figure 5. Sample of plant photos at Sammis at Block B (Note: “DAP” stands for “Days After Planting”)

Santa Ana Wind Events

The “Santa Anas” are winds in Southern California that have speeds over 25 knots (28.6 mph) and can range to over twice that speed. Data for the events are monitored by NOAA. Santa Ana-type conditions are usually associated with hot, low humidity (around 10-20%). These winds typically occur from October to March when there is high pressure in the Great Basin, which adiabatically heats as it travels down to the low pressures at the coast. Such dramatic weather comes at a crucial time for strawberry growers and requires more irrigation in order to prevent crop loss.

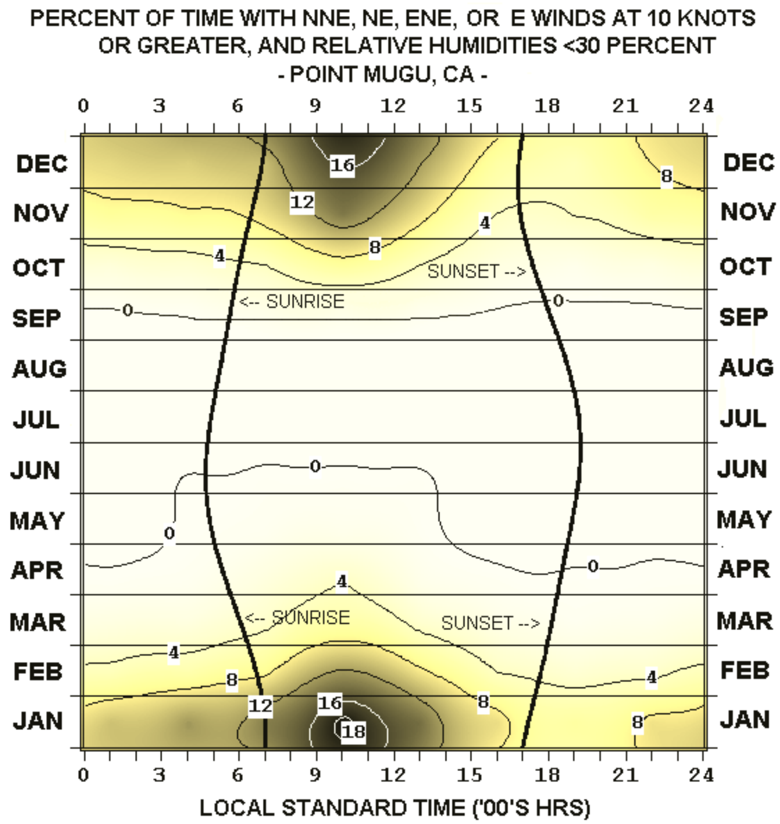


Figure 6. Graph from NOAA: "Two-way" Climatological Time-Section Plot from Charles Fisk - Meteorologist with Geophysics Branch - Naval Base Ventura County (NBVC) 2010

Results and Analysis

Soil Salinity

Continuous Data. All continuous data was obtained from the Decagon data loggers rather than the Ranch Systems. The Ranch Systems nodes and sensors proved unreliable early in the season and were quickly abandoned. Similar problems occurred occasionally with the Decagon data loggers, but were much less frequent.

The resulting data was highly variable between all of the test plots. This made a statistical analysis of the salinity data infeasible. Clearly there is a tremendous amount of uncertainty associated with managing salinity. Additionally, the charts clearly show the huge effect that rainfall has on salinity. The data showed that a heavy rain in January lowered salinity levels by up to 50% while sprinkler irrigation events had much less impact on the soil salinity. This was primarily due to the fact that the rainwater has a low pH value and no salt content.

From the soil salinity data collected, salinity contours graphs were made. The graphs display values of salinity (dS/m) in the plant beds. These are useful to the grower for analyzing where the salt is pushed by applied water. Areas of red signify EC values of 10 dS/m or higher and are considered toxic to the plant if not leached.

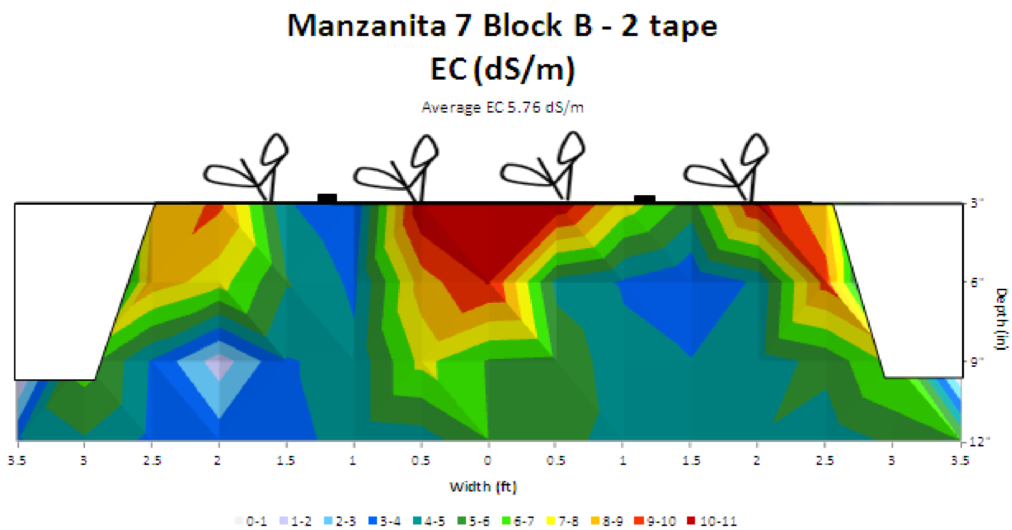


Figure 7. Contour graph of salinity (dS/m) in Manzanita 7 block

Rainfall Data

The data from the sensors is uploaded to a spreadsheet. This spreadsheet contains data from the entire study, displaying salinity levels in both water and soil. They also contain precipitation data, as well as number of minutes the sprinklers were running. All of the data is collected from the fields except for the precipitation data. The precipitation data is obtained from CIMIS or the Weather Underground website (www.wunderground.com) using the nearest airports as the location. After all of the data is uploaded into the spreadsheet, graphs are made to visually monitor the salinity levels.

The salinity levels displayed in the graph showed some common trends. The salinity levels fluctuated daily. There were noticeable drops in the salinity level after periods of rain. This would indicate local leaching had occurred near the sensors. Then the salinity levels would begin to rise after the rain subsided. However, this held true for the sensors only in the 0”-3” range. The sensors deeper than that did not record as prominent of a fluctuation. This would indicate there was not a lot of downward movement of the irrigation water.

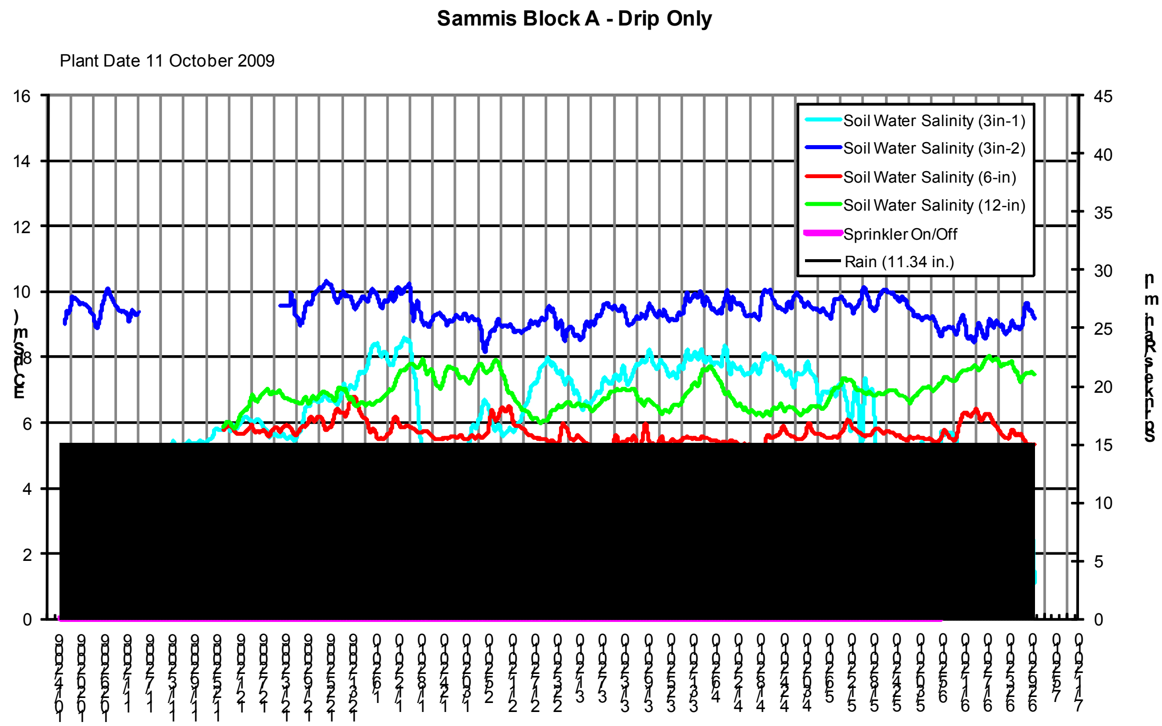


Figure 8. Sample salinity sensor tracking from Sammis Block A

Impact on Yields

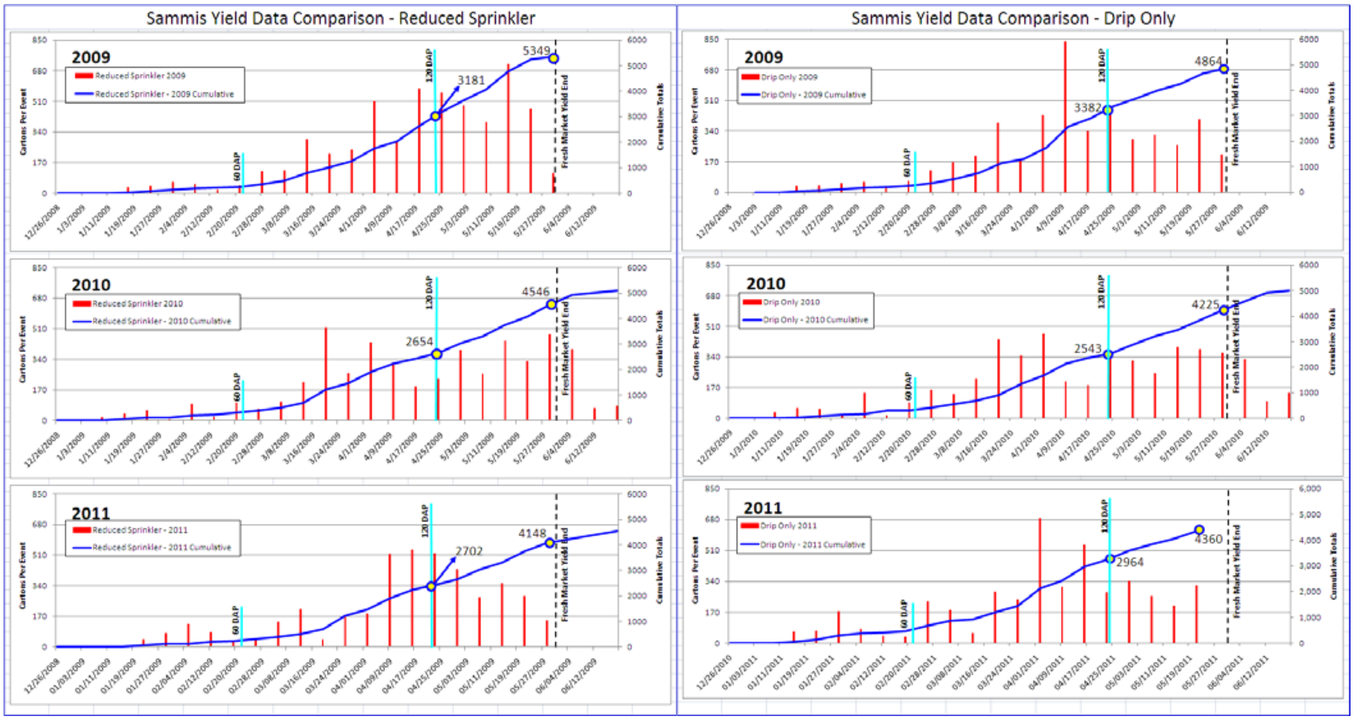
The yields in the first season showed little impact due to the irrigation method. However, in the first season there was noticeable damage to plants where the salinity levels were very high due to the placement of the drip irrigation tape. The conclusion was that even though there was some die-off, the other plants seemed to respond better, which kept the yields about equal to previous years. The other conclusion was that the placement of the drip tape was important.

The second season yields were higher with the new irrigation protocol. The yield increase in Manzanita was 13% on the partial sprinkler protocol compared to the conventional protocol. The grower also reported the yields on the partial sprinkler protocol resulted in early field gains at a time when the market prices were favorable.

The data from Sammis in 2009-2010 also indicated that the yields improved using the new irrigation methods. The partial sprinkler protocol had an 8% increase in yield and the drip only protocol had a 13% increase in yield.

The third year of data has seen a dramatic drop-off in the data collection of yields by the early innovators. These growers have switched their whole fields over to the new protocol and have abandoned the “conventional” irrigation approach. The exception is the Sammis field managed by Reiter Affiliated Companies (RAC). Below is a side-by-side comparison of the partial sprinkler and drip only protocols for 3 years.

Table 2. Yield data from Sammis for three seasons (2009-2011)



Several preliminary conclusions can be drawn from these graphs:

Yields fluctuate on a year-to-year basis based on numerous factors. The overall weather seems to be a major determinant on yields. The first year of the project the rainfall was less abundant. The third year had three times more rainfall than the first. The hotter, dryer weather may have led to better yields in the first year. Keep in mind that the first year on the drip only saw a 30% die-off due to salinity damage.

For two of the years, the drip only protocol resulted in higher yields at the 120 days after planting mark. This is significant since several of the growers have noticed higher yields early in the season, when prices tend to be higher.

The Sammis grower has abandoned the conventional irrigation protocol. The first year results convinced this early adopter that the new protocol would be beneficial to his operations.

Lessons Learned

The study is still at the beginning stages so the conclusions are based on limited information. The results from the first year (2008-2009) were mixed due to some major die-off issues (up to 30% in one demonstration plot). The first year seemed to be dominated by low rainfall and numerous Santa Ana wind events. While generally unsuccessful in terms of results, the grower wanted to continue the study since the potential seemed promising, and there were numerous key lessons learned.

The second year had some incredible results for increases in yield and decreases in water use. There were decreases in water use of up to 10% and a surprising increase in yields was reported.

The third year has been one where the focus has shifted to more of the details. For example, is 4-tape better than 2-tape? If 2-tape will work, what are the soil texture characteristics that will allow that to happen? There are some key items that we are seeing as we approach the end of the third year:

- Salinity is a key determinant in the healthy establishment of the strawberry transplants. The young plants will not tolerate high levels of salts. The damage in the plants will appear similar to a plant that lacks sufficient water.

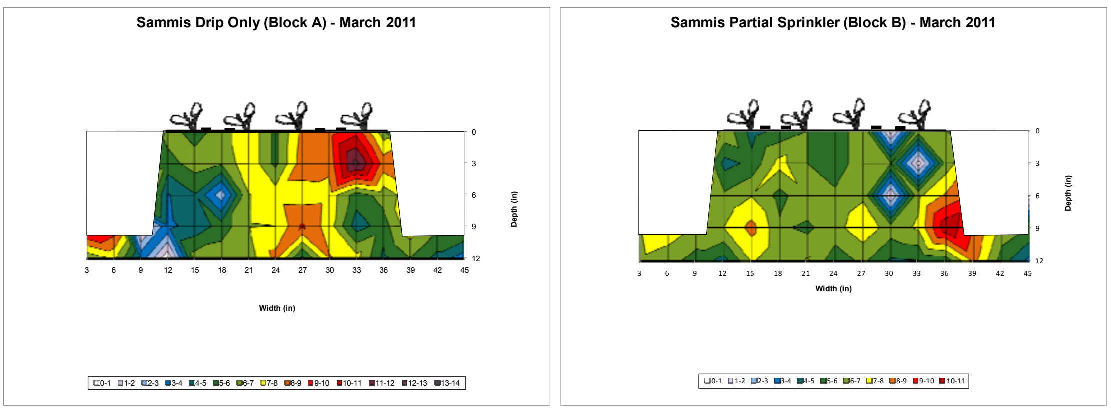


Figure 9. Sample salinity contours from Sammis Block A and B

- Row crop drip tape placement must be done correctly in order to micro-leach salts in the beds. This means that in the Oxnard Plain, growers may need to use four low flow tapes in order to successfully switch to the drip only or partial sprinkler protocols. Growers in Santa Maria might be able to use only two tapes per bed (on lighter soils) but the salinity must be evaluated in order to make sure the salts are not building up at the base of the plant. Using three tapes is **NOT** recommended on beds with four plant rows.

Figure 10. New 4-tape machine

- Monitoring the salinity of the soil and the irrigation water will help growers switch from the conventional irrigation method to a new protocol. The soil salinity should be less than 7 dS/m (EC_e) and the water salinity should be less than 1.0 dS/m (EC_w). Monitoring can be done with portable measurement equipment but should be verified using professional soil labs.
- The irrigation water is one of the key determinants of whether there may be a problem. If the water quality is 1.0 dS/m or less, the impact is minimal. If the salinity of the irrigation supply water is 1.2 dS/m, the grower could see a 10-25% yield impact. It should be noted that well water, surface water, and reclaimed water sources have changing salinity characteristics during the season.

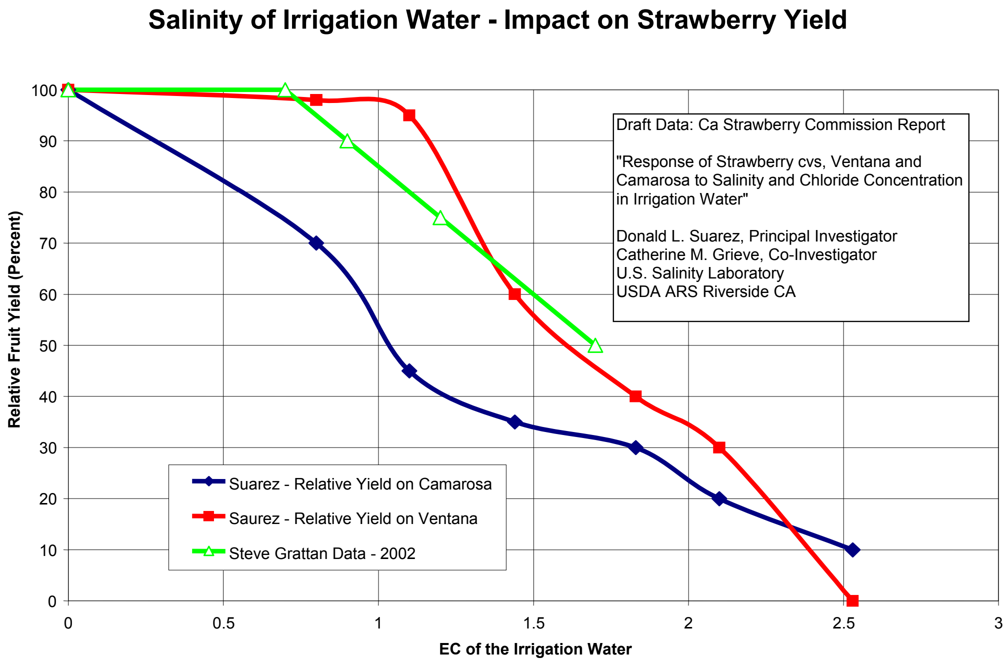


Figure 11. Impact of supply water quality on yield

- Salts come from various sources. Some sources of salt include the irrigation water, gypsum applications, fertilizers (both pre-plant and liquid), and composting (which can be a significant source).
- Traditional salinity references have used soil salinity as the key determinant for the salt impact on yields. The traditional approach states that if the soil salinity (EC_e) approaches 4.0 dS/m the yield will be 100% impacted (i.e., no yield). However, this research confirmed most growers in the Oxnard Plain routinely work in soils at 4-6 dS/m with very little impact on yields. <u>The reason is that they have been managing their salts properly near the roots of the young plants.</u>
- Soils that are lighter will be easier to irrigate and manage than soils that are heavy. This has been observed in the various plots as part of this research.
- Rain washes salts away from young strawberry transplants. The data clearly show that rainwater (which is essentially salt-free and acidic) can push harmful salts away from the plants. The data show how dramatically the salinity level dropped after the rain.
- The new protocols result in a yield increase up to 10%. The new protocols have also decreased the water use by over 10%. This research project has shown that the new approach has resulted in ***more crops per drop***.

Figure 12. View of strawberries at 120 days after planting (DAP)

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Monitoring Environmental Conditions and Substrate Water Content to Increase Efficiency of Irrigation in Nurseries

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Abstract. Competition for world water resources continues to increase due to population growth and increased agricultural and industrial water demand. This will result in a reduction in the availability of freshwater worldwide (Jury and Vaux, 2005). Efficient irrigation practices can have many benefits for both nurseries and society-at-large. Benefits for nurseries may include better control over plant quality, reduced water and fertilizer use, less power consumption (related to running pumps for irrigation), fewer problems with root pathogens, and less runoff. Benefits for society-at-large include a reduction in potential pollution from nurseries (e.g. runoff of fertilizer and pesticides), a decrease in competition for water resources, and decreases in CO_2 emissions.

Irrigation is necessary during the production of containerized nursery crops due to the relatively small volume of substrate that is used to produce container plants. To assure rapid growth, it is crucial to supply the plants with water and nutrients as needed. Irrespective of how the fertilizer is applied, irrigation and fertilization are closely linked, since movement of nutrients through the substrate depends on water (Majsztrik et al., 2010). Excessive irrigation leads to leaching of nutrients. This leaching constitutes an economic loss to the grower, since these nutrients are no longer available to the crop and pose a potential environmental risk, since fertilizer runoff can contribute to eutrophication of water bodies. Excessive irrigation can also produce conditions amenable to root pathogens, and thus lead to significant crop losses (Blaker and MacDonald, 1981). Finally, excessive irrigation carries a direct cost for nursery growers, since the expenses for the power to run irrigation pumps can be significant. Thus, more efficient irrigation practices can have many benefits for nurseries. At the same time, there are benefits to society-at-large when irrigation practices are improved. A reduction in runoff, and less risk of environmental pollution, can help safeguard environmental quality and reduce the need for water treatment. Reductions in power consumption will result in a decrease in CO_2 emissions, and may thus contribute to slowing global climate change.

Perhaps the most significant barrier to implementation of more efficient irrigation practices is the lack of knowledge regarding when plants need to be watered and how much water needs to be applied. More sophisticated systems, such as real-time soil moisture monitoring systems, have the potential to drastically reduce the amount of water needed for irrigation by using more precise irrigation control. Soil moisture sensors monitor substrate water content, and when used in conjunction with a computer-controlled irrigation system, can be used to initiate irrigation when substrate water content drops below a user-specified set point. Here we describe the use of soil moisture sensors combined with a wireless network to remotely monitor environmental conditions, substrate water content of selected crops, and irrigation water applications. Such networks can provide growers with real-time information regarding the water status of their crops and provide valuable information regarding the efficiency of water applications. Finally, without a clear understanding of daily plant water use, it is extremely difficult to irrigate with maximum efficiency. Therefore, research is being conducted to quantify the volume of water or volumetric water content required to maintain acceptable growth rates of nursery crops, using *Hydrangea macrophylla* and *Hibiscus acetocellus* 'Panama Red' as model crops.

Key words: production horticulture, irrigation automation, soil moisture sensor

Objectives & Materials and Methods

Objective 1: Wireless Irrigation System Implementation

The objective of this project was to test a wireless sensor network in a commercial nursery, and to determine whether real-time sensor data can be used to improve irrigation practices. This work was done in collaboration with Evergreen Nurseries in Statham, GA. At this nursery, a wireless network, consisting of four dataloggers (EM50R, Decagon Devices, Pullman, WA) was installed. These dataloggers can be used to measure a wide variety of sensors. In this case, one of the dataloggers was configured as a weather station by connecting a photosynthetic photon flux sensor (Apogee Instruments, Logan UT), a relative humidity and temperature sensor (Decagon Devices), and a rain gauge (Decagon Devices). The other three dataloggers were used to monitor substrate water content in various crops, by connecting four soil moisture sensors (EC-5, Decagon Devices) to the datalogger. Later on, a rain gauge was connected to these loggers as well, with the purpose of monitoring rainfall and irrigation of each crop. The dataloggers measured each sensor once every 20 minutes. All crops were irrigated using overhead sprinklers and grown in hoop houses covered with shade cloth. All four dataloggers communicated wirelessly with the basestation connected to a computer running DataTrac software (Decagon Devices). This software provides a simple interface to allow users to graph the data from multiple dataloggers. This allowed the grower to have easy access to all data as they were being collected. Researchers had remote access to the computer at the nursery using remote access software (TeamViewer 5.0, TeamViewer GmbH, Göppingen, Germany).

Objective 2: Growth of *Hibiscus acetocellus* 'Panama Red' as a function of soil volumetric water content.

The objective of our study was to determine the effect of substrate water content on the growth of *Hibiscus acetosella* 'Panama Red' and to quantify the water requirements of this plant. On June 17, 2010 rooted cuttings of *Hibiscus acetosella* 'Panama Red', pruned to the third node above substrate level, were planted in one gallon containers filled with soilless substrate (Fafard Nursery Mix; Conrad Fafard Inc., Agawam, MA). Pots were topdressed with 24 grams of 16 month, slow release fertilizer (Graco 14-8-14 with minors; Graco Fertilizer Co., Cairo, GA) and watered in. Plants were grown in a glass-covered greenhouse throughout the study.

The irrigation system used in the experiment was based on the design described by Nemali and van Iersel, 2006, with substrate water content set points of 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, and 0.45 $L \cdot L^{-1}$. Treatments were started on June 24. The experiment was designed as a randomized complete block with eight treatments and four replications (32 total plots). Each plot contained two pots which were monitored with soil moisture sensors (EC-5, Decagon; Pullman, WA). A data logger (CR10; Campbell Scientific, Logan, UT) stored readings from the two sensors and initiated irrigation when the average of the two sensor readings dropped below the assigned substrate water content set point, providing 44.5 mL of water per irrigation event. The number of irrigation events was recorded by the datalogger, allowing for the calculation of the amount of irrigation water applied to each plant. On August 2, the experiment was ended and plant growth measurements were taken. Substrate water content was measured using a ThetaProbe soil moisture sensor (Delta-T Devices, Cambridge, UK). Shoots were cut off at the substrate surface and dry weight was determined. Data were analyzed with linear and non-linear regression using SigmaPlot (v. 11, Systat Software, San Jose, CA).

Objective 3. Calculating Daily Water Use of *Hydrangea macrophylla* in a Production Nursery Environment

Our objective was to investigate the relationship between plant size, environmental factors, and water consumption of *Hydrangea macrophylla*. Data obtained in this study may be used at a later date to develop predictive modeling software that would control irrigation frequency and duration in accordance with the needs of the plants. Our study took place at the Center for Applied Nursery Research (Dearing, GA). Sixty four rooted cuttings of two *Hydrangea macrophylla* cultivars, 32 'Fasan' and 32 'Pia' (James Greenhouses, Colbert, GA), were transplanted into 7-liter containers filled with a composted pine bark growing mix (bark, 4 lbs. lime/cu. yd., 1.5 lbs. micromax/cu. yd., 1.5 lbs gypsum/cu. yd., 2 lbs. talstar/cu. yd., 4 lbs. Osmocote Pro 18-6-12/ cu. yd.). The plants were irrigated using a custom drip irrigation system with four plants of each cultivar mounted on load cells (LSP-10, Transducer Techniques, Temecula, CA). The system was controlled using a datalogger (CR10, Campbell Scientific, Logan, UT) and multiplexer (AM25T, Campbell Scientific) and the datalogger controlled water applications and stored environmental and water use data. Light levels were monitored using a quantum sensor (QSO-sun, Apogee instruments, Logan, UT), while temperature and humidity data were collected with a temperature/humidity probe (HMP50, Vaisala, Helsinki, Finland).

The plants were watered daily at 10 pm for 30 minutes to bring the growing mix moisture level to container capacity, ensuring that water would not limit water use. Water was allowed to drain from the pots for an hour and a half before the plants were weighed at midnight, establishing a base weight for the start of each day. At 10:00 pm every night, the datalogger recorded the weights of the eight plants mounted on the load cells as the final weight for each day, before the plants were irrigated again. The datalogger then calculated the decrease in weight that occurred during that day and stored that value as the daily water use (DWU). Light levels, temperature, and relative humidity were measured every 5 minutes and compiled at 11:55 pm, at which time the datalogger calculated the daily light integral (the cumulative light integrated over the whole day). The datalogger also calculated the vapor pressure deficit from temperature and humidity measurements. Vapor pressure deficit, the additional amount of water it would take to saturate the air with water, provides the driving force for transpiration and thus likely affects plant water use. Maximum, minimum and daily average values were stored for photosynthetic photon flux, temperature, and vapor pressure deficit.

After 84 days, the plants mounted on the load cells were harvested. Total plant leaf area measurements were taken (LI 3100, Li-Cor, Lincoln, NE) to quantify the size of the plants at the end of the study. The containers, still filled with growing mix and roots, were brought to container capacity, weighed, dried, and weighed again to calculate the total water holding capacity of the pine bark growing mix. Due to poor growth of one ‘Pia’ and one ‘Fasan’ plant, only three plants of each cultivar were used in the data analysis. The effects of environmental and plant parameters on daily water use of the plants were tested using linear and multiple regression. Stepwise selection was used to eliminate non-significant factors from the model (proc REG, SAS 9.2, The SAS Institute, Cary, NC).

Results and Discussion

Objective 1: Wireless Irrigation System Implementation

Figure 1 is a screenshot from the DataTrac software showing the environmental conditions in the Evergreen Nursery growing production area during a one week period. Relative humidity was generally close to 95% pre-dawn and decreased to 20-30% in the afternoon. There was a clear, inverse relationship between relative humidity and temperature, which ranged from 40 to 55 °F pre-dawn to 75 to 85 °F in the early afternoon. There was only one small rain event during this period, in the morning of October 20.

The substrate water content as measured in one hoop house with both lantanas and gaillardias is shown in Fig. 2. Irrigation practices were changed during the two-week period shown here: during the first week, the crops were irrigated for 15 minutes on most days, while the crops were not irrigated on October 8 and 11. During the second week shown in this graph, the crops were irrigated twice daily, 8 minutes each time. The goal of using cyclic irrigation was to reduce leaching. The gradual increase in substrate water content following the switch to cyclic irrigation does indeed suggest that more of the applied irrigation water was retained by the substrate.

The data in Fig. 3 are from a hellebores crop during the period August 14 – September 4, 2010. These data show the average of the readings from four different sensors. As can be seen in the top graph, there was regular rain from August 13-23, and, as expected, each significant rainfall event resulted in a rapid increase in substrate water content. The rain largely stopped after August 22 and the substrate starts to dry out gradually from that time on. The substrate dries out much faster during the day than at night, presumably related to the greater vapor pressure deficit and opening of the stomates during the daylight hours. In early September, the crop was irrigated twice (as indicated by the red arrows).

The data obtained from the wireless sensor network clearly show the dynamic changes in substrate water content. However, looking at the change in substrate water content from one measurement to the next can add valuable information. To do so, we simply subtracted the current substrate water content from that measured 20 minutes earlier (Fig.4, red line). Note that only decreases in substrate water content (leaching and/or evapotranspiration) are shown. Irrigation and rainfall would appear as large negative values and are excluded for clarity.

When looking at the change in substrate water content, it is clear that each significant rain event is followed immediately by a rapid decrease in substrate water content (i.e., the spikes in the red curve). This indicates that very shortly after a rainfall event, the water drains to below where the sensor is in the container. Given the size of the pots, that likely means that this water leached out of the pots. Such leaching events are much easier to see when looking at the change in substrate water content, rather than the substrate water content itself. This also can be seen in the data from the two irrigation events near the end of this period: the first irrigation, on September 1, apparently resulted in very light leaching, while there was a fair amount of leaching after the irrigation on September 2, as indicated by the rapid decrease in substrate water content following that irrigation.

The information that can be obtained using these wireless networks can be used to make irrigation practices more efficient. Substrate water content readings can be used to determine when irrigation is needed. By adjusting the irrigation time, and determining how much the substrate water content increases after irrigation will allow for the determination of how much water needs to be applied during an irrigation event. A rapid decrease in substrate water content is indicative of leaching.

The currently available hardware is able to monitor substrate water content, and can help growers make decisions regarding irrigation. Planned improvements in the hardware include the incorporation of a relay, which would allow these dataloggers to open and close irrigation valves, based on grower-defined conditions. We also expect that sensors that can measure both substrate water content and electrical conductivity will soon be available. Such sensors will help to further integrate irrigation and fertilization. Measurements of electrical conductivity could be used to determine whether leaching is needed or whether additional fertilizer applications may need to be made.

Objective 2: Growth of *Hibiscus acetocellus* 'Panama Red' as a function of soil volumetric water content.

The soil moisture sensor-controlled irrigation system was able to maintain soil moisture levels close to the specified set points, with set points being reached before the tenth day (Fig. 5). A strong correlation (r = 0.81, p < 0.0001) between ThetaProbe measurements and substrate water content set points confirmed differences in substrate water content among the treatments (Fig. 6). Plant growth, represented by shoot dry weight, was affected by water availability. This is demonstrated by the correlations between dry weight and substrate water content (Fig. 7) (r = 0.83, p < 0.001) as well as dry weight and total irrigation volume (Fig. 8) (R^2 = 0.84, p = 0.001). Total irrigation volume increased with increases in substrate water content set points (r = 0.82, p < 0.001) (Fig. 9).

Analysis of shoot dry weight as a function of total volume of irrigation water applied shows volume distinct non-linear response (Fig. 8). A sharp increase in growth can be observed as the irrigation volume increases from 2 to 14 L/plant, but little effect on growth is seen amongst plants receiving 22.5 L of water or more. These observations agree with van Iersel et al. (2009) and suggest that plant growth is dependent on the amount of water applied up to a threshold, after which additional water supplied no longer significantly increases growth. This shows that plants of similar size can be obtained with differing substrate water contents, and therefore reduced irrigation volume. Our results suggest that growers using an automated irrigation system would be able to reduce total irrigation volume by approximately 20 L/plant by using a set point of 0.35 $L \cdot L^{-1}$ instead of 0.45 $L \cdot L^{-1}$, while still obtaining similar size plants. Although our results are from plants grown in a controlled greenhouse setting, they suggest it is possible to achieve similar results in a nursery setting in which plants are exposed to varying environmental conditions, and our results from to studies in outdoor nurseries confirm this (unpublished results).

Objective 3. Calculating Daily Water Use of *Hydrangea macrophylla* in a Production Nursery Environment

Average DWU of both cultivars showed a gradual increase over time from 50 to 300 mL/day (Fig. 10), likely as the result of increasing plant size. There was a 12% difference in average DWU between 'Fasan' (231 mL/day) versus 'Pia' (207 mL/day). Overall, the plants only used 2.5 - 15% of the approximately 2 L of water present in the growing mix at container capacity per day, indicating that water use was never limited by water availability in the growing mix. In total, individual plants only used 17-19 L of water over the course of the 84 day experiment.

On the 48th day of the study, shade cloth was pulled over the greenhouse structure. This resulted in an immediate and sustained decrease in DWU of both cultivars (Fig. 10). DLI was the only environmental factor significantly decreased by the application of the shade cloth, while temperature and VPD remained similar (Fig. 11). There was a clear effect of DLI on DWU; on days with low light levels, DWU was low as well (*e.g,*, day 3, 61, and 73). Surprisingly, there was no correlation between DLI and DWU (Table 1), but there were strong correlations between DWU and the interaction of DLI and plant age, as well as the three-way interaction among DLI, plant age, and leaf area. Other factors correlated with DWU include temperature, VPD, and the interaction between leaf area and plant age (Table 1).

For a more in depth analysis of those factors important in determining DWU, multiple regression was used with stepwise selection. Partial R^2 values were used to quantify the effect of various factors on DWU. This regression indicated that 83.2% of day-to-day changes in DWU of 'Fasan' could be explained by the plant age, final leaf area, DLI, and their interactions combined (Table 11, Fig. 12). Although VPD and temperature were statistically significant, they only explained another 6.5% of fluctuations in DWU and were not as biologically important as plant age, leaf area, and DLI. 90.8% of fluctuations in DWU of 'Pia' could be explained by the combination of plant age, final leaf area, DLI, and their interactions (Table 1, Fig. 12), while VPD and temperature only explained an additional 4.0%. Our finding that DLI is by far the most important environmental variable affecting plant water use is consistent with earlier findings that showed that 79% of fluctuations in daily water use of petunia could be explained based on plant age and DLI (van Iersel et al., 2010).

Our results suggest that by monitoring plant size and DLI, growers can more accurately determine the daily water requirements of hydrangea and irrigate their stock more efficiently, improving both economical and environmental aspects of ornamental plant production. Although other environmental factors, such as temperature and vapor pressure deficit also affect water use, they are much less important than light levels. We have found load cells to be an accurate and inexpensive way for growers to track plant water use to exacting tolerances, and their implementation in ornamental plant production could greatly increase irrigation efficiency.

Conclusions

The three research objectives reported above demonstrate successful monitoring of real-time soil moisture and environmental data, actual plant water use requirements of two genera and the effects of various environmental conditions on plant daily water use. In objective 1, implementation of a wireless monitoring system afforded Evergreen Nursery the ability to change irrigation practices based on real-time data to make irrigation practices more efficient. Substrate water content readings were used to determine when irrigation was needed. Irrigation practices were changed during the two-week period this study was in place. During the first week, crops were irrigated for 15 minutes on most days. During the second week, crops were irrigated twice daily, 8 minutes each time. This change to cyclic irrigation was implemented to reduce leaching. The gradual increase in substrate water content following the switch to cyclic irrigation suggests that more of the applied irrigation water was retained by the substrate. The currently available hardware is able to monitor substrate water content, and can help growers make decisions regarding irrigation. Planned improvements in the hardware include the incorporation of a relay, which would allow these dataloggers to open and close irrigation valves, based on grower-defined conditions. We also expect that sensors that can measure both substrate water content and electrical conductivity will soon be available. Such sensors will help to further integrate irrigation and fertilization. Measurements of electrical conductivity could be used to determine whether leaching is needed or whether additional fertilizer applications may need to be made.

In field trials utilizing soil moisture probes, the soil moisture sensor-controlled irrigation system was able to maintain soil moisture levels close to specified set points. *Hibiscus acetocellus* 'Panama Red' plant growth, represented by shoot dry weight, was affected by water availability. This is demonstrated by the correlations between dry weight and substrate water content as well as dry weight and total irrigation volume. A sharp increase in growth can be observed as the irrigation volume increases from 2 to 14 L/plant, but little effect on growth is seen amongst plants receiving 22.5 L of water or more. This shows that plants of similar size can be obtained with differing substrate water contents. Our results suggest that growers using an automated irrigation system would be able to reduce total irrigation volume by approximately 20 L/plant by using a set point of 0.35 $L \cdot L^{-1}$ instead of 0.45 $L \cdot L^{-1}$, while still obtaining similar size plants.

In another genera/species, *Hydrangea macrophylla*, average daily water use of both cultivars showed a gradual increase over time, likely the result of increasing plant size. Overall, the plants only used 2.5 - 15% of the approximately 2 L of water present in the growing mix at container capacity per day, indicating that water use was never limited by water availability in the growing mix. When correlating environmental factors with daily water use, daily light integral was the only environmental factor significantly decreased by the application of shade cloth, while temperature and VPD remained similar. There was a clear effect of daily light integral and plant size on daily water use. These results suggest that by monitoring plant size and DLI, growers can more accurately determine the daily water requirements of hibiscus and hydrangea and irrigate their stock more efficiently, improving both economical and environmental aspects of ornamental plant production.

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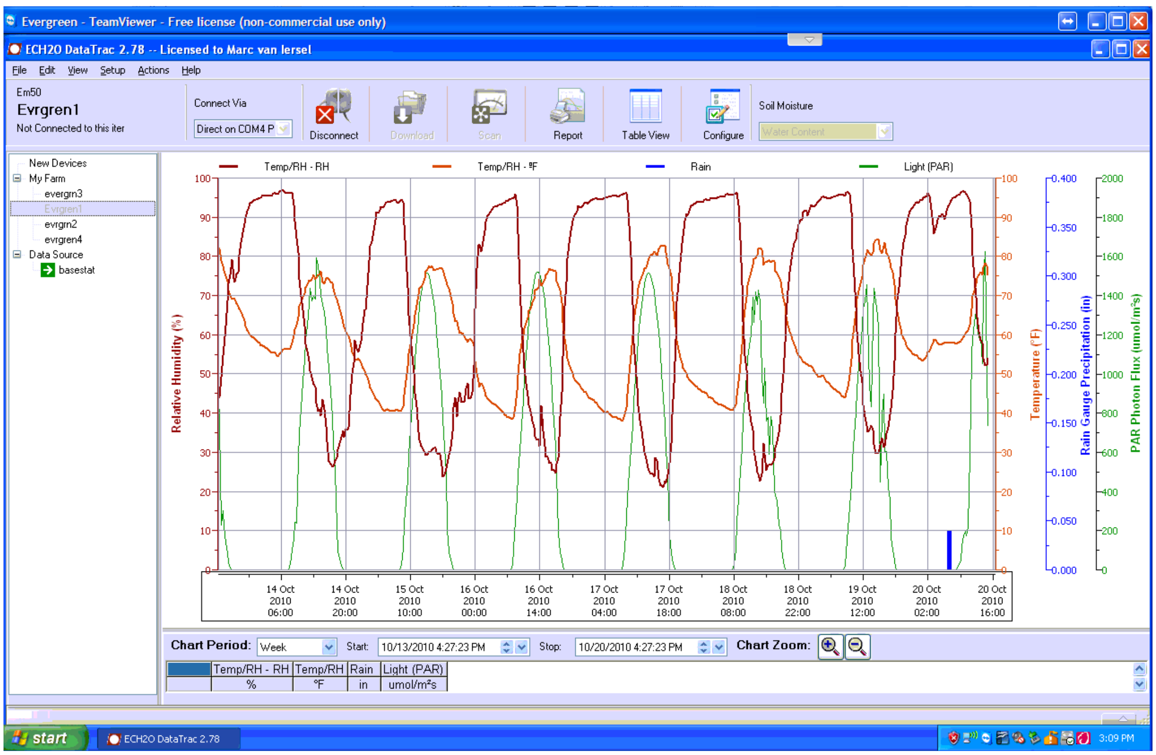

Figure 1. Screenshot of the DataTrac graphic user interface showing environmental conditions in a nursery during a one week period. Data include temperature, light intensity, relative humidity, and rainfall.

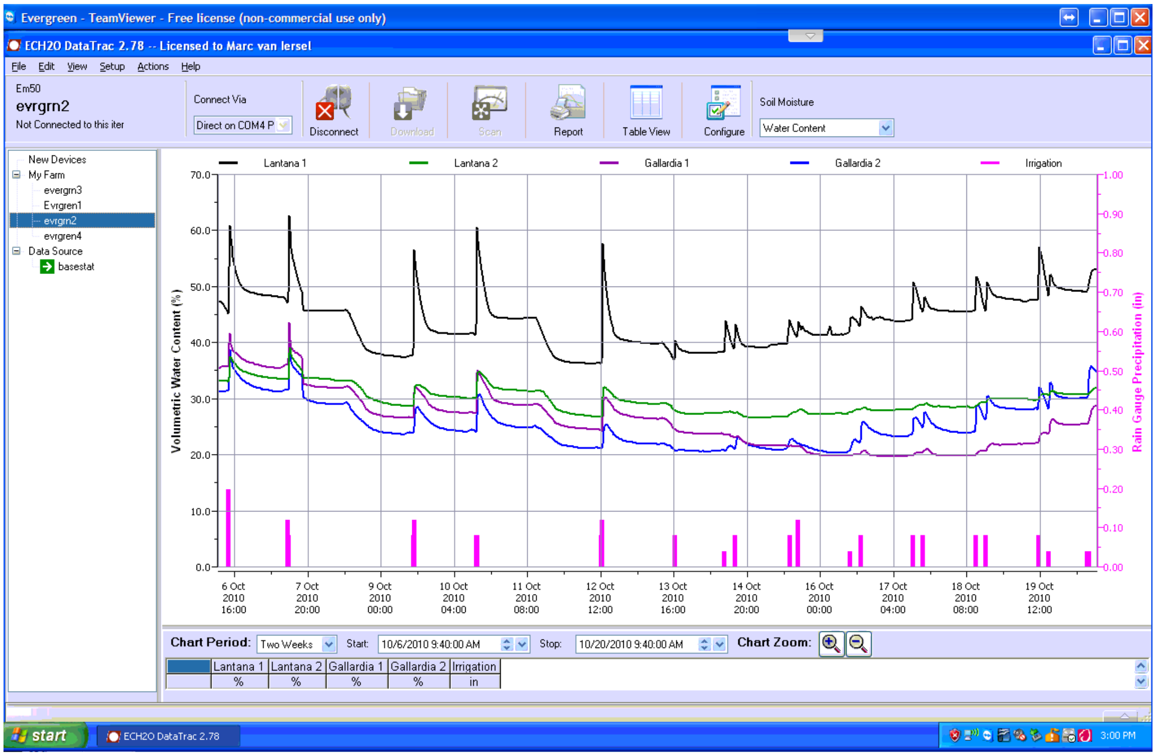

Figure 2. Screenshot showing the DataTrac graphic user interface. The four lines show substrate water content of two containerized lantana (green and black, plants in #2 containers)) and two gaillardia plants (purple and blue, #1 containers). Pink bars indicate rainfall or irrigation events. Irrigation was changed from once daily to twice daily on October 14.

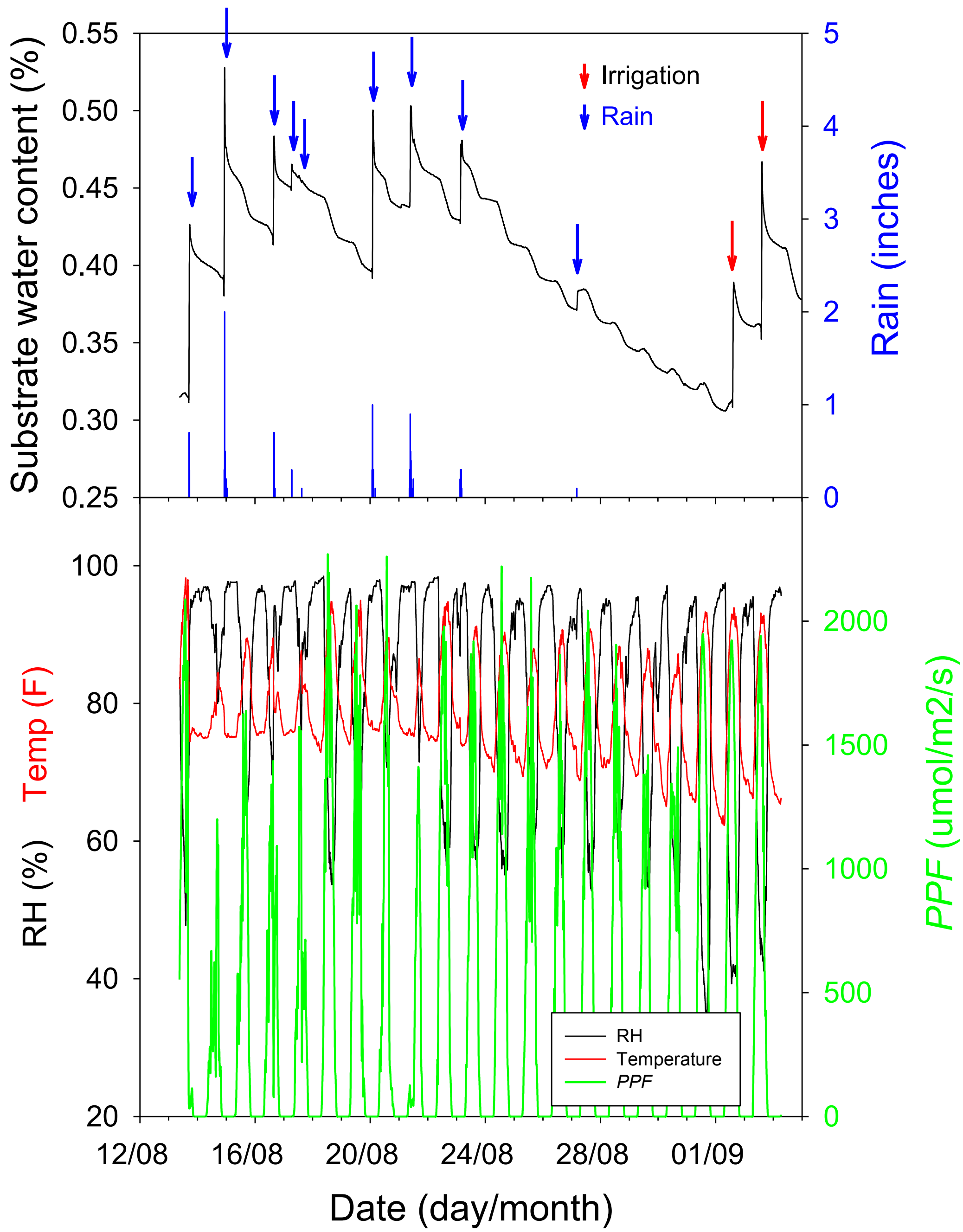

Figure 3. Substrate water content of a *Hellebores* crop (top, average of four sensors) and environmental conditions (rain, top and RH, temperature and photosynthetic photon flux, bottom) in a commercial nursery. Plants were grown in #1 containers.

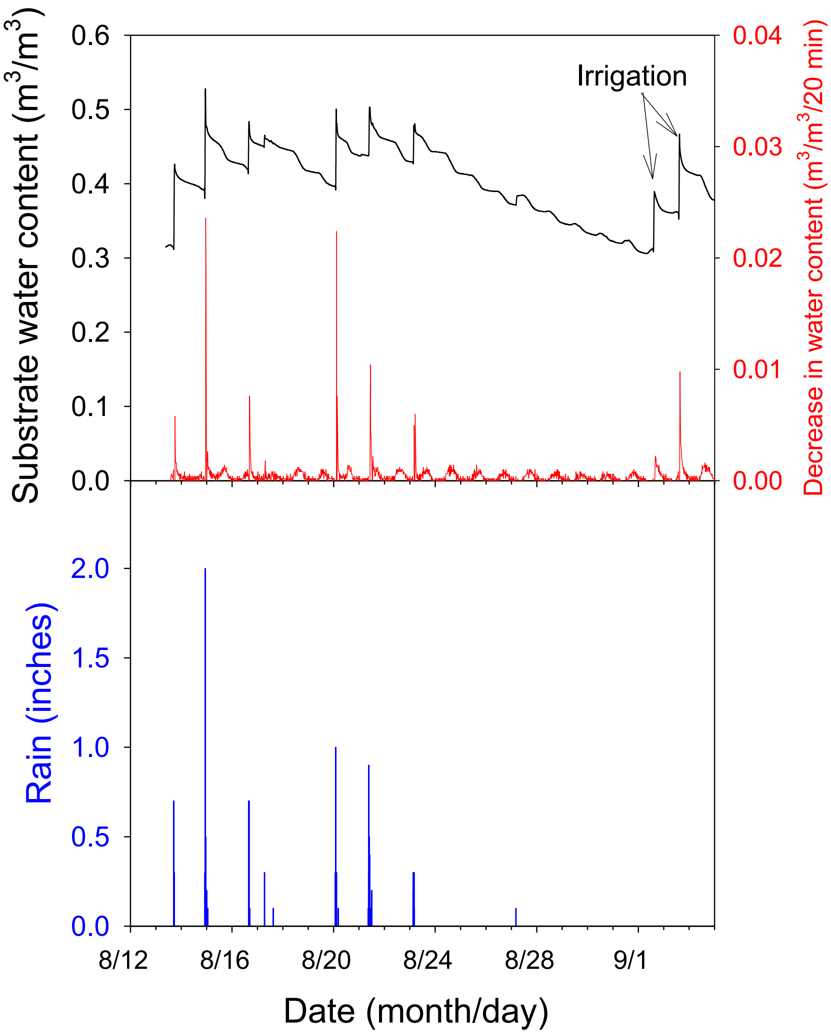

Figure 4. Substrate water content of a hellebores crop (top, black line) and the change in substarte water content ina 20 minute period (top (red line). Note that there is a rapid decrease in substrate water content following each significant rainfall event (blue bars, bottom). This is indicative of leaching. Plants were grown in #1 containers.

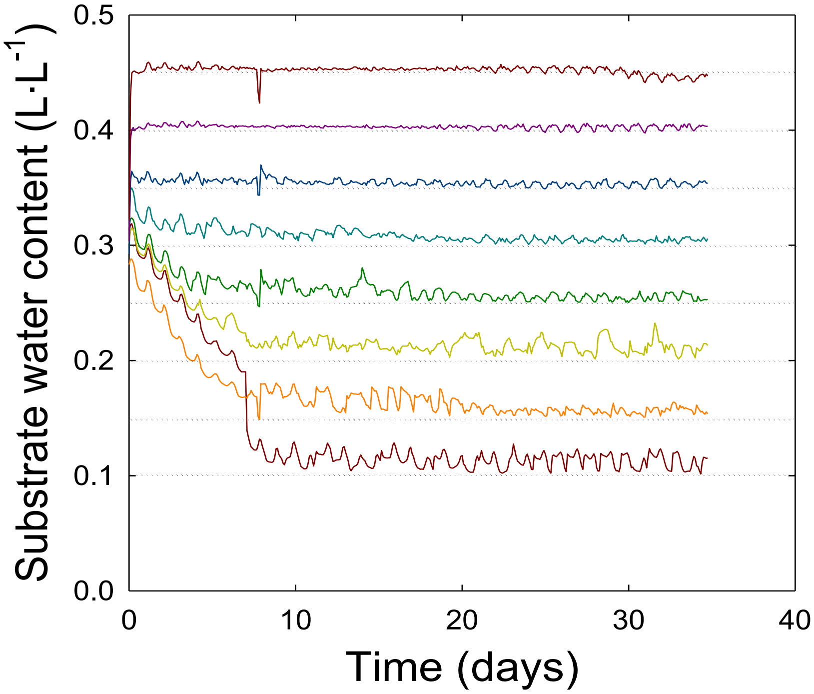

Figure 5. Substrate water content over the length of the experiment. Dashed lines indicate set points for irrigation.

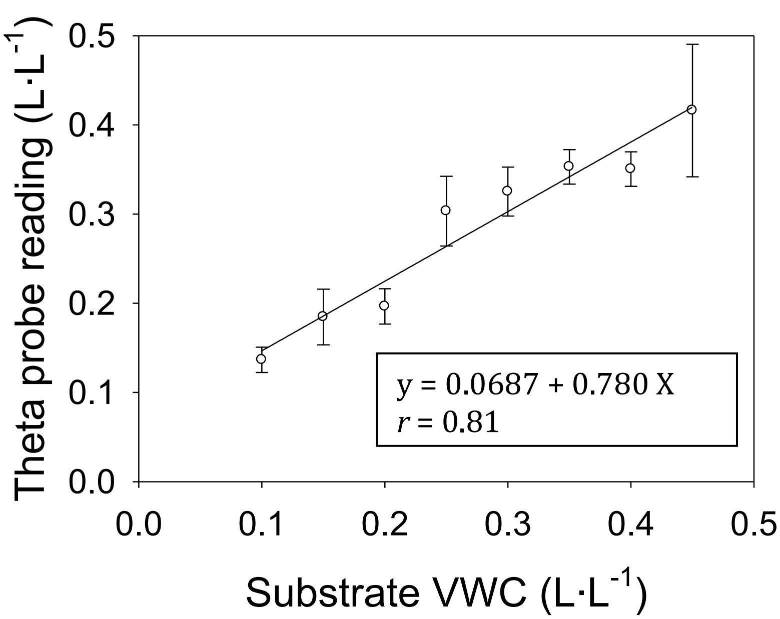

Figure 6. Theta Probe readings of substrate moisture content versus substrate water content set points of the automated irrigation system. Symbols represent means with standard errors for each treatment (n=4).

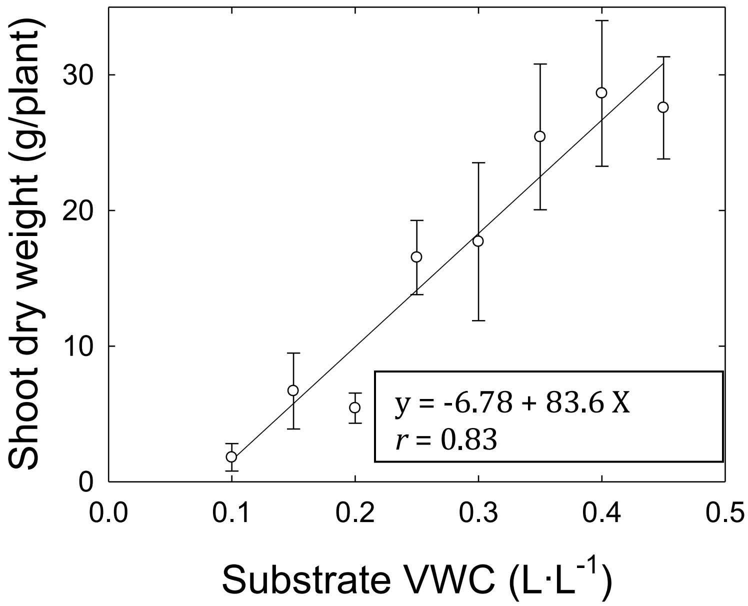

Figure 7. Shoot dry weight of hibiscus ‘Panama Red’ as affected by substrate water content set point at which the plants were irrigated. Symbols represent means with standard errors for each treatment (n=4).

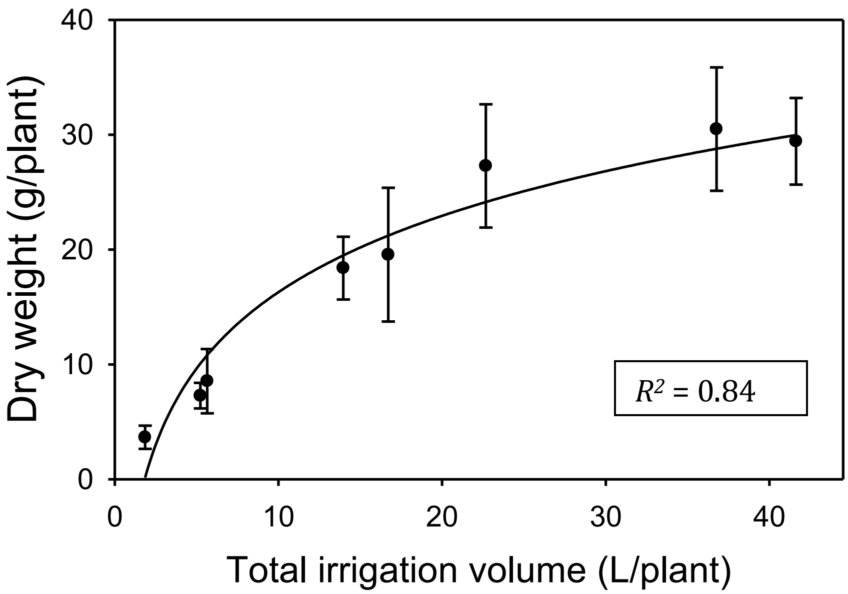

Figure 8. Shoot dry weight of hibiscus ‘Panama Red’ as a function of the total amount of water the plants received during the experiment. Symbols represent means with standard errors for each treatment (n=4).

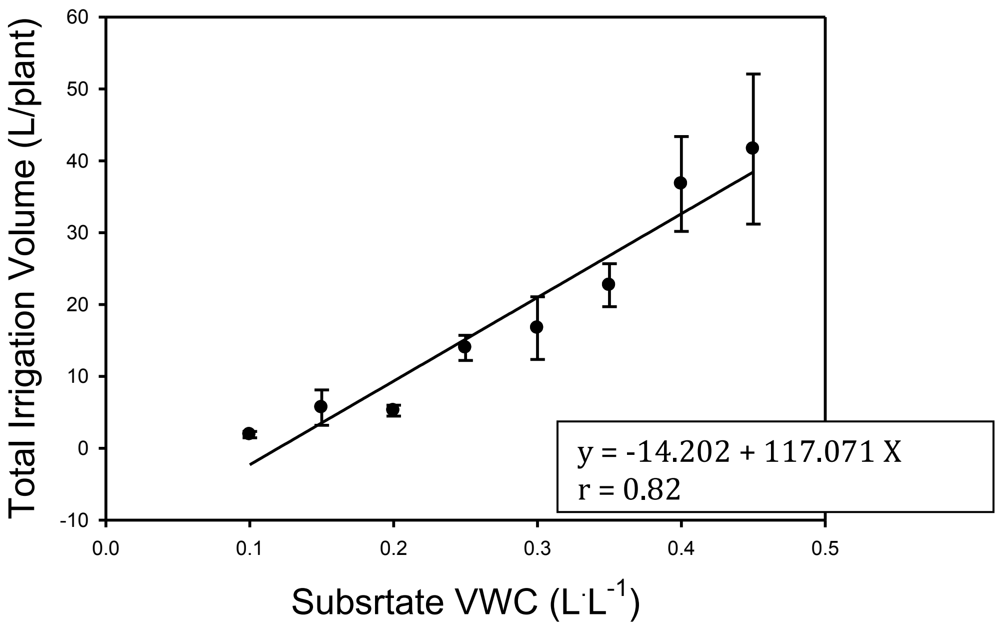

Figure 9. Total irrigation volume as affected by substrate water content set point at which the plants were irrigated. Symbols represent means with standard errors for each treatment (n=4).

Table 1. The relationship between daily water use and various parameters used to explain day to day changes in water use of two hydrangea cultivars as indicated by Pearson's correlation coefficients (*r*) and significance (*P*). DLI = daily light integral, VPD = vapor pressure deficit.

Cultivar	----- 'Fasan' ----		-------- 'Pia' --------	
	r	*P*	*r*	*P*
Day	0.646	<.0001	0.581	<.0001
DLI	0.064	0.3186	0.077	0.2338
Temperature	0.806	<.0001	0.719	<.0001
VPD	0.750	<.0001	0.690	<.0001
Leaf area	-0.169	0.0085	0.413	<.0001
Day * DLI	0.885	<.0001	0.804	<.0001
Day *leaf area	0.582	<.0001	0.721	<.0001
DLI * leaf area	0.012	0.8526	0.234	0.0002
DLI * leaf area * day	0.812	<.0001	0.923	<.0001

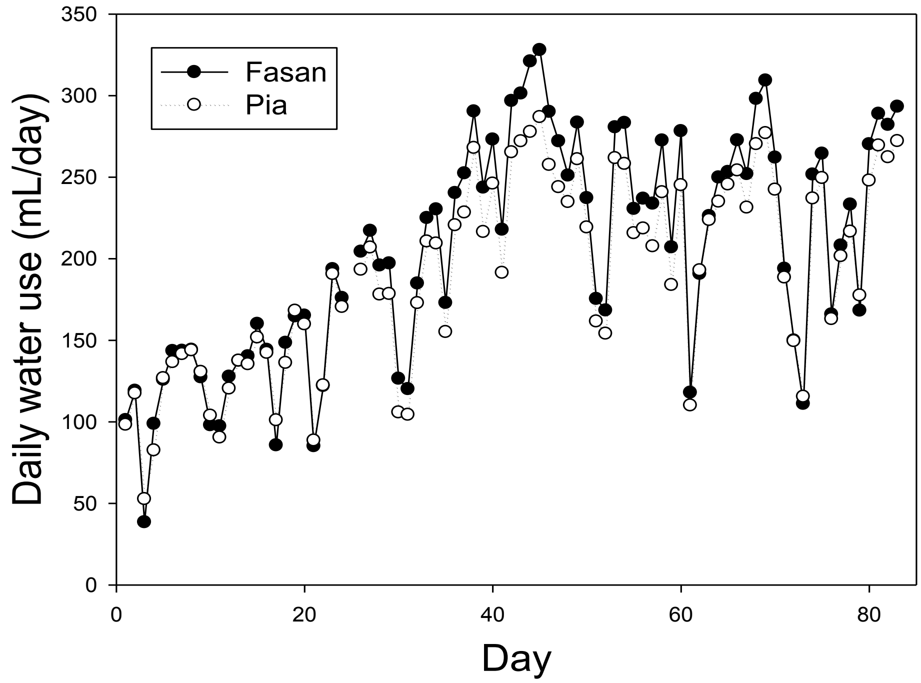

Fig. 10. Daily water use of Hydrangea macrophylla cultivars 'Fasan' and 'Pia' from May 01, 2010 to July 21, 2010 in Dearing, GA. Data points are the mean of three plants.

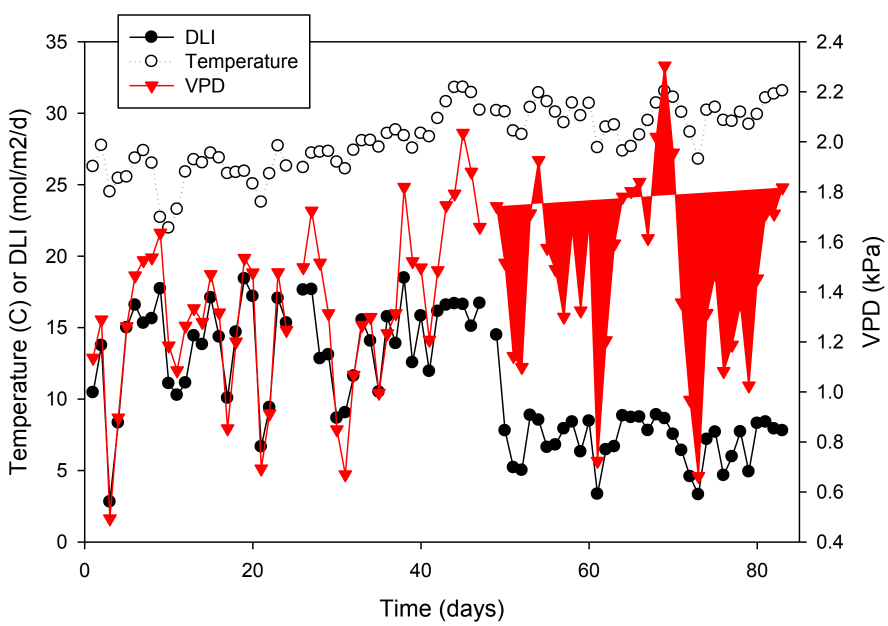

Fig. 11. Daily light integral (DLI), temperature, and vapor pressure deficit (VPD) from May 1, 2010 to July 21, 2010 in Dearing, GA.

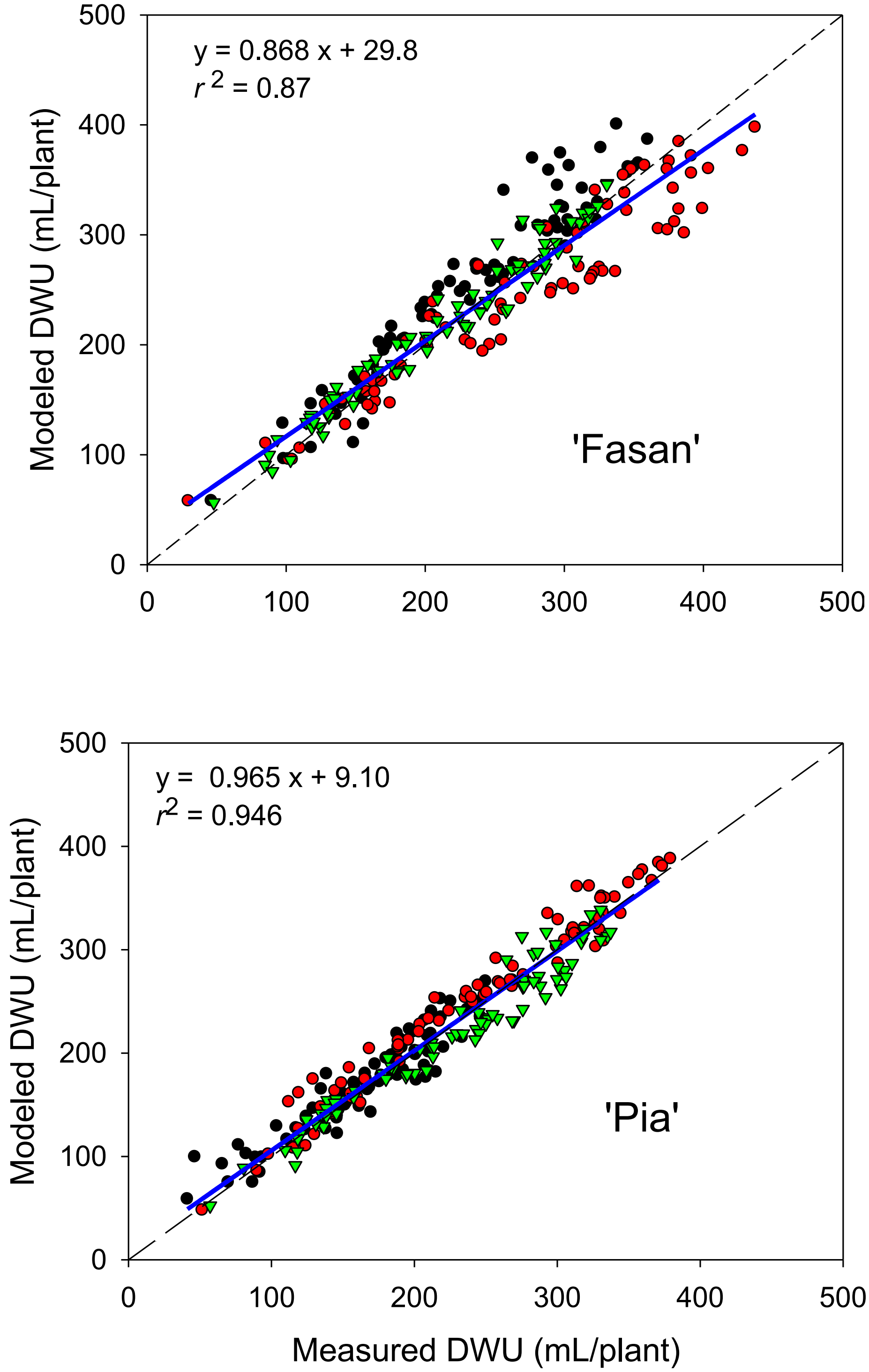

Fig. 12. Measured daily water use (DWU) values versus modeled DWU of *Hydrangea macrophylla* 'Fasan' (top) and 'Pia' (bottom). Different symbols represent different plants. Blue lines indicate regression lines

Forecast climate data use in irrigation scheduling models

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Abstract *Forecast climate data sets are increasing in their role in planning models for water resources. Irrigation scheduling models use solar radiation, air temperature, humidity, and wind speed to calculate reference evapotranspiration. The objective of the research was to determine the error caused by using forecast climate data in an irrigation scheduling model. Daily National Weather Service (NWS) forecast climate data was acquired for locations in New Mexico where an automated weather station was located. Monthly bias of measure-forecast data increases by a factor of 2 when the forecast time increases from 24 hours to 120 hours. Yearly maximum temperature bias ranged from -0.2 to -1.3 degrees C. Evapotranspiration monthly bias ranges are positive and range from 0 in the spring to 0.4 mm/day in midsummer. The main difference between forecast - measured reference evapotranspiration is caused by the overestimation of wind speed.*

Keywords Irrigation, climate, evapotranspiration, forecast

Introduction

The quality of climate and atmospheric data sets has been become more important now that they are being used in planning and prediction models for water resources, evapotranspiration calculations, and air-quality issues. This raises the priority of understanding spatial and temporal variability of the measured and predicted climate parameters. Ideally, the spacing between adjacent climate stations to measure these climate parameters should be such that the error in interpolating climate values for an intermediate station is comparable to the instrumental error at any single station. The recommended spacing for temperature measurements ranged from 160 km for uniform terrain to 15 km for non uniform terrain along the coast where climate conditions change rapidly (Linacre, 1992). Microclimate influences on temperatures observed at nearby (horizontally and vertically) U.S. Climate Reference Network stations were potentially much greater than influences that might be due to latitude or elevation differences between the stations (Gallo, 2005).

The climate element and the time period of the average of the data also affect the spacing to obtain a given accuracy (Wilmott et al., 1991; Hubbard, 1994a; Snyder et al., 1996;

Ashraf et al., 1997). Based on an analysis of climate data from the High Plains (Hubbard, 1994a), a 60 km spacing is required to explain 90% of the variation between sites for maximum daily air temperature. For minimum temperature, relative humidity, solar radiation, and potential evapotranspiration, that spacing reduces to 30 km, and for wind speed and precipitation, spacing of 10 km and 5 km are required, respectively. Spacing requirements varied with the time of year. Using the NWS Cooperative Observers Network, Greco and Smith (2011) determined that in more than 80% of the United States, the climate stations need to be less than a radius of 33 km from each other to resolve air temperature climate variability to within 5 degrees C for a 30-year normal mean monthly air temperature. Consequently, care must be taken in spacing climate stations and in using climate-station data to calculate reference Et or growing degree days over areas greater than 30 km. Forecast data from the NWS forecast office (Saha et al., 2006) is now available on a 2.5 km grid. Reference Et calculate from forecast climate data minus reference Et calculated from the measured CIMIS climate network (CIMIS, 2009) showed a percent difference on a year-time scale that ranged from -8% to 31%, with the largest error in San Diego on the coast of California and the smallest error of -1% in the San Joaquin valley in the center of California (Senay et al., 2008). The grid size of the forecast data used in the study was 100 km.

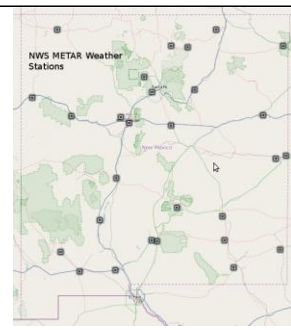
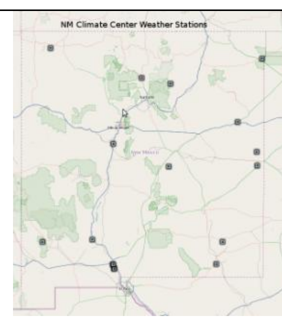
Automated station output must have quality control software (QC) that finds and corrects, or estimates, missing and bad data. The standard quality control software (QC) involves the use of multiple stations where a station's data is compared to the data from neighboring stations (Wade, 1987; Gandin, 1988; Eischeid et al., 1995; Hubbard, 2001). Thus, bad data can be replaced using various statistical approaches (e.g., multiple regression, Eicheid et al., 1995; linear regression, Hubbard et al., 2005). Often, the corrections are inverse distance-weighted interpolations using surrounding stations (Guttman, 1988; Wade, 1987). Camargo (et al., 1998) determined that seven years of data are needed to stabilize the variation between stations in order to develop models to replace missing data based on surrounding data.

The objective of the research was to determine if forecast data could replace missing measured data or replace measured data entirely in an irrigation scheduling model and still result in acceptable accuracy in scheduling irrigation dates.

Materials and Methods

Forecast data is available from the NWS Real-Time Mesoscale Analysis (RTMA), which is a gridded analysis of the meteorological variables (NOAA. 2011). The forecast system model is described by Saha et al. (2006). It produces a 12 km grid of data over the entire United States four times a day for temperature, dew point, relative humidity, wind speed, wind direction, and sky cover for every hour up to five days in advance. The RTMA on the NWS website has interpolated data to a finer grid (2.5 km) and hourly time step. This interpolated data can be obtained by a user by entering a latitude and longitude or selecting a map location (NWS forecast climate data, 2009). The data was captured starting in September 2010 using a python software package (Figure 1) from the 2.5 km grid and hourly interpolated data for locations where five automated climate networks are maintained in New Mexico (Table 1).

Mott (et al., 1992) describes the NMSU automatic climate network. The METAR automated stations are located at airports and represent the average of a two-minute time just before the hour, not the average for the entire hour, as is the case for the other automated networks (METAR Surface Weather Observations, 2011). Snotel is a high-elevation automate climate network operated by NRCS to measure both snow depth and climate data, and the climate network is described by Schaefer and Werner (1996). RAWS is a Remote Automated Weather Stations system maintained by the National Interagency Fire Center with most of the stations located on BLM land (RAWS, 2011). The NMSU Vineyard Network is a subset of the NMSU climate network and has a design similar to that network but is operated by the vineyard extension specialist.

Network name	Number of station and description of instrumentation and data logger	Description map of station location in New Mexico
METAR – airport weather stations (METAR Surface Weather Observations, 2011)	28 station, precipitation, wind speed at 10 m height, barometric pressure, air temperature and due point temperature.	
NMSU State Climate Network (Mott et al., 1992)	17 stations measure precipitation, temperature/relative humidity, wind speed at 3 m height and direction, solar radiation, soil temperature.	

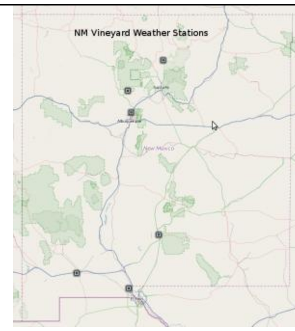
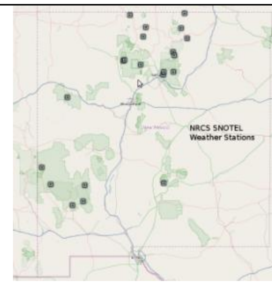
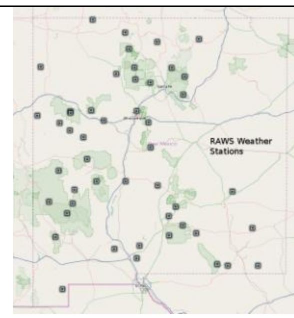
NMSU Vineyard Network	Six stations measure precipitation, temperature/relative humidity, wind speed at 3 m height and direction, solar radiation, soil temperature.	
NRCS Snotel Weather Station – weather stations to measure snowpack (Schaefer and Werner, 1996)	21 stations measure snow water content, precipitation, snow depth, air temperature.	
RAWS – Remote automated weather stations maintained by National Interagency Fire Center (RAWS 2011)	48 stations measure wind speed at 2 m height, precipitation, barometric pressure, soil moisture, air temperature/relative humidity, solar radiation.	

Table 1**.** Automated climate networks measure climate data in New Mexico.

Both measured and forecast databases were written to a database management system that allows importation of the data with different units into a common database. For each forecast location and weather station location, the mean and standard deviations were calculated for the climate variable of interest on a monthly basis. If missing data from either data set occurred, then that day was excluded from the analysis. The biases were calculated using Equation 1.

The mean bias of the forecast data to measure data is Equation 1.

$$\text{MBIAS}= \frac{\sum_{i=1}^{N} forecast - measured}{N} \qquad (1)$$

Consequently, two databases were created, one for measured data and one for forecast data predicted one day into the future. The climate data then was used to calculate reference evapotranspiration (Et_o) (Equation 2) using the standardized penman Monteith equation (Allen et al., 2005).

The Penman Monteith equation described by Allen is:

:

$$Et_o = \frac{0.408\Delta\,(R_n - G) + \gamma\,[900/\,(T+273)]\,U_2\,(e_s - e_a)}{(\Delta+\gamma)\,(1+0.34U_2)} \qquad (2)$$

Where: ET_o = (mm day^{-1})

R_n =net radiation at the crop surface (MJ m^{-2} day^{-1}).
G =soil heat flux density (MJ m^{-2} day^{-1}).
T =mean daily air temperature at 2 m height (°C).
U_2 =wind speed at 2 m height (m s^{-1}).
e_s =saturation vapor pressure (kPa).
e_a =actual vapor pressure (kPa).
e_s - e_a =saturation vapor pressure deficit (kPa).
Δ =slope vapor pressure curve (kPa °C^{-1}).
γ =psychrometric constant (kPa °C^{-1}).

In the case of solar radiation, the NWS day light hours average cloud cover forecast data was used to adjust the calculated clear-sky radiation to actual daily solar radiation (FAO 24) because the forecast model does not predict hourly or daily solar radiation levels. A second daily solar radiation product produced by NASA also was downloaded from the Internet (NASA 2011) and was used to replace the calculated total daily solar radiation from the forecast cloud-cover data and clear-sky calculated solar radiation. This solar radiation satellite data is available on a grid of 1 degree latitude by 1 degree longitude (approximately 100 km grid). The computed solar radiation data (Flashflux 2010) comes from the Terra and Aqua (Modis) satellite (Stackhouse et al., 2008). The Modis solar radiation data has a reported bias of plus 2.25%.

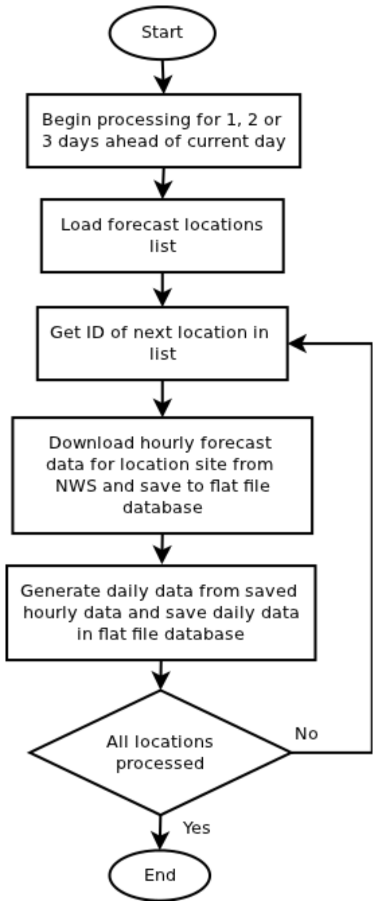


Figure 1. Flow chart of Python based NWS data capture and processing software package.

In Las Cruces, NM, two Campbell weather stations were set up side by side to evaluate the error between two measured climate stations.

The forecast data were compared to the automated climate METAR –airport weather stations station using the NWS analysis presented on its website for the entire United States. The meteorological variables evaluated by the NWS (NWS, 2010) are:

- Maximum highest temperature observed from 7 a.m. to 7 p.m..
- Minimum temperature lowest temperature observed from 7 p.m. to 8 a.m. .
- The ambient temperature observed at 2 meters above ground level.
- Relative humidity: computed from the ambient temperature and dew point 2 meters above ground level.
- Wind speed at 10 m height.

Results and Discussion

Because the NWS also used the METAR data to calibrate the forecast model, this comparison between measured and forecast data sets represents the best forecast data for those sites and is the standard against which to compare the other automated weather station data set. The NWS (NWS, 2010) reported that the 12 Greenwich Mean Time forecast showed decreased accuracy as the forecast data moves into the future with the first 24 hours having the best prediction compared to the measured METAR data for the entire United States (Figure 2). Figures 2, 3, and 4 were derived from data presented by the NWS website: http://www.weather.gov/ndfd/verification/. Because the bias calculation consists of over and under predictions of measured data, the absolute error will be larger than the bias, but the bias data gives information about the monthly or yearly error that will occur when calculating heat units, or evapotranspiration using the forecast data. Generally in agriculture, the daily error is not as important as the weekly, monthly, or seasonal error or bias because the climate data is used for a region, and spatial location within that region also can cause errors in daily values for a region but are consistent when averaged over time (Senay et al., 2008). The average over the years of maximum absolute error (MAE), was 1.29 C for 1,321 sites in the United States, and it increased to 2.03 C for a forecast 108 hours into the future (NWS, 2010). The mean bias calculated increased with the forecast into the future (Figure 2) with the bias being positive from July to January and negative from February to May, with a yearly average biomass of -0.05 C. Similar values of MAE and bias were determined for minimum temperature forecast versus measured data (not shown). The distribution of the absolute error and bias around the sites throughout the United States is consistent in all regions during the summer. In the winter, a higher increase in MAE of 1.1 degrees C occurs in the north-central states (see maps at http://www.weather.gov/ndfd/verification/), but the biases are the same around the United States.

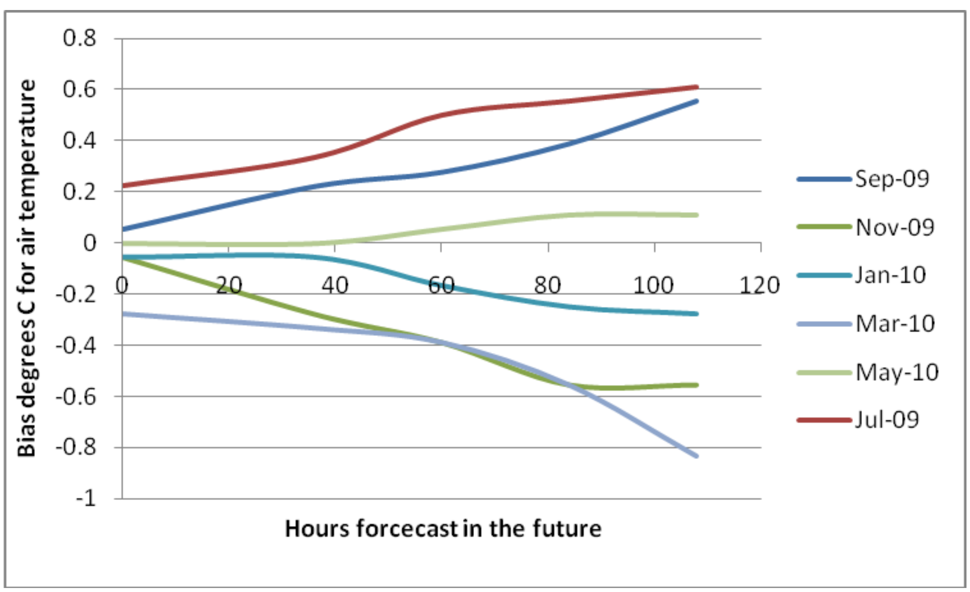


Figure 2. Bias of maximum air temperature in degrees Celsius calculated by the National Weather Service for 1,221 airport locations.

The hourly humidity bias also increases with forecast time (Figure 3) but has a cyclic nature unlike the temperature bias, which steadily increases with time.

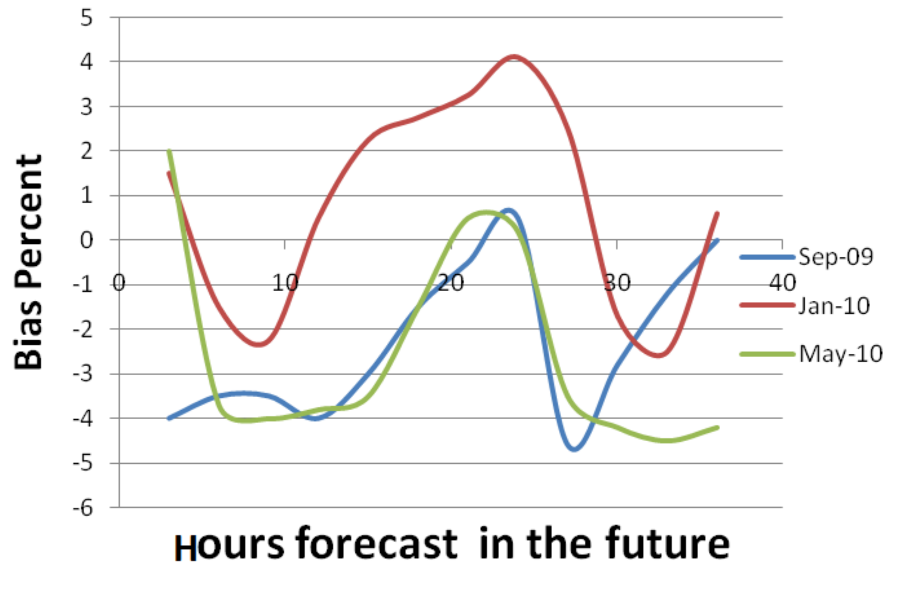


Figure 3. The hourly humidity-bias percent changes with increasing forecast time in the future is calculated by the National Weather Service for 1,221 airport locations.

The wind-speed forecast data at a height of 10 m had a bias that increased with forecast time but still was small (0.5 m/s). However, the forecast model also predicts a wind speed at a height to 2 m, which has a much higher positive bias, as is discussed later in this paper.

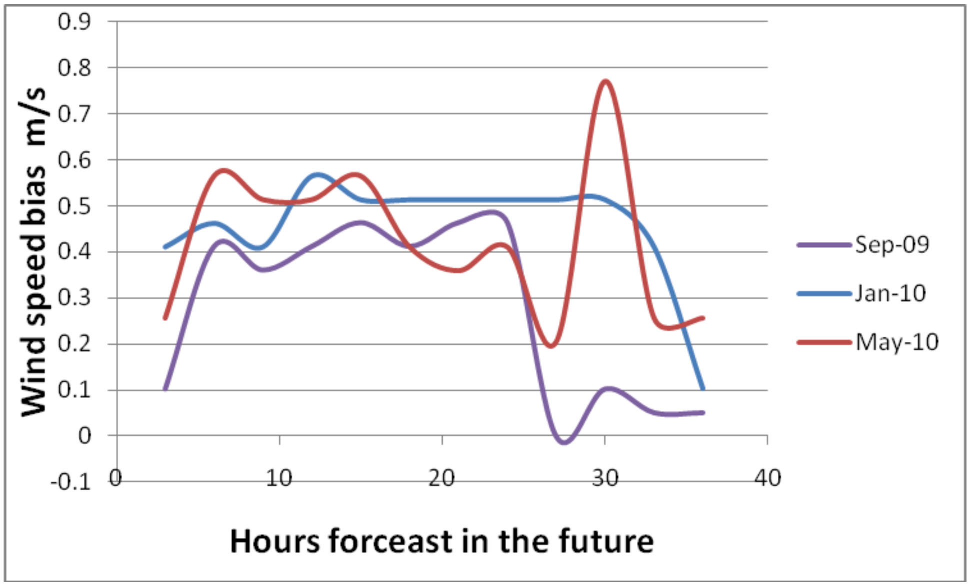
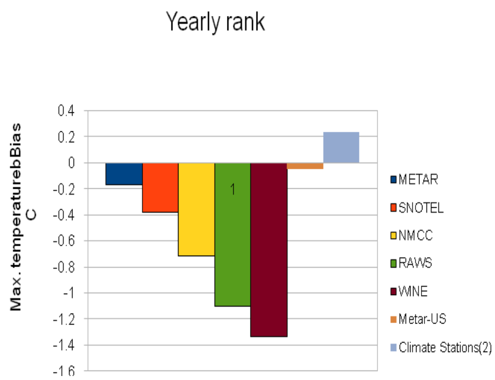


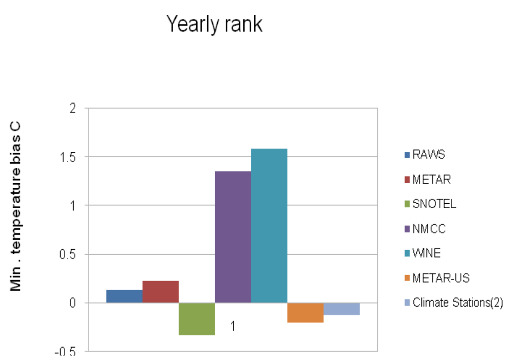
Figure 4. The hourly wind-speed (m/s) bias change with increasing forecast time in the future is calculated by the National Weather Service for 1,221 airport locations.

In general, the forecast error and bias for all of the climate variables are similar across the United States, with only the north-central states requiring more careful analysis before using the forecast data in place of measured data. Because more errors occur in the future, the latest forecast for the current day should be used to predict the climate for the next day, and that forecast data should be used in any crop or irrigation simulation model. The latest forecast run in any given day will depend on the location of the desired simulation. Consequently, the latest run time of day that should be captured will be different for East Coast states compared to West Coast states. All data must be captured for the next 24 hours and stored in the database. Because url data is updated hourly throughout the day, the time of capturing the data is important.

The different networks in New Mexico then were analyzed for comparison between forecast-measured data, and the yearly comparison of the maximum air temperature for the METAR stations only in New Mexico shows a bias of -0.17 C compared the METAR U.S. bias of -0.05 (Figure 5), which is expected when biases are averaged over a larger area. However, the biases between forecast-measured data for the other automated climate networks are larger than for the METAR climate network, increasing from -0.38 for the SNOTEL climate network to -1.3 C yearly bias for the WINE network. The largest network is the RAWS network, which has 48 stations and a yearly maximum temperature bias of forecast-measure data of 1.1 C. The minimum temperature bias is similar to the maximum temperature bias (Figure 5).

The wind speed in the forecast data, in addition to being interpolated temporally and spatially, is interpolated to a 2 m height through the use of a log-wind profile equation (Campbell and Norman, 1998). Consequently, because the roughness length which is a function of the vegetation height in this interpolation equation may not represent the vegetation condition at the other network sites, the wind-speed bias that is always positive for all networks needs to be adjusted before the data can be used in the evapotranspiration equation, or this bias (Figure 5) will lead to an overestimate of reference evapotranspiration (results shown later in this paper).





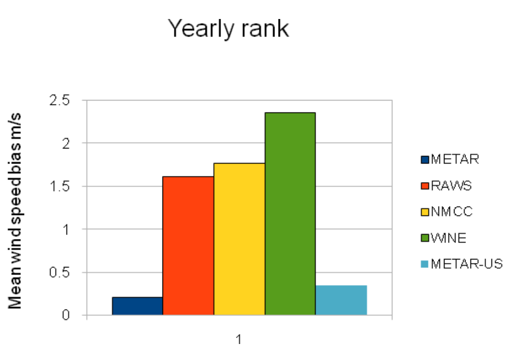
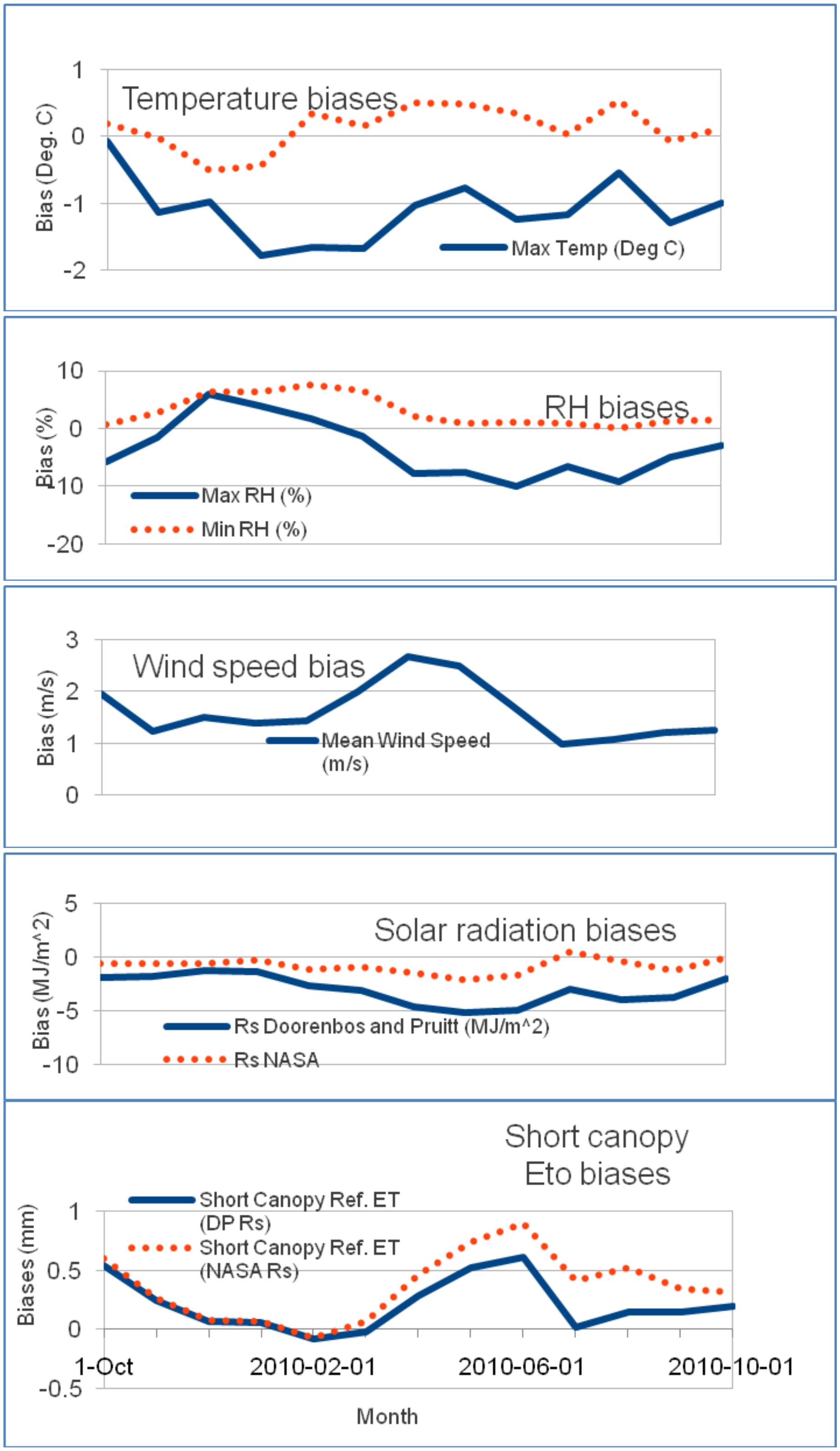


Figure 5. Yearly ranking of maximimum and minimum air temperature and mean daily wind speed bias for five climate networks. The SNOTEL network does not have wind-speed data.

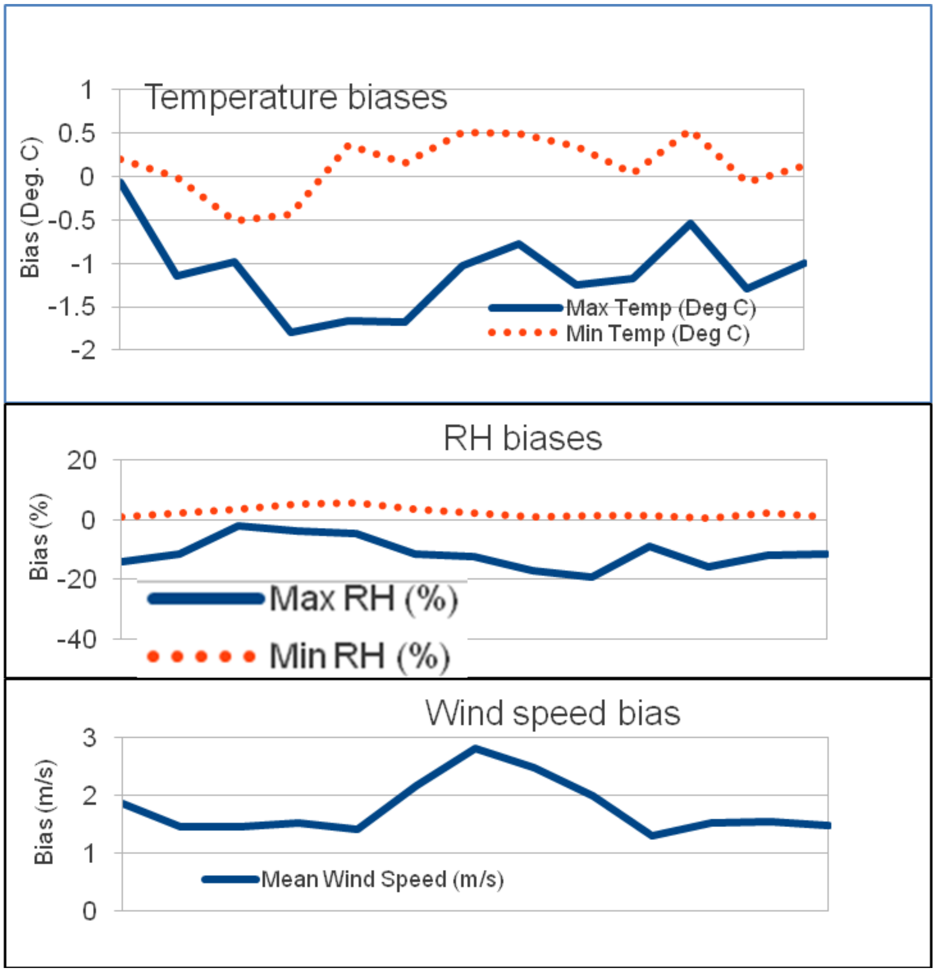
A complete climate data set, including maximum and minimum daily temperature, maximum and minimum daily humidity, average daily wind speed and total solar radiation, is needed to calculate evapotranspiration under non water stress conditions using the reference Et Penman-Montheith equation which is scaled for each crop using a crop coefficient (Equation 2). Consequently, only a comparison between forecast and measured data for the networks having a complete climate data set can be conducted. These include the RAWS, NWCC and the WINE climate networks. The other networks are lacking in one or more measured climate elements needed by Equation 2. Again, these represent a reason to use forecast data instead of measured data because many automated climate networks are missing one or more climate elements needed to calculate the Penman-Montheith equation. Simpler equations to calculate reference Et that use only temperature or temperature and solar radiation can be used with these climate networks, but research has shown that the simpler equations have more error than use of the Penman-Montheith equation.

The forecast monthly series deviates from the measured RAWS data more during the winter months for temperature and humidity compared to the summer months (Figure 6). The bias error for the NWS and WINE data is similar througout the years (Figures 7 and 8). However, wind-speed forecast estimates are more accurate during the winter than during the summer months for both RAWS and NWS, and WINE data sets (Figures 6, 7 and 8). The forecast solar radiation determined from the percent cloud cover has a larger bias during the summer months compared to the rest of the year for both data sets because during the summer months, solar radiation is affected by thunderstorm activity where part of the sky is covered with clouds and part is open sky. Consequently, this patchy cloud cover results in errors when using the simple regression model of FAO24 to reduce clear-sky radiation to cloud cover solar ratiation levels (Figures 6, 7 and 8).



Temperature biases
Bias (Deg. C)
1
0
-1
-2
Max Temp (Deg C)
RH biases
Bias (%)
10
0
-10
-20
Max RH (%)
Min RH (%)
Wind speed bias
Bias (m/s)
3
2
1
0
Mean Wind Speed (m/s)
Solar radiation biases
Bias (MJ/m^2)
5
0
-5
-10
Rs Doorenbos and Pruitt (MJ/m^2)
Rs NASA
Short canopy Eto biases
Biases (mm)
1
0.5
0
-0.5
Short Canopy Ref. ET (DP Rs)
Short Canopy Ref. ET (NASA Rs)
1-Oct
2010-02-01
2010-06-01
2010-10-01
Month

Figure 6. RAWS climate network monthly biases (forecast-measure from Oct. 1, 2009, to Oct. 31, 2010, for the different climate elements and reference ETcalculation. The solar radiation uses the FAO 24 formula or NASA-measured satellite solar radiation.



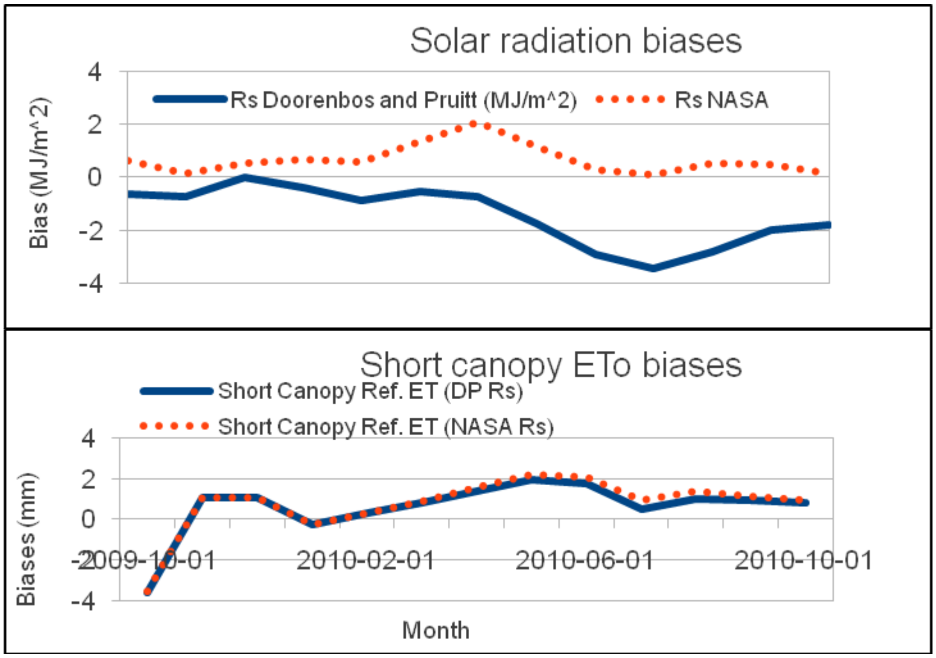
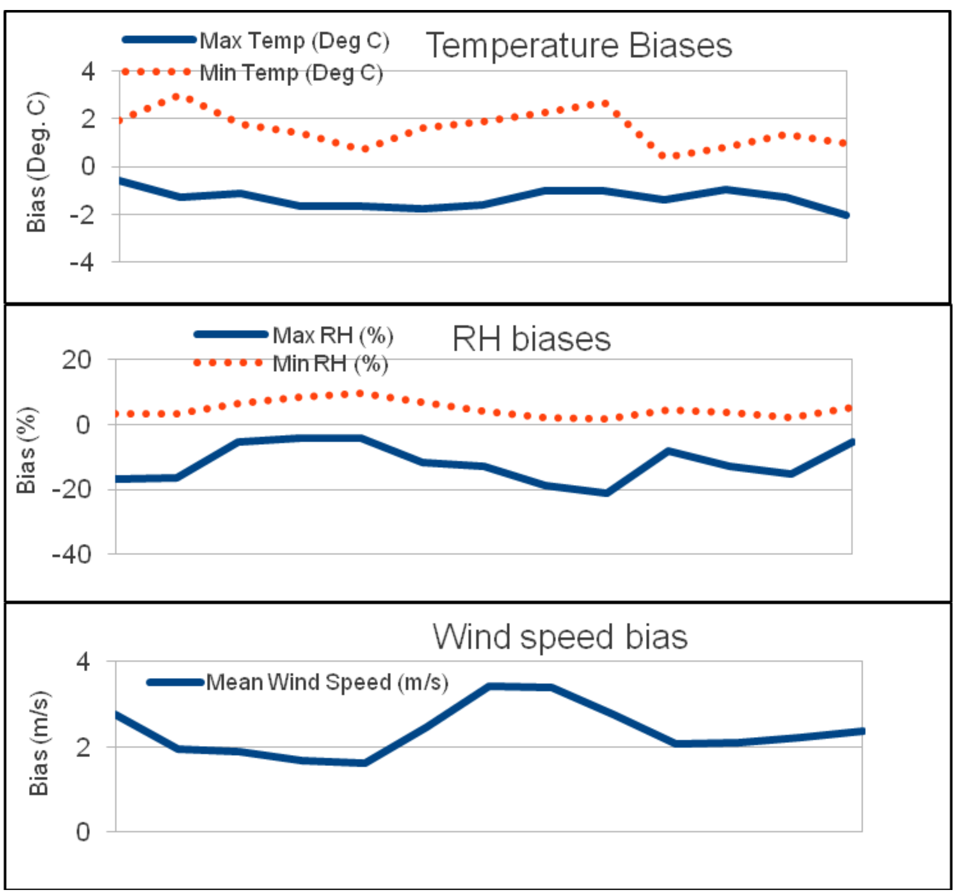


Figure 7. NMCC climate network monthly biases (forecast/measure) from Oct. 1, 2009, to Oct. 31, 2010.



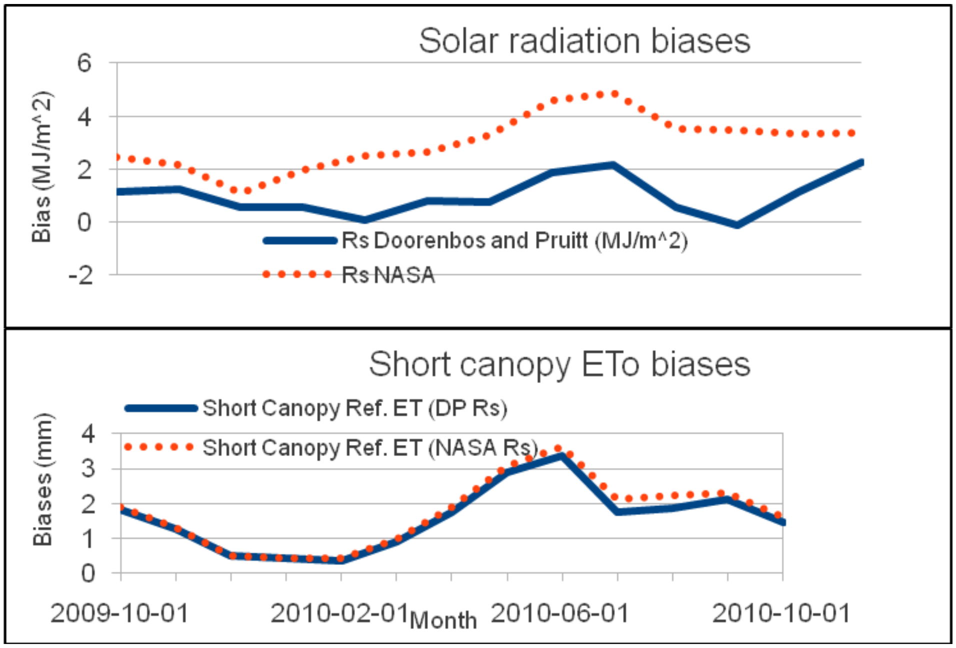


Figure 8. WINE climate network monthly biases (Forecast-measure from Oct. 1, 2009, to Oct. 31, 2010.

The solar radiation bias for all of the forecast data compared to the measured data is reduced when the radiation forecast estimated data is replaced by the measured solar radiation data from the Modes Satellite even though the footprint of the product is a grid of one degree. The yearly bias decreased from -2.99 MJ/m^2 day to -0.76 for the RAWS climate database and from -1.42 MJ/m^2 day to 0.66 MJ/m^2 day for the NWCC climate database. The decrease in bias still represents a higher bias than reported by Stackhouse et al., 2006 of 2.25% for the same product when comparing forecast-measure data. The increased bias is due to the measurement error associated with the use of Licore solar radiation instruments in the climate data sets compared to the use of Epply or equivalent solar radiation instruments used in the measured data set used by Stackhouse et al., 2006 when comparing measured to forecast solar radiation data.

The error in bias for the forecast data compared to measured data must be put into the context of the error between two adjacent climate stations. The bias for temperature and wind speed between two climate stations (data not shown) is in the same range as the difference between the forecast and METAR climate network (Figure 5). When all of the climate elements are combined in the reference evapotranspiration equation (2), and after correcting for wind bias, the average yearly bias of the difference between calculated daily reference evapotranspiration was two to two-and-a-half times larger for the forecast data minus measured data compared to the measured data of two climate stations (Figure 9). The bias of using forecast climate data goes from a plus bias to a small negative bias when wind a yearly wind speed reduction scaling factor is used in the calculations. Bias means that on an average during summer months when reference Et is 8 mm/day, the difference in calculated reference Et using two different climate stations located side by side is 2% whereas the difference between reference Et using measured climate data compared to reference Et using climate data from a forecast model is 5% . The error doubles during the winter months when reference Et is 4 mm/day (Figure 9).

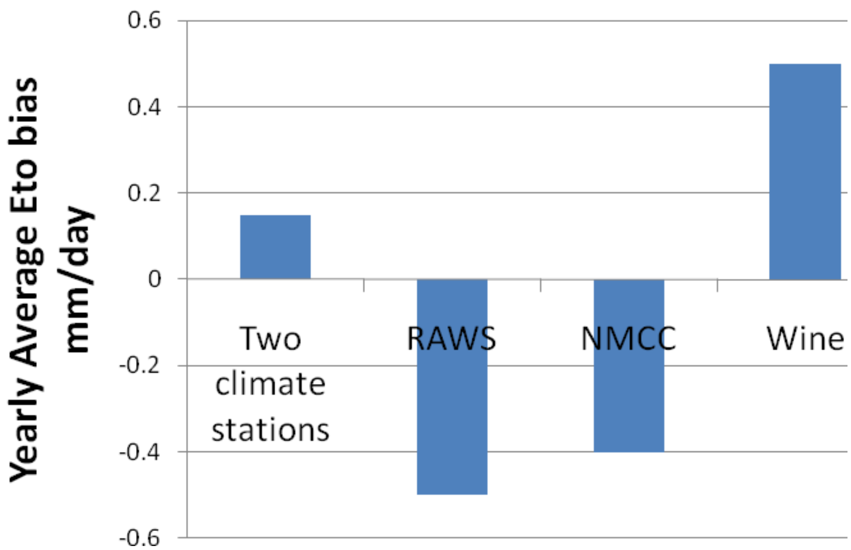


Figure 9. Reference evapotranspiration biases for different networks and for two adjacent climate stations corrected for the wind bias.

Irrigation Scheduling Model.

The forecast climate data was used to drive an irrigation scheduling water balance model to predict the evapotranspiration of alfalfa for Las Cruces, NM. The wind speed was corrected by scaling it by 0.56, the same scaling factor as used in figure 9, and the resulting daily Et was calculated with irrigation water being applied whenever soil-water stress occurred (Figure 10). The forecast data underestimates the Et in July through September, indicating that a monthly wind-correction factor should be used to adjust the forecast wind speed rather than a yearly correction factor. During those months, the correction factor should be 1.0. In Las Cruces, the July through September represent thunderstorm activity instead of frontal storms that occur during the winter months. The forecast wind data is not overestimated during this time period as it is during the rest of the year.

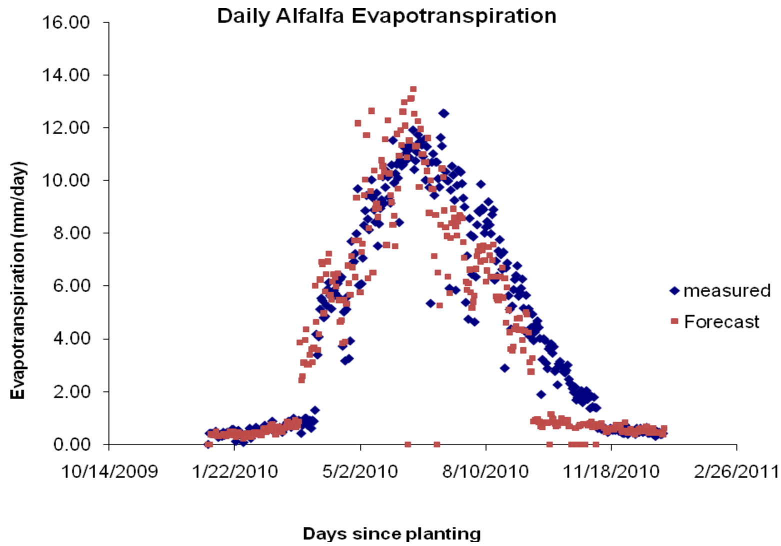


Figure 10. Simulated daily evapotranspiration of alfalfa for Las Cruces, using measured and forecast climate data.

Conclusion

Forecast climate data can be used to replace measured data to be used in agricultural support systems requiring climate data. The spacing of climate stations to measure climate parameters depends on topography, microclimate, vegetation in the surrounding area, and the geography of the area. Computer-based irrigation scheduling models use solar radiation, air temperature, humidity, and wind speed to calculate reference evapotranspiration and then schedule irrigation based on the water balance equation. The forecast data has the smallest bias when compared to measured data at METAR sites because this data is one of the major data sets used to calibrate the forecast model. However, the bias is smaller when comparing the biases over the entire United States to the bias of climate variables for New Mexico. As the climate network switches from the federal government-maintained stations to state networks, the bias error increases. Some of the increase could be due to the location of the climate stations, or the bias error could be due to poorer maintenance. Consequently, if funding is available to maintain the network and good quality control is performed on the measured data, then measured data is preferable to forecast data. Results indicate that monthly bias of forecast-measured data increases by a factor of two when the forecast time increases from a 24-hour forecast to a 120-hour forecast. Reference evapotranspiration's monthly bias ranges are positive and range from 0 in the spring to 1 mm/day in the middle of the summer for the RAWS network and 0-2 mm/day for the irrigated New Mexico Climate Network because of the overestimation of temperature, underestimation of humidity and overestimation of wind speed. However, the main difference in reference Et calculations when using forecast or measured climate data is caused by the overestimation of wind speed in the forecast climate data set. The forecast model is a large-scale macro model and does not represent the small irrigated areas in the valleys of New Mexico but represents the climate conditions in the large, surrounding dry-land mesa where wind speeds are high due to spares vegetation and consequent less wind surface drag. The forecast model is calibrated in the United States using airport data, and in the western United States, airports typically are on dry-land mesas, not in irrigated valleys. If the forecast climate data is used to calculate reference Et it in an irrigated scheduling model, then the wind speed needs to be adjusted downward.

Acknowledgements

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Agricultural Irrigation Using Municipal Effluent

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Abstract. *The paper describes the development of a design and management plan for disposing of secondary effluent originating in the urban communities. It highlights the differences in approach that a public utility must take, versus a typical agricultural irrigation application. Costs and requirements for municipal effluent irrigation are many times greater. The complexity of regulations and agency procurement procedures relegates the actual irrigation system design to a relatively small role in the total project.*

Keywords. Irrigation, agriculture, effluent, regulations, management.

Introduction

An irrigation project involving the application of secondary effluent is very different from a typical agricultural irrigation project. Costs and complexity are many times greater because of (i) the way municipal utilities are accustomed to doing business, and (ii) the involvement of numerous regulatory agencies that range from local county governments to the US Corps of Engineers to the State Regional Water quality control board. These agencies and utilities take the project out of the hands of the farmers and designers and add multiple unique layers of issues into the system design and implementation.

Typical Agricultural Irrigation Approach

In a typical agricultural center pivot application on a farm that is not utilizing secondary effluent, a farmer will call up one or more irrigation dealers and get a quote for an irrigation system. The dealer will give the farmer a price with very few detailed specifications. The decision about which dealer to select may be based more on personal comfort levels than on price and detailed bid specifications. No permits are typically needed for the installation. The dealer installs the pivot and the supply pipe (if needed) and cable. Either the dealer or a local pump company will install the well, pump, and pump driver (electric or diesel, for example). Everything can be done within a very short time period.

The farmer already knows how to farm, and has the required equipment for land preparation, seeding, harvesting, etc. If the farmer is lucky, there will have been conversations about possible runoff problems and wheel ruts and how to deal with them. If the farmer did not have a good irrigation dealer, the farmer will somehow, over a few seasons, learn how to deal with those problems. A little bit of runoff and spray loss is usually no big concern.

Public Utility Approach to Irrigation

For a utility that decides to dispose of secondary effluent via agricultural irrigation, there is a completely different approach. The utility will generally pursue the following course of action (abbreviated here):

1. Feasibility studies of the property must be conducted by various consulting firms. They will examine the water supply and water quality, develop soils maps, compile GIS maps that include boundaries and topography, study the extent of high water tables in the area, etc. This will take a few years.
2. The utility will then need to obtain a whole range of initial permits, from county government to regional water quality control boards. Each agency will add special requirements to the package – including those related to appearance, mitigation of wetlands, etc.
3. Another consulting firm will examine the feasibility of irrigation, and make recommendations regarding how many acres can be farmed, where they will be, and what methods of irrigation should be used. Up to and through this step, commercial agronomists and irrigation dealers have not been involved.
4. Using the preliminary irrigation design, the utility will issue a Request for Proposals (RFP), receiving responses from a variety of consulting engineering firms. The RFP will describe the needs for engineering services to include the final design of the irrigation system and drawings and specifications. The selected engineering firm will also be responsible for responding to requests from various regulatory agencies, obtaining various permits, performing more detailed topographic and soil surveying, etc.
5. The selected consulting engineering firm must then examine the available information and recommendations, and decide if/what changes should be made. Detailed design and specification documents must be developed, and cost estimates must be made. A complete farming plan is also generally needed, with advice regarding the crops to be planted.
6. The design then goes through numerous iterations as comments are received from other agencies, continuously morphing until a final project is identified. At this point, the project goes out to bid.
7. Because public utilities are accustomed to working with general contractors that handle a complete project via one contract, the utility will usually favor having one contractor be responsible for the center pivots, the piping, pumps, remote monitoring, soil moisture sensors, construction of reservoirs and concrete structures, berms, and land preparation – all done in accordance with detailed specifications and drawings that are typical of civil engineering projects such as bridge construction or building design.

The Contrast

For a typical farmer, almost everything is related to just getting a pivot installed and operating. The farmer does not expect to see detailed drawings of everything, and the irrigation dealers will field-fabricate parts and pieces as necessary. Irrigation dealers will have minimal drawings, and instead rely on an installation crew that is very familiar with that type of installation, and which can improvise when needed. If a concrete block somehow appears in a field, the dealer will make adjustments on the spot and remove it or go around it. The utility approach is quite different; it is expected that everything be defined in advance. On-the-spot adjustments are not expected.

A farmer will also contract independently with various companies for unique services. For example, the farmer would usually not expect the irrigation dealer to also know about fertilizer mixes and the details of irrigation scheduling. The farmer will obtain farming equipment from one source, fertilizer from another, the pumps and electrical from a third source, and the pivots and piping from a fourth source. In this way, the farmer hopes to "cherry pick" or select from the best available expertise or equipment for each function. In a sense, the farmer acts as the general contractor and arranges for each of the "subcontractors".

A public utility, on the other hand, has established procurement procedures. As a public agency, it must open the bidding process to a wide range of companies. So the specifications must be very tight so that everyone is bidding on the same package. Furthermore, since it is not a "design/build" project, it is expected that all of the details are presented in the bid package so that there are very few, if any, unknowns for the contractors.

Another big difference is that utilities generally have a policy of not wanting to favor one brand or model over another. This has merit, of course, but it is also problematic in the agricultural irrigation world. The fact is that there can be substantial differences in quality and performance between various brands and models. A reputable irrigation dealer will know, through experience, which brands and models will function well and continue to function over time. The dealer will know that although the written specifications of product "A" and product "B" may look the same, it could be devastating to use product "B" because of poor quality control.

This type of judgment cannot enter into the bid package of the utility. Instead, the utility will require that the consulting engineer write very detailed specifications (hundreds of pages long) to avoid getting inferior products. But since the consultants often have very little field experience with agricultural irrigation systems, this is problematic.

The bid package documents must also follow utility specifications that require complex insurance coverage, adherence to various pay rates, and numerous other contract-related items.

In the end, the project documents are so exhaustive that a typical irrigation dealer is likely unable to bid on a project for one or two center pivots. The process will be dominated by activities and concerns that usually fall outside the normal scope of work by irrigation dealers. Therefore, the dealer will be one of several subcontractors on the job and primarily function as a supplier of equipment and installation, as opposed to a supplier of technical expertise.

Environmental Considerations in Design and Management

There are good reasons for the involvement of regulatory agencies in the review of secondary effluent irrigation applications – although sometimes the involvement can be excessive and unrealistic. Secondary effluent can have two problematic constituents not found in typical agricultural irrigation projects: (i) disease-causing organisms, and (ii) high nitrogen loads. Because of these concerns, a number of careful precautions must be put into place.

Runoff and Wind Drift. The extent of disease-causing organisms will depend upon the extent of the effluent treatment. In some cases, large devices and clumps of various materials will appear in high quantities in the irrigation water. In such cases, not only are there health issues, but filtration becomes very important. In other cases, the secondary effluent has been filtered and chlorinated before reaching the irrigation system. It is not drinkable, but it won't plug sprinklers. In all cases, however, people do not want to see even a drop of effluent irrigation water spraying or drifting across the fence or running off a field. Drivers on county roads who get a wet windshield tend to become agitated. Bikers become even more agitated when they get wet with effluent water.

Special consideration must be given to the sprinkler packages to avoid wind drift of spray/sprinkler droplets. This means that end guns may not be a viable option, for example. Instead, sprinklers that rotate at relatively low pressures and that can be suspended relatively low are ideal. Center pivots are often the irrigation method of choice for large installations because of their relative simplicity, low cost, and the ability to remotely control them and minimize human contact.

Due to the controllability of pivots, they can easily be managed to not operate during windy times of the day, by turning on and off either manually or automatically. This, of course, requires a reservoir buffer for the water supply – which is generally a part of any effluent project because the flow rate from a treatment plant will not be constant.

Surface runoff can also be a major consideration, especially during a rain. Regulatory agencies generally require that no surface runoff be allowed. This means that berms must be constructed with some type of pumpback and storage system. The sprinkler package must also be selected to minimize runoff, and the pivot rotation speeds are generally set as high as possible in order to maximize evaporation (completely different from typical production agriculture) and to minimize runoff.

Because some effluent water has a high percentage of sodium, it is important to assess the water and soil quality and attempt to preempt water-quality related infiltration problems. While water-applied gypsum treatments can be valuable, their complexity often leads to high soil-applied gypsum treatments to counter the influence of sodium. Special attention also needs to be paid to surface roughness. For example, if furrows are used they should be on the contour if possible, and dammer-dikers can be used to temporarily store small amounts of runoff.

Nitrogen. The dominate factors regarding nitrogen in secondary effluent that impose special requirements on irrigation system design are:

1. The nitrogen concentrations are much higher than in irrigation water.
2. Some deep percolation of irrigation water will always occur due to non-uniformity and timing issues. Rainfall cannot be completely anticipated and will often cause additional deep percolation.
3. Regulatory agencies will limit how much nitrogen can deep percolate, in an attempt to protect the quality of the groundwater and surface water supplies.
4. Regulatory agencies will generally require some type of field verification program that demonstrates adherence to regulations about not contaminating the groundwater with high nitrogen loads.
5. The flow rate from sewage treatment plants is relatively constant throughout the year, but the evapotranspiration rate of irrigated plants is quite variable; it is highest during the summer and lowest during the winter.

Cropping Patterns. A cropping pattern must be developed that will consume the irrigation water plus the nitrogen. Alfalfa is a legume that is capable of fixing atmospheric nitrogen to meet its nitrogen needs, but if other nitrogen sources are available (for example, from the irrigation water), alfalfa has a preference for these other sources. Alfalfa is also a crop that has a relatively high annual evapotranspiration (ET) rate.

However, having only alfalfa as the irrigated crop can only be successful if there are huge storage (reservoir) facilities that can store winter treatment plant flows and apply that effluent to the fields during the summer. The reservoir is needed because the variable ET of alfalfa is not compatible with the constant sewage treatment plant outflow. This is the strategy that the Los Angeles County Sanitation Districts (LACSDs) now uses in the Palmdale and Lancaster projects for which ITRC provides irrigation management and monitoring services. The South Tahoe Public Utility District design, which ITRC is currently working on, has a similar reservoir storage capacity.

Another cropping strategy is to vary the acreages of different crops to create a relatively constant ET rate throughout the year. This was an early strategy by LACSDs in Palmdale and Lancaster, and the ITRC-developed cropping pattern and water management was definitely more complex than with a large seasonal reservoir. Varying the crops also requires a very large acreage, because the ET rate is low during the winter. ITRC used a combination of perennial alfalfa plus winter small grains to meet the objectives of consuming both nitrogen and water.

Irrigation System Distribution Uniformity. Irrigation systems for effluent disposal require higher-than-typical distribution uniformities (DU). An excellent DU helps to minimize deep percolation, but just as important is the need to be able to have excellent soil monitoring. Regulatory agencies will typically require extensive monitoring of soil moisture contents as part of the verification program. The concept is very simple, but in reality, if different parts of the field have different applications of water, the soil monitoring can become fairly meaningless. It is difficult enough to get good soil moisture readings in uniform soil moisture conditions; having different application rates can make the monitoring program incredibly complicated.

Crop Uniformity. Residual soil moisture (which results in deep percolation) is impacted by uneven crop ET rates across a field, just as it is impacted by uneven water application rates. Therefore, it is important that highly monitored fields have uniform crop growth. This requires special attention to spatial variability of nutrition and soil types, and the development of spatially variable treatment programs.

Irrigation Scheduling. Assuming that water is applied uniformly, and crop ET is uniform across a field, the next concern regarding deep percolation management is the correct estimate of crop ET rates. This requires a mix of classical weather-based procedures and soil moisture monitoring. However, for effluent disposal the scheduling is somewhat more complex because a serious attempt must be made to anticipate rainfall events in order to deliberately dry out root zones so that as much rainfall as possible can be stored within the root zone (as opposed to deep percolating).

An additional layer within the irrigation scheduling is the nitrogen balance. For regulatory purposes, both the water and nitrogen must be consumed. Plant nitrogen uptake rates must be estimated and then verified with frequent plant tissue samples.

Verification and Reporting. As mentioned above, regulatory agencies may require that the public utilities submit quarterly and annual reports that provide evidence of good management and verification. This is a major economic consideration. It requires an excellent monitoring program that involves soil moisture and nitrogen sensors, flow rate measurement to individual parcels, crop pattern reporting, verification of irrigation system DU, automated weather station data and ETo values, etc. All of this information must be organized for both daily scheduling/management purposes and for the reports.

Summary

A casual glance at an agricultural irrigation system used for effluent disposal will give no indication of the costs, or of the efforts required for design, planning, management, verification, and reporting. What to an irrigation dealer should be a simple, inexpensive center pivot design is in fact a part of a very complex process, most parts of which fall outside the realm of agricultural irrigation dealers. In current secondary effluent irrigation projects, the design/bid process is generally structured so that the dealer is only a provider and installer of equipment as specified by others. However, the design of a successful system requires the special expertise that, in many cases, the dealer has but the utility's contractor does not. A major challenge is to bring the dealer's expertise into the process at the earliest possible time and in a manner such that the knowledge and expertise of the dealer can be effectively used.

Nitrate Levels at Different Growth Stages of “Biofilter” Forages Irrigated with Dairy Effluent and Municipal Waste Water

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Abstract. *There is an increasing need to minimize the potential of nitrate contamination of groundwater from dairy effluent and municipal waste water. One such remediation technique is to grow nitrogen (N) scavenging crops, commonly referred to as “bio-filters”, which also have the potential to be used as forages. In our previous studies Elephant grass (Pennisetum sp.) has been identified as a highly nutritious forage crop with the ability to readily take up N from soils subjected to high N rates. In this phase of our research, our objective was to evaluate optimal harvest time for Elephant grass and Sudan grass (Sorghum bicolor) irrigated with secondary treated municipal waste water (MW) and dairy effluent (DE). The grasses were grown in 5 gallon pots in greenhouse experiments set up as completely randomized designs (CRD) with three rates (0, 50 and 100 percent) of effluent, and replicated four times with three harvest times (8, 10 and 12 weeks). Findings from the first round of trials completed in Spring 2011 indicate that the average biomass for the grasses harvested at 8 and 10 weeks were generally higher for plants irrigated with the DE than those irrigated with the MW. By the 12th week, similar yields were obtained for each grass regardless of the water source. Generally, the highest crude protein (CP) content and total digestible nutrients (TDN) were detected in grasses harvested at eight weeks. The exception was the EG treated with MW, which had its greatest CP and TDN values at 12 weeks. Grasses irrigated with DE exhibited their greatest nitrate content earlier (at 8 weeks) than those receiving MW. More importantly, the grasses receiving MW accumulated as much as five times more nitrate than the grasses treated with DE.*

Keywords. Elephant grass, Sudan grass, biofilter, scavenging crop, dairy effluent, municipal wastewater, water reuse, secondary treated wastewater, nitrate contamination.

Introduction

In California, which is now the number one dairy producing State in the U.S. (CDFA 1999 & 2003), dairy manure is commonly handled as an effluent stream of liquid or slurry by means of a hydraulic flushing - lagoon storage - irrigation system. Dairy effluent with high nutrient contents can cause overloading of land with nutrients, especially nitrogen and phosphates, and thereby have the potential to contaminate surface and ground water resources. The Central San Joaquin Valley of California with its growth of Concentrated Animal Feeding Operations (CAFO) and sprawling urban development is a paramount example of the serious problems in the United States of accommodating population growth in prime agricultural land areas. An intensive study of shallow groundwater wells around diaries in this Valley indicates that within the diaries nitrate-N (nitrogen) levels were 64 mg/l compared to 24 mg/l immediately up-gradient of these dairies (Harter, 2001).

In addition to dairy products, land application of secondary treated municipal wastewater (MW) from wastewater treatment facilities allows for the beneficial reuse of nutrients, organic matter, and water. In this scenario, the soil profile is expected to "treat" the process water and prevent degradation of groundwater. However, some constituents may pass through the soil profile and detrimentally impact groundwater.

Excess nutrients from irrigation of crops with recycled wastewaters from municipal facilities can therefore be a major potential source of groundwater pollution. Hence, a major component of any Best Management Practice (BMP) should be the inclusion of either an agronomic crop or perennial forage capable of utilizing the nutrients applied in the wastewaters. "Promor A" perennial forage grass (*Pennisetum Sp.*), commonly called Elephant grass, was introduced into California in 1994. Elephant grasses are perennials and are grown throughout the tropical world and are one of the most widely used forages for large and small animals. Since the introduction of the Elephant grass into the U.S. via official quarantine channels it has been subjected to a series of trials to test its bio-filtering characteristics, forage qualities, agronomic qualities, water use efficiency and its tolerance to insect pests and diseases.

In a previous study (Goorahoo et al., 2004) a trial with Elephant grass was conducted at the Center for Irrigation Technology (CIT), in Fresno, California with the following objectives:

- Determination of the nitrogen and phosphorus filtering characteristics of the grass;
- Determination of water consumption of the grass; and,
- Estimation of any possible interactions between bio-filtration and water consumption.

In that study a "Nutrient Farm Balance" protocol was established to determine the biofiltration characteristics of the grass (Barry et al, 1993; Goss and Goorahoo, 1995). The irrigation protocol was based on the daily reference evapotranspiration index (ETo), and treatments consisted of water applications of 40%, 80%, 120%, and 160% of the daily ETo. General findings were that the Elephant grass appeared to have significant potential for scavenging excess soil nitrogen and phosphorus and can be very useful in a bio-filtration system aimed at managing irrigation or recycled water, such as dairy or food processing wastewaters. The stooling growth habit of this grass should provide a secondary benefit through reduction of water velocity and consequent sedimentation of water borne particles when the grass is used as barrier plantings or buffer strips.

In the current study, our overall goal was to continue to evaluate the potential of the Elephant grass as both a biofilter and as a forage grass. Specifically, the objective was to evaluate optimal harvest time for Elephant grass irrigated with secondary treated municipal waste water (MW) and dairy effluent (DE). For comparison a similar experiment was conducted on Sudan grass (Sorghum bicolor).

Materials and Methods

The study was conducted in one of the California State University- Fresno (Fresno State) greenhouses. The grasses were grown in five gallon pots filled with a sandy soil collected from a wastewater treatment facility (WWTF) and a sandy loam soil the campus fields, for experiments irrigated with secondary municipal wastewater (MW) from the WWTF and with dairy effluent (DE) from the Fresno state dairy, respectively. The pots were lined with plastic bag to maintain a closed system.

Two experiments were set up as completely randomized designs (CRD) with three rates (0, 50 and 100 percent) of effluent, and replicated four times (Figure 1). Hence each experiment consisted of 72 pots of which half were Elephant grass (EG) and the other half were Sudan grass (SG).

A starter fertilizer was applied for the onset of the plants and plants were irrigated on a regular basis based visual and “feel” observations of soil moisture during the first six weeks. Starting from the seventh week MW and DE were applied based on the soil moisture content in the pots.

The pots were labeled for the harvest time and at the end of the 8, 10 and 12 weeks whole plants were removed for analysis. The plant samples were analyzed for biomass, crude protein (CP), total digestible nutrients (TDN) and nitrate (NO_3). A representative soil sample was taken from each pot after plant harvest for determination of pH, Electrical Conductivity (EC), total nitrogen, ammonia and NO_3 at a later date, using the techniques outlined by Gavlak et al. (2003).

Data collected was subjected to analyses of variance using the univariate general linear model available for a completely randomized design using the SPSS® software (SPSS, 2010).

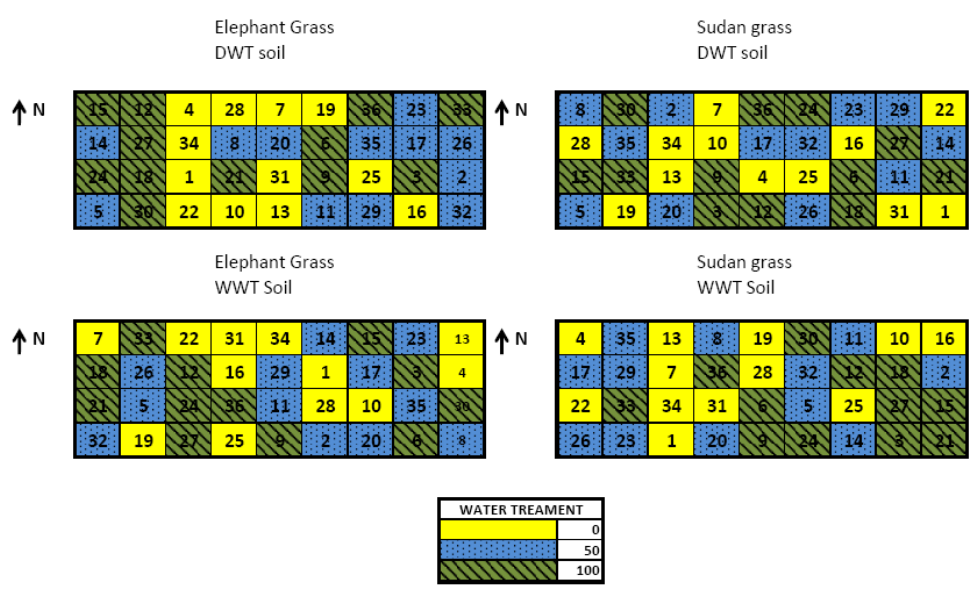

Figure 1. Greenhouse experimental layout and irrigation treatments

Results and Discussion

Figure 2 in an example of trends observed for average biomass of the grasses for plants grown in the sandy loam soil and irrigated with DE. Similar trends were observed for plants receiving MW. Generally, the average biomass for the grasses harvested at 8 and 10 weeks were generally higher for plants irrigated with the DE than those irrigated with the MW. By the 12th week (Harvest 3), similar yields were obtained for each grass regardless of the water source.

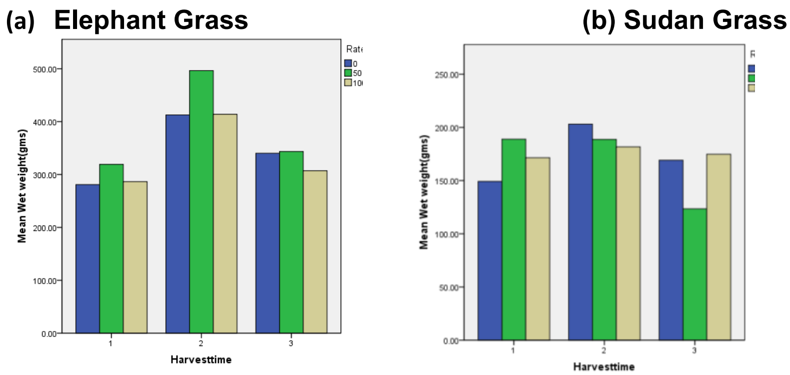

Figure 2. Average biomass values for grasses irrigated with dairy effluent (DE) at harvests 1, 2, and 3 which is equivalent 8, 10, and 12 weeks, respectively after planting.

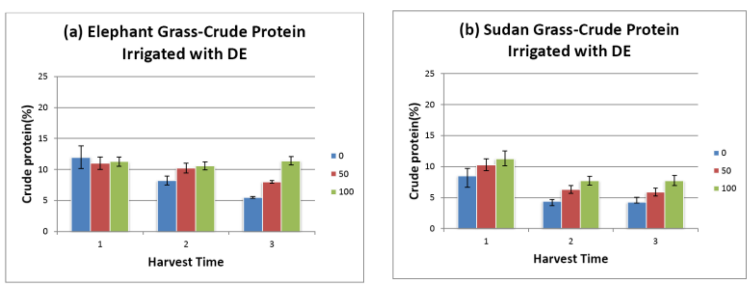

Figure 3. Crude protein (CP) content of grasses irrigated with dairy effluent (DE) at harvests 1, 2, and 3 which is equivalent 8, 10, and 12 weeks, respectively after planting.

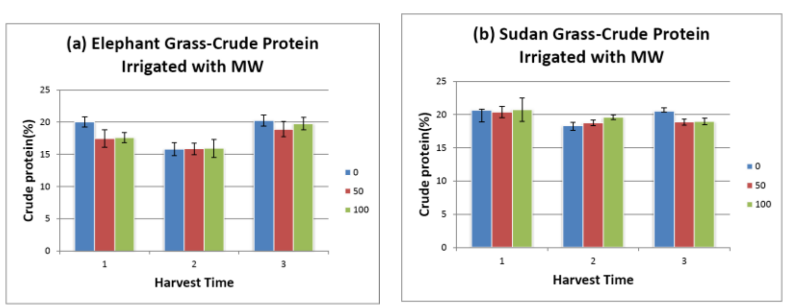

Figure 4. Crude protein (CP) content of grasses irrigated with municipal wastewater (MW) at harvests 1, 2, and 3 which is equivalent 8, 10, and 12 weeks, respectively after planting.

Figures 3 and 4 show trends in the crude protein contents determined for the two grasses subjected to the various irrigation waters. Generally, the highest crude protein (CP) content and total digestible nutrients (TDN) (Figures 5 and 6) were detected in grasses harvested at eight weeks. The exception was the EG treated with MW, which had its greatest CP and TDN values at 12 weeks. The CP and TDN values represent the total protein of the feed from all sources, and an estimate of the digestible protein, fiber, carbohydrates and fat, respectively, of the feed (SDK, 2011). Based on the laboratory interpretations provided by SDK (2011), it would appear that any given harvest time, the quality of both grasses were similar in term of protein content. This is an important finding for the EG as growers are constantly seeking out alternative forages to SG which can be used to feed animals and also have the potential to take up nitrates- i.e. be an effective biofilter.

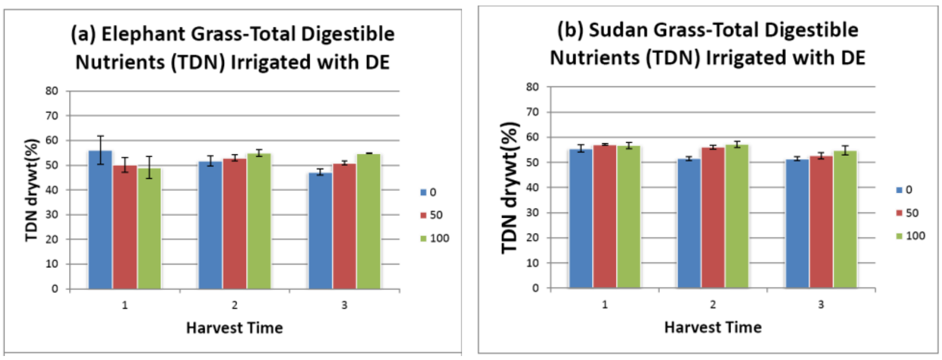

Figure 5. Total Digestible Nutrients (TDN) of grasses irrigated with dairy effluent (DE) at harvests 1, 2, and 3 which is equivalent 8, 10, and 12 weeks, respectively after planting.

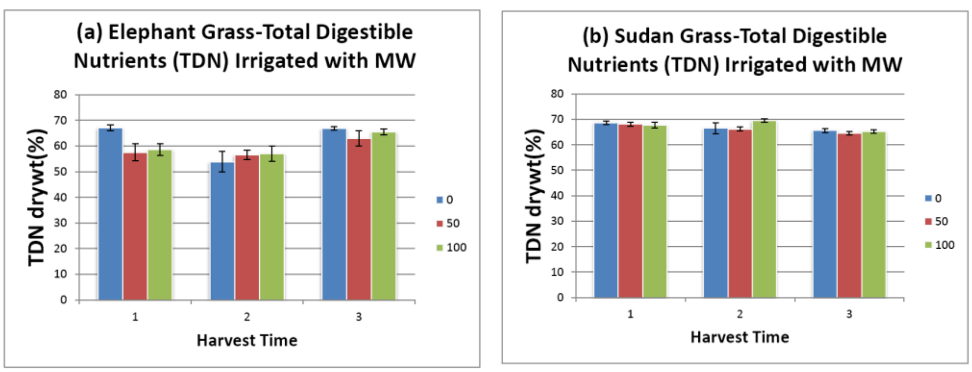

Figure 6. Total Digestible Nutrients (TDN) of grasses irrigated with municipal wastewater (MW) at harvests 1, 2, and 3 which is equivalent 8, 10, and 12 weeks, respectively after planting.

Figure 7 is an example of the nitrate trends detected in the grasses irrigated with the DE and harvested at 8, 10 and 12 weeks after planting. Generally, grasses irrigated with DE exhibited their greatest nitrate content earlier (at 8 weeks) than those receiving MW. More importantly, the grasses receiving MW accumulated as much as five times more nitrate than the grasses treated with DE. Furthermore, with the exception of the EG receiving 100% DE and harvested at eight weeks, the grasses should be safe for animal consumption. For example, forages with nitrate levels ranging from 0- 6,500 ppm can be safely fed to non- pregnant animals (SDK, 2011). In the case of forages with levels between 6,500 and 9,000 ppm nitrate, these can safely fed if limited to 50% of the total dry matter ration. The current findings concur with those from our previous studies (Goorahoo et al., 2004) in which Elephant grass was been identified as a highly nutritious forage crop with the ability to readily take up nitrate from soils subjected to high rates of N fertilization.

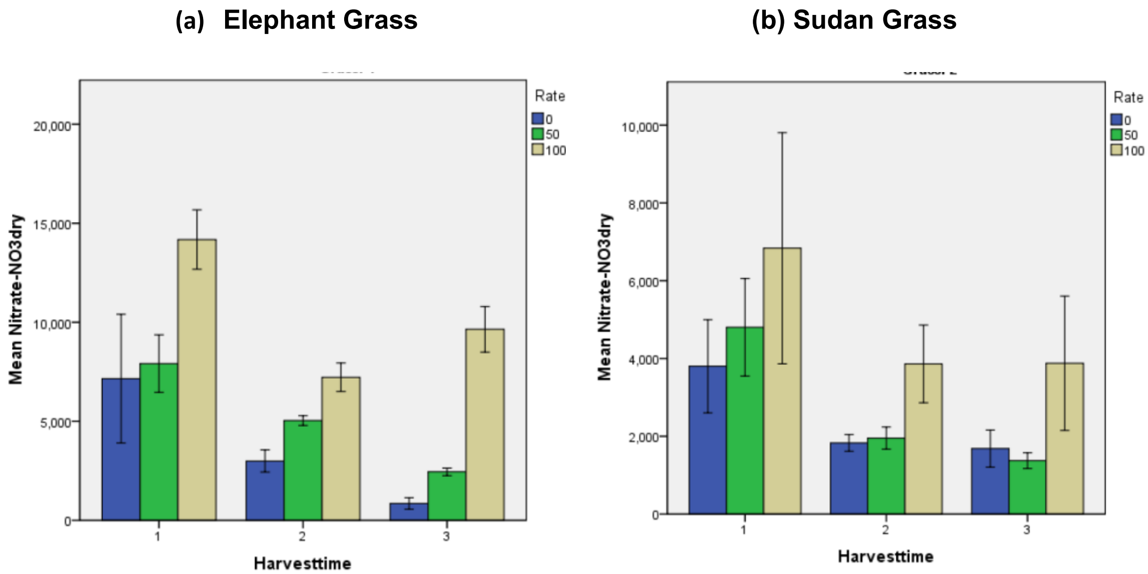

Figure 7. Average nitrate levels in grasses irrigated with dairy effluent (DE) at harvests 1, 2, and 3 which is equivalent 8, 10, and 12 weeks, respectively after planting.

Conclusion

The findings summarized below represent those obtained from the first rounds of our ongoing study to evaluate optimal harvest time for Elephant grass and Sudan grass irrigated with secondary treated municipal waste water (MW) and dairy effluent (DE). A second trial will be conducted during Spring 2012 and complete findings should be available by June 2012.

- The average biomass for the grasses harvested at 8 and 10 weeks were generally higher for plants irrigated with the DE than those irrigated with the MW.
- By the 12th week, similar yields were obtained for each grass regardless of the water source.
- Generally, the highest crude protein (CP) content and total digestible nutrients (TDN) were detected in grasses harvested at eight weeks. The exception was the EG treated with MW, which had its greatest CP and TDN values at 12 weeks.
- Grasses irrigated with DE exhibited their greatest nitrate content earlier (at 8 weeks) than those receiving MW.
- Grasses receiving MW accumulated as much as five times more nitrate than the grasses treated with DE.
- The findings from this current trial concur with those from our previous studies in which Elephant grass has been identified as a highly nutritious forage crop with the ability to readily take up N from soils subjected to high rates of N fertilization.

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Fertigation management for tomato production in saline soils

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Abstract. *Nutrient availability is a major problem for vegetables grown in saline environments. In tomatoes, calcium deficiency can lead to blossom-end rot during periods of reduced plant transpiration. The objective of our study was to evaluate different management strategies to increase calcium availability in saline soils, including calcium fertilization and irrigation water acidification. Four treatments were compared in a commercial processing tomato field: two calcium-based fertilizers (calcium ammonium nitrate and calcium thiosulfate), water acidification, and a conventionally used nitrogen fertilizer (urea ammonium nitrate). Treatments were applied through a sub-surface drip system and replicated four times in a randomized complete block design. Results indicated that the calcium thiosulfate treatment produced the highest yield (66.2 tons/acre; $p<0.002$) in 2009. However, no significant difference was obtained among treatments in 2010 (average of 37 tons/acre). Acidification resulted in higher incidence of blossom-end rot. Fertigation strategies did not influence the total soluble solids (Brix of 5.5-6.5^o) and root dry weights.*

Keywords. Tomato, fertigation, salinity, calcium, blossom-end rot.

Introduction

Tomato constitutes the second most important vegetable crop grown worldwide after potato with about 100 million tons produced annually on 9.1 million acres. The United States (U.S.) is the second largest producer of processing tomatoes behind China (FAO, 2008). About 96% of the nation's produce is grown in California, and particularly in the San Joaquin Valley (SJV) and Sacramento Valley (USDA, 2009; Hartz 2008).

In the western SJV where soils are predominantly saline-sodic, growers have traditionally produced cotton because of its ability to tolerate high salinity levels (Maas and Hoffman, 1977). However, in response to declining prices, cotton production has been decreasing steadily and replaced with higher value vegetable crops, such as tomatoes and onions, grown with more efficient irrigation systems, i.e. drip.

However, such transition represents new challenges. Vegetable crops are more sensitive to salinity and more susceptible to disease/deficiency when grown under saline-sodic soil conditions (Letey, 2000). In tomatoes, studies have shown that low calcium (Ca) availability in saline-sodic soils may lead to blossom-end rot (BER) (Swift, 1997; Sherf and Woods, 1979), which is a very common problem in the Westside SJV. Yield of tomatoes start decreasing when soil EC reaches 2.5 dS/m. High sodium (Na) content in soils reduces Ca uptake by plants. Furthermore, leaching of salts is much slower under drip irrigation, which can prevent optimal crop development. These problems can be addressed by supplying additional Ca fertilizer to increase soil availability or by reducing the soil pH and exchangeable sodium through acidification.

Therefore, the overall goal of this study was to evaluate different management strategies to increase calcium availability in a commercial processing tomato field characterized by high salinity levels. We compared the effects of soil calcium fertilization and irrigation water acidification on yield, incidence of blossom-end rot (BER), total soluble solids (Brix index), and root dry weights.

Materials and Methods

The research study was conducted in a commercial processing tomato field owned by AZCAL Farms, Lemoore, CA. The field was characterized by a lethent silt clay soil which exhibited salinity levels in the range of 2-8 dS/m at 0-1 ft depth. The study was conducted during two growing seasons in 2009 and 2010.

The experimental design consisted of four fertigation treatments replicated four times in a randomized complete block (RCB) design. Therefore, there was a total of 16 plots, each extending over a length of 300 ft and covering five 5.5ft-wide beds (Figure 1). The fertigation treatments were as follows:

- T1- Ammonium Nitrate (AN)
- T2- N-Phuric + Ammonium Nitrate (US + AN)
- T3- Calcium Ammonium Nitrate (CAN)
- T4 – Calcium Thiosulfate + Ammonium Nitrate (CTS + AN)

Treatments 3 and 4 included calcium (Ca)-based fertilizers; Treatment 2 was used for acidification of the irrigation water and Treatment 1 represented the conventionally used nitrogen (N) fertilizer.

The total study area, encompassing 80 field rows, was equipped with a separate sub-surface irrigation system installed to accommodate the four different fertigation treatments. Four separate manifolds were used to apply the various treatments. In 2009, acidification of the irrigation water was performed using a peristaltic pump on which the flow could be adjusted to attain a pH of 6.0-7.0. In 2010, N-Phuric was added using a Mazzei® injector. The pH was checked daily during irrigation events with a pH meter. The AN, CAN, and CTS fertilizers were stored in large tanks and injected through the sub-surface drip system. The total Nitrogen and

Calcium application rates during the growing seasons in both years were 250 lbs N/ac and 125 lbs Ca/ac, respectively. Irrigation scheduling was based on the California Irrigation Management Information System (CIMIS) data and a flow meter was installed to calculate the amount of irrigation water applied.

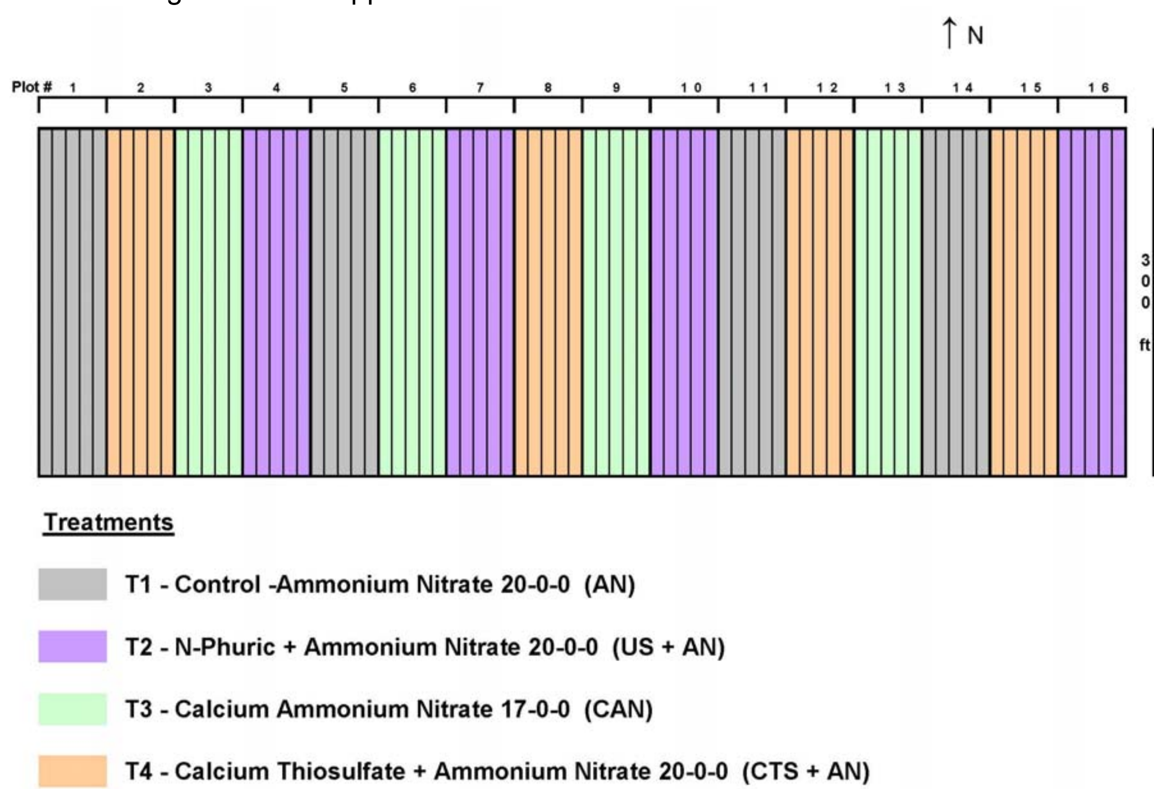

Figure 1. Field experimental layout and fertigation treatments

Plant, fruit, and soil samples were collected during both growing seasons. Leaf, petiole and fruit samples were collected at full bloom, one inch diameter fruit, appearance of first red, and at harvest. Sampling was performed at three random locations in each plot. All tissue samples were analyzed for calcium concentration. Fruit samples were analyzed for total soluble solids (expressed as degree Brix), titratable acidity and calcium concentration. Tomato harvest was performed at nine sampling locations within each plot. Tomatoes were sorted by reds, greens, breakers and blossom-end rots for yield calculations and the incidence of BER for each treatment was determined by measuring the number of fruits showing visible symptoms.

Root samples were collected at harvest and oven-dried to obtain dry mass weights. Soil sampling was performed pre-plant, post-harvest and during plant tissue sampling. Soils were analyzed for moisture, saturation percentage (SP), sodium adsorption ratio (SAR), electrical conductivity (EC) and pH (Gavlak et al., 2003). Soil sampling was performed in every plot at three locations (head, middle and tail) and at four depths (0”-6”, 6”-12”, 12”-18” and 18”-24”).

Data collected for each growing season was subjected to analyses of variance using the univariate general linear model available for a randomized complete block design in the SPSS® software (SPSS, 2010).

Results and Discussion

Figure 2 shows the average marketable yields obtained for tomatoes harvested in 2009 and 2010. Results show that there was a significant difference among treatments (p=0.002) for the marketable yield in 2009. Treatment 4 (Calcium thiosulfate + Ammonium Nitrate) provided the highest yield with 66 t/ac. However, yields obtained with Treatments 1 (Control with Ammonium Nitrate), 2 (water acidification with Ammonium Nitrate), and 3 (Calcium Ammonium Nitrate) were not significantly different. In 2010, fertigation treatments did not have an effect on yields (p=0.340).

It is noteworthy that tomato yields in 2010 were lower than those obtained in 2009, which could be attributed to differences in variety, seeding procedure and climatic conditions. Tomatoes were transplanted in 2009 whereas seeds were used in 2010. Additionally, the year 2009 was characterized by hot and dry days during much of the growing season; climatic conditions were wetter and cooler in 2010.

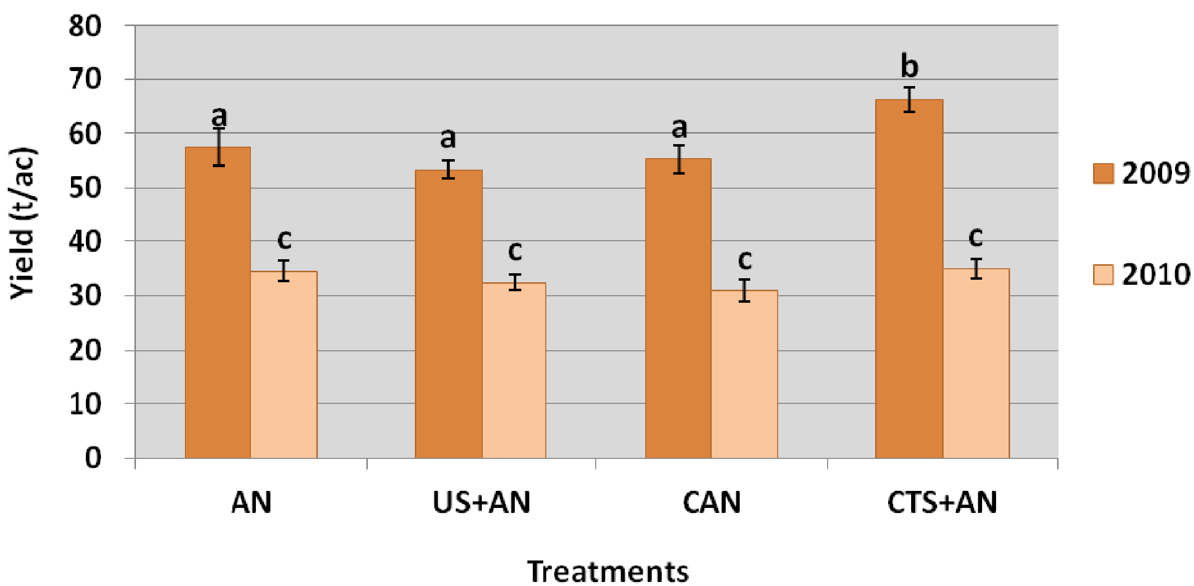

Figure 2. Average marketable yield of tomatoes (t/ac) in 2009 and 2010 (letters indicate significant difference at p =0.05).

The number of blossom end rots (BER) in tomatoes was significantly different among treatments in both 2009 (p=0.009) and 2010 (p=0.008) (Figure 3). In 2009, higher occurrence of BER was observed in tomatoes fertilized with Ammonium Nitrate only (Treatment 1) and in Treatment 2 where irrigation water was acidified to reduce soil pH. In 2010, the latter treatment resulted in significantly higher incidence of BER compared to Treatment 4 where tomatoes were fertigated with Calcium Thiosulfate and Ammonium Nitrate. It is important to note that the second-year study was characterized by a greater occurrence of blossom-end rot tomatoes.

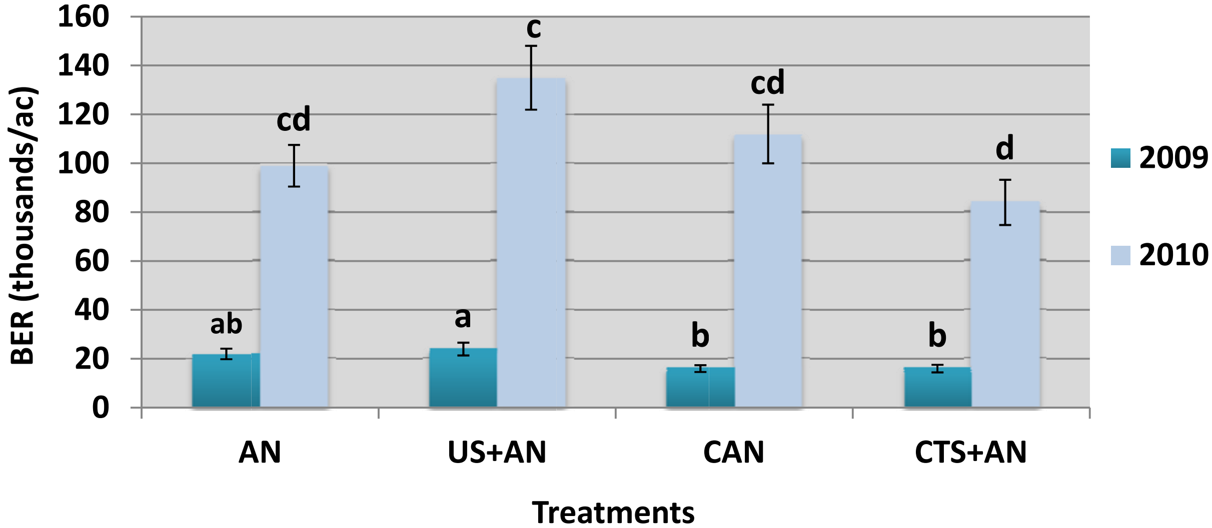

Figure 3. Incidence of blossom-end rot tomatoes in 2009 and 2010 (letters indicate significant difference at p =0.05).

Table 1 shows the total soluble solid levels (TSS) obtained at harvest for tomatoes in 2009 and 2010. TSS was expressed as degree brix and was computed on three tomatoes for each replicated treatment. Results indicated that the fertigation treatments did not affect the total soluble solids of tomatoes in both years ($p>0.05$) (Table 1). The average brix levels were 6.5^{o} in 2009 and 5.5^{o} in 2010.

Table 1. Average degree Brix at harvest for 2009 and 2010

Treatment	2009	2010
AN	6.4	5.3
US+AN	6.7	5.3
CAN	6.5	5.8
CTS+AN	6.4	5.6

The dry weights of roots taken at harvest were not significantly affected by the fertigation treatments in both years ($p>0.05$) (Table 2). Root weights averaged 16.3 g in 2009 and 10.0 g in 2010; and were statistical greater during the first-year study.

Table 2. Average dry weight (g) obtained on 12 tomato roots in 2009 and 2010.

Treatment	2009	2010
AN	18.2	8.1
US+AN	15.3	11.3
CAN	13.8	11.5
CTS+AN	17.9	8.9

Conclusion

- Tomatoes fertilized with Calcium Thiosulfate (T4) resulted in highest yield in 2009. No differences in yields among treatments was observed in 2010.
- Tomato yields in 2010 were lower than those obtained in 2009, which could be attributed to differences in variety, seeding procedure (transplants in 2009 and seeds in 2010) and climatic conditions.
- In 2009, higher occurrence of BER was observed in tomatoes fertilized with Ammonium Nitrate only (T1) and where irrigation water was acidified to reduce soil pH (T2). In 2010, tomatoes grown under T2 also showed higher incidence of BER when compared to tomatoes produced with Calcium Thiosulfate (T4).
- There was a higher incidence of BER in 2010 when compared to 2009.
- Total soluble solids and root dry weights did not differ with any fertilizer treatment. Greater dry root weights was observed during the first-year study.

Acknowledgements

Funding for this project was provided by the California State University Agricultural Research Initiative Program and Azcal Farm Management. The authors acknowledge the help of the many individuals involved in this project, including Dr. Denis Bacon, G. Jorgenson, S. Yellareddygari, P. Vasquez, R. Allende, S. Mettler, D. Adhikari, R. Devadi, S. Kovvali, S. Melkonian, J. Robles, G.Wiyono, J. Garcia, G.Orozco, N.Mendez and C. Arnold.

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Earthquakes and Irrigation in the Mexicali Valley

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Abstract. *On April 4, 2010, a 7.2 magnitude earthquake occurred within the Mexicali Valley approximately 30 miles south of the U.S. Border. Fields and canals within approximately 64,000 acres were severely damaged, with about 141,000 total acres damaged. This paper reports on the types of irrigation and drainage damage that occurred, the response by the governments and farmers, and the corrective efforts that have been and will be made on-farm and to the irrigation water distribution system that supplies the canals.*

Keywords. Irrigation, drainage, earthquake, Mexicali, Baja California.

The Mexicali Valley

The Mexicali Valley in the Mexican state of Baja California (plus some area in the state of Sonora) has approximately 500,000 acres of irrigable land. It is comparable to its northern neighghor, California's Imperial Valley, which also has 500,000 acres of irrigated land and which has the same water supply – the Colorado River. Crops are similar, but Mexicali Valley has less water allocation per acre, so in Mexico there are higher acreages of grains and cotton. The Mexicali Valley also lacks the good regional drainage system that the Imperial Irrigation District operates and maintains in the Imperial Valley.

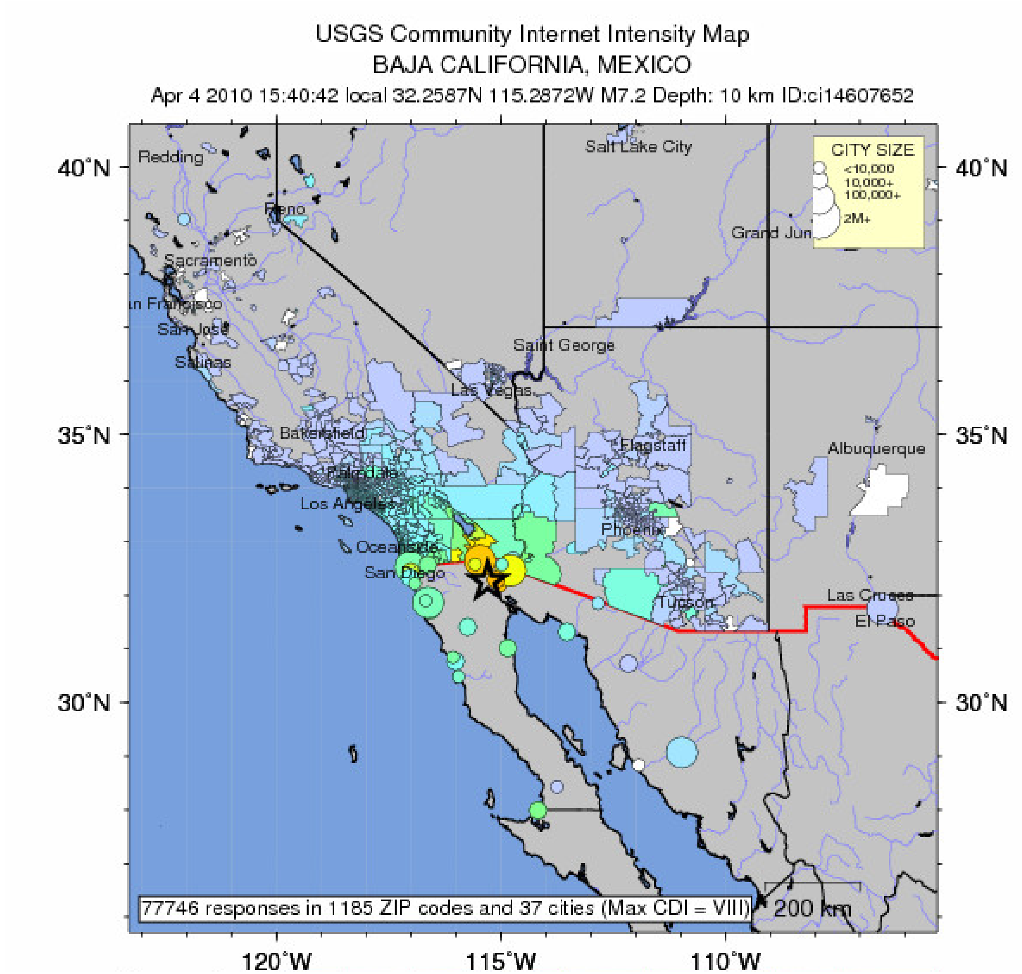


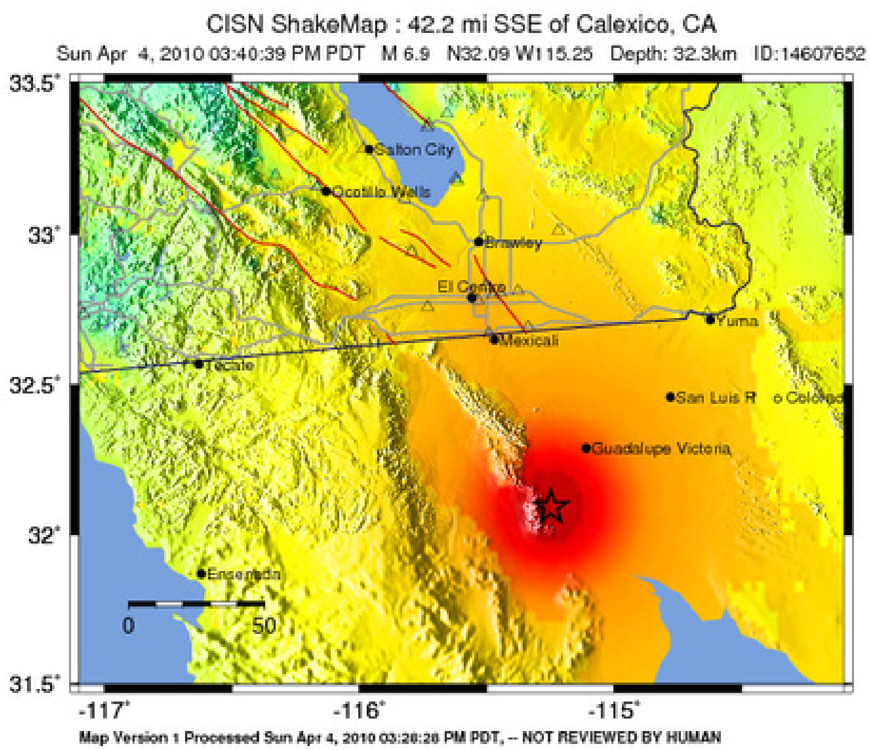
Figure 1. USGS map showing location (black star) of the epicenter of the April 4, 2010 earthquake in Mexicali Valley, approximately 35 miles south of the US border. http://earthquake.usgs.gov/earthquakes/dyfi/events/ci/14607652/us/index.html

In Mexico, the water is owned by the national government and adminstrated by CONAGUA, the Mexican equivalent of the USBR. The Baja California CONAGUA office is responsible for the network of major canals (District 014) that distribute water to both agricultural districts and municipalities (primarily Tijuana and Mexicali cities). The major canals are maintained and operated by the "Colorado River Irrigation District, S. de R.L. I.P. de C.V.", which is an umbrella water-user organization such as the Friant Water Users Association in California.

The Mexicali Valley District 014 is administratively and hydraulically divided into 22 "modulos" or smaller irrigation districts (water user associations), each responsible for operation and maintenance of smaller canals and direct deliveries to field turnouts. These "modulos" provide the board members for the S. de R.L. Just as in the USA where there can be arguments between the USBR and individual irrigation districts, there can be friction between CONAGUA and the modulos and S. de R.L.

The Earthquake of April 4, 2011

The Imperial Valley and Mexicali Valley have both experienced frequent earthquakes over the decades. The magnitude 7.2 (Richter scale) was the largest recent quake, and could have been much more devastating (i) if the epicenter had been in the city of Mexicali, and (ii) if it had occurred on a workday rather than on a Sunday afternoon. Figure 2 shows the location of the epicenter, which is in a largely rural area. The primary brunt of the devastation was felt on irrigated agriculture, with some local communities being flooded by water from collapsed canals.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 2. Shake map for the April 4, 2010 earthquake. http://www.myfoxla.com/dpp/news/local/major-earthquake-hits-baja-california-20100404

Figure 3 shows the clearly visible scarp of the fault in the aftermath of the earthquake.

Figure 3. The quake pushed this mountain six feet into the air and 10 feet to the side in some places. The dark ribbon that runs through the mountain shows freshly exposed dirt. Photo by John Fletcher, Ensenada Center for Scientific Research and Higher Education (CISESE).

The earthquake was devastating to approximately 80,000 acres of irrigated land, with further damage on additional acreage (summarized later in this paper). The leveling of fields was completely destroyed; level fields became undulating and in many cases the slopes were reversed. The major drainage ditches for the lower part of the valley simply collapsed and filled in. Large canals cracked and heaved, and smaller lateral canals were often completely filled in with soil. Perhaps one of the most damaging and visually interesting aspects was the appearance of "volcanoes" of salty water that covered vast acreages of land, covering fields with sand and salty water. These were caused by liquefaction of the saturated subsoil.

Figure 4. "Volcanoes" of sand brought up by salty water onto fields.

Figure 5. Typical covering of fields with liquefied subsurface soil that upwelled during the earthquake.

Figure 6. Damage to canal lining.

Figure 7. Field that was flooded by water from a damaged canal.

Figure 8. Damaged secondary canal.

Figure 9. Drainage ditch that had collapsed and was partially excavated to provide limited remedial removal of salty water.

Figure 10. Fissures in the embankment road. Photo courtesy of CONAGUA.

The modulos that suffered the most damage were Modulos 10, 11, and 12 (see Figure 11). The irrigation water to these modulos was supplied by the concrete-lined Nuevo Delta Canal (about 15 miles long), which was in turn supplied by the Reforma Canal, which receives its water from the Colorado River at Morelos Dam (Presa Morelos on Figure 11). The Nuevo Delta Canal was almost completely destroyed.

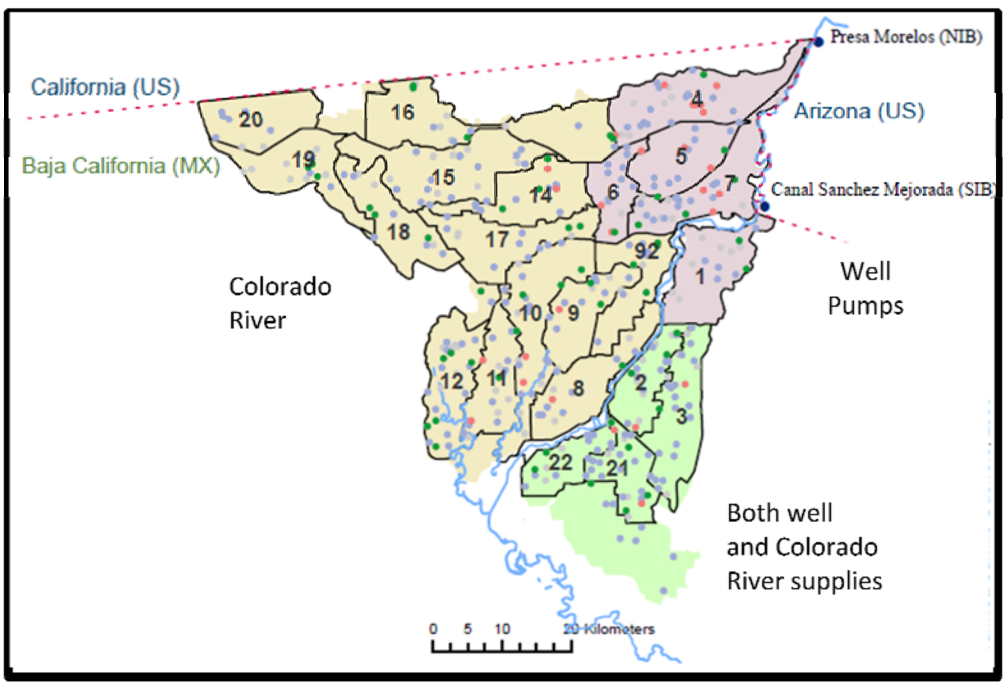


Figure 11. District 014 (Mexicali Valley) showing Modulos (by number) and sources of water (by color).

Table 1. Types of Damage to Farm Land (Orozco-Riezgo, 2011). Area in hectares (1 ha = 2.47 acres). In many cases, multiple problems occurred on the same fields. Therefore the final row "total area" does not equal the sum of the previous rows.

Type of damage	High	Medium	Low	Impacted surface (Ha)
Lack of irrigation water	24,083	16,705	3,285	44,073
Unevenness of land	18,666	12,667	1,719	33,052
Water table flooding	9,679	9,122	3,205	22,007
Land cracking	8,712	7,600	1,713	18,024
Flooding by ruptured irrigation canals	810	305	58	1,173
Total area with one or more problem	**26,106**	**18,390**	**12,539**	**57,035** *(140,877 ac)*

Main damages to the hydraulic system and drains (Orozco-Riezgo, 2011) were:

- 57 km of main irrigation canals; Reforma, Nuevo Delta and Revolución canals.
- 350 km of secondary canals.
- 380 km of the drainage system.
- The total affected farming land area was 57,035 ha. (140,877 acres).

Reaction to the Damages

The modulos and S. de R.L. were very quick to respond in various ways. The S. de R.L. quickly diverted water into drains if canals had been destroyed – as a simple means of just getting water out into the agricultural area so farmers could pump from the drains. The S. de R.L. also began almost immediate emergency repair of canals. But substantial, deliberate reconstruction required the involvement of the federal government's CONAGUA – both because CONAGUA held the money, and also because permanent improvements required a more detailed design approach than the modulos and S.de R.L. were accustomed to using. Therefore, the majority of the impacted area has not had crops for two seasons.

While the irrigation district and S. de R.L. were rapidly re-establishing water delivery service wherever possible, the state and federal governments began to assess the damage and to develop a specific plan. During the first 60 days, intensive surveys were conducted to identify the areas and types of damage.

A very interesting aspect of the Mexicali situation was that the Federal government held an insurance policy that covered damage to the primary and secondary canals in the event of a natural disaster. The exact dollar figure is not known, as the final designs for the reconstruction of those canals is nearing completion at this time. It is anticipated that re-construction of the large canals will begin in early 2012. Therefore, except for the design portion of this work, the insurance has not yet had an impact.

Meanwhile, there was no crop insurance policy in place that covered damage due to earthquakes. Therefore, the government has spent about $32 million (US) to help farmers recover crop losses and to re-level their fields. Approximately $101 million (US) has been spent on temporary rebuilding/patching of main and secondary canals.

Replacing the Nuevo Delta Canal

The damaged Nuevo Delta Canal traversed multiple fault lines and liquefaction zones. Plus, it fell within zones of anticipated subsidence due to groundwater extractions (without recharge) from an adjacent geothermal field.

A design feasibility contract was provided by CONAGUA to Ingeniería Dennis of Mexicali, with the Cal Poly ITRC as a sub-contractor. Over thirty different replacement routes were analyzed and compared in terms of economics, right-of-way acquisitions, road crossings, topography, costs, available pressure, command area, and ability to enhance existing water delivery service. These considerations were overlaid on the maps of subsidence, liquefaction, and faults. The final route of the replacement canal, called "April 4", is shown in Figure 12.

Figure 12. Route of new April 4 canal, showing faults, subsidence, and liquefaction zones.

While large diameter (3 - 96" diameter) ribbed polyethylene pipelines were considered at first, that idea was discarded due to their expense and unknowns. Therefore, the focus was on how to properly construct the new canals to minimize the type of embankment failures that occurred during the April 4, 2010 failure.

There was very little to go on. Certainly, there has been a long history of soil mechanics work on embankment failure. There are also many earth-filled dams. But there was almost no guidance for the construction of new agricultural irrigation canals in seismic prone areas. And the new feasibility design of the replacement for the Nuevo Delta Canal needed to be completed within a few months, eliminating the possibility of doing research on new techniques. Therefore, Ing. Dennis and ITRC visually examined the types of failures that had occurred in the Mexicali canal embankments during the April 4, 2010 earthquake, and combined those observations with basic knowledge of soil mechanics to generate a solution. It was noted that canal bank failure appeared most commonly in the following situations:

1. The canal banks were constructed of native materials, with a high silt percentage, that were not well compacted. From basic soil mechanics applied to slope stability problems, we know that this is undesirable.
2. There were high seepage losses from the canals prior to the earthquake due to cracked concrete lining. We concluded that in many areas, the soil under the concrete was saturated.
3. A high water table existed, indicating that the soil immediately under the base of the canal and its embankment were saturated.

Ing. Dennis recommended that the following features be incorporated into the final design to minimize problems that existed on the old canal:

1. The soil will be over-excavated, filled with compated soil, and then the cross section for the new canal will be cut from the compacted soil.
2. The canal embankments, and the “footing” of the canal itself will be kept dry by preventing moisture from entering from above and below. The two solutions will be:
    a. The canal will be lined with a geomembrane to prevent seepage from “above”. That geomembrane is equipped with a fuzzy material on its surface so that concrete will adhere to it. Concrete will be applied with a 3” thickness over the geomembrane. The concrete will provide mechanical protection from cleaning operations and other physical damage that might occur.
    b. A tile drain will be installed approximately 6’ below the bottom of the canal, and to the side, to help lower the water table immediately under the canal. This will help minimize moisture from entering the embankment from below, and will possibly provide a more stable footing for the whole structure.

Furthermore, the new canal will be designed to provide much better water delivery service to the modulos. The old Nuevo Delta Canal cross regulators (check structures) were manual sluice gates, and the flow measurement devices at all bifurcations and turnouts were uncalibrated.

The replacement (April 4) canal will incorporate the following key control features:

1. A broad-crested weir at the head to measure flow rate.
2. Long-crested weirs for check structures within the canal to stabilize water levels.
3. New standardized submerged orifice flow meters for turnouts.
4. Two large regulating reservoirs, with pumps in and out to automatically maintain the adjacent canal pool water level.
5. Improved flow control and measurement at the heads of major bifurcations.

There will be no automation except for on the pumps that put water into and out of the reservoir. The programmable logic controller (PLC) will use an ITRC design of two simple water level probes (rather than pressure transducers) and fixed speed pumps (as opposed to using VFDs). Canal pool capacities have been defined to avoid excessive cycling of the pumps.

Conclusion

A devastating 7.2 Richter scale earthquake struck the Mexicali Valley irrigated area on April 4, 2010. It caused damages to about 141,000 acres of fields and the supply canals. Fields were primarily damaged from flooding, upwelling of sand and saline water, and destruction of the land leveling. The Mexican federal and state governments implemented programs to help farmers, and an insurance-funded program will pay for new canals and reconstruction of damaged canals. A new canal design was developed to avoid future failures in this seismic-intensive zone.

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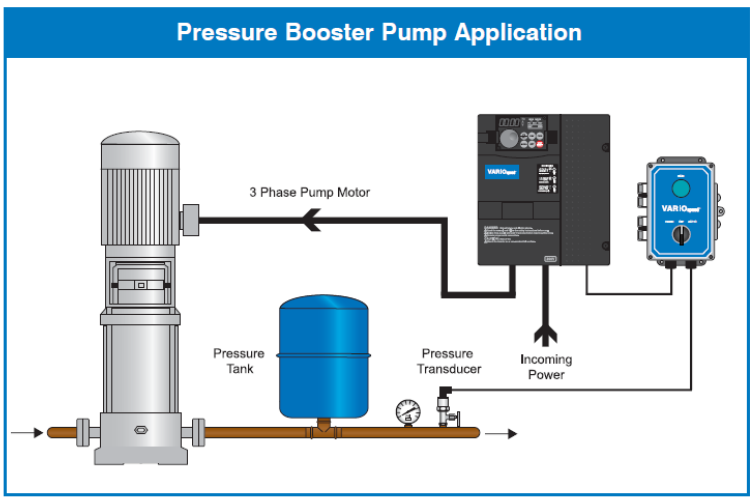
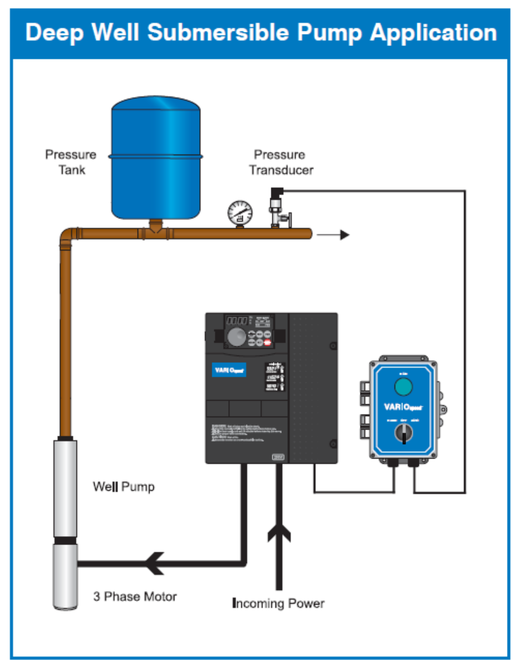
Advanced Pressure Control and Pumping Protection Using Variable Frequency Drives





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Executive Summary

In this world of ever advancing technologies, the water and waste water pumping industry has seen an explosion in the use of highly technical variable frequency drives, or "VFD's". Known by many generic names, and produced by many manufacturers, these technical marvels have advanced to provide endless possibilities, for ways in which a liquid pump and motor can be controlled. This expansion of possibilities has opened up many methods that can be used in controlling the discharge pressure in a pumping system.

This paper is intended to sort out the main methods for controlling pressure in a water/wastewater application, and in doing so will also discuss the primary, and advanced methods of pump, motor, and piping protection. A side benefit of VFD's is that the operator is also able to monitor system status and ongoing electric power consumption. Undetected inefficiencies can significantly increase utility bills, that when added among many systems can cripple the owner's maintenance budget or utilities managing many systems.

Controlling Pressure

The common components for controlling pressure in a pump system include:

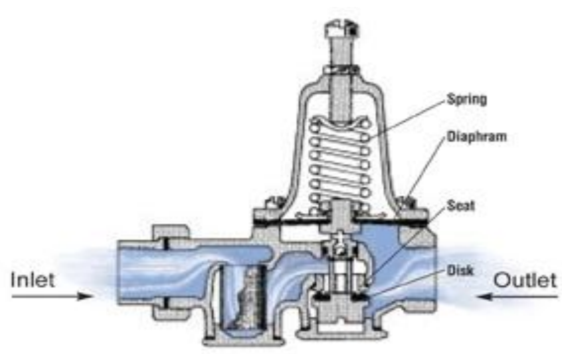
- Manual Pressure Switch
- "PRV" Pressure Reducing Valve
- Pressure Transducer

Manual Pressure Switch

This method has been the mainstay of liquid pressure systems for many years. It has served the industry well and remains the pressure controlling method for a large percentage of systems. Systems utilizing this method will experience pressure increase and decrease from start to stop points based on pressure in their system, or will need to substantially increase the pressure tank in the system in order to decrease the pressure differential and still maintain the minimum run time required by pumps.

"PRV" Pressure Reducing Valve

There are two categories of PRV used in systems, depending on location and application. For municipal systems, the incoming water to a residence or business is considerably higher than needed. This is intentionally done to allow for variations due to elevation, demand fluctuations, and fire suppression requirements that typically come off of the same municipal system. The PRV in this case eliminates or mostly eliminates pressure variations by simply stopping excess water from



flowing beyond the PRV. From an energy consumption point of view, this is an acceptable method given that pressure must be constant within one system throughout a whole community where there are huge variations in volume and pressure needs.

A second PRV method employed for systems, is commonly referred to as a cycle stop valve or CSV. These units are designed to limit the maximum pressure in a system by restricting the output through the valve based on the pressure on the output side similar to more common PRV's. CSV's also do two more things. When the pump turns on at the low pressure switch point, the valve causes the buildup of pressure to a desired point between the low and high and then reduces the output volume by restricting it to only the amount required to maintain the desired point while also maintaining a minimum amount of flow to prevent damage to the pump. When usage shuts off completely and the set pressure is reached, the valve then diverts the flow through a bypass to the pressure tank to restore the backup capacity. This method maintains a constant pressure for a time, however allowing the pump to run at maximum head conditions and restricting the flow to this degree, greatly reduces the running efficiency of the pump.

Pressure Transducer

The pressure transducer acts simply as an information source. This information is provided typically to a variable frequency drive or VFD. The VFD is able to use this information to control the amount of energy sent to a motor/pump and slow down or speed up the pump to maintain a constant pressure. This is done by changing the frequency of the electrical pulses through what is known as an inverter. This allows for full control of the output of the system. Coupled with a modestly priced VFD the user is also able to monitor and subsequently protect the system from damage.

The Historical Problem

Water pressure systems historically included a pump/motor with capacitor starter, controlled by a simple pressure switch that would turn on the pump when the pressure in the system dropped below a pre-determined “start” point, and turn off the pump when the same switch would open back up. The differential between the “start” and “stop” points and the size of the pressure tank attached to the system, determined the run time of the pump. To avoid excessive “cycling” of the pump, the pressure tank was sized to allow for the minimum run time required, based on the manufacturer’s recommendation to ensure long life of the pump/motor combination and to maintain the warranty.

Problems occur when the operating conditions of the system change. The following are variables that, when changed, affect the system’s ability to maintain intended results.

- Demand on the system changes
- The supply reservoir cannot replenish itself at the rate required
- A broken line in the system
- The pump/motor begins to fail
- A foreign object gets lodged in the pump

Without a method of detecting these conditions, the system continues to run; causing physical damage to pumping equipment and potentially causing substantial physical damage beyond the system itself. Even before noticeable external damage, substantial increases in electricity usage results from most of these conditions, when not detected promptly.

The Solution

A properly sized variable frequency drive, motor and pump, coupled with a pressure transducer, provides for; a constant pressure within the pumping range, maximum energy efficiency for the given system, and peace of mind knowing the drive is monitoring the system, shutting it down to protect it, other equipment in the system, and external physical damage in the area. Let's look at each of these benefits in more detail.

Consistent Performance

Society has come to expect that when they turn on the faucet, the water will flow at the same rate and pressure regardless of how many people are using the system at one time. The VFD is best suited to provide this "variable" rate and still maintain an efficiently running system. Without getting too technical, the drive does this by reproducing the AC sine wave at a variable frequency. This frees us from the limitations given by the electrical utility that typically provides electricity at sixty pulses per second or 60 hz. Historically motors were designed to run most efficient at this speed; however new electric motors, windings and insulating material, are designed specifically to take advantage of this ability. These motors are "inverter duty rated". By changing how fast the pulses are fed to the motor, the output of the pump can be controlled variably without restricting the flow and reducing efficiency of the pump.

Maximum efficiency

Getting a constant pressure by controlling the electrical energy sent to the motor, rather than restricting the output of the liquid, VFD's are able to gain efficiency over other methods, and reduce the utility cost of the system.

Monitoring, Protecting, and Notifying

The monitoring abilities provided by modern VFDs, are only limited by the imagination of the designer and the ways in which the system is intended to be used and protected from damage. The most commonly used protections in water pressure applications are discussed below.

System Pressure

Basic to water systems, the pressure of the water is monitored constantly. This information is used in many ways to determine the health of the overall system.

Low/No Flow (also known as dry run)

When the system is properly installed, the normal operating speed will be established that determines how fast the motor needs to run to maintain the system or “set pressure”. If the system is not maintaining the pressure required within the normal speed range, it assumes there is not enough water and will stop running to protect the pump from “dry running”

Seal Fail

This protection requires a pump motor equipped with a sensor that can detect when a seal on the motor has failed and there is water getting into the motor. Typically used in larger systems, this notifies the user that maintenance is required to restore the system to health.

Motor Overload Protection

By setting the maximum amperage based on the nameplate, the motor is not damaged by over-current. Branch circuit protection is still provided by the breakers required by local code. Advanced functions available in most modern drives, allows that the drive will not only shut down on over-current, but will also report by error code when the condition occurred. This is very helpful when diagnosing the root cause of the failure; during startup, running, or deceleration.

Under-voltage

Damage to the motor is prevented should there be a brownout or other under voltage condition on the input line power.

Three Phase Power Issues

In three phase systems, the VFD protects the drive and motor, should an unexpected phase loss occur in the incoming power supply. Parameters can also be set to protect from an un-acceptable amount of phase imbalance. These measurements are on the incoming side of the VFD, and depending on how the drive is sized; a larger amount of error can be tolerated, without affecting the output of the drive to the motor. In fact, many drives are used just for this purpose. Running a 3 phase motor, where 3 phase power is not available, drives can be sized and setup to convert single phase incoming power to three phase output (motor) power.

Self Protection

In addition to the advanced protections for the pump, motor and piping system, modern VFD's have a multitude of protections built into the drive to protect itself from being damaged, provided it was installed and setup properly to match the other components in the system.

Notification of Protections

All these represent a large advancement in protecting your pump, motor and piping; however does nothing to notify you if the system is shut down as a result of one of these protection faults. If your system is critical, you will want to consider adding a remote monitoring or notification module. These systems are as simple or advanced as needed to match the desired notification level. Full "SCADA" (Supervisory Control And Data Acquisition) systems are quite advanced, used typically in large scale systems, and can add a large expense to the initial and monthly expense of operating the system.

For most irrigation, well pumping, and pressure boosting systems, an economical add-on that offers a cell phone based notification when faults occur, can add peace of mind when the system is in an area not checked frequently to prevent physical damage should the system shut down.

No shortcut for good design

While modern VFD's provide a much higher level of monitoring and protection for your system, drives cannot make up for a poorly selected motor and pump combination. Solid system design and an up-front investment is money well spent when installing a pressure controlled water system. One of the most common issues blamed on VFD systems is asking a constant pressure system to operate on the flat portion of the pump curve. If the requirements of the system will operate the motor at the top 15-20% of the frequency available, there is little range left to allow for a variable flow. If your system operates satisfactory at 60hz yet is at no flow (dead head) at 50-55hz. your system is prone to issues in the future. This condition gives the variable frequency drive an unwarranted bad name when the real issue is in the design of the pumping system itself. There is no substitute to having a good, well designed setup by a reputable company with experience with these types of systems.

Summary

The large supply of VFD's from a variety of manufacturers, and the ever advancing technology built into them, is proof in and of itself that this technology makes sense for advancing the reliability and protections available to systems in this market. It also lends well to the "smart grid" technology and connectivity necessary to monitor and control energy usage throughout the life cycle of a pumping system. The use of variable frequency drives in this market has now gone beyond critical mass and its future use in this market will continue to increase. PN

Accuracy: Irrigation Design Software and Google Earth

Ben van den Heever. B Ing. (Civil)

Abstract. *In the past, an irrigation designer was reliant on the surveyors' data to provide an accurate digital terrain model.*

In many cases when the data was not available, the designer would proceed as if working on a flat surface or make vague assumptions about the terrain. Looking at the software tools available today, it is safe to conclude those days are over and irrigation designers can produce accurate designs at low cost.

By utilizing Google Earth, the irrigation designer can save a lot of time basing initial calculations and design decisions on very realistic survey data.

This presentation will be a comparison between the gain and loss of accuracy when designing irrigation on an undulated terrain assuming it is flat, using a Google Earth surface model and using an actual surveyed DTM. Analysis of the hydraulic results will prove that modern irrigation design software, using Google Earth, is invaluable.

Keywords. Irrigation Design Software, Digital terrain model simulation, Google Earth, Hydraulic calculations.

Irrigation design and elevation differences.

Any irrigation design project should be done based on accurate topographical terrain elevations.

Depending on the height differences in the terrain, a few survey coordinates could suffice. On steeper, complex areas the irrigation designer has to take special precaution to ensure the base survey model is appropriate and representative of the elevation detail. Ignoring this fact can result in inaccurate irrigation designs that:

- Do not produce the required pressure needs
- Are not economical
- Yields a sub standard production crop.

Making use of Google Earth (GE).

Google Earth is available in two license versions:

- A Free version with limited function.
- Google Earth Pro ($399 per year), which is intended for commercial use.

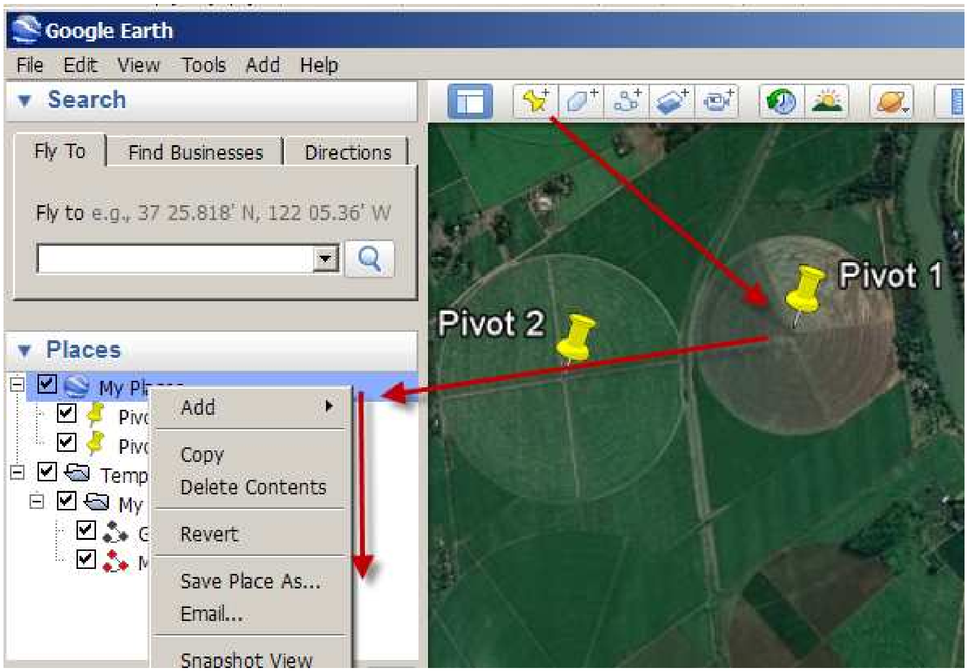
The free version was used in analyzing the data for this report.

Getting elevations from Google Earth.

There are various ways to get elevations from GE. Two basic methods are discussed in this paper.

1) Exporting KML files.

In GE the user can set place marks and then export the place marks as a KML file.



To create a KML file, do the following.

- Use the place mark button and position it.
- The place marks are added to the My Places group.
- Right click on My Places, use the Save Place As and create the KML file.
- Use an appropriate survey/cad/irrigation design program to import the KML file.

2) Using an independent program to communicate with GE to create and extract DTM points.

On larger designs, this will be the appropriate way of interacting with GE.

Software programs available these days are designed to send data to GE and also to receive information back from GE.

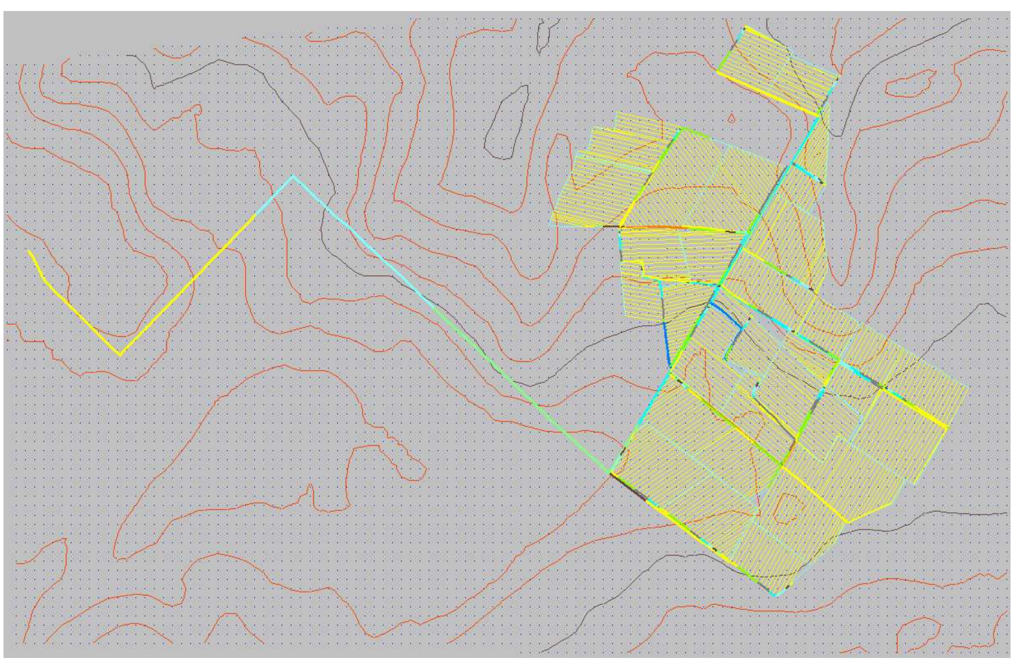
The following are the typical steps taken to set up a digital terrain model in an irrigation design software program.

- Open GE and position the screen over the proposed irrigation design area.
- Import the GE image as backdrop into the irrigation design software.

- On the image backdrop, define the area where the DTM is to be generated.
- Generate DTM points on a regular grid. These points would not have any defined elevations.
- Have the irrigation design software interact with GE and assign related elevations to the grid DTM points.
- Start doing the irrigation design on top of the new DTM.

GE image as back drop for the irrigation design.

Grid DTM data and contours used for the irrigation design.



Irrigation design.

With modern technology and software programs, designing an irrigation project should be doable, accurate and comprehensive. Many factors can affect the accuracy of the design. Working with incorrect topographical elevations should not be one of them. By using the methods described in the section (**Getting elevations from Google Earth**) above, the designer can produce a more accurate irrigation design rather than just making rough assumptions about the terrain.

- The following comparisons and findings were produced by using GE and the irrigation design software program called Irri-Maker.

Four different irrigation projects were analyzed. These projects were initially designed based on actual surveyed topographical data but for this paper, the designs were also placed onto a flat surface and also a GE produced DTM surface.

To determine how far off one could be by assuming a level surface, for each design the critical valve was identified and the pressure calculated. The same was done with the designs when placed onto the GE surface. The system pressure at the critical valve was calculated.

Using the same pipes the designs were then draped over the actual surveyed model and the pressure at the critical valve was re-calculated.

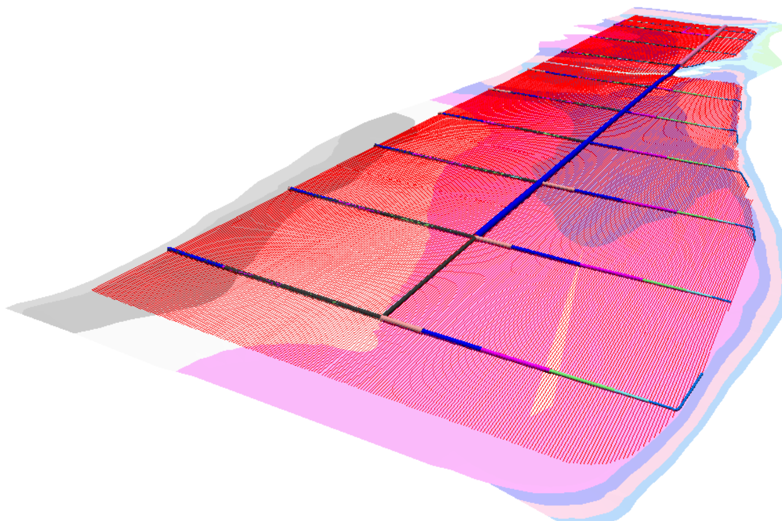
One would assume that the pressure differences between a flat surface and the actual surface would be quite great, especially on a terrain with high elevation differences. On the other hand, how acceptable would the pressure differences be when a design is done on a GE surface?

The following comparisons give an indication of the accuracies.

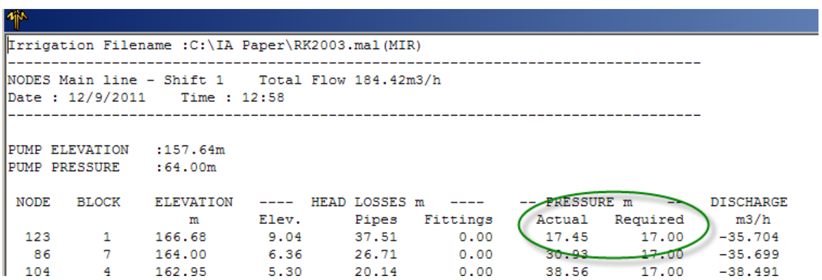
Project 1:

This project is on a fairly level terrain with slopes between 0 and 3% and the designer could easily assume it is flat enough to design without any elevation differences.

- A 3 dimensional view of the relative flat terrain and irrigation layout.



- Typical printout of the hydraulic results showing the actual and required pressures at the critical valve.



```
Irrigation Filename :C:\IA Paper\RK2003.mal(MIR)
--------------------------------------------------------------------------------
NODES Main line - Shift 1    Total Flow 184.42m3/h
Date : 12/9/2011    Time : 12:58
--------------------------------------------------------------------------------

PUMP ELEVATION   :157.64m
PUMP PRESSURE    :64.00m

 NODE    BLOCK     ELEVATION    ----  HEAD LOSSES m   ----      -- PRESSURE m   --   DISCHARGE
                        m        Elev.       Pipes   Fittings     Actual   Required      m3/h
  123       1      166.68        9.04        37.51       0.00      17.45      17.00    -35.704
   86       7      164.00        6.36        26.71       0.00      30.93      17.00    -35.699
  104       4      162.95        5.30        20.14       0.00      38.56      17.00    -38.491
```

The design for this project was run on a level DTM and a also DTM created from GE elevations. On each DTM model, the pipes for the design were optimized for velocity and pressure requirements. The 2 designs were then placed on the actual surveyed DTM model and without changing pipe diameters. Pressures at the critical valves were calculated.

Note that the pump pressure had to be adjusted upwards when the correct elevations were used.

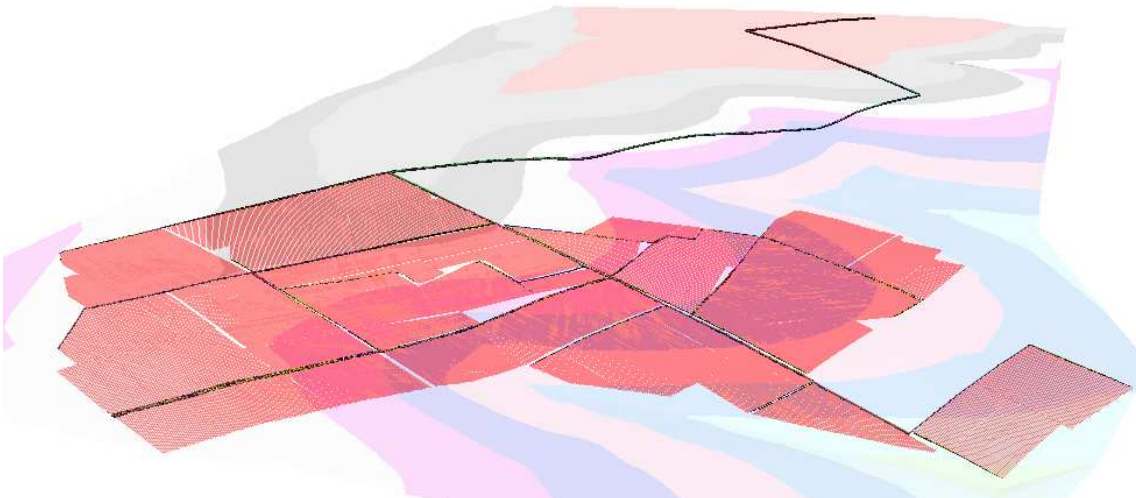
Results

The required pressure at the critical valve is 17m

Design / Surface	Pump Pressure (m)	Actual Valve pressure (m)	Difference (m)
Flat on Flat	55	19.45	+ 2.45
Flat on Actual	55	10.40	-6.60
GE on GE	64	17.79	+0.80
GE on Actual	64	19.45	+2.45

Project 2:

This project is on a steeper terrain and has slopes up to 6%.



Similar to the analysis of project 1, the irrigation design was placed on a flat surface and the pipe sizes and pump pressure calculated. The exact design was then draped over the actual survey data and the pressure at the critical value evaluated. The same was done with the design in relation to the GE model and actual model.

Results

The required pressure at the critical valve is 16m

Design / Surface	Pump Pressure (m)	Actual Valve pressure (m)	Difference (m)
Flat on Flat	40.5	16.01	+ 0.01
Flat on Actual	40.5	46.93	+20.93
GE on GE	16	16.30	+0.30
GE on Actual	16	21.19	+5.19

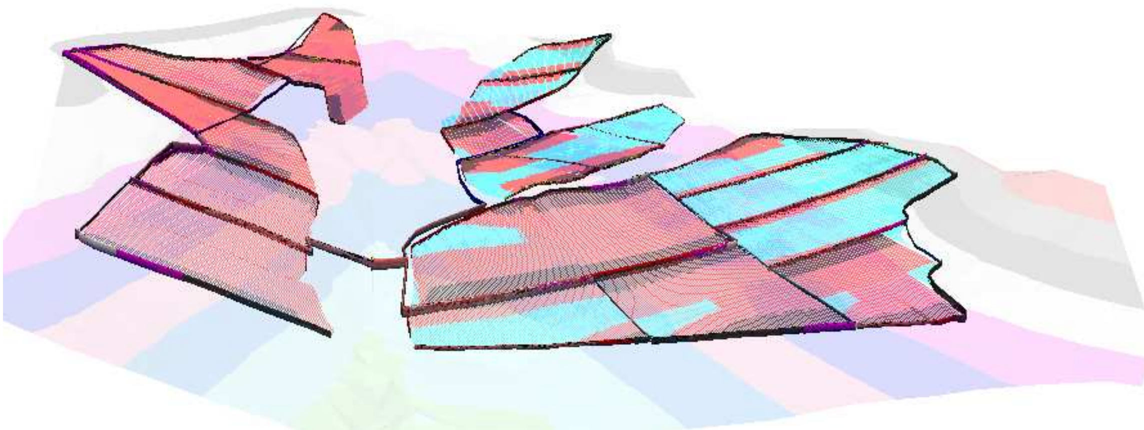
On this design the pump is at a higher elevation than the irrigation area. The presumed flat scenario does not take that into account and starts of with a pump pressure that is far too high.

The GE design however works on accurate elevations and is only off by 5 meters over the actual surface.

Project 3:

This project is on the steepest terrain and one would expect the differences to be huge.

3 Dimensional view of project 3.



Results

The required pressure at the critical valve is 15m

Design / Surface	Pump Pressure (m)	Actual Valve pressure (m)	Difference (m)
Flat on Flat	60	15.32	+ 0.32
Flat on Actual	60	15.08	- 34.50
GE on GE	63	15.10	+0.10
GE on Actual	63	18.08	+3.08

DTM grid size:

The results for the GE calculations were done on a DTM grid of 10x10 meters. As an additional check the area was also modeled with GE elevations at a 20x20 meter grid.

The critical node for GE on GE was 15.25m (as against 15.10) and when the design was draped onto the actual model the pressure went up to 18.26m. The difference is slightly more than that of the 10x10m grid but still quite accurate.

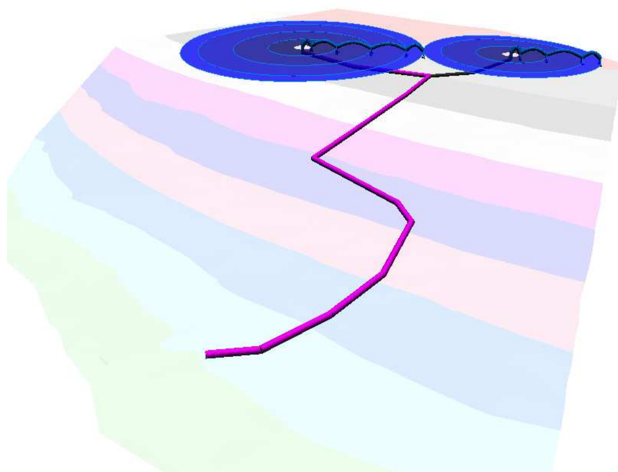
From the results it is clear that assuming such an area as flat is out of the question. Because of the actual elevation differences, an error of more than 35 meters is made.

The GE design is remarkably accurate and has a difference of only 3 meters at the critical valve when the design is placed on the actual survey.

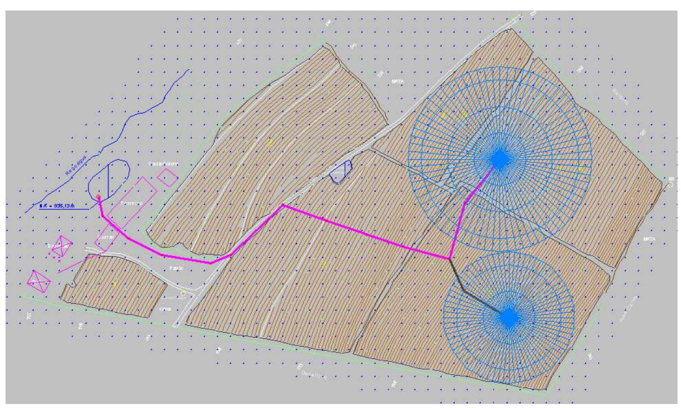
Project 4:

This project consists of a mainline running two pivots at an elevation higher than the pumping station.

3 Dimensional view of project 4.



Plan view of Project 4.



Results

The required pressure at the critical pivot is 20m

Design / Surface	Pump Pressure (m)	Actual Valve pressure (m)	Difference (m)
Flat on Flat	30	21.13	+ 1.13
Flat on Actual	57	21.37	- 27.0
GE on GE	51	20.84	+0.84
GE on Actual	51	16.62	-3.38

In this example the pump pressure for the flat model was totally wrong and had to be adjusted just to get the water to flow on the actual terrain.

Conclusion

Although the 4 examples in this test are by no means comprehensive and the results not scientifically accurate, a few general points have been proved.

- No irrigation design should be done without taking the topography into account.
- Designs done on elevations derived from Google Earth are fairly accurate. On average the pressures at the critical valve were off by an average of only 3 meters or about 4 psi.
- Irrigation design software programs are available that will interact with Google Earth and easily produce suitable terrain models.
- Google Earth can be used as an alternative to an actual survey when doing preliminary irrigation designs.
- Final irrigation designs must always be based on actual surveyed data.

It is not good practice to assume that an irrigation design done on a flat surface will yield acceptable answers in the field. With the software tools at the disposal of the modern irrigation designer, no design should be done without incorporating the correct topographical elevations.

References

Website related to Google Earth

- http://en.wikipedia.org/wiki/Google_Earth#Resolution_and_accuracy
- http://www2.jpl.nasa.gov/srtm/
- http://www.ciesin.org/documents/yuri_accuracy.pdf

Irrigation design software used in this article:

- http://www.irrimaker.com/

Other irrigation design software:

- http://www.irricad.com/
- http://www.wcadi.org/

OILSEED CROP WATER USE AND WATER PRODUCTIVITY

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Abstract. *Oilseed crop water use is primarily affected by canopy formation and weather conditions. A 'yield threshold' indicates the amount of water use required before the first unit o yield is obtained; subsequent yield increases contribute to crop water productivity. The yield threshold is least for sunflower and largest for soybean; subsequent yield increases are greatest for soybean and least for sunflower; water productivity for canola is intermediate. Oilseed crop water productivity can increase by crop and irrigation management which increases the transpiration fraction of ET and crop water use, as well as crop improvement to increase transpiration efficiency and the conversion of biomass to oilseed yield.*

Keywords. Crop water use, water productivity, oilseed crops, transpiration fraction, crop improvement.

Introduction

Water use of a crop, with adequate available soil water supply, is primarily affected by its canopy and weather conditions (Tanner and Sinclair, 1983; Albrizio and Steduto. 2005; Suyker and Verma, 2010). These effects are represented by seasonal crop coefficients and the reference evapotranspiration (ETr) demand of the atmosphere (Allen et al., 2005). The crop coefficient indicates the fraction of ETr which the crop is expected to utilize on a given day. The crop coefficient value typically changes with crop stage. Crop water productivity (also known as water use efficiency) refers to the amount of "crop yield/ water consumptively used in ET" (Kassam and Smith, 2001, p. 15). This article will present oilseed crop water use and crop water productivity field results from the U.S. central High Plains. Also, we review findings of environmental and management factors which can improve the water productivity of oilseed crops in this region.

Oilseed crops

The primary oilseed crops considered here are soybean, sunflower and canola (winter or spring). Limited information is available for other spring oilseed crops (Indian Brown Mustard, Baltensperger et al., 2004; Crambe, Nielsen, 1998) and summer oilseed crops (Safflower, Istanbulluoglu et al., 2009; Lesquerella, Puppala et al., 2005). In the U.S. central High Plains, winter canola is typically planted in mid-August, flowering in mid-May and matures in early July (Rife and Salgado, 1996); spring canola can be planted early March, flowering in late-May and maturing in mid-July (Aiken, 2010). Figure 1 shows expected water use and crop productivity for spring canola (Nielsen, 1998). Soybean can be planted in early May, flowering in mid-July for late-September harvest (Kranz et al., 2005). Sunflower is planted in mid-June to avoid pests, flowering in mid-August for harvest in late-September or early October (Rogers et al., 2005). Double-cropped soybean or sunflower can be planted after wheat harvest in early-July with flowering in late August and early October maturity. Figures 2 and 3 show expected crop productivity and water use for these summer oilseed crops. These spring and summer oilseed crops provide opportunities to shift irrigation applications among fields throughout the growing season (Klocke et al., 2006). Aiken and Lamm (2006) discussed crop development stages and yield sensitivities to water deficits for these crops.

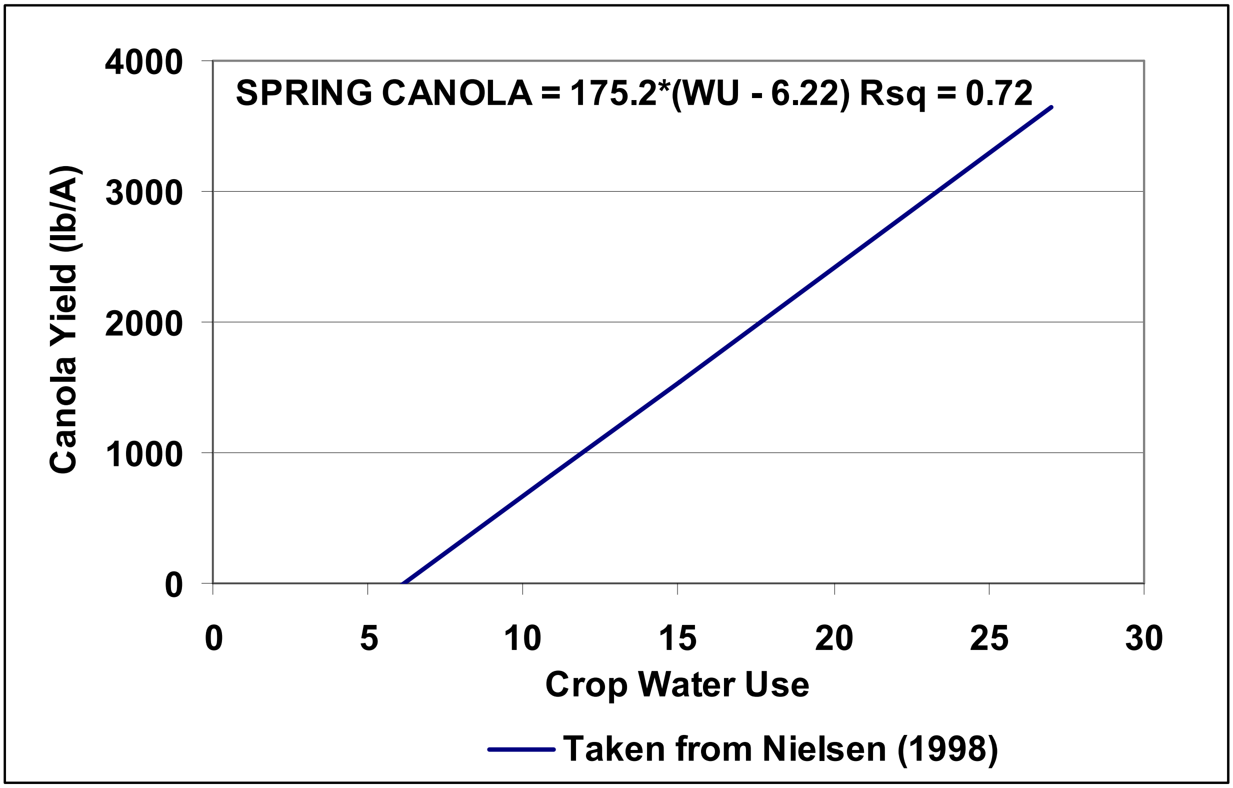

Figure 1. Expected oilseed yields of spring canola are presented, in relation to expected crop water use (soil water depletion plus precipitation and irrigation) in this crop water production function (taken from Nielsen, 1998).

Water Production Functions

Crop Water Use

Oilseed yield is expected to increase with water use, up to a maximum yield potential (Anastasi et al., 2010; Demir et al., 2006; Payero et al., 2005). The oilseed yield-water use relationships (Fig. 1 - 3) show that a certain amount of water use (i.e. intercept of line with water use axis) is required before oilseed yield is expected. This apparent 'yield threshold' (6.2" for spring canola, 6.1" for soybean and 3.6" for sunflower) indicates the amount of water use required before the first unit of yield is obtained. The magnitude of this yield threshold can vary, to some extent, depending on early season soil water evaporation, prevailing humidity conditions and water used in vegetative growth. The rate of yield increase, relative to increased water use (slope of the yield response line), represents a measure of water productivity (175 lb/A-in for spring canola, 219 lb/A-in for soybean and 167 lb/A-in for sunflower). This factor is affected by

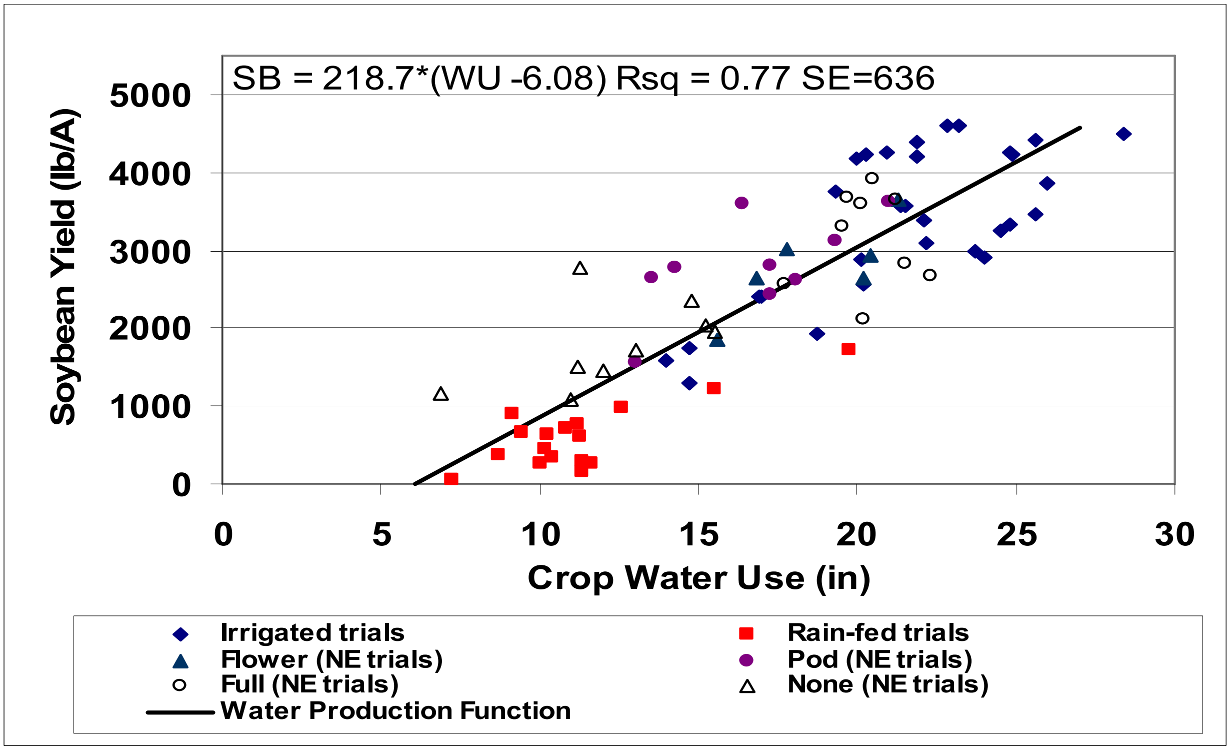

Figure 2. Expected oilseed yields and crop water use of soybean are derived from Colby, KS and Nebraska trials (NE trials indicate irrigation delayed to begin at flowering or pod development (Ellmore et al., 1988, Specht et al., 1989).

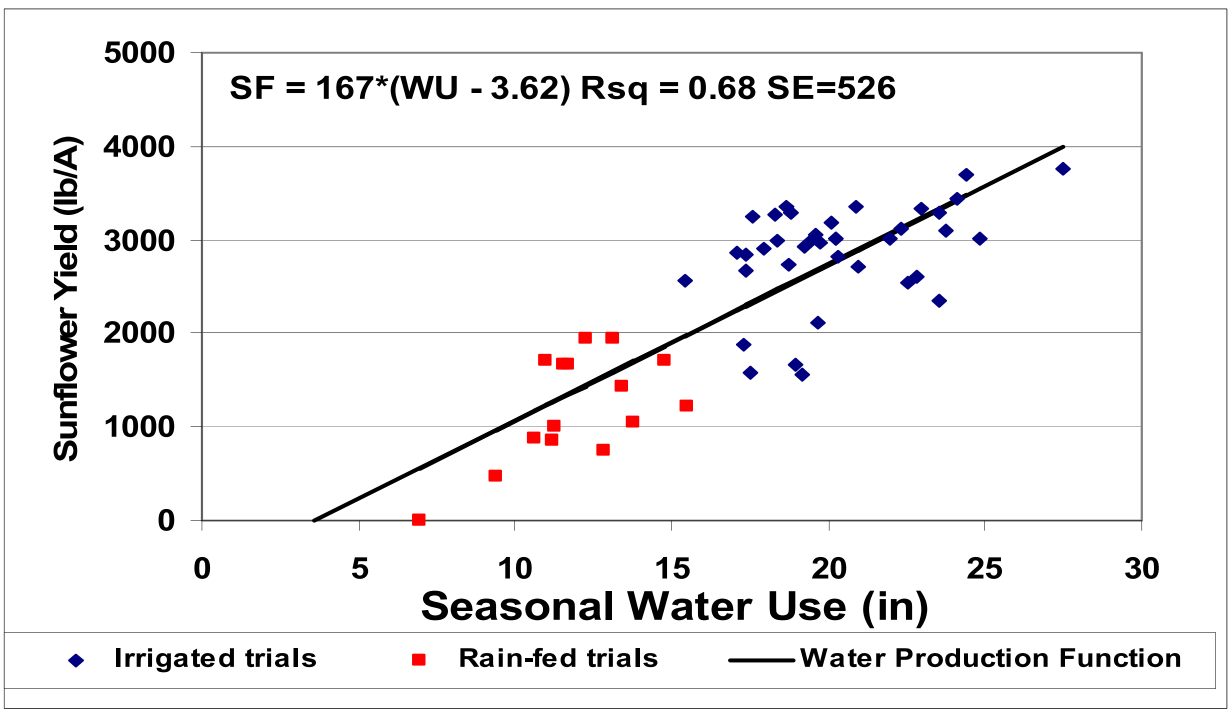

Figure 3. Expected oilseed yields and crop water use of sunflower are derived from Colby, KS trials.

inherent crop productivity, growing conditions (particularly amounts of sunshine and effects of atmospheric temperature and humidity) and harvest index (the fraction of biomass represented by economic yield). These water productivity functions have been developed from experimental data (e.g. Colby, KS, Tribune, KS, Akron, CO, North Platte, NE). The similarity in predicted yield responses to water use indicates applicability throughout the region.

A comparison of yield production functions (Figure 4) for spring canola, soybean and sunflower (corn is also shown, for comparison) indicates the apparent yield threshold is least for sunflower, but largest for soybean (among oilseed crops). In contrast, the marginal water productivity (yield increase per additional unit of water use beyond the yield threshold) is largest for soybean and least for sunflower; water productivity for spring canola is intermediate. The inherent productivity of corn exceeds that of oilseed crops. Suyker and Verma (2010) reported that corn had 50% greater assimilation, 100% greater biomass productivity than soybean. Figure 4 indicates that expected corn yields are more than three times that of soybean, at 25" of crop water use. This difference is primarily due to the greater inherent productivity[1] of warm-season grasses as well as the larger energy content of oilseeds, which require greater use of assimilates[2]. However, when oilseed yields are converted to a glucose equivalent, the productivity responses of spring canola (175 lb/A-in) and sunflower (167 lb/A-in) to increased

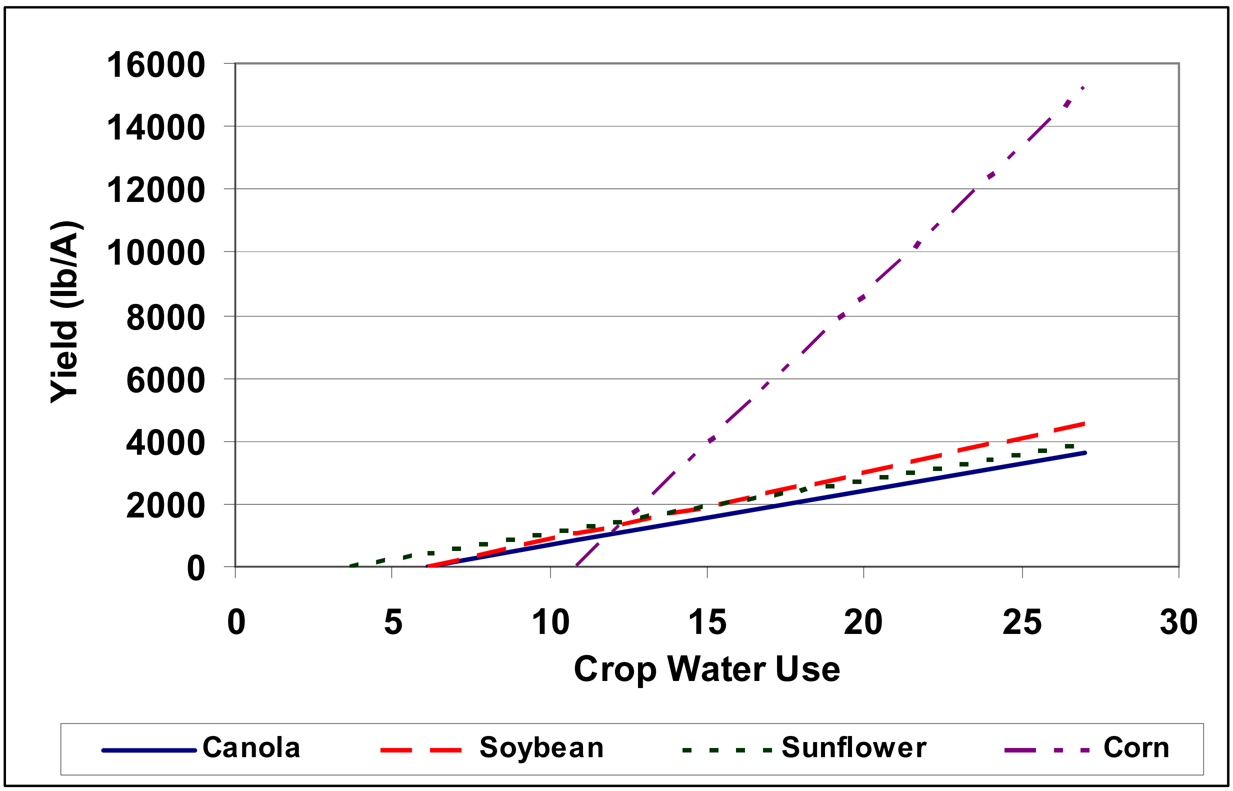

Figure 4. Crop water production functions for spring canola, soybean, sunflower and corn. The crop water production for corn was taken from Stone (2003); those for oilseeds are presented in Figures 1-3 (Grassini et al., 2009).

[1] Plants with C4 physiology characteristically have greater CO_2-fixing efficiency than plants with C3 physiology--due to Kranz anatomy and PEP carboxylase which permit sequestration of the Rubisco enzyme in bundle sheath cells where O_2 concentrations are typically maintained at less than 2%.
[2] The fraction of a sugar molecule which results in oil (33%) or protein (40%) is substantially less than that for starch (83%); see Tanner and Sinclair (1983), p. 13.

water use is similar to that of cool-season crops (e.g. wheat, ~300 lb/A-in), which also rely on C_3 physiology. Further, the yield thresholds of oilseed crops appear to be less than that of corn; and the harvest price of oilseeds are typically greater than that of corn. As a result oilseeds may provide greater economic returns to water use than other crops at intermediate levels of irrigation.

Crop Water Productivity

Opportunities to increase crop water productivity are indicated by analysis of water use and yield formation components. Oilseed yield can be represented as a linear function of above-ground (shoot) biomass (Vega et al., 2000). Note a threshold shoot biomass, B_T, below which no oilseed yield is expected.

$$Y = k_{YF} \cdot \left(B - B_T\right) \qquad [1]$$

where Y = oilseed yield (lb/A)
k_{YF} = oilseed yield fraction of shoot biomass, greater than threshold (B_T)
B = shoot biomass of oilseed crop (lb/A)
B_T = threshold shoot biomass, below which no yield is expected (lb/A)

In principle, shoot biomass of an oilseed crop can be represented as a linear function of transpiration (Tanner and Sinclair, 1983).

$$B = k_B \cdot T \qquad [2]$$

where B = shoot biomass of oilseed crop (lb/A)
k_B = oilseed shoot biomass productivity, relative to transpiration (lb/A in)
T = transpiration of oilseed crop (in)

The transpiration fraction of ET, T_F, can be represented as the ratio of T/ET.

$$T_F = \frac{T}{ET} \qquad [3]$$

where T_F = transpiration fraction of ET
T = transpiration of oilseed crop (in)
ET = crop consumptive use of water as evapotranspiration (in)

The threshold biomass, the minimum biomass at which oilseed yield is expected, can be related to ET as

$$B_{YT} = k_B \cdot T_F \cdot ET_{YT} \qquad [4]$$

where B_{YT} = threshold biomass, less than which no oilseed yield is expected (lb/A)
k_B = oilseed above-ground biomass productivity, relative to transpiration (lb/A in)
T_F = transpiration fraction of ET, adjusted for apparent soil evaporation prior to canopy closure)
ET_{YT} = crop consumptive use of water as evapotranspiration, corresponding to threshold biomass, (in)

Substituting equations 2, 3 and 4 into equation 1, oilseed yield can be related to ET by

$$Y = (k_{YF} \cdot k_B \cdot T_F \cdot ET) - (k_B \cdot T_F \cdot ET_{YT}) \quad [5]$$

where Y = oilseed yield (lb/A)

k_{YF} = oilseed yield fraction of biomass, greater than threshold

k_B = oilseed shoot biomass productivity, relative to transpiration (lb/A in)

T_F = transpiration fraction of ET, adjusted for apparent soil evaporation prior to canopy closure)

ET = crop consumptive use of water as evapotranspiration (in)

ET_{YT} = crop consumptive use of water as evapotranspiration, corresponding to threshold biomass, (in)

Combining terms and dividing by ET, we obtain a relationship between crop water productivity and components of crop productivity and crop water use.

$$\frac{Y}{ET} = k_B \cdot T_F \cdot \left(k_{YF} - \frac{ET_{YT}}{ET} \right) \quad [6]$$

where all terms are as previously defined. This relationship indicates that oilseed water productivity can increase with increasing k_B, k_{YF}, T_F and ET, and with decreasing ET_{YT}. These opportunities to increase crop water productivity, by improved irrigation and crop management, as well as crop improvement, are discussed below.

IMPROVING CROP WATER PRODUCTIVITY

An upper limit to water productivity of oilseed crops is likely constrained by the characteristics of C_3 physiology and the large assimilation requirements for oil or protein biosynthesis. Crop water productivity may approach this upper limit when 1) irrigation is delayed (minimizing evaporation from soil surface) when available soil water is sufficient for vigorous canopy expansion to intercept radiation and increase the crop transpiration fraction of ET; 2) harvest index approaches the maximum potential; and 3) growing conditions are optimal, with minimal pest damage.

Increase Transpiration Fraction

Delaying initial irrigation can reduce evaporation from the soil surface prior to canopy closure (Conner et al., 1985) and increase the crop transpiration fraction of ET. Specht et al. (1989) reported soybean yields equivalent to scheduled irrigation when irrigation was delayed to flowering or mid-pod stages. A similar response was reported by Lamm (1989a) with greater or equal soybean yields occurring with reduced irrigation during the vegetative period. However, maintaining sufficient soil moisture for vigorous canopy formation may require irrigation prior to canopy closure. Rapid canopy formation is vital to productivity as conversion of sunlight into biomass requires light interception by a healthy crop canopy (Albrizio and Steduto, 2005; Suyker and Verma, 2010).

Soybean and sunflower crops appear to differ in response to soil water deficits. Soybean exhibited tolerance of soil drying by maintaining non-stress photosynthetic rates when available soil water was 47% of full water-holding capacity (Wang et al., 2006). Also, soybean reduced crop transpiration by 67% under these deficit conditions. In contrast, sunflower maintained crop water use near non-stress rates when available soil water was 40% of water-holding capacity (Casadebaig et al, 2008). Also, sunflower reduced leaf expansion rates when available soil water was 60% of full capacity, indicating sunflower producitivity declines under water deficits while water use continues at rates near the expected maximum. These results indicate a potential advantage to soybean--maintaining productivity while reducing transpiration under vegetative water deficits. Lamm (1989b) demonstrated increased water productivity for soybean by reducing irrigation during vegetative development.

Spring oilseed crops such as spring canola avoid evaporative losses, as crop canopy is established under cool conditions with modest evaporative demand. Water productivity can be increased by minimizing evaporative losses from soil by delaying initial irrigation, seeking rapid canopy closure, or planting a early spring oilseed which forms canopy under conditions of low evaporative demand.

Managing Harvest Index

Increasing harvest index (the fraction of biomass represented by economic yield, related to k_{YF}) can improve crop water productivity. Establishing yield potential involves components of yield (plant population, potential seeds per plant[3], actual seeds per plant and seed mass). Vega et al. (2001) showed that seeds per plant increased with plant growth rate during seed set for soybean and sunflower. The indeterminate growth of soybean permitted branching and continued flowering, for continued increase in seeds per plant for plants with large growth rates. However, the rate of seed set for sunflower was smaller at the greatest growth rates, compared to rate of seed set at intermediate growth rates due to limits in the potential number of seeds per head. It follows that yield formation in sunflower is more sensitive to sub-optimal populations than indeterminant crops such as soybean. Likewise, the indeterminant spring oilseed crops, such as canola, should be able to compensate for low population with increased branching and flowering.

Maintaining vigorous growth during floral development and seed set is critical for all grain crops, but can depend on weather conditions as well as crop management. Grassini et al., (2009) found that harvest index in sunflower was reduced under cloudy or hot conditions (low photothermal quotient, ratio of photosynthetically-active radiation to temperature) during the flowering period. Andrade (1995) reported that soybean yield formation was most sensitive to water deficits during seed fill, while sunflower yield was sensitive to water deficits during flowering and seed fill stages; canola exhibits yield sensitivity during flowering and seed fill (Champolivier and Merrien, 1996; Istanbulluoglu et al., 2010). Increased harvest index can be favored by planting optimal populations, selecting appropriate planting dates, varieties or hybrids, and avoiding water deficits for vigorous growth during floral development and seed fill.

Genetic Advance

Genetic gain in crop water productivity may result from restricted transpiration, crop tolerance of soil water deficits and increased harvest index. Hufstetler et al., (2008) compared adapted soybean lines with non-adapted accessions; adapted lines had greater crop water productivity and lower transpiration rates at night than accessions. Lines also differed in sensitivity of transpiration to soil water deficit thresholds and in recovery upon re-wetting. Sinclair et al. (2000) screened 3,000 soybean lines and identified eight with substantial tolerance of N2 fixation to soil drying. This trait could enhance the growth response of soybean to a delayed irrigation strategy (see Increase Transpiration Fraction, above). Developing varietals and

[3] Components of yield for indeterminant crops, such as soybean and canola, include pods per plant and seeds per pod. Determinant crops, such as sunflower, typically have seeds arranged in a single head.

hybrids which maintain crop productivity and yield formation under water deficits and environmental stress can increase crop water productivity.

Conclusions

Seasonal crop growth, in relation to crop water use, is known as a crop water productivity function; typically, these consist of a yield threshold (water use prior to expected economic yield) and a yield response (rate of yield increase per unit water use). Field studies in the U.S. central High Plains indicate sunflower has least yield threshold as well as least yield response; soybean has greatest yield threshold as well as greatest yield response. An upper limit to oilseed crop water productivity is primarily set by characteristics of the C3 physiology, which governs CO_2 fixation by oilseed crops, and the large energy requirements for oil and protein biosynthesis. An adaptive management strategy can help growers achieve the maximum crop water productivity expected for oilseed crops. Components of this strategy include selecting crops and managing vegetative water supply to minimize the evaporative component of ET during vegetative growth, selecting seeding rates, planting dates and water management to ensure vigorous growth during flowering and seed-fill growth stages, and developing varieties and hybrids which tolerate water deficits to maximize harvest index.

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Practices to improve production while reducing groundwater contamination

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Abstract. ***Agriculture in southeastern Oregon and southwestern Idaho has depended on furrow irrigation using heavy inputs of water and nitrogen (N) fertilizer. Crop rotations include onion, corn, wheat, sugar beet, potato, bean, and other crops. By 1987 groundwater had become contaminated with nitrate and residues of the herbicide DCPA. An official groundwater management area was established by the Oregon Department of Environmental Quality along with an action plan and well monitoring network. The action plan allowed for a trial period of years to see whether voluntary changes would improve contamination trends. Researchers, producers, and agencies cooperated to develop production options that had the possibility of being both environmentally protective and cost effective. Options to improve irrigation practices, increase N fertilizer use efficiency on several rotation crops, and find a cost effective replacement for DCPA were tested. Irrigation research demonstrated the opportunity for increased productivity through both irrigation scheduling and adoption of drip and sprinkler systems. Fertilization research demonstrated that N applications were more efficient with better timing and in smaller increments. Effective, lower cost herbicides replaced DCPA. Research results were effectively delivered through many means and voluntarily adopted. Both groundwater nitrate and DCPA residues are declining. Productivity has increased.***

Introduction

Development of Irrigated Agriculture

Prior to the development of irrigation projects, agriculture in Malheur County was impossible due to arid conditions during the growing season. Agriculture was restricted to narrow strips of irrigated land along rivers. Some water could be diverted with water wheels or in-stream diversion structures. With the construction of dams for reservoirs in the early 1900s, irrigated agriculture expanded in Malheur County (BOR, 1997; BOR, 2011; Stene, 1996).

Today agriculture in Malheur County uses up to date practices producing diversified products. Family owned farms use crop rotation practices that keep soil healthy and reduce disease and weed pressures. Growers associations cooperate to improve the yield and quality of the products and foster sustainable agricultural practices. Many by-products of agricultural processing are recycled into the local agricultural sector.

A. Importance of irrigation water

Malheur County agriculture is dependent on irrigation. Since most precipitation falls during the time of the year when freezing temperatures prohibit crop growth and the soil dries before dryland crops can set seed, having irrigation water available during the growing season is indispensable to the economic health of the county. This water comes from snow melt and spring rains captured and stored behind dams. Having water available during the growing season is essential to maintaining agriculture's economic contribution to the county.

Good agricultural farm management can not only conserve scarce water resources, but can minimize agricultural contributions to sediment loss and water pollution.

A. Crops

The crops that have been grown in Malheur county have changed with changing economic opportunities over the years. In 1935 when the county agricultural agent made a survey of crop yields, the record shows the number of farms growing a crop, not the number of acres planted. The largest number of farms grew some alfalfa, wheat, or red clover seed, followed by corn, potatoes, and barley. There was also some production of oats, alfalfa seed, apples, and prunes. By 1944 the greatest number of acres produced wild hay, sugar beets, and potatoes. Acreages for wheat, corn, and lettuce were less, followed by onions and celery (Gregg, 1950). In 1961 the way of surveying crops changed; Malheur County Extension now estimates acreage and values of the major crops.

1. Forage crops

Over the last 45 years, alfalfa, other hay, and wheat have been grown on the most acreage in Malheur County. Hay is grown not only with irrigation below the dam, but is the principal crop on irrigated acreage in areas of the lower Owyhee subbasin above the dam. Eighty-five percent of the alfalfa hay produced in the county is either fed to animals by the producer or sold for local animal consumption. The best quality alfalfa hay is normally utilized by dairies and the remainder is utilized as feeder hay. Grass and rye hay are consumed locally (Schneider, 1990).

About 40,000 irrigated acres are devoted to pasture production. The majority of pasture is produced on ground that is not well suited for intensive farming. The ground may either be too steep, the growing season too short due to elevation, or the soil is too shallow for annual cropping but it still is quite productive for producing feed. The majority of irrigated pasture is utilized by beef cattle with some also being produced for dairies as well as sheep operations. Corn grown for silage is all fed locally, either by the grower or nearby neighbors. It contributes heavily to the nutrient requirements for local dairy cattle and feedlots (Schneider, 1990).

1. Cereal crops

Wheat is the major cereal crop produced. Soft white wheat is famous in world markets for quality pasta and pastries. In addition to serving as a cash crop, wheat is also produced as a rotation crop with row crops in order to maintain soil with lower amounts of weeds and diseases of the cash crops. Over 90% of the wheat is raised on irrigated soil. Barley and field corn are raised primarily as feed grains and are utilized locally by feed lots and dairies (Schneider, 1990).

1. Row crops

Onions, sugar beets, and potatoes have produced the greatest income per acre and have had a very large impact on the county economy in terms of jobs created by processing and handling in addition to the field production. Recently, Amalgamated Sugar, the only processor of sugar beets, closed the Nyssa factory, and beets are now trucked to Nampa, ID. After being purchased by Heinz Foods, the Ore-Ida factory in Ontario quit producing some lines of products which had utilized local crops (sweet corn and onions).

Onions are generally considered the most important cash crop in Malheur County. All the onions are produced for the open market which can be quite volatile; the value of onions is based on the national and worldwide supply of onions and consumer demand. The county's overall economy is impacted quite heavily by the fluctuating onion market. A large majority of the onions produced are yellow Sweet Spanish. Some acreage is also planted to red and white onions. Most of the onions are stored either in growers' storages or packing shed storages to be sold at a later date. Some are shipped fresh. Onions are packed locally and shipped by truck or rail (Schneider, 1990). The number of acres of onions has tended to increase over the years compared to the other row crops (Figure 1). The volatility of the onion market contributes to fluctuations in the amount of acreage planted. Onions are also processed into frozen chopped onions or onion rings at factories in Ontario, Oregon, Fruitland, Idaho, and Weiser, Idaho.

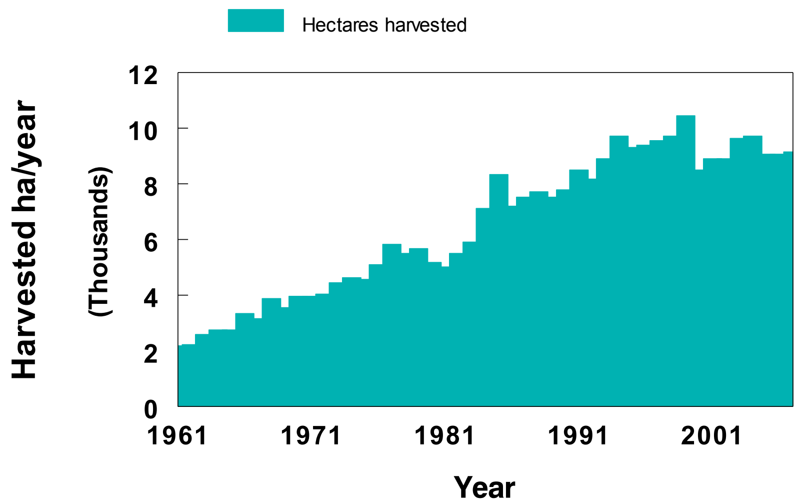

Figure 1. Increase in the cultivated area of onion production in the Treasure Valley over the last 50 years. Half of the area is in Malheur County and the other half is in the adjoining in Idaho.

Most of the potatoes in the county have been produced for processing under contract with Heinz and Simplot. Contracts have continually become more stringent on quality. Potatoes are the most difficult crop to produce because of their sensitivity to heat stress which makes it imperative that excellent irrigation techniques be practiced (Schneider, 1990). Potato acreage in the county has been declining due primarily to subsidies to producers and processors elsewhere.

Sugar beets are a traditional row crop that has been produced in Malheur County since the 1940s. All sugar beets are grown under contract with the Amalgamated Sugar Company. The beet company regulates the number of acres and subsequent production that can be produced based on the company's processing capacity and sugar market quotas. Sugar beets have been a relatively stable crop in terms of price and yield but the effect of recent trade agreements is as yet unknown (Schneider, 1990). Acreage planted to sugar beets in Malheur County has been declining.

A. Irrigation, fertilization, and pesticide management

1. After the reservoir construction and before 1980

Most of the land that farmers settled had to be modified before it could be brought into production. The surface soil in the alluvial basins was very salty and sat atop a hard layer of caliche. The caliche developed by calcium carbonate leaching from the surface soil into subsoil over thousands of years. After irrigation water from the dam became available it was first used to eliminate salt from the surface soil. A berm was built around a field and the field was flooded to leach the salt from the soil. In the 1940s the Malheur Experiment Station discovered that deep plowing would break up the nearly impermeable caliche and mix it with the topsoil and salt, promoting salt leaching (Lovell, 1980; Anon., 1983).

Prior to the advent of modern herbicides, growers used the same land year after year for crops which required excellent weed control. Onions cannot compete well with weeds. Fields were kept fairly weed seed free by frequent hand weeding. The onion yields and size would decline considerably with repeated years of planting onions in the same field since root disease organisms proliferated. Onions are a high user of nitrogen fertilizer and are sensitive to water deficits. Supplying the needed water and nitrogen probably caused nitrogen to leach into the vadose zone (the zone between the roots and above the ground water level) and into the shallow aquifers.

In early agriculture of the area, the only rotation crops used with onions were sugar beets and potatoes. Potatoes and sugar beets could also benefit from the dominance over weeds which had been established in the onion fields. High rates of nitrogen were also applied to sugar beets. Growers were paid by the ton, so growers disregarded the low percentage of sugar in highly fertilized beets and tried to achieve maximum tonnage per acre. Alfalfa, wheat or corn could have helped use up the excess or carry over nitrogen in the fields following row crops, but they were not used until the advent of effective herbicides which allowed growers to use most of the fields at their disposal in rotation with row crops.

After World War II, chemical fertilizer was readily available and inexpensive. More row crops were planted due to the increase in consumer demand and higher commodity prices created by the war effort and the strong economy following the war. Due to high demand and commodity prices, more farmers switched from cereal crops to row crops. Row crops were fertilized at higher nitrogen rates and these crops were more sensitive to water management. Fewer cereal crops were grown because they were less profitable.

1. Situation about 1980

a. Irrigation

In 1980, irrigation in meadows and pastures was still dominated by surface flood irrigation from dirt ditches. Irrigation of crops was primarily surface furrow irrigation from dirt and concrete ditches. Siphon tubes were used to deliver the water from the ditch to the irrigation furrows. Fields had been leveled, but not with laser leveling. Irrigation scheduling was based on the calendar and grower intuition and experience.

Gated pipe, turbulent fountain weed screens, PAM, and straw mulch were not used. No soil moisture measurement tools or evapotranspiration estimates were used for irrigation scheduling.

b. Soil preparation and Dacthal use

Soil was prepared in the fall after harvest and in the spring. Spring soil preparation tended to compact and dry the soil. Since efficient weed control was becoming established through the adoption of herbicides in the 1970s, this innovation was already leading to fall bedding of the soil (conserving winter soil moisture and protecting the soil from physical damage when the soil was worked wet in the spring) and leading to the adoption of environmentally sound crop rotations. Crop rotations included onions, sugar beets, wheat, corn, dry beans, potatoes, alfalfa, alfalfa grown for seed, spearmint, peppermint, and other crops. Growers used many different crop rotations.

The herbicide Dacthal (DCPA) was widely used in Malheur County by onion and alfalfa seed growers to control a wide spectrum of weeds. Several chemicals such as Dacthal were applied at the full broadcast rate, 12 pounds per acre broadcast to prepare the ground for planting. Ample labor was usually available to help conduct supplemental hand weeding.

By the mid 1980's groundwater in northeastern Malheur County had become contaminated with the breakdown products of DCPA and with nitrate from the heavy use of nitrogen fertilizers (Bruch, 1986).

c. Fertilization

Prior to the 1980s, fertilization management decisions were based on perceived need of crops, not analytical chemical assessments of what nutrients were lacking. Farmers formulated their own special mixes of fertilizer. Few soil analyses or follow-up plant tissue testing of root or petiole (the stem that supports the blade of a leaf) samples were taken. Each grower had his own special blends of fertilizer for onion, potatoes, and sugar beets. Up through the early 1980s it was common practice for farms to have their secret crop mix made up of 1000 to 1500 pounds of 16-16-16 per acre for fall fertilizer. Fall fertilizer mixes containing 150 to 200 lb/acre of nitrogen were followed up in the spring with another 150 to 300 lb/acre of nitrogen sidedressed. Due to relatively high commodity prices and relatively low fertilizer prices, excess nitrogen was applied, trying to achieve maximum yields.

Two of the main reasons for fall applications were that the fertilizer was thought to act as a soil conditioner to help mellow the soil crust that builds up during the winter months and fall application helped avoid soil compaction from spring broadcast fertilizer application and other spring tractor work.

Fertilizer rates were determined by the growers financial condition and yield aspirations, not based on carefully identified crop needs. Even the published fertilizer guides appeared to be based on assured yield maximization, with little thought as to the fate of excess nutrients, not yet a part of the public environmental mindset (Shock et al., 1996a,1996b, 1998c, 2004d; Feibert et al., 1998).

d. Pesticides

Prior to their being banned, growers used DDT, Aldrin, Endrin, and other similar products. These products have very long half lives. Hence they decay slowly. Traces of the legacy pesticides can be found in runoff water and sediment.

e. *Crop residues*

Crop residues from growing wheat and sweet corn and growing and processing sugar beets were largely recycled. Beet pulp was recycled into cattle feed. Manure from dairies was recycled onto farm lands as a fertilizer.

Alfalfa seed screenings, the by-product of processing alfalfa seed, were hauled to the landfills for burial due to environmental regulations against their traditional use as an animal feed supplement. Alfalfa seed screenings constituted 16 percent of local land fill volume in the 1980s. Potato processing waste was fed to cattle, but the residual sludge from processing was trucked to holding ponds where it was stored and accumulated. Cull onions were buried in shallow pits.

2. Challenges in 1980

By the end of the 1970s, environmental concerns for irrigated agriculture in Malheur County included: 1) the reduction of soil loss and nutrient loss from crop land, 2) improvement in irrigation efficiency, 3) the reduction of nutrients added to groundwater, 4) preservation of soil structure, and 5) the transformation of agricultural chemical use so that very low rates of agricultural chemicals would be required. Where chemical products were required, they needed to degrade quickly without effects off the farm. Irrigation-induced losses of phosphorus (P) and sediment were documented problems through the actions of a local citizen's committee (Malheur County Court, 1981).

Looking back we can see the types of changes which would solve the environmental challenges of the 1980s. The reduction of soil and nutrient losses from crop land would be managed with additional field leveling, better irrigation management, and the adoption of more efficient irrigation systems. Increases in irrigation efficiency would facilitate reductions in irrigation-induced erosion and excessive nitrate leaching. Irrigation management also would better time watering to plant needs. Reexamination of fertilization practices was needed to redirect fertilization toward only satisfying plant nutrient needs and economical crop responses. Keeping sediment on the crop fields and water in the root zone of the crops would reduce the contaminate load leaving the field in both runoff and in losses to the ground water. Reduced and timely tillage could reduce the physical damage to the soil that was resulting from cultivation. Innovations in the development of integrated pest management and the use of short half-life agricultural chemicals would reduce the pesticide load carried off of farms.

Nitrogen management and irrigation management are closely linked, and trying to manage one without the other becomes self-defeating. In a semiarid environment with rare large precipitation events, nitrate usually only leaches when excess water is applied and conversely excess water can only leach large amounts of nitrate if substantial amounts of nitrate are available to be leached from the soil profile. The goal is to have just enough nitrogen available to maximize crop growth and just enough water in the soil profile to keep crop growth adequate without excess water carrying nutrients to greater depth. Both goals required irrigation innovation since reducing the application of excess nitrogen is hard with furrow irrigation systems. It is difficult to use furrow irrigation systems without substantial downward water movement and nitrate leaching. Nutrients are also washed off the field when large amounts of water move across the field with substantial force and remove soil from the field.

B. Changes since 1980

Major changes in agricultural practices have occurred over the last two and a half decades in Malheur County. Progress has been made in reducing groundwater contamination, reducing soil loss and nutrient loss in runoff, and improving water use efficiency.

These changes have been made through a cooperative process led by the Malheur County Soil and Water Conservation District (SWCD), the Natural Resource Conservation Service (NRCS), the Farm Services Agency (FSA), the Malheur Watershed Council, the Lower Willow Creek Working Group, the Owyhee Watershed Council, and both the Malheur Agricultural Experiment Station (MES) and the Malheur Cooperative Extension Service (CES) of Oregon State University (OSU) with participation of growers' associations, growers, ranchers, other members of the community, and agency representatives. Research, education, and implementation funding was obtained to pursue long term environmental goals while respecting economic constraints faced by producers.

Agencies contributing to this cooperative endeavor included the Oregon Watershed Enhancement Board (OWEB), Oregon Department of Agriculture (ODA), Oregon Department of Environmental Quality (ODEQ), US Bureau of Reclamation (BOR), and the Agricultural Department of Treasure Valley Community College (TVCC).

A wide range of research, demonstration, and implementation efforts were planned and conducted to improve production efficiency and ameliorate environmental problems associated with conventional farming practices. With each initiative the potential benefits and extent to which a new practice would be adopted were unknown, as was how it would eventually modify crop production, product quality, or the ease of farming.

Incentives toward implementing change include attitudes of stewardship and farming practices which result in decreased costs, improved productivity, improved crop quality, and the eligibility for cost share programs. Disincentives for change are practices which increase costs, reduce productivity, increase risk or uncertainty, require large capital outlays, or involve substantial red tape.

1. Furrow irrigation

A wide array of practices were investigated to improve the efficiency of furrow irrigation and reduce irrigation-induced erosion.

a. Laser leveling

i. The challenge

Prior to the 1980s, fields had been leveled by conventional means. Fields were surveyed, staked, and soil was moved about within a field by farm tractor powered equipment. Fields with slopes of 0.6 to 0.7 or more feet per hundred feet required too much water to irrigate due to excessive runoff and resulted in too much soil erosion.

Fields with slightly irregular slopes or flat spots would have parts which required long duration furrow irrigation resulting in excessive water infiltration and associated with excessive deep leaching in other parts of the same field. Crop plants growing on steeper, drier spots were subject to yield and quality losses from water stress. Plants growing on flatter spots were subject to losses from ponded water and decomposition.

ii. The changes

Dressing fields with laser leveling to a slope of 0.3 to 0.4 feet per hundred feet provided immediate benefits for surface irrigation. Herb Futter of the Soil Conservation Service (SCS, later to be the NRCS) was able to show less soil was lost from the field and the field irrigated much more uniformly. The uniformity of irrigation allowed for the conservation of water, less leaching in the wetter parts of the field, and improved crop performance. During the early 1980s the Agricultural Stabilization Conservation Service (ASCS) would not fund laser leveling, but starting in the latter half of the 1980s laser leveling was included in cost share practices based on Herb Futter's results.

From 1985 through 1999 approximately 4500 acres of cropland in Malheur County were laser leveled through cost share programs, improving irrigation efficiencies. Efficiency increases of 15 to 20 percent have been obtained from leveling alone. The practice became widely accepted by growers at their own initiative to the point that the practice now seldom receives cost share incentives.

b. Straw mulch

i. The challenge

In the early 1980s Malheur County growers Vernon Nakada and Joe Hobson were applying wheat straw mulch by hand to reduce irrigation-induced erosion. The process of using straw mulch on fields is not a new concept. In fact, the hand mulching of onions and other various crops has been used for many years. Spreading the mulch by hand can be extremely expensive, so there was a need for another cost effective way to spread mulch.

ii. The changes

One method of reducing soil movement within the field and loss of sediment and nutrients off the field is to use mechanical straw mulching techniques.[Shock et al., 1997] Joe Hobson's mechanical mulcher made the spreading of mulch economically feasible for farmers. Several variations of his original idea are used in the Treasure Valley. Early mechanical mulching trials starting in 1985 demonstrated its effectiveness in reducing erosion (Shock et al., 1988a) and improving sugar beet yields (Shock et al., 1988b). Mechanical straw mulching furrows that were compacted by tractor wheel traffic improved onion yield and size. The measurements made in onion fields showed that mechanical straw mulching had conservation benefits by reducing soil erosion and irrigation water runoff (Shock et al., 1993d, 1997). In addition, onion yield and market grade were improved, (Shock et al., 1999b) providing a financial incentive to growers to adopt this practice (Shock et al., 1993a).

From 1985 to 1999 growers applied straw mulch to approximately 4000 acres through cost share funds.

c. Gated pipe

Gated pipe was introduced to allow more uniform irrigation of many surface irrigated fields. The water set in each furrow can be less than with siphon tubes. Gated pipe allows for surface irrigation with conservation of water, reduced irrigation induced erosion, and lower leaching potential.

Gated pipe was first used in a substantial way in Malheur County in 1977, a year of severe drought. The project was promoted by the SCS and was cost shared by the ASCS. The fiber glass pipe proved to have poor durability outdoors in the sunlight. More durable plastic gated pipe was introduced and supported by cost share programs. From 1985 to 1999 growers converted the water delivery systems from siphons off open ditches to gated pipe on approximately 60,000 acres of cropland. Gated pipe decreased water use by 35-40%.

d. Weed screens

With trash flowing in the water, gates in gated pipe have to be set to wider openings or larger siphon tubes have to be used to ensure that trash does not clog the gate or tube. With trashy water, more water has to be set on a field than is really necessary, hence more water is present than is required to irrigate the row. The extra water promotes irrigation induced erosion and excessive leaching of nitrates to groundwater. With cleaner water, gates and siphon tubes can be set with greater accuracy insuring that the furrow irrigation will continue to run as set without clogging.

Herb Futter of the SCS introduced weed screens to Malheur County to clean irrigation water. Several small weed screens were installed at the Malheur Experiment Station and were highly visible near other trials and helped show growers their advantages. Adoption of weed screens followed the 1985 Malheur Experiment Station field day when Herb Futter promoted the use of bubbler weed screens to remove weed seed and trash from irrigation water. Growers started building and installing weed screens on their own, with fabrication by local irrigation dealers. Especially noteworthy were the efforts of Dale Cruson in Ontario, who gave a big boost to screen adoption by manufacturing many of the screens.

In 1990 cost sharing was implemented to promote weed screens. By 1999 the practice had become wide spread enough that cost share incentives were only being used in large scale projects where the size of the weed screen might be cost prohibitive. PAM use more than doubled in the following decade.

e. PAM to reduce irrigation-induced erosion

Polyacrylamide (PAM) is a synthetic water-soluble polymer made from monomers of acrylamide. It binds soil particles to each other in the irrigated furrow. PAM is highly effective in reducing soil erosion off of fields and can increase water infiltration into irrigated furrows (Lentz et al., 1992; Trenkel et al., 1996). PAM was shown in experiments done at the Malheur Experiment Station to significantly reduce sediment loss, generally a 90-95 percent reduction. Increases in infiltration rates varied from 20-60 percent. PAM added to irrigation water in either liquid or granular form reduced sediment losses and increased water infiltration into the soil (Burton et al., 1996; Shock and Shock, 1997). From 1990 to 1999 irrigation systems serving approximately 3500 acres of cropland in Malheur County were treated with PAM via cost sharing. Use of PAM diminished both soil losses and concomitant nutrient losses to streams (Nishihara and Shock, 2001; Iida and Shock, 2007a, 2009b).

f. Sedimentation basins and pump back systems

A sedimentation basin is a pond at the bottom of an irrigated field to catch water runoff. Water can be pumped back uphill to reuse in irrigation (Shock and Welch, 2011b). Sediment in the pond can be dredged and added back to the fields it came from.

Some of the first sedimentation basins promoted by the SCS in Malheur County were designed as demonstration-education systems. They demonstrated to grower the dimensions of their irrigation-induced erosion problem. Many functional sedimentation basins with pump back features were built in the late 1980s and 1991 and 1992 with active participation of the SCS (later the NRCS), ASCS, and SWCD. From 1990-1999 cost share assistance was provided for approximately 15 tail-water recovery sediment basin systems with water savings of 0.5 acre-foot of water per acre irrigated under each system. Current sedimentation ponds with pump back systems reduce irrigation water diversions to furrow-irrigated fields by 1/3 (1 acre-foot of water per acre) and can eliminate or nearly eliminate sediment loss off farm (Shock and Welch, 2011b).

2. Changes in irrigation systems

a. Sprinkler irrigation

Prior to 1985, very little sprinkler irrigation was used on row crops in Malheur County. Research and demonstrations were conducted in 1987 and 1988 to compare the efficiency of sprinkler irrigation to surface irrigation and to determine the effectiveness of sprinkler irrigation in producing better quality potatoes. Water was used more efficiently and potato quality was improved through the use of sprinkler irrigation (Shock et al., 1989, 2007d). Solid set sprinkler systems are a means to cool the potato plant during hot weather and decrease water and nutrients loss from the plant's root zone. From 1990-1999 approximately 16,000 acres of cropland in Malheur County were converted from furrow irrigation to sprinkler irrigation through cost share programs.

Dick Tipton spearheaded a large scale demonstration project using gravity fed water to power sprinkler irrigation sponsored by the SCS, the SWCD and the Agricultural Research Service (ARS) on Morgan Avenue. Alfalfa, small grains, pasture, and sugar beets were successfully grown by the project. Other gravity pressured systems were built following Tipton’s example. In 2002-2003 a gravity pressured system to power sprinkler irrigation was installed by the South Board of Control and cooperating growers south of Adrian. Large cooperative piping projects have recently been installed northeast of Mitchell Butte in the lower Owyhee subbasin and in lower Willow Creek. The successes of these projects are due to the cooperation of many growers and partners.

Over the last five years there has been a vigorous expansion of gravity fed sprinkler irrigation, especially by the Lower Willow Creek Working Group in concert with the Malheur Watershed Council with the support of OWEB, BOR, and others. Micro sprinklers have been used effectively in experiments (Shock et al., 2002c) and in growers fields for poplar production.

b. Drip irrigation

Starting in 1992, drip irrigation, sprinkler irrigation, and furrow irrigation were compared for onion bulb production on fields in Malheur County that were difficult to irrigate (Feibert et al., 1993, 1994, 1995). Drip irrigation was very promising in terms of bulb yield, bulb quality, water use efficiency, and apparent nitrogen (N) fertilizer use efficiency. In 1993 the first Treasure Valley grower adopted drip irrigation for onion production. The success of these efforts prompted further research to optimize the irrigation criteria for drip-irrigated onions, (Shock et al., 2000a) determine the duration of irrigation sets, (Shock et al., 2005a) use ideal plant populations and N fertilizer rates with drip irrigation, (Shock et al., 2004d) and understand the timing of water stress that leads to the defect of internal bulb multiple centers (Shock et al., 2007a).

Drip irrigation for onion uses approximately 28-32 acre-inches of water or about 60 to 65% as much as furrow irrigation with gated pipe (Shock et al., 2002b, 2004a, 2005).

Drip irrigation has been shown in Malheur County to combine the environmental advantages of less leaching of nutrients into the aquifer, less use of scarce water, and less nitrogen application with the financial advantages of higher onion yields and quality (Shock et al., 2005c; Klauzer and Shock, 2005). The benefits to the growers mean that even though the concept of drip irrigation is relatively new in the region, by 2004 there were 1,800 acres of drip-irrigated onions in Malheur County and approximately 1,200 acres in adjoining areas of Idaho. These acres have vastly reduced N inputs and no irrigation-induced erosion and associated pollutant runoff. The drip irrigation techniques developed for onion in Malheur County have been rapidly adopted by onion growers in other parts of the country. By 2011 42 percent of the onion acreage in Malheur County and the adjoining six counties of Idaho were produced using drip irrigation.

Research work on other crops in Malheur County supported by ODEQ, OWEB, US Forest Service, and the BLM has examined the use of drip irrigation for other crops. Potato variety performance with drip irrigation, (Eldredge et al., 2003) irrigation criteria for drip-irrigated potato, and potato plant populations and planting configurations under drip (Shock et al., 2002a, 2006a, 2006b). Drip irrigation has been used effectively for poplar production (Shock et al., 2004c, 2005b), alfalfa seed production (Shock et al., 2003b, 2007b), and seed production from valuable native range plants for rangeland restoration (Shock et al., 2011).

3. Irrigation scheduling

Irrigation scheduling consists of applying the right amount of water at the right time. Irrigating only when crops need water avoids both under-irrigation and over-irrigation. Crops highly sensitive to water stress, like potatoes, onions, and many vegetable crops, require precision irrigation scheduling, that is determining both irrigation frequency and duration (Shock et al., 2006a).

Over-irrigation leads to a loss in water to runoff and subsurface aquifers and increases crop needs for nitrogen due to leaching. Nitrogen is lost to groundwater. Soil losses in terms of sediment in runoff are aggravated by over-irrigation. Irrigating only when a crop needs water means that less water is used, less energy is used for pumping, less nitrogen is leached preventing additional groundwater pollution, and both crop yield and quality can be higher.

Under-irrigation of potato and onions may lead to losses in yield and quality (Eldredge et al., 1992, 1996; Shock and Feibert, 2002; Shock et al.,1993b, 1998b, 2000a, 2002a).

In 1984 irrigation scheduling in Malheur County was based exclusively on intuition and a calendar, specifically the number of days since the last irrigation. Although growers had tried to use tensiometers these meters were cumbersome. No instruments were used to measure soil moisture to assure that irrigations were applied at the right time for the plants.

a. Criteria for irrigation

Soil water criteria for irrigating vary depending on the crop, the type of soil, and the type of irrigation (Shock et al., 2007c). For Malheur County, the criteria for different crops have been developed at the Malheur Experiment Station of Oregon State University (Eldredge et al., 1992, 1996; Shock, 2003; Shock and Feibert, 2002; Shock et al., 1993b, 1998b, 2000a, 2002a, 2002c., 2007c, 2010; Shock and Wang, 2011; Thompson et al., 2008).

b. Soil moisture monitoring devices

When irrigation criteria based on soil moisture have been established, an easy reliable method of measuring soil water is essential for grower adoption of this irrigation scheduling technique.

Watermark soil moisture sensors (GMS) Model 200 were introduced at the Malheur Experiment Station in 1986. Studies were initiated comparing various soil moisture monitoring techniques. Tensiometers were compared with Watermark soil moisture sensors, neutron probes, gypsum blocks and gravimetric soil water content (Eldredge et al., 1993; Shock, 1998; Shock et al., 1998a). New innovative GMS designs (models 200SS and 200SSXX) were evaluated at the Malheur Experiment Station (Shock, 2003). In 2001 and 2002 GMS model 200SS was compared to AquaFlex, Gopher, Gro-Point sensors, Measure-Point, Tensiometers, Neutron Probe and gravimetric soil moisture calculations (Shock et al., 2003a). GMS were effective at measuring soil water tension (Eldredge et al., 1993; Shock, 2003; Shock et al., 1998a; Shock and Wang, 2011). Meters to read the GMS data or log soil moisture change over time make these sensors a valuable tool for scheduling irrigation (Shock et al., 2005d).

Some of the growers in Malheur County have adopted GMS and automated data loggers to record soil water conditions and frequently use them in drip irrigated onions

(Shock et al., 2005d, 2010). Lower cost logging of GMS sensor readings has been accomplished by numerous companies. These systems have proven to be effective and reasonably easy for growers to use (Shock et al., 2004b; Pereira et al., 2008).

c. Irrigation scheduling

Starting in 1988, after the initiation of a successful research program at the Malheur Experiment Station, GMS soil water potential readings made in growers' fields were used to schedule irrigations. In the beginning the potato extension specialist, Lynn Jensen, lead the program. As the experimental trials went forward, Lynn Jensen started demonstrating the effectiveness of these scheduling practices on grower fields through funding from the US Department of Agriculture (USDA). This effort was later expanded by Ron Jones of the SWCD through funding from the Oregon DEQ. The program evolved to the point where 87 Malheur County potato fields were monitored in 1995 by the Soil Water Conservation District under the management of Ron Jones. The cost was paid for by the growers. Actual readings were made and graphed by student summer labor.

Eventually the Malheur County Potato Growers Association directed the program in conjunction with their potato integrated pest management program until the growers were familiar enough with the program to conduct irrigation scheduling on their own.

The advent of the Hansen Meter to read GMS installations eliminated the need for students to manually read and graph soil moisture since a series of GMS could be attached to the meter and could then be read and graphed three times per day. The process was simplified to the point that a grower could readily install the sensors and meter and track soil moisture with a minimum of training. Currently most soil moisture monitoring is being conducted by growers, especially those using drip irrigation, with the aid of Hansen Meters or Watermark Monitors.

d. Synergy of onion drip irrigation and irrigation scheduling

The combination of drip irrigation and irrigations scheduling for onion proved to be a powerful combination to increase onion yield (Figure 2) and marketable yield (Figure 3) in both Malheur County and the adjoining areas of Idaho, known collectively as the Treasure Valley.

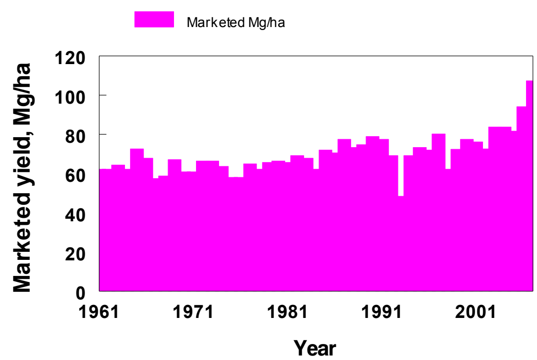

Figure 2. Average marketable yield on onion per cultivated hectare in the Treasure Valley. Marketable yields have increased in recent years, due to the expansion of drip irrigation coupled with careful irrigation scheduling.

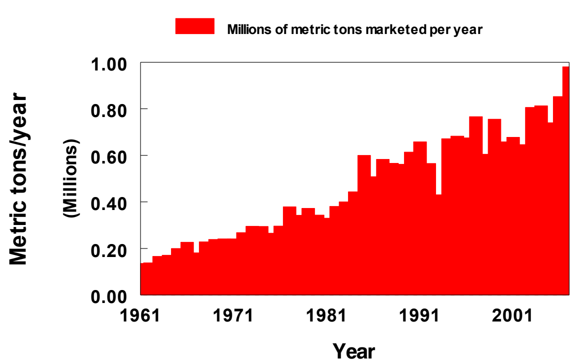

Figure 3. Total annual onion yield marketed from the Treasure Valley of Oregon and Idaho.

e. Crop evapotranspiration

Crop evapotranspiration is a fancy word for the consumptive use of water. Consumptive water use is composed of evaporation of water off of the soil surface, transpiration of water through plant tissue to the air, and the small amount of water incorporated into a crop's tissues. Crop evapotranspiration is estimated using weather station data or an atmometer. Excellent estimates of crop water use can be provided by automated weather stations and local knowledge about when crops emerged, how quickly they developed, and when they matured.

In 1992 an AgriMet weather station was installed at the Malheur Experiment Station to provide evapotranspiration measurements. The annual maintenance costs are paid by the agricultural experiment station. The data are especially useful for the management of sprinkler and drip irrigation. Growers in Malheur County who use crop evapotranspiration to schedule irrigation have local data on which the calculations are based. Written explanations are available on how to use evapotranspiration data to schedule irrigations (Shock, 2007; Shock et al., 2006a).

1. Nutrition management

a. Changes to nitrogen fertilization management

Nitrogen fertilizing practices have changed in Malheur County. Current practices are much more environmentally sound than traditional fertilization practices. These changes have come about due to the research and outreach/demonstration projects completed by the OSU Malheur Experiment Station, the OSU Cooperative Extension Service, SWCD, NRCS, the Malheur Watershed Council, the Owyhee Watershed Council, United States Department of Agriculture programs such as Environmental Quality Improvement Program administered by the Farm Service Agency and NRCS, and others. The economics of fertilization and the cooperation of the local fertilizer dealers have played important roles in these changes. These changes occurred through cooperative financial and educational help from many partners. Some of those partners include United States Environmental Protection Agency (EPA), ODEQ, CES, MES, ODA, SWCD, FSA, NRCS, TVCC Agriculture Department, the watershed councils, and the local fertilizer dealers.

The improvements in nutrient management can be summarized as reducing the amount of nitrogen fertilizer used, budgeting the nitrogen to meet crop needs and account for all sources of nitrogen, and utilizing deep-rooted crops planted in rotation with shallow-rooted crops (Shock et al., 1993c, 1996a, 1998c; Stieber and Shock, 1993). All of these improvements decrease the amount of nitrogen available for leaching into the groundwater and decrease the amount of nitrogen that a grower must purchase. These improvements have been made without damage to crop quality and productivity.

The amount of nitrogen fertilizer applied to a crop can be reduced through determination and utilization of optimal timing, placement, and rate of fertilizer. Budgeting nitrogen allows a better match to be made between the amount applied during a year to the amount used by the crop while it is growing. To do this, the growers can incorporate soil testing results (how much nitrogen is already in the field from previous crops), plant tissue testing results (how much nitrogen the plant has taken up), and nitrogen mineralization (knowledge of how nitrogen will be freed by the soil during the summer and become available) into the budget. Growing deep-rooted crops (e.g., sugar beets and wheat) after onions and potatoes allows the deeper rooted crops to recover residual soil nitrate and mineralized nitrogen that the previous shallowly rooted crops did not use (Shock et al., 1993c, 1998c, 2000b; Stieber and Shock, 1993).

Much less N fertilizer is now applied in the fall than 30 years ago. Fall nitrogen is more apt to be leached and interfere with crop seeding establishment. Soil samples are now commonly analyzed prior to any fertilizer application, and the amount of residual nitrogen in the soil as nitrate and ammonium is factored into the total amount of fertilizer to be applied to the next crop. Nitrogen applications are typically applied in the spring, with split applications starting in March and ending in July. After the plants reach a prescribed maturity, tissue samples are taken to see if more nutrients are needed for the plants to continue to be productive through full maturity. Routinely petiole samples are taken from potato (Jones and Painter, 1974) and sugar beet plants, root samples are taken from onion, and less frequently, flag leaf samples are taken from wheat.

The Ontario Hydrologic Unit Area (HUA) Final Report indicated that traditional nitrogen application rates had been reduced by 1997 (Anon., 1997). The report also explained that nitrogen was being applied more efficiently and at rates closer to plant needs. Since 1990, information and education activities targeting awareness of how much nitrogen is needed for crops as well as more efficient application methods have resulted in dramatic increases in practices such as soil testing, petiole testing, side dressing, banding, split applications, and converting from fall to spring nitrogen applications. Field acres where nutrient management practices are being applied in cooperation with the SWCD and NRCS steadily increased throughout the seven-year period of the HUA project from less than 5,000 in 1991 to over 44,000 acres by 1997, representing approximately 28% of the 157,000 acres in the HUA (Anon., 1997; Anon. 1998). Many other areas had careful nutrient management based entirely on private initiative.

Crops grown in Malheur County without N fertilizer consistently obtained more residual and mineralized (RAM) N from the soil environment than predicted by soil tests (Shock et al., 1993c, 1996a, 1998c, 2000b, 2004d; Stieber and Shock, 1993). Large amounts of RAM-N complicate fertilizer recommendations because it is difficult to predict the mineralized N and its timing. Since large RAM-N supplies can occur, crop responses to applications of N fertilizer may be small in many fields (Shock et al., 1993c, 1996b, 1998c, 2000b, 2004d; Feibert et al., 1998). Growers are adjusting N application rates downward (Table 1). Reducing N application rates can reduce crop production costs, increase profits, and reduce nitrate leaching.

Table 1. N use efficiency of furrow- and drip-irrigated onion production for Malheur County, Oregon, and Idaho surveyed February 2008, compared to a 1989 survey and 1980 estimates.

	Malheur County, 1980	Malheur County, 1987	Malheur County, 2008	Idaho, 2008
Furrow-irrigated				
Yield, Mg/ha	26.7	30.2	44.2	43.8
Total N applied, kg/ha	448	318	288	291
kg onions/kg N applied	**120**	**190**	**307**	**301**
Drip-irrigated				
Yield, Mg/ha			45.6	44.1
Total N applied, kg/ha			196	181
kg onions/kg N applied			**485**	**486**

b. Summary of N management practices

Fertilizer and chemical application practices in Malheur County have changed significantly over the past 25 years. Large amounts of fertilizer are no longer being applied to assure high yields without regard for plants' usage or the fate of excess fertilizer.

In the mid 1980s more growers started soil sampling and tailored their fertilizer rates according to the soil sample recommendations. Following recommendations by the Malheur Experiment Station in 1990 to reduce nitrate leaching, growers cut down on the amount of fertilizer applied in the fall. In the spring, they put the rest of their fertilizer needs on by sidedressing one to three times.

In the early 1990s many farmers cut out most of the fall nitrogen except for the nitrogen required to break down crop stubble. The remainder of the fertilizer was often spoon fed over three sidedress applications determined by plant tissue sampling before each application.

Today, a few growers are experimenting with sampling the soil in one to two acre grids may be sampled in the fall to determine what each acre's fertility needs are. GPS technology is then used to help variable fertilizer applicators apply only what each small acreage needs. Simplot Growers Services (Ontario, Oregon) and Western Laboratories (Parma, Idaho) are local leaders in precision fertilization.

Efficient use of soil nitrate and the other available N sources listed above depends on irrigation being roughly in balance with crop water needs so that nitrate leaching is minimal. The first furrow irrigation has great potential to leach nitrate because the loose soil and often dry subsoil has a high infiltration rate and water plus nitrate is carried beyond the reach of most of the roots of plants. Applying nitrogen after the first irrigation dramatically reduces the potential of leaching. This technique alone has allowed onion growers to reduce nitrogen applications by about 25% without reducing yield or quality. The goal of reducing ground water nitrate addition is being met by fertilizer management and the right amount of irrigation water applied at the right time.

1. Use of crop residues and animal waste

Organic agricultural wastes are recycled as fertilizers and soil conditioning agents. Potato and onion wastes from processing facilities were not utilized as fertilizer until recently. These materials are now being used in partial substitution for commercial fertilizers. Nitrogen release curves were developed for potato and onion sludge by local OSU extension and research (Jensen, 1997,1998; Shock, 1997; Shock et al., 1998c, 1999a). Following testing by OSU MES and Oregon Trail Mushrooms (Vale, Oregon), alfalfa seed screenings were no longer hauled to the land fills but were being used as an ingredient in the compost used to grow mushrooms. Spent mushroom compost was no longer accumulating as waste but was utilized as a soil conditioner, largely for landscape purposes. Animal manures from confined animal feeding operations are being used extensively for their nutrients on crop and pasture lands, through well defined nutrient management plans.

Major initiatives by growers, ranchers, ODA, SWCD, NRCS, and others have resulted in the capture and reuse of most of the waste from confined animal feeding operations (CAFOs) in Malheur County. Many individuals and groups have help to reroute or pipe irrigation and drainage water to avid water contamination in CAFOs.

2. Transformations in agricultural chemical use

Agricultural chemicals and their uses have changed in the entire Snake River plain with our greater understanding of chemistry and the environment. From the inception of modern agriculture through the 1950s, little attention was paid to the persistence and unintended effects of pest control products. In recent decades the pesticide industry has been transformed by the adoption of products, including herbicides, with much narrower target species and short half lives so the products break down more quickly.

Onions are one of the most important irrigated crops in this valley. Onions compete poorly with weeds and efficient weed control is essential to maintain an economically viable onion industry. DCPA (sold as Dacthal) is an effective herbicide to control weeds in onion fields and was commonly used in the past. DCPA metabolites, however, have been found in shallow aquifers underlying parts of the intensively farmed areas of Malheur County, Oregon (Bruch, 1986,Parsons and Witt, 1988). This product is not known to be in current usage.

DCPA was first registered as a pesticide in the US in 1958 as a selective preemergence herbicide for weed control on turf grasses. This herbicide is effective in other situations such as onion fields. When it was reregistered in 1988, the EPA concluded that “DCPA and its metabolites do not currently pose a significant cancer or chronic non-cancer risk from non-turf uses to the overall US population from exposure through contaminated drinking water”. However, they also stated that DCPA "impurities have chronic toxicological properties (including oncogenic, teratogenic, fetotoxic, mutagenic or adverse effects on immune response in mammals) that are of particular concern in the reregistration of DCPA pesticide products" (Mountfort, 1988).

Due to concerns about residues of DCPA and its metabolites in surface water and sediment runoff from furrow-irrigated crop land, as well as through deep percolation through the soil profile, MES conducted intensive studies to trace the fate of DCPA and DCPA metabolites' with both banding and broadcast DCPA application techniques (Shock et al., 1998e).

The method of herbicide application has a role in how much herbicide leaves the field. Under traditional furrow irrigation, banded applications were better. The quantities of DCPA and its metabolites in transported sediment was 33% less when banded than when broadcast. In surface water runoff, the difference was greater with 41% less of the herbicide lost from banded applications. For both application methods, straw mulch reduced DCPA and DCPA metabolite losses in transported sediment by about 90% from losses in traditional furrow irrigation. Straw mulch also reduced DCPA and its metabolite losses in surface water runoff by 30% for banded application and by 50% for broadcast application. The benefits of straw mulch were primarily achieved by reductions in soil erosion and volume of runoff water.

In the mid 1980s, farmers started banding all the post emergence chemicals on onions.

Even without a product to substitute for DCPA, it was possible to lower the amount of chemical loading by banding DCPA in a narrow band directly where the onions would grow, rather than broadcasting DCPA over the entire soil surface. Less DCPA was applied. The area of soil between the banded DCPA did not need the product because weeds were controlled there by cultivation. Growers were quick to adopt the banding of DCPA, because costs were reduced with no loss in weed control. By 1990, many growers using DCPA banding were saving two thirds of the DCPA expense (Jensen and Simko, 1991).

Malheur Experiment Station studies concluded that omitting DCPA or banding DCPA during onion production immediately reduced the losses of DCPA residues through downward leaching or runoff. One objective of the Ontario HUA had been to reduce DCPA application by 30%. Surveys conducted by the Malheur Extension Service showed that this goal was easily met by the end of 1997.

Additional research at MES and "on farm" demonstrations by Lynn Jensen of OSU Cooperative Extension have shown that other herbicides with shorter half-lives could control weeds in onions on a wide range of fields at lower cost (Stanger and Ishida, 1990,Stanger and Ishida, 1993). The use of DCPA was no longer necessary. With the registration of pendimethalin (sold under the trade name of Prowl) in about 1993 or 1994, growers rapidly switched to pendimethalin because it was lower in cost, more effective, and did not have the undesirable environmental effects of DCPA. DCPA inventories in Malheur County were depleted by the 1998 growing season and is no longer applied.

B. Implementation of new practices

Major changes in agricultural practices have occurred since groundwater contamination was identified in the Malheur River area in the late 1980s (Shock et al., 2001). The method of nitrogen application in this area has been changed. Reduced nitrogen loading has been accomplished by changes in the timing and the application of nitrogen as well as the rate of application. Plant tissue and soil sampling have also played a major role in modifying practices for the application of nitrogen and other nutrients, enabling producers to apply only the amount of nutrient needed and only when that nutrient is needed. Changes in irrigation management practices have also occurred that increase the protection of groundwater quality.

Many best management practices (BMPs) have been implemented in the Northern Malheur County Groundwater Management Area (GWMA) that are protective of groundwater quality. Some of this progress is documented in the Ontario Hydrologic Unit Area Final Report 1990 - 1997 (Anon., 1997).

Extension brochures have been prepared to help growers effectively implement many of the newer BMPs. Oregon State University publishes extension brochures on the use of PAM, on irrigation scheduling, and on drip irrigation (Shock, 2006; Shock et al.,2005b, 2005c, 2005d, 2006a., 2006b; Iida and Shock, 2007a, 2007b, 2009a, 2009b; Shock and Welch, 2011a, 2011b, 2011c).

Some challenges continue. Growers use many different crop rotations. Crop rotations with onions every third year tend to degrade the field with infestations of yellow nutsedge, compared with longer crop rotations.

C. Progress on water quality

Water quality was measured over time by establishment of a well sampling network and well sampling protocols by ODEQ. Wells were sampled every 2 months or less often as resources allowed. Analyses of nitrate and DCPA plus metabolites were conducted by ODEQ.

Nitrate trend analyses were conducted by Phil Richerson of ODEQ (Richerson, 2010) using season and regional Kendal statistical methods (Helsel and Hirsch, 1992; Helsel and Frans, 2006; Helsel et al., 2006) and Robust Locally Weighted Regression and Smoothing Scatterplots (LOWESS) (Cleveland, 1979). Groundwater nitrate trends are slowly but significantly negative (Figure 4).

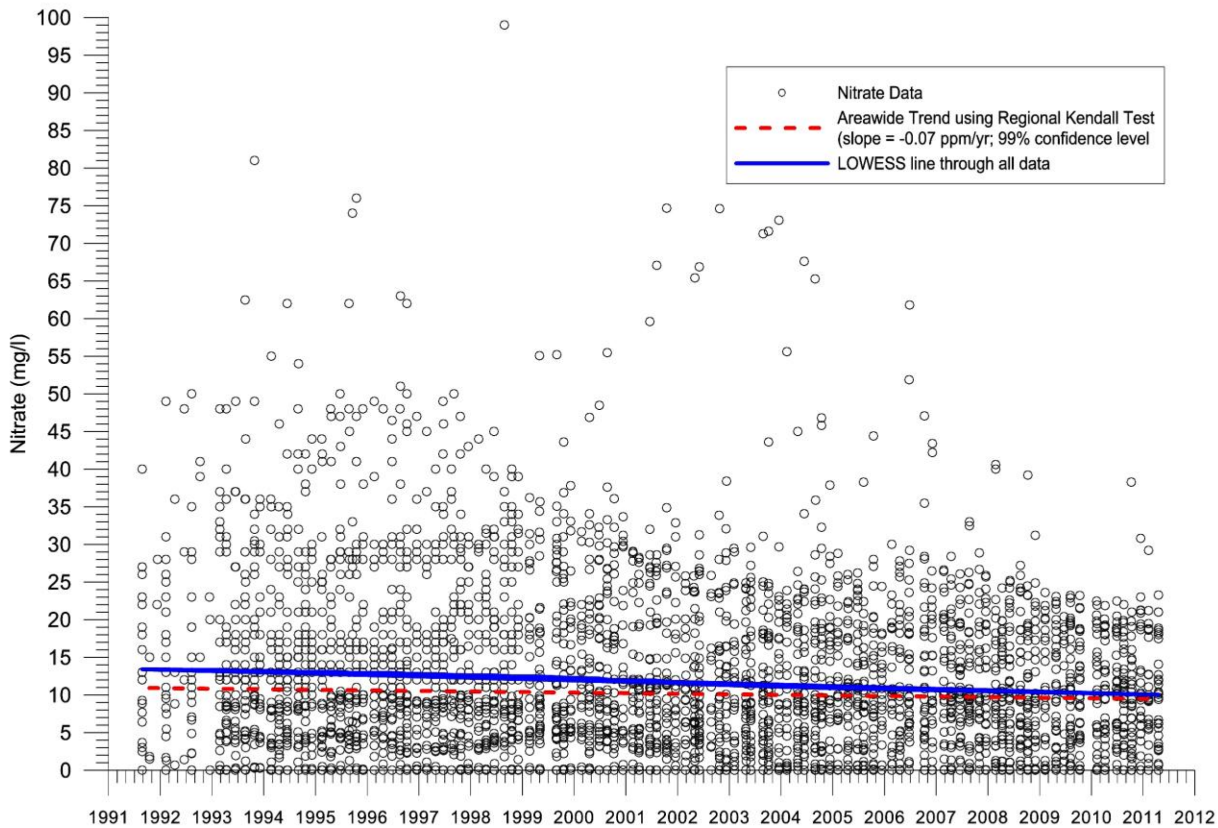

Figure 4. Decline in the groundwater nitrate content over the last two decades in all of the wells in the northeast Malheur County Groundwater Management Area (Richerson, 2010).

DCPA and its metabolites were not analyzed in the water following all water sampling dates. The reduced contamination is evident by graphing the concentration of any of the most contaminated sites over time (Figure 5).

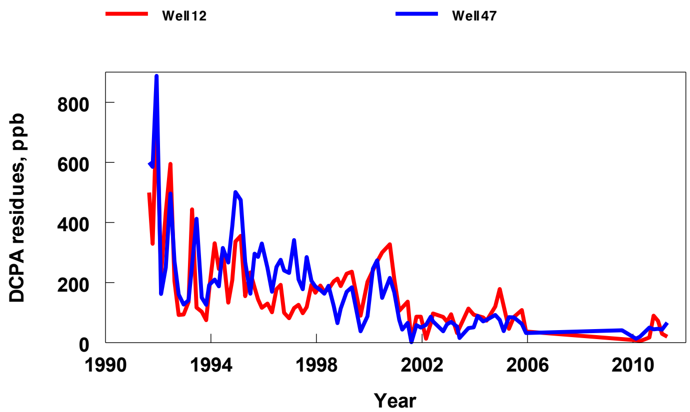

Figure 5. Decline in the groundwater DCPA residue content over the last two decades in two of the most contaminated wells in the northeast Malheur County Groundwater Management Area.

Progress on improving groundwater quality was accomplished entirely through voluntary cooperative action. Irrigation, nutrient management, and groundwater contamination are inherently complex and spatially variable. At the start of the groundwater efforts, onion production, nitrate contamination, and DCPA contamination were shown to be closely linked (Bruch, 1986). As onion acreage increased, onion productivity and N use efficiency rose, and groundwater quality has slowly improved. These improvements have only been possible through innovations in practices and the implementation of improved practices.

D. Future uncertainties

1. Water availability and competition for water

Water is the grower's second most important resource after the land itself. Some years there is a serious irrigation water shortage due to nature's unpredictable ways. However, the growers also face increasing pressure to restrict their water use so that the water can be redirected to other purposes.

With the current power crises, there may be more and more pressure applied to use the water for power generation. Increased demands for water in the cities of the deserts of Nevada may place pressure upstream to divert water from the upper reaches of the Owyhee to uses in Nevada. There may be pressure to release irrigation water from storage for endangered species such as salmon.

A Bureau of Reclamation study concluded that "based on the historical period of record (1939-1992), the Owyhee River basin above Owyhee Reservoir would yield no additional water for storage in over 50 percent of the years."[4] Although the study was conducted to see if increased storage in Owyhee Reservoir would be a potential source of water for flow augmentation in the lower Snake River for salmon, the conclusion that extra "water would be available . . . only in good water years,"[4] means that any allocation for other purposes would remove water from that available to irrigated agriculture in the lower Owyhee subbasin and other areas benefiting from this irrigation water. In the last two years Idaho and Nevada have allocated more water upstream of the Treasure Valley in the Owyhee subbasin for additional irrigation use.

Growers have made and are making many changes to conserve water. These changes will help cushion the effect on irrigated agriculture from drought years. These changes can not generate a reliable source of water for allocation to other uses. Any allocation for other purposes would be detrimental to the health of irrigated agriculture in Malheur County.

1. Population growth

Reallocation of land in Malheur County to residential and industrial purposes will have a concomitant reallocation of water away from agriculture.

1. Regulations

Since the water which growers use contains more nutrients and has a higher temperature than is allowed by the Total Maximum Daily Load (TMDL) to return to the Snake River, once this water is used on farms it will continue to exceed TMDL parameters for the Snake River. To reduce or eliminate water run off from farm ground, vast capital investments in irrigation infrastructure will be required by the rules adopted by the Oregon Department of Environmental Quality and the Environmental Protection Agency. It is not known whether the rules for agriculture that are being adopted by many governmental agencies will allow growers to operate in a “level playing field” in the global economy.

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Controllers vs. Tune-Up? Where Are the Real Savings Opportunities?

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Abstract

Since visual assessment of a property can be misleading in regards to over-watered landscapes, it is important that irrigation audits be performed on the large consumers of water found in the industrial, commercial and institutional (ICI) sector. The impact of outdoor irrigation audits demonstrate that while eliminating over-irrigation has no negative impact on the health of the lawn, it does result in significantly lower water bills for the customer. The Region of Peel began by implementing a pilot program at eight ICI facilities. Detailed audits focused on zone-by-zone water use analysis, hardware correction and irrigation schedules.

Keywords

Audit, Central Control, ICI, Irrigation, Outdoor, Peak Day, Region of Peel, Smart Controller, SMART Watering Systems, System Improvements, System Upgrades, Veritec Consulting.

Background

When it comes to water consumption, water treatment plants are typically designed to meet summer time peak demands. Often the cause of these peak demands is heavily attributed to outdoor irrigation. Outdoor irrigation itself is not a negative practice rather it is the idea conveyed by many North American water agencies that lawns need 1 inch of water per week. The 1 inch of water per week message can be misunderstood that this quantity is to include both natural rainfall and irrigation. During dry periods when there is no rainfall, the entire 1 inch must be supplied via irrigation. This implies that if people were to only irrigate 1 inch per week then we would eliminate peak demand problems. This is not the case. In 2008 the OWWA (Ontario Water Works Association) developed a *Water Use Reduction Manual* to identify effective ways to reduce peak day demands. Since the primary cause of peak day demands is irrigation, the manual focused on ways to reduce irrigation impact. The Region of Peel used these reduction strategies to supplement peak day research and analysis and to identify potential water savings through the implementation of its ICI Outdoor Irrigation Audit Pilot Program.

Research

The initial focus was to assess how much people in the GTA (Greater Toronto Area) are currently irrigating and then to quantify the potential water savings if customers limited irrigation to 1 inch per week. Data analysis was attained from different sources including:

- Gross billing data
- Single-family billing data
- District Metered Area (DMA) monitoring data
- Individual household monitoring
- Hose-bib metering

The results for all data sets analyzed indicated that the average single-family home was applying about 8-10 mm (about 1/3 of an inch) of irrigation per week to their lawns and gardens; far less than the target of 1 inch per week. Research also identified that many customers with automatic irrigation systems apply greater than 1 inch (in some cases 3 or 4 inches) per week. With the volume of irrigation being a function of application rate and area being irrigated, then larger lawns require more water. Since the average homeowner applies less than 1 inch per week, the logical focus for the Region of Peel was to concentrate on Industrial, Commercial and Institutional (ICI) properties that are large and have automatic irrigation systems.

Program Development and Implementation

The 2009 Peel study used water billing data to identify sites with large summer to winter water use ratios. Suitable sites then were selected and sub-meters and data logging equipment were installed to determine the current level of irrigation. Data obtained through the sub-meters and controller records were used to calculate the depth of water to each zone per week based on the flow rate and schedule. In order to assess the functionality and efficiency of irrigation, a system audit was performed at the participating sites by SMART Watering Systems Inc. and Veritec Consulting. The audits focused on looking at spray heads, nozzles etc., type of controller, schedule and type of landscape being irrigated. Two levels or potential water savings were identified:

1. System Improvements: Optimize current irrigation system i.e., install proper spray heads/nozzles, pressure regulation, properly adjust irrigation schedules and repair faulty equipment and/or leaks.

2. Control System Upgrades:
   - Smart Controller: adjusts irrigation schedule based on local ET (evapotranspiration) values. Most systems are wirelessly linked to a weather network and adjust zone run times on a nightly basis based on current ET.

   - Central Control System: Central control systems receive irrigation schedule changes through a remote system or by human adjustment. This allows for changes in the system in one or more zones to account for local conditions or forecasted precipitation. Centralized control systems also allow for real-time flow measurements that may reduce water loss to leaks caused by vandalism or other damage.

Table 1 below displays an example of metered data and calculated savings from a single ICI customer. This highlights the potential for water savings on a zone by zone basis through system improvements and system upgrades.

Table 1 - Zone Summary

										Potential Savings, m^3/yr		
Zone Number	Area, m^2	Landscape Type	Flow rate, L/min	run time min/cycle	cycles/week	mm/week	inches/week	m3/year	Leak Observed	Hardware Savings [1]	Additional w/ Smart Controller [2]	Additional w/ Central Controller [3]
1	180	MIXED	80	30	3	40	1.58	144		98	18	23
2	101	SHRUBS	100	15	3	45	1.76	90		64	10	13
3	180	TURF	63	15	3	16	0.62	57		11	18	23
4	814	TURF	149	30	3	16	0.65	268	✓	61	83	103
5	1,231	TURF	209	30	3	15	0.60	376	✓	64	125	156
6	1,255	TURF	211	30	3	15	0.60	380	✓	61	128	159
7	2,123	TURF	202	30	3	9	0.34	364			40	94
8	1,958	TURF	143	30	3	7	0.26	257				9
9	485	TURF	155	15	3	14	0.57	140		16	49	62
10	83	TURF/TREES	85	15	3	46	1.81	77		55	8	11
11	44	TURF/TREES	119	15	3	123	4.84	107		96	4	6
12	575	TURF/TREES	124	15	3	10	0.38	112			24	39
13	649	TURF/TREES	163	15	3	11	0.44	147			48	64
14	1,612	TURF	78	30	3	4	0.17	140				
15	1,644	TURF/TREES	180	30	3	10	0.39	324			73	115
							Total Annual Irrigation Demand, m3/year =	2,982				
									Total Estimated Annual Savings, m3/year =	527	629	876
									Percentage Savings =	18%	21%	29%

Table 1. Zone summary of ICI outdoor irrigation data. Data was obtained from a participating audit site for 2009 within the Region of Peel, ON.

Throughout the test sites it was determined that in zones where the customer applied approximately 12 mm (1/2 inch) of water per week, the grass was still green. It was decided that a baseline of 12 mm per week would be set for ICI sites that used standard controllers.

Evaluation

Many of the ICI customers had been operating their outdoor irrigation with a 'standard' controller and not a 'smart controller'. Operation in each zone was performed on a pre-set run time on pre-set days (e.g., 40 minutes/day, 3 days/week). The drawback to this approach is that run times are often set at the start of the irrigation season to provide sufficient water during the most severe summer conditions. The tendency with this setup is to over-irrigate unless manually adjusted. Paired with this, leaks were observed on multiple sites and without correction would account for significant water losses.

Recommendations were provided to each of the pilot ICI customers. In the summer of 2010, following a 20 week season, the post monitoring of irrigation demand was conducted and data was collected. The results from the ICI pilot customers all indicated significant water savings; shown in four specific examples:

Microsoft

Table 2. Pre vs. Post Irrigation Demands

Microsoft	
PRE	
PRE Irrigation Demands per 20-week season	5,994 m^3
Area of Irrigation	10,073 m^2
Weekly Irrigation Demands	30 mm/week
Maximum Target (estimated) savings	4,715 m^3
POST	
POST Irrigation Demands per 20-week season	2,128 m^3
Weekly Irrigation Demands	11 mm/week
Savings	
Actual water savings	3,866 m^3
Percentage water savings	64%
Percentage of Target Savings Achieved	82%

Microsoft implemented a monitored Central Control System and focused on corrections recommended for system improvement. This included pressure regulation, rotary nozzle upgrades and sprinkler adjustment/replacement. Equipment upgrades and repairs to sprinkler system infrastructure resulted in a water savings of 3,866 m^3 (1,020,624 US Gallons). The weekly irrigation application was reduced from 30 mm/week in 2009 to 11 mm/week in 2010 resulting in a water savings of 64%.

Meadowvale Corporate Centre

Table 3. Pre vs. Post Irrigation Demands

Meadowvalve (2000 Argentia Road)	
PRE	
PRE Irrigation Demands per 20-week season	10,463 m^3
Area of Irrigation	21,125 m^2
Weekly Irrigation Demands	25 mm/week
Maximum Target (estimated) savings	7,244 m^3
POST	
POST Irrigation Demands per 20-week season	4,503 m^3
POST Irrigation Demands per 20-week season	11 mm/week
Savings	
Actual water savings	5,960 m^3
Percentage water savings	57%
Percentage of Target Savings Achieved	82%

Meadowvale Corporate Centre installed a Centralized control system and made corrections recommended for system improvements. This included pressure regulation, wiring repairs and sprinkler head relocation. Equipment upgrades and repairs to the sprinkler system infrastructure resulted in a water savings of 5,960 m^3 (1,573,440 US Gallons). The weekly irrigation application was reduced from 25 mm/week in 2009 to 11 mm/week in 2010 resulting in a water savings of 57%.

Psion Teklogix

Table 4. Pre vs. Post Irrigation Demands

Psion (irrigate 18 weeks/year)	
PRE	
PRE Irrigation Demands per 20-week season	2,504 m^3
Area of Irrigation	12,935 m^2
Weekly Irrigation Demands	10 mm/week
Maximum Target (estimated) savings	1,263 m^3
POST	
POST Irrigation Demands per 20-week season	1,643 m^3
POST Irrigation Demands per 20-week season	6 mm/week
Savings	
Actual water savings	861 m^3
Percentage water savings	34%
Percentage of Target Savings Achieved	68%

Psion Teklogix made minor schedule changes in 2009 and applied slightly less irrigation than predicted. Changes in the irrigation schedule (applied by the existing smart controller) resulted in a water savings of 861 m^3 (227,304 US Gallons). The weekly irrigation application was reduced from 10 mm/week in 2009 to 6 mm/week in 2010 resulting in a water savings of 34%.

Delta Meadowvale Resort

Table 5. Pre vs. Post Irrigation Demands

Delta Hotel	
PRE	
PRE Irrigation Demands per 20-week season (6,634)	15,097 m^3
Area of Irrigation	17,943 m^2
Weekly Irrigation Demands (21)	42 mm/week
Maximum Target (estimated) savings	12,908 m^3
POST	
POST Irrigation Demands per 20-week season	4,860 m^3
POST Irrigation Demands per 20-week season	14 mm/week
Hours of Operation per 20 week season	
Savings	
Actual water savings (1,774)	10,237 m^3
Percentage water savings	68%
Percentage of Target Savings Achieved	79%

Delta Meadowvale Resort made significant changes to their schedule through installation of a smart controller. A master valve installation also reduced water loss form mainline leaks. Changes and system improvements resulted in a water savings of 10,237 m^3 (2,702,568 US Gallons). The weekly irrigation demand was reduced from 42 mm/week in 2009 to 14 mm/week in 2010 resulting in a water savings of 68%.

Conclusions

Healthy, green lawns are possible with reduced water application amounts of 10-15 mm (less than 1 inch per week) with no sacrifice to curb appeal. Savings are achieved from both system improvements (maintenance) and system upgrades ("smart" or central controllers). The greatest potential for water savings may be related to proper maintenance and scheduling. This can be achieved through assessment and infrastructure improvement of the irrigation sprinklers, pipes and valves.

The Region of Peel has experienced some positive results since the implementation of its ICI Outdoor Irrigation Audit Pilot Program. The average savings per participating site was greater than 3,000 m^3 of water per year. In response to the positive results achieved in the pilot program, the Region has now made the Outdoor Irrigation Audit Program available to all facilities in Peel.

Research will continue to find the best way to estimate and identify potential savings, monitor and verify savings and finally sustain savings.

Acknowledgements

Bill Gauley, Veritec Consulting.

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1-101

Evaluating the Efficiency of a Large Commercial Site with Multiple Systems

Abstract: The intent of this paper is to provide a comprehensive understanding on resolving the issues that arose during the process of proposing and conducting an evaluation of existing irrigation systems on a 70 acre corporate campus site with municipal water supplying 8 separate irrigation systems, controlling over 115 zones that service a perpetually changing landscape containing plant materials with a wide range of watering requirements with the purpose of providing to the owner, an inventory of irrigation system components and furnishing general recommendations for improving irrigation system efficiency.

Drafting the proposal

A preliminary meeting with clients' representatives (Director of Facilities and Director of Operations and Engineering) and the landscape/irrigation contractor who currently maintains the irrigation systems determined that the goals for performing an audit and evaluation of the irrigation systems were two fold:

- Provide an inventory of components of the systems currently in operation along with an evaluation of their performance in terms of irrigation efficiencies.
- Furnish general recommendations to help guide the client in all decisions regarding future modifications or redesign of the irrigation systems.

The inventory and evaluation included a review of all of the components which make up the existing irrigation systems including sprinklers, valves, controllers, sensors and point-of-connection components. This was necessary due to the absence of an existing 'as-built' landscape irrigation plan. There have been many changes to the landscape since it was originally installed over 15 years ago. Changes to the landscape resulted from construction of new buildings, roads, parking lots whereas lawn and bed areas were modified to accommodate new walkways and fences. . The site comprises 13 buildings on 70 acres and receives vehicle and pedestrian traffic 24 hours a day, 7 days a week. New construction was currently taking place on the site and one of the systems to be evaluated was only partially in operation.

On-site conditions that influenced projecting time required to perform the audit were:

- high security facility that required sign-in/sign-out procedures, security escorts into buildings to access controllers and view points of connection
- no remote control options available to manually operate controllers from outside the building due to radio interference from on-site communication satellite dishes and radio towers
- absence of as-built design and lack of knowledge on the part of the contractor and facilities staff as to the location and condition of valve boxes out in the field

- limited time frames in which to activate systems without affecting pedestrian traffic flow and other on-campus activities
- absence of separate irrigation water meter readings from that of water used for cooling tower use and other facility needs inhibited establishing a priority list of areas within the landscape receiving excessive amounts of irrigation water as well as inhibiting preparation of monthly and yearly water use/cost comparisons

Based on our preliminary on-site meeting with the clients we developed a proposal to provide an Evaluation/Water Audit Report that included:

- Obtain, familiarize and study existing irrigation systems without the aid of as-built plans
- Evaluate existing system hardware, i.e.: sprinklers, valves, control systems, pipe, fittings, pumps, drip-system components and controls
- Meet and obtain input from maintenance personal as to present operational programs, system maintenance and repair records
- Based on existing landscape, prepare submit a statement of estimated monthly and yearly water use/cost to be compared to future utility records
- Submit written report of observations and recommendations pertaining to #1 - #4 above plus evaluation obtained through the following:
    - methods of water and energy conservation
    - control system options
    - system distribution of uniformity
    - sprinkler precipitation rates vs soil percolation (infiltration) rates
    - evaluation of existing system in light of today's technology
- Attend one (1) review meeting to discuss evaluation report

Included in the proposal was a separate quote to provide a GPS mapping of the irrigation system using AutoCAD Map 2010 software on an accompanying new landscape design plan being provided by a landscape architect firm.

A Time Worksheet in Excel format was used to determine the dollar amount in labor costs and reimbursable expenses based on a projected number of site visits to perform a minimum two (2) catch can tests on each of the 9 controllers throughout the site which included a manual test cycles of a minimum 5 minutes per zone for each of the 9 systems to evaluate valve and sprinkler head performance. The test cycles would help determine which zones were most suitable for catch can tests whereby having the fewest performance issues caused by poor head spacing, spray deflection, broken equipment and pedestrian traffic flow.

Conducting the Audits

System Overview:
The clients existing irrigation systems were separated into eight systems, each with a separate point of connection to the local municipal water supply. Points of connection

were contained in mechanical rooms that also housed points of connection for domestic potable water supply, fire sprinkler system and HVAC service. Each system is controlled by a single automatic controller with the exception of one system that had two controllers. Most of the systems irrigate landscaped areas that have undergone design and construction changes since the system was initially installed. As a result, the original irrigation systems have been modified to accommodate the addition of new plant materials, fence or paved surfaces. In most cases, this has compromised the efficiency of the irrigation systems and in some cases may require a complete re-design and installation of a new irrigation systems, improving on the quality of the turf and reducing water consumption. Most of the bed areas contain mature plants and as a result, the drip irrigation systems installed in the bed areas are not currently on the active irrigation schedule.

Water Supply and Controller evaluation:
Each point of connection to the municipal water supply was reviewed and the following data was recorded on Worksheet #2 of the Irrigation Associations' Rotor and Spray Audit Worksheets, June 2010 edition:

- type of piping and it's size throughout the mainline system, from connection to potable water supply to connection to irrigation mainline outside the building
- meter size and model
- backflow manufacturer, model number, size and date of latest inspection
- dynamic and static pressure and time of day at which tests were conducted
- pressure regulator make and model
- isolation valves
- components for winterizing the system
- controller make and model, programming features and current operating schedule

The components for each point of connection were uniform in size and manufacturer with the exception of one system that was comprised of only 4 zones. Our final report included evaluations of each water supply and control system with recommendations to improve flow monitoring capabilities by upgrading the controllers to newer "Smart" controllers with moisture and flow sensing features and remote capabilities. Even though each point of connection had a water meter separate from the potable water supply for each building, it wasn't until we made our final presentation to the Facilities Department that we learned that irrigation water had also been diverted for cooling tower use during the summer months and thereby making historical water billing statements irrelevant for projecting water savings based on system upgrades.

Field Audits
Catch can test were performed on selected turf areas or zones on each of the 8 systems on the campus. Determining which areas were to be tested was based on which zones had the fewest problems observed during a 5 minute manual test cycle run for each program as well as areas deemed by the facilities management team as a priority to maintain for marketing events held on campus. Tune-ups were performed to correct head and valve issues but many zones had severe design issues and were deemed impractical for testing.

Those zones or areas that performed best after tune-up procedures and would appear to have the highest efficiency rates were selected to have catch can tests performed. Linking information from one zone and applying to others was utilized. At least one spray zone and one rotor zone was chosen from each system and these zones were also representative of the other zones on the same system in terms of soil type and microclimate conditions. All but one system had twelve or more zones and all had conventional wiring to the controller to the valve.

Since most controller locations were deep within building structures that inhibited hand-held remote access and required security guard escort to access to mechanical rooms, most of the catch can tests required manual activation from the remote control valve in the field. Many of these valves required the use of a wire tracking device to locate and identify the correct valve.

The catch can tests were conducted according to the guidelines developed by the Irrigation Association and Cal Poly catchment devices with 16.5 square inch surface area were used to collect data. Pressure tests were conducted at the sprinkler head prior to as well as during the tests if there was a sprinkler on the zone that was not in the area being tested.

Site conditions that influenced audit procedures were:

- Wind conditions varied over the two week period in which tests were performed but on most days there were wind gusts between 5 to 10 mph between buildings. Tests were frequently interrupted and then restarted during calm conditions.
- Pedestrian traffic and scheduled events on some of the lawns required conducting tests either on weekends or early morning.
- Lack of remote access to controllers

There were a total of 18 catch can tests performed throughout the campus and 3 of the areas tested had overlapping zones and the results of two runtimes were combined to provide accurate performance data for an area. Test results were recorded on IA Worksheets and a site map was drawn for each area showing head location, catch can location, distance between heads and catch cans.

Catch Can Test Results:

Even though areas tested has similar microclimate and soil conditions as well as having minor or no observed problems with equipment, the DU and PR rates varied greatly between areas. DU rates ranged from 16% to 67% on spray zones and 23% to 51% on rotor zones. The lowest rates were a result primarily from design issues such as poor head spacing and insufficient head counts to provide head-to-head coverage.

Knowing that most of the tests were going to produce results well below the industry efficiency standards for both rotor and spray head zones, the results helped us prioritize zones that were in most need of renovation. Priority was also given to areas where marketing events were hosted and taped for promotional purposes. These priority areas were determined in a preliminary meeting with the owners representative and the current landscape maintenance contractor prior to testing.

Summary:

Upon completion of the catch can tests conducted throughout the campus, we conducted a GPS mapping of all eight existing systems locating all heads, valves, controllers and points of connection along with estimated pipe and wire runs to provide an As-Built irrigation plan. A Landscape Architect firm provided a new AutoCAD landscape plan for us to use AutoCAD Map and add the irrigation.
A final presentation with the Facilities Management staff included:

- Audit worksheets with documents explaining test results and included a glossary of terms
- Estimated Annual Water Use data for each irrigation system that included projected water use in gallons for each day, week and month from April through October which incorporated historical rainfall and ET data, specific plant watering requirements and system efficiency rating. Quattro Pro X3 software was used to compile data.
- Recommendations for controller field units that have flow sensing, moisture sensing, remote capabilities and potential for central control upgrade. The recommendations were non-proprietary and our report is intended to provide the client with necessary information on control system features and use as a reference when researching different product lines.
- Re-design irrigation system for areas with lowest DU rates and have high profile status.
- Establish a Base Irrigation Watering Schedule to be monitored and altered throughout the irrigation season to accommodate changing demands upon the irrigation system relating to weather conditions and activity schedules

References:

Irrigation Association, March 1996 Second Edition. Landscape Irrigation Auditor Training Manual

Irrigation Association, September 2009. Recommended Audit Guidelines.

Maximizing Climate Based Irrigation Efficiencies

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Abstract. *After nearly 20 years of utilizing an Et based central irrigation control platform, the economic conditions profusely compelled us to maximize the potential savings, whether technology driven, educational pieces, or other means deemed worthy of assessment to enhanced our water management program.*

At the forefront, staff education, involvement, and support was determined to be of the utmost importance, as well as elaborating on strategies developed by Portland Parks & Recreation over the past several years to achieve higher levels of irrigation effectiveness for both new and existing systems.

Being one of the largest water users in Portland and having the luxury of our water provider being a sister bureau, various pilot programs have been developed. Testing of numerous devices, software platforms, and most importantly, development of educational pieces have produced significant water and cost savings.

Based on the Irrigation Association's Best Practices and Standards, an entire process of integration between software, hardware, and people has created a successful water management program.

Keywords. Climate Based Irrigation Efficiencies, Water Management, Water Savings, Water Conscience Education, Water Conservation Software, Water Conservation Hardware, Water Conservation Education

Beyond the Technology:

As one of the first public entities in the Pacific Northwest to get started in the central control mindset, Portland Parks & Recreation has learned not only by education but by the oldest method, that of trial and error. The success we are encountering today is in direct response to the forward thinking and perseverance of longtime staff. While others have struggled, PP&R has made climate based irrigation a successful standard throughout the park system.

Currently, 80 of our 150 irrigated parks are controlled by Et or moisture sensors. Our directive is such that each year, 6 to 12 of the remaining stand alone controller parks are brought into the climate based system. Also, all new park facilities are required to install the necessary equipment allowing them to be centrally controlled as well.

With a dedicated Irrigation Services workgroup as the backbone, the installation process of the sophisticated control equipment is straightforward and predictable. But, beyond the actual hard goods mounted on the wall or buried in the ground, the need to gather the required data, work through technical difficulties, and keep up with other daily work orders for all elements of responsibility of the Irrigation Services workgroup prove challenging.

It was determined a few years back, that for our control systems to continue to be truly beneficial, the support from the Park Technicians and Horticulturalist whose responsibilities it is to take care of the day to day maintenance requirements at their assigned facilities was needed.

After years of seeing savings in water use by central monitoring it was dramatic when the savings stopped and actually started to reverse. After a few season and countless hours spent analyzing data, the truth finally was obvious that our delivery systems now being 8 to 10 years old, were aging and becoming less efficient.

Enlisting the Daily Maintenance Staff:

Given the findings, a program was developed that would garner the necessary support from the specific zone personal that would get us back on the water savings track.

Starting in 2009, an audit completion was developed that provided valuable insights to the park staff. Conducted by local CLIA's, a series of workshops were conducted, both in the classroom and in the field. Each of our 6 zones was attached to a park that had shown signs of declining water savings.

A pre-audit was conducted, system enhancements suggested, and each team was allowed to determine how best to capture the greatest savings gain while being cost conscience. When the post audits were conducted, the most improved efficiency team was rewarded with PP&R wearables.

This initial, albeit simplistic step, was amazingly a huge eye opener for the park field staff. Yes, they had been to numerous local distributor trainings but to actually have hands on experience and see the physical changes that afforded a higher level of irrigation efficiency was undeniably a breakthrough.

Since this time, the phrase "Tune Up" has been uttered daily throughout our PP&R staff. The solid proof (fig. 1 below) has convinced not only those responsible for the daily maintenance activities at the park facilities but their direct supervisors and upper management. This became extremely true this past year as looming budget cuts had all areas of our park system looking for savings.

Water is a large cost item, especially when all water aspects of the bureau are rolled up under this line item. From 2010 to 2011, Portland water users experienced a 15% increase in water alone not to mention the increase in sewer and storm water fees.

A program was launched at the end of last year and carried through this irrigation season that not only continued the focus on "Tune Ups" at our centrally controlled parks but on the stand alone parks as well. Added to the "Tune Up" was a Water Allocation component where Park Tech's and Horticulturalist were challenged with the concept that they were required to determine the volume of water their facilities would require.

Utilizing current, readily available and accessible technologies within the City of Portland those participating attended a series of workshops to introduce them to the next step in our water conservation efforts and the functionality of technological aids.

The first step was introducing the water budget components. Modeled after the EPA's online calculator, data was collected for 12 parks representing 2 in each service zone.

Once the concept of water budgeting was digested, the "what next" was entertained. To provide a true and meaningful learning experience that could be easily conveyed and demonstrated, the need for timely water use amounts was discussed. A workshop was held on meter reading and a part time position was funded by the Water Bureau that would not only allow the meters to be read on a weekly basis, data inputted into usable spreadsheets, but also provide guidance during the irrigation season.

Providing all the tools necessary for each park staff member responsible for irrigation was critical to the success of the program and more importantly to meeting the budgetary limits imposed on water.

Knowing the anticipated amount of water, getting weekly input, understanding that efficient irrigation starts at the sprinkler, that the moisture in the ground is what really matters, are all educational elements that enhance what the technology side of irrigation cannot capture.

To date, the 12 parks in the pilot program have experienced a combined savings this year over last, with weather being similar, of 15% (fig 2 below). Part, indeed is due to the focus on each park, part being the message to stay under the fiscal budget from management, but the largest part is that the knowledge was given and supported with relevant, timely information. Portland Parks & Recreation understands that this is just the beginning. With a large and dynamic array of facilities and a diverse staff, ongoing education and systems refinement will continue.

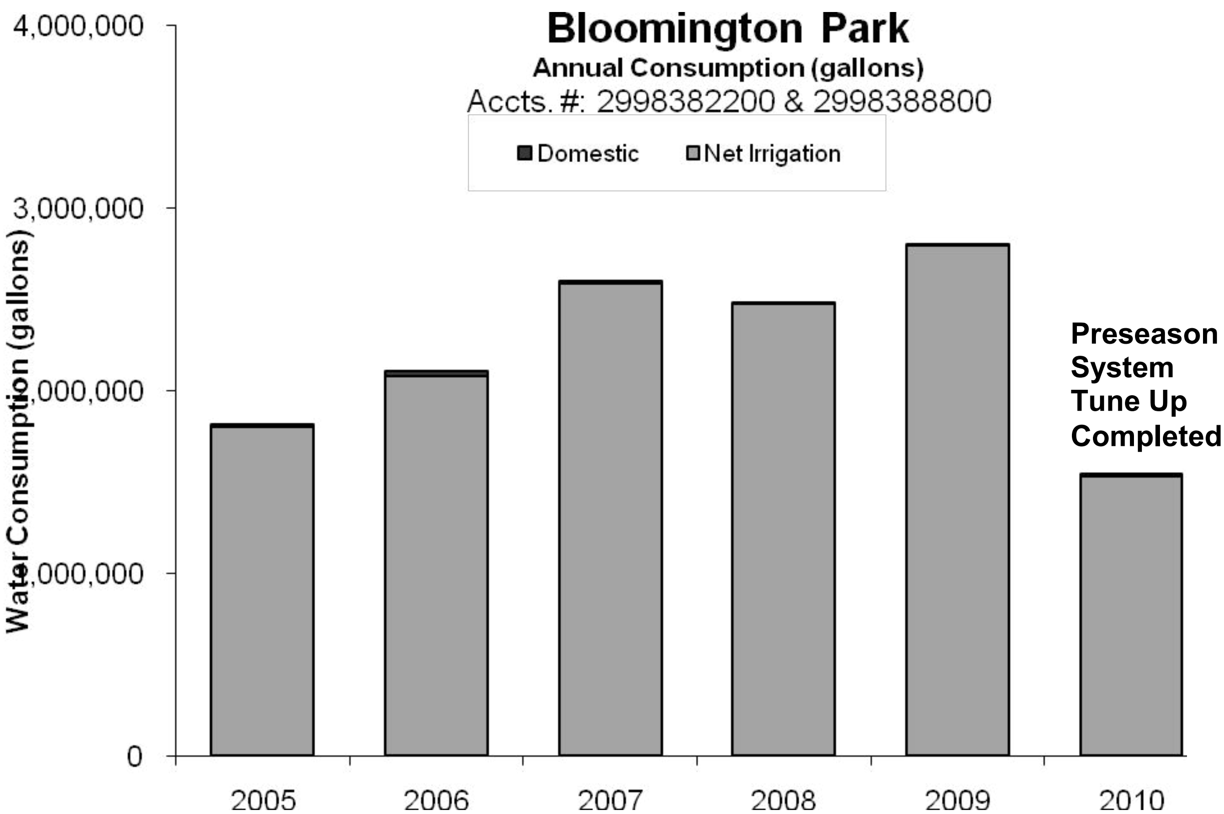

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Fig 1 Et based control system steadly showed signs of increase water use prior to tune up.

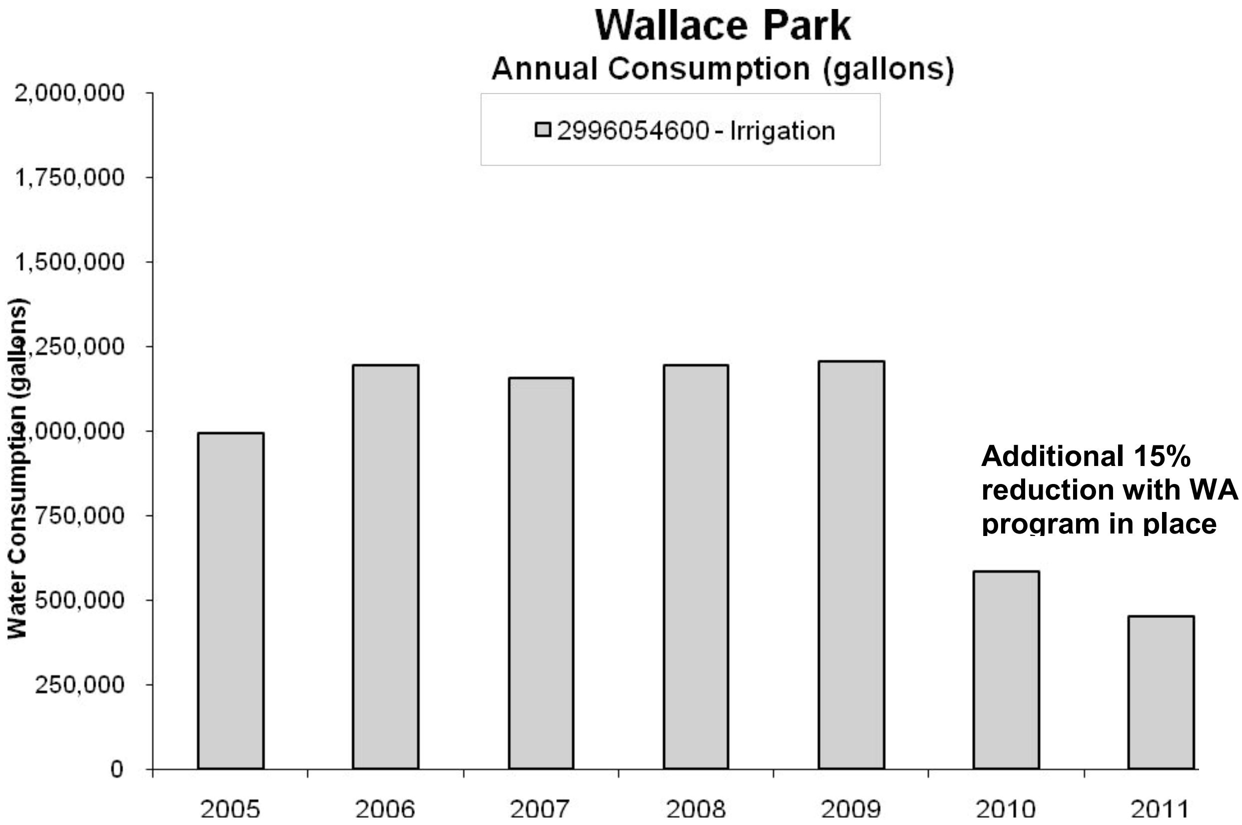

Fig 2 Tune up and water allocation program in place, brought back to back years of savings.

Conclusion

Regardless of all the technological advances throughout the irrigation industry, it still comes down to the actual person or persons in the field. Whether daily, weekly, or sporadically through the season, the need for staff to have a working, hands on knowledge and grasp of the important functions they have control over, greatly impact the actual water required to maintain an expected aesthetic appearance of the areas requiring irrigation.

An unexpected result of the first year's program was the passion that was unleashed from the ranks. A consensus was voiced for the knowledge gained, supporting what some had been practicing, and served to enlist their support. In the field, the peer to peer transfer of knowledge is insurmountable at building the momentum necessary to keep our program moving forward.

As a special note, the one in the group that was the most skeptical by the end was the strongest advocate. The reality that simple instruction and provision of tools allows for a means to actually simplify the day, saving time, money and most importantly our most precious resource.

A Comprehensive Strategy for Improving Water Management in Parks

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ABSTRACT. *As a result of severe budget constraints that jeopardized the health of the City's parks, Colorado Springs Utilities developed a comprehensive water strategy to help maintain a healthier and more sustainable parks system, short and long term. The strategy is a holistic approach to irrigation management that includes: a budget-based rate to encourage efficiency and appropriate management practices; irrigation system evaluations, retrofits, and replacements designed to improve the system's aging infrastructure and incorporate new technologies; and a customized education program that provides the information and tools necessary to ensure effective resource use and initiate a lasting culture of efficiency.*

This paper highlights the key elements and results of the program. It also provides a valuable case study for other irrigators, business, and homeowners.

Keywords. Water conservation, irrigation efficiency, sprinkler retrofit, conservation water rate, irrigation water management, municipal park irrigation, holistic irrigation management

BACKGROUND: The Economic Downturn Hits City Hard

Largely as a result of the economic downturn, 60 miles south of Denver, the citizens of Colorado Springs, experienced severe cuts in basic municipal services which most Americans take for granted. The national media outlets represented Colorado Springs as a poster child of government cutbacks, with reports of brown park grass, dark street lights, shuttered police helicopters and buses sold or on scaled-down schedules.

The deep recession bit into Colorado Springs sales-tax collections forcing drastic budget cuts. The city spent $19.6 million on parks in 2007, and 3.1 million in 2010.

Through early retirement and layoffs, the City reduced headcount by nearly 200 employees, and refrained from filling public safety jobs from 2007 to 2010. More than a third of the city street lights were shut off.

City recreation centers, indoor and outdoor pools, and a handful of municipally-funded museums closed or found private funding to stay open.

ABC News Anchor Diane Sawyer said in one broadcast, “The parks department removed trash cans (Figure 1), and residents are being asked to bring their own lawnmowers if they want the lawns trimmed in the park, but there may not be much to trim. Water is being cut off to the parks, too.”

Figure 1: P&R staff remove trash can due to budget cuts.

Municipal Entities

Colorado Springs Utilities (Utilities) and the City of Colorado Springs Parks and Recreation and Cultural Services (P&R) are municipally owned yet uniquely funded and operated enterprises; each governed by City Council. More than 50% of Parks funding is a result of sales tax revenues, while Utilities budget is primarily funded by ratepayers.

PROGRAM DEVELOPMENT

At the direction of City Council, Utilities entered into two water conservation pilot programs with P&R on May 1, 2010: the Water Conservation Rate Pilot Program and the Pilot Irrigation Efficiency Program.

The collective program goals are to:

- Provide a short-term solution to keep parks more attractive and healthier under tough budget constraints.
- Make available more water through a budget-based rate structure which encourages proper watering and discourages over watering.
- Implement parks efficiency audits, evaluations, and retrofits that assure long-term sustainability of parks irrigation infrastructure.
- Promote a lasting culture of efficient irrigation management.

The programs were designed as a test over a two-year period with the intent to determine the costs associated with program administration and operations, and to analyze and promote "lessons learned" from these programs with other large potable irrigators.

PART I: Water Conservation Rate Pilot Program

The rate pilot program is a budget-based approach that provides a water allocation for each park according to its irrigated turf acreage and historical weather conditions. Water is priced according to use, relative to the allocation so that reasonable and efficient use is encouraged.

Historically, 24 inches of irrigation water is considered "ideal" to manage a healthy stand of turf in a park setting in Colorado Springs. Prior to implementation of the rate pilot program, the 2010 P&R budget allowed for an average of 12 inches of supplemental irrigation to be applied to parks (Table 1). The 2011 Parks budget allows for 16 inches of supplemental irrigation. Early in 2010, P&R leadership determined that not all parks would receive an identical irrigation allocation. Several high-use and priority parks were identified to receive higher allocation amounts, while other lower priority parks would receive less.

Seasons	2010	2011
# of parks on the rate	132	153
Total park and median acreage covered by rate	725	753
Parks budgeted irrigation	12"	16"

Table 1

Table 1 shows the number and acreage of parks on the Rate, and P&R's 2010/11 budgeted irrigation amounts for the parks.

The rate pilot program has the following intent:

- Provide a significant short-term financial benefit to P&R for watering within generous parameters, while penalizing excessive use (Figure 2).
- Provide more irrigation water to parks during severely constrained budget years to keep parks greener and healthier.

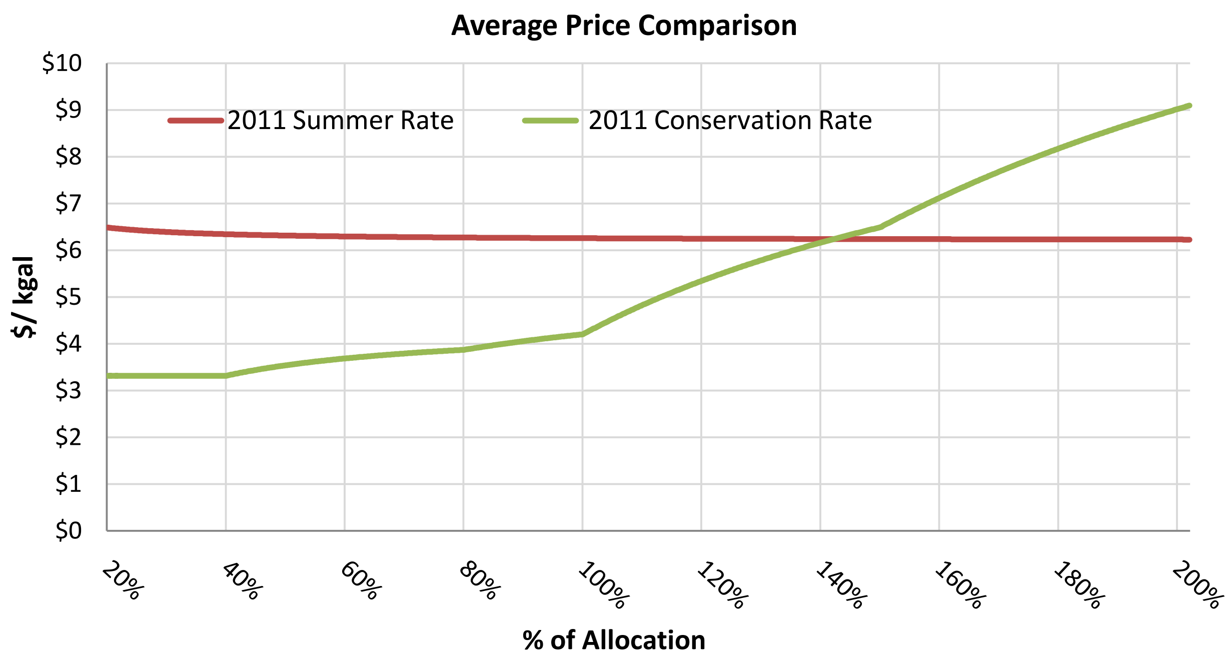

Figure 2: Compares the former P&R summer rate, to the current conservation rate.

Water Conservation Rate Pilot Results

Overall the Water Conservation Rate (Rate) worked as intended. In 2010, P&R was able to apply an average of about 16 inches of supplemental irrigation to parks from May through October. While this is still about a third less than ideal, it is four inches more than would have been possible without the Rate. The results through August of 2011 are slightly better. The parks are on schedule to receive about 17 inches of supplemental irrigation which is about 70% percent of ideal and about 1 inch more than was budgeted for. Overall the program has saved P&R 31%. A complete overview of the pilot results are shown in Table 2.

	2010 Total	2011 Total Through August	Program Total Through August, 2011
# of parks & medians on the rate	132	153	153
Total park and median acreage covered by rate	725	752	752
Total water allocation for participating parks & medians (CF)	65,998,481	51,721,729	169,441,939
Total consumption of participating parks (CF)	41,571,351	36,083,002	113,737,355
Percentage of total water allocation used in parks and medians	63.0%	69.8%	67.1%
Total billed on conservation rate ($)	$1,323,281	$1,109,690	$3,542,661
Would-be bill without conservation rate ($)	$1,760,556	$1,691,789	$5,144,134
Parks and Rec savings due to rate ($)	$437,275	$582,099	$1,601,473
Parks and Rec savings due to rate (%)	24.8%	34.4%	31.1%

Table 2

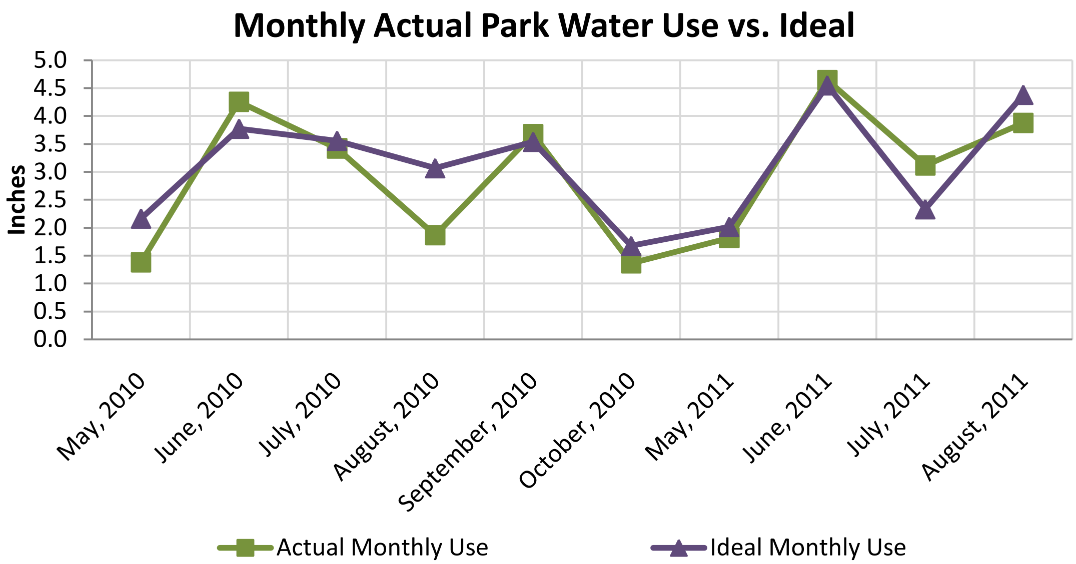

Figure 3

Figure 3 shows average monthly park use compared to what is considered optimal accounting for budget constraints and weather conditions. This figure indicates that Parks irrigated within 20% of ideal in every month but three. May of 2010 was explained by late irrigation start-up, August 2010, was driven by increased budget concern, and July 2011 was likely P&R taking advantage of an increased budget to overseed parks.

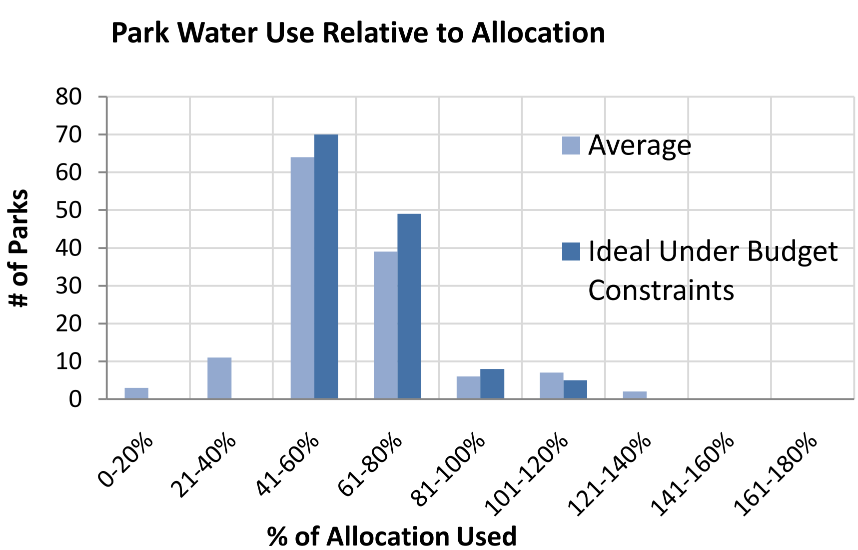

Figure 4

Figure 4 represents the average seasonal park water use distribution relative to assigned allocations for May through October 2010 compared to a theoretical "ideal" distribution given the City's budget constraints and park watering priorities. This figure indicates that, on average, Parks watered very near ideal ranges in 2010 - which is what the Rate is designed to encourage.

<u>PART II</u>: Parks Efficiency Pilot Program

The Parks Efficiency Pilot Program is a comprehensive program designed to work with P&R to help improve the efficiency of park irrigation systems and initiate a lasting culture of efficiency. Many park irrigation systems are 20-30 years old and have not been updated or maintained for optimal irrigation efficiency.

The program is designed to:

- Conserve water through increased irrigation efficiency
- Allow Parks to take full advantage of the conservation rate
- Help manage limited budget dollars more effectively
- Influence long-term water savings and sustainability of the Park's System
- Encourage efficient irrigation practices and efficiency-oriented culture

Additionally, the program is designed to determine the benefit and potential water savings of a holistic approach to water management, which in turn, provides better informed water management decisions for both P&R and our community.

Efficiency Program Implementation

The services of a full-time Irrigation Specialist, four part-time staff, and five area contractors work in cooperation with Parks staff to identify areas that provide the greatest water and dollar savings potential.

A combined 2010/11 program budget of $700,000 has been fully utilized the last two seasons to complete a variety of work (Table 3), ranging from park evaluations, audits, and rain sensor installation (Figure 5), to full irrigation system replacements (Figure 6).

2010-2011 Parks Efficiency Program Summary			
Work Performed	**2010 Season**	**2011 Season** (Through Aug.)	**Program Total** (Through Aug. 2011)
Evaluations	43	13	56
Audits	39	21	60
Park Retrofit/Replacements	(20) parks - 91 acres	(13) parks - 48 acres	33 parks - 139 acres
Rain sensors installed	35	77	112
Controllers installed	14	2	16
Pressure regulators installed	14	3	17
Remote control adapters	4	170	174
Irrigation system designs	4	1	5

Table 3 lists the majority of the work completed from May 2010 through August 2011

Figure 5: Rain sensor installation

Figure 6: Installation of new irrigation system

Irrigation system audits (Figure 7) are performed prior to and following system retrofits (Figure 8) and replacements. The results of these audits show significant improvement in overall irrigation system uniformity resulting from retrofits and system replacements (Table 4).

Figure 7: Irrigation audit

Figure 8 shows old impact sprinkler being replaced with new more efficient sprinkler.

Park Efficiency Pilot Results

Parks Efficiency Pilot Program Retrofit Results	
Average irrigation uniformity prior to retrofit	59%
Average irrigation uniformity following retrofit	77%
Total acres retrofitted	139
Total cost per acre retrofitted	$2,926
Estimated year-one year return on investment	39%
Estimated annual CF allocation for retrofitted parks	12,956,335
Estimated year-one CF savings	$4,726,234
Total retrofit cost	$406,792
Estimated overall savings potential	36%
Estimated five-year dollar savings	$571,939
Estimated project payback period (years)	2.97
Estimated 5-year return on investment	141%

Table 4

Table 4 shows that retrofits and replacements result in an average increase in uniformity of nearly 20%. The addition of a rain sensor brings water and monetary savings potential to 36%. Fully utilized, these savings lead to an average project payback of about three irrigation seasons (an estimated annual water savings decrease of 20% is assumed in these results and can be mitigated by ongoing system maintenance). Water savings results are theoretical, and only will be realized through the promotion of a lasting "culture of efficiency."

LESSONS LEARNED: Parks Efficiency - Creating a Culture of Efficiency

To realize consistent water/monetary savings from this program requires an ongoing commitment and investment to a culture of efficiency. The potential 36% savings from retrofits and replacements are largely a function of system operation which is dependent on the following comprehensive factors:

- **Leadership Buy-in** is key to any successful organizational initiative. Leaders are likely more willing to invest time, energy, and the necessary resources if they understand and accept the potential benefits of a program, including long-term economic value.

- Regular **irrigation system maintenance** is essential to efficient water use and water savings. Routine system checks and maintenance are necessary for optimum efficiency and reliable irrigation delivery.

- **Proper scheduling** perhaps offers the greatest opportunity for water savings. Its purpose is to maximize irrigation efficiencies by applying the appropriate amount of water needed to replenish the soil moisture to the desired level without waste.

- **Adequate funding** is necessary to allocate personnel appropriately and provide other necessary resources.

- Irrigation efficiency is improved when pursued in conjunction with a comprehensive **turf maintenance program**.

- The use of **new technology** improves the ability to manage water, labor and energy more efficiently.

- Providing **training for employees** (Figure 9) helps develop their skills and knowledge, and is also a motivational building block to organizational success.

- Finally, culture change begins and ends with **individual accountability.** Staff must be accountable for efficient and effective water use.

Figure 9 an off-season training program for P&R staff. Staff training is a critical component of the Parks Efficiency Program.

SUMMARY

The Water Conservation Rate Pilot Program met its goal of providing an average annual financial benefit of $500,000, and 25-30% more water to neighborhood parks. The program has helped keep city parks greener and healthier. And, the increased price for water in the highest tiers of use helped decrease previous over-watering by nearly an average of 40%. The true conservation potential of this rate structure is yet to be evaluated - analysis over a longer period of time and the absence of significant budget constraints would assure reliable results.

The Parks Efficiency Pilot Program has the potential to save P&R water and money far into the future. Efficiency upgrades and improved uniformity achieved from irrigation system retrofits and replacements indicate the potential for an average payback of three irrigation seasons. Program findings will help P&R and other customers make better-informed water decisions now and in the future. Looking forward, much of the success of this program depends upon the extent to which P&R staff embrace and commit to a long-term cultural change in water conservation and improved water management practices. With such a change, a long-term future of sustainable healthy parks system is assured.

The recent economic downturn in Colorado Springs provided an opportunity for the City to get creative to find ways to help bridge the economic gap while maintaining and restoring basic services. The resulting Parks Rate and Parks Efficiency Pilot programs indicate that a comprehensive and proactive approach to park water management can provide a tremendous benefit to both P&R and the community.

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How Efficient is Landscape Irrigation?

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Abstract. *The terms efficiency and uniformity are often incorrectly used interchangeably in landscape irrigation. Efficiency consists of hardware associated issues and management. Hardware includes design, installation and maintenance; management is essentially irrigation scheduling, the right amount applied at the right time. Irrigation efficiency tended to be less than 50% on homes and on plot based studies where "typical" time clock schedules were used. Optimizing time clock programming with a rain sensor could increase efficiency substantially. Smart controllers such as soil moisture sensor (SMS) or evapotranspiration (ET) controllers tended to result in irrigation efficiency above 70%.*

Keywords. Landscape irrigation, uniformity, efficiency.

Irrigation Efficiency and Uniformity

The terms efficiency and uniformity are often incorrectly used interchangeably in landscape irrigation. Irrigation system efficiency can have multiple definitions focusing on crop yield for a given amount of water supplied to the amount of water that is delivered to the crop root zone as a fraction of the amount of water pumped (Burt et al., 1997). In landscape irrigation, efficiency can be defined as the gross irrigation requirement relative to the gross irrigation delivered or pumped. The gross irrigation requirement is the net irrigation requirement multiplied by an efficiency factor to account for "reasonable" and allowable irrigation inefficiencies or other beneficial uses of water not associated with meeting plant growth needs.

Irrigation system uniformity is defined as a measure of difference in water applied to a target area relative to the amount of water intended for the target area. The majority of landscaped areas are irrigated with sprinkler irrigation, thus uniformity is a measure of variation in water applied across the target area.

Efficiency and Uniformity Data in the Literature

A few studies have been published documenting irrigation uniformity. Baum et al. (2005) documented low quarter distribution uniformity (DU_{lq}) on homes in Florida as 0.45 compared to a maximum potential uniformity of 0.55 for rotary sprinklers and 0.49 for spray heads. Although DU_{lq} is a common measure used in industry to characterize irrigation system performance, it is not analogous to irrigation system efficiency (Burt et al., 1997) and a wide range of DU_{lq} values can give relatively uniform soil moisture conditions which are conducive to good landscape quality (Dukes et al., 2006). Furthermore, while DU_{lq} may be an indicator of sprinkler irrigation performance, it does not account for irrigation system management. For example, the most uniform system achievable may be designed and installed; yet mismanagement may lead to inefficient use of water.

In this work, data on irrigation and gross irrigation requirements were assembled for a variety of plot studies, which had a wide range of irrigation application ranging from excessive irrigation to non-irrigated plots. Studies were primarily aimed at evaluating smart irrigation controllers such as soil moisture sensor (SMS) based or evapotranspiration (ET) based controllers. These controllers are intended to optimize irrigation management (i.e. scheduling), which should optimize irrigation efficiency. All of these studies included comparison irrigation treatments based on a standard time and calendar schedule. The irrigation systems were designed and installed with uniformity typical of field installations similar to those documented by Baum et al. (2005). In addition, several studies with cooperating homes were used to assess irrigation efficiency under "real-world" conditions.

Irrigation efficiency was defined based on the Smart Water Application Technologies (SWAT) protocol (IA, 2008) using a calculation of over-irrigation, scheduling efficiency, and a calculation of under-irrigation, irrigation adequacy. Scheduling efficiency is gross irrigation requirement divided by the gross irrigation applied with a provision that any number greater than 100% is fixed at 100%. Irrigation adequacy is the gross irrigation requirement minus any deficit divided by the gross irrigation requirement. Thus, if there is no soil water deficit, adequacy would be 100%.

Scheduling efficiency on actual homes tended to be around 50% or lower where landscape quality was maintained at or above acceptable levels (Fig. 1). Adding devices such as a rain sensor or SMS controller tended to increase scheduling efficiency while maintaining irrigation adequacy above a level required for good landscape quality (Fig. 2). In plot studies, generally irrigation adequacy above

70% guaranteed good turfgrass quality; however, turfgrass quality could be maintained at an acceptable visual appearance down to adequacy levels of 60% in some cases.

Conclusion

A high scheduling efficiency and irrigation adequacy in most cases was a result of an advanced irrigation scheduling technology such as SMS or ET controllers. Careful programming of a time clock irrigation schedule could also result in both high scheduling efficiency and irrigation adequacy simultaneously. In particular, schedules that apply smaller amounts of water at an irrigation event tend to promote high scheduling efficiency while maintaining irrigation adequacy. This type of irrigation scheduling needs to be evaluated with respect to turf and landscape plant health. Finally, work is needed to evaluate the concept of irrigation adequacy in terms of maintaining plant health.

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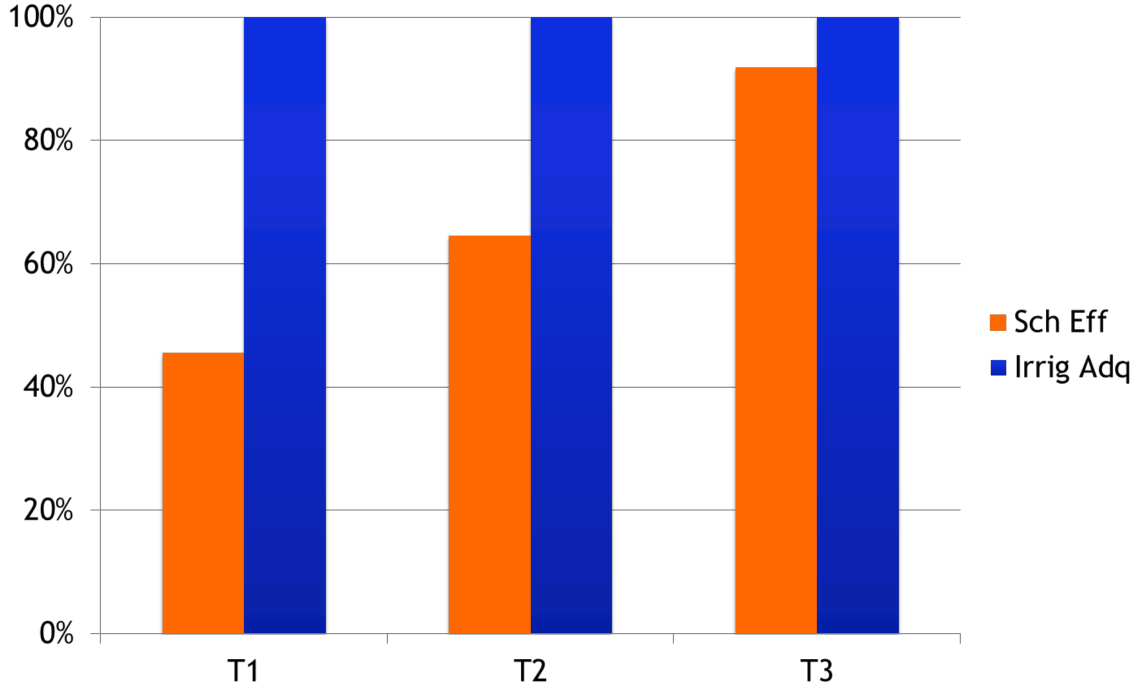

Figure 1. Irrigation scheduling efficiency and adequacy (IA, 2008) from a study by Haley et al. (2007) where T1 was homeowner scheduled irrigation, T2 was scheduled based on UF-IFAS recommendations (Dukes and Haman, 2002), and T3 was scheduled as T2 but included substantially less sprinkler irrigated area than T2. Turf quality on all homes was adequate and not significantly different across treatments.

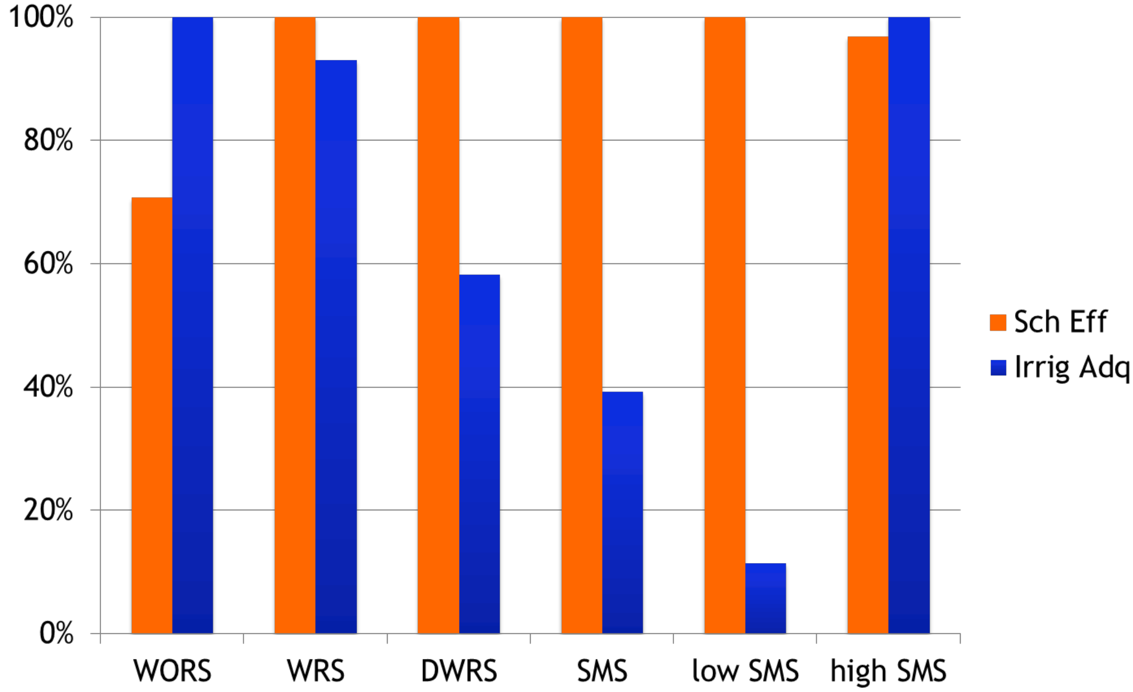

Figure 2. Irrigation scheduling efficiency and adequacy (IA, 2008) from a study by Cardenas-Lailhacar et al. (2008) where treatments were as follows: WORS, UF-IFAS recommended schedule (Dukes and Haman, 2002) without a rain sensor; WRS, UF-IFAS schedule with a rain sensor; DWRS, reduced UF-IFAS schedule; SMS, overall average soil moisture sensor treatment (4 brands and 3 day of the week frequencies); low SMS, SMS treatments with low irrigation; high SMS, SMS treatments with relatively high irrigation.

Title: Wireless and Wired Flow Sensors and Dedicated Submeters used to manage Large Residential Estates and improve Irrigation Efficiency.

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Abstract:

Using wired and wireless flow sensors and dedicated submeters, we have saved on average 35 % water savings for residential estates and have dramatically improved irrigation efficiency. The purpose of this paper is to present findings for a 2 year study of using flow sensors and submeters. Each property has a water history that has been compared to the last 2 years of irrigation management using flow sensors and dedicated submeters. Readings are taking from the submeter monthly and the flow sensor is a real time device that reports the water usage through the internet. Major conclusions are to continue to implement flow sensors and preferably wireless flow sensors into the technology for conducting irrigation management and maintaining efficient irrigation practices.

Blue Watchdog Systems manages irrigation systems for large estates in San Diego, California. For over 2 years we have successfully saved water for our clients using flow sensors combined Residential Estates with flow sensors and irrigation submeters. For this study we chose estates that vary in size from 1 acre to 11 acres and also have irrigation systems that are 14 zones to 330 zones. 8 estates managed with flow sensors and submeters. One site was managed using a wireless flow sensor and a submeter. For comparison purposes one site was managed without a flow sensor and without a submeter. The results from this 2 year period have been substantially in favor of using flow sensors and submeters. Wireless flow sensors have added even more benefits to this approach to managing irrigation systems. Estates managed with a flow sensor and submeter average savings is 35%. The savings is based on a comparison to site historical water usage of at least 5 years. The site without a flow sensor or a submeter did not save any water relatitve to its past water usage.

You cannot manage what you cannot measure. Effectively managing irrigation systems relies on the combination of two key components: a flow sensor and a dedicated irrigation submeter.

The following are **benefits from the use of flow sensors**:

1. system design awareness- establishes baseline flow per station.

2. Leak detection- during operation detect the sensor detect breaks in the sprinkler system. Also detects mainline breaks when irrigation system is not operating.
3. Quicker site inspections- all zones are running at baseline flows, then only inspect for breaks with the zones that have alarms.

The following are additional **benefits of a wireless flow sensor**:
1. installation costs are significantly cheaper as there is not the need to run the wire across a landscape or under driveways.
2. Wireless flow sensors can replace two devices (submeter and standard flow sensors) if they are able to detect low flows.
3. There is no risk of wires getting cut by other trades.

The following are **benefits from dedicated irrigation submeters**:
1. Exact water usage –define water savings and usage through periodic readings to stay within water budgets.
2. Leak detection at very low flows- quickly determine that the irrigation system does not have any leaks using a water meter's leak indicator. Do not have to turn off house water to do this check since it is separated.
3. Defines indoor vs. outdoor use – understand exactly how much water is used outside versus inside and also help quickly identify leaks that may be inside home such as toilet leaks.

Flow Sensor and submeter detected the following events during the 2 year study:
1. Garbarge Truck hit sprinkler in driveway (2 times- he was pretty determined).
2. Telephone service broke riser by street
3. Lawnmower broke sprinkler heads in turf
4. Tree Service broke sprinkler shrub risers
5. Valve cracked and created mainline leak
6. Broken or clogged nozzles
7. Cracked irrigation pipe due to root intrusion

Conclusion:
Tracking water use is a key service to the clients that would like to save water. It is also a critical performance measure for any landscape. This paper has highlighted some of the successes using the should continue to address the need for economical solutions for clients. Wireless flow sensors is a step in the right direction.

Multi-Stream, Multi-Trajectory Nozzles; How they save water, labor and installation costs

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Abstract. *Irrigating spaces in the 8'-20' range efficiently has always been a challenge in Residential and Commercial applications. Impending Federal and State regulations imposing requirements for minimum levels of efficiency have forced the irrigation industry to seek out and explore new methods and technology to improve the way water is applied. Excessive watering (flood irrigating) has been the practice of irrigating smaller areas since the introduction of brass nozzles many years ago. Irrigating with emission devices, such as spray nozzles, that perform at high precipitation rates has been the status quo for over three decades. However, in the last few years, a new and innovative technology has been introduced in the form of Multi-Stream, Multi-Trajectory (MSMT) rotating nozzles. Introduced by the Walla Walla Corporation with roots back to the stream nozzle, the MSMT nozzles offer performance similar to highly efficient single-stream rotors in smaller radii. In addition, these new nozzles are simple and easy to install on top of existing pop-up sprinklers and propel performance to never before seen water savings. This higher level of performance is accomplished by achieving significantly higher Distribution Uniformities which more closely match soil absorption rates, resulting in a significant reduction of wasteful runoff. Additional benefits of these new nozzles include cost savings to the irrigation contractor upon installation. Case studies have shown contractors can save considerably on overall labor and cost of materials when compared to traditional spray nozzle installations.*

Keywords. Multi-Stream Multi-Trajectory nozzles, Distribution Uniformity, Soil Infiltration Rate, Intake Rate, Soil Texture Class

Never before has the residential/commercial irrigation industry been offered a revolutionary line of products that cover spray applications which break the routine of water wasting and move towards water conservation. This product category is the Multi-Stream, Multi-Trajectory (MSMT) line of nozzles.

This line of products has proven itself to have changed the game when compared with traditional spray heads. First introduced to the commercial irrigation industry in 2005 by Walla Walla Corporation, the MSMT nozzle has changed the way designers and professional contractors think about irrigating smaller areas where typically sprays have been used. MSMT technology has actually been around for some time, but, due to manufacturing challenges, it was not possible to produce a nozzle small enough that could easily be installed or retrofitted on a pop-up spray body. Since the introduction of MSMT nozzles, many major irrigation manufacturers have followed with versions of their own.

MSMT nozzles deliver water to its precise location by using individual streams of water thereby significantly increasing the uniformity of how that water is being delivered. MSMT nozzles are just as they sound, they have differently angled streams which are designated to throw given distances and do not interfere with other streams that place water to other locations.

Distribution Uniformity

Distribution uniformity (DU) measures the evenness with which water is applied to the landscape by an irrigation system (Irrigation Association, 2005). It is measured by conducting an "audit," or catch-can test, of the system (Irrigation Association, 2004). DU calculation is based on the average volume of water caught in catch-cans in the least watered areas when compared to the average volume of water caught in catch-cans in the entire area.

DU_{LQ} (lower quarter) is used to classify the quality of coverage (as related to irrigation water usage) in a fixed spray zone using the lowest quarter as the least watered. Table 1 below is a guideline to be applied to DU's measured in the field and terms them as Excellent, Good and Poor. (Irrigation Association, Landscape Irrigation Auditor, 2007, Table 3-4, page 52):

SPRINKLER TYPE	EXCELLENT (Achievable)	GOOD (Expected)	POOR (if lower than this, consider not scheduling)
Rotary Sprinklers	80%	70%	55%
Spray Sprinklers	75%	65%	50%

Table 1

Increasing Distribution Uniformity (DU) is a key component in decreasing the amount of water that needs to be applied for irrigation purposes. Independent testing as well as manufacturer testing shows that 80% DU is attainable with MSMT nozzles. Below is a simple method that can be applied to DU and plant watering needs.

DU %	Water the Plant needs	÷	DU (decimal)	=	Amount of water needed to apply to keep dry area green
30%	1 in	÷	0.30	=	**3.33**
50%	1 in	÷	0.50	=	**2.00**
70%	1 in	÷	0.70	=	**1.43**
80%	1 in	÷	0.80	=	**1.25**

Table 2

Independent studies have shown that typical irrigation systems utilizing spray nozzles are inefficient (Mecham, 2001). Mecham conducted over 6800 independent audits on spray zones and identified that most systems average 50% in DU. Referencing Table 2 and assuming that most turf in the highest summer demand need 1" water/week, a system that is 50% efficient needs to deliver a total of 2" of water in order to overcome inefficiencies. MSMT nozzles have been tested at Center for Irrigation Technologies at California State University Fresno and have shown that it is reasonable to reach 80% DU. When converting from 50% DU sprays to 80% DU MSMT nozzles in the above scenario, 2" minus 1.25" results in an immediate .75" of water per hour reduction in consumption of water. (Kissinger/Solomon 2005) conducted 13 independent audits for their study of potential water conservation with spray nozzles converted to MSMT nozzles. The average of their spray zone audits was 44% DU_{LQ}. Measuring this off of table 1, all zones were rated poor. On average, conversion to the MSMT nozzles improved DU_{LQ} from 44% to 70% DU resulting in a 37% reduction in water consumption.

Case Study on increased Distribution Uniformity

In June of 2011, a case study was conducted at the Washington State Liquor Control Board Distribution Center to measure Distribution Uniformities of their spray zones. Figure 1 displays the zone which was audited with 15 ft. spray nozzles in the Quarter, Half, and Full configuration with 20 spray heads in total.

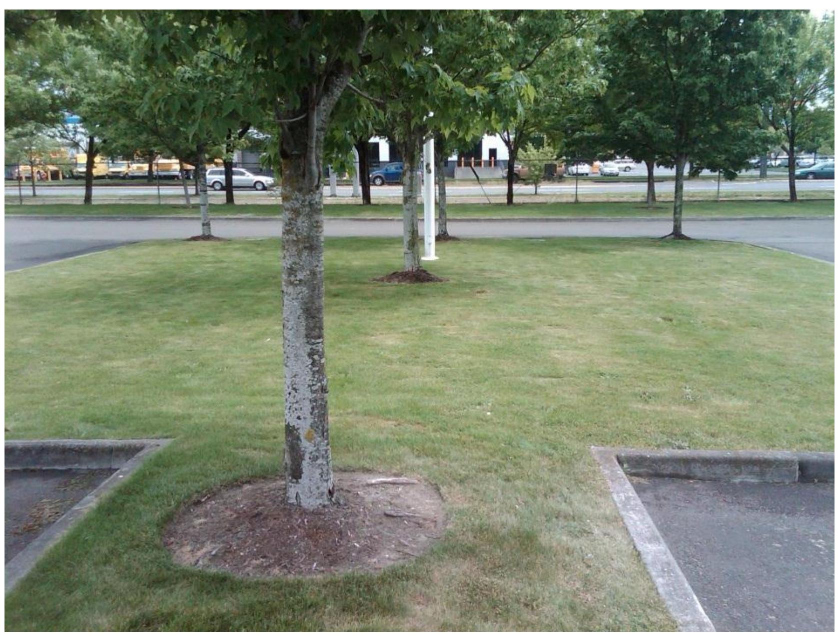

Figure 1

After the system was tuned up with straightening of pop-up sprinklers and cleaning filter screens, the pressure was measured at 25 psi dynamic pressure. A total of 32 catchments were evenly spaced over the entire zone and the audit was conducted for 6 minutes. Once the spray zone audit was complete, the nozzles were removed and MSMT nozzles were installed and adjusted. Pressure was measured prior to the audit at 40 psi dynamic. This increase in pressure was the result of installing a lower flow nozzle thereby maintaining more of the overall system pressure. Catchments remained in place and the audit was run for 10 minutes. A longer runtime was needed due to the lower precipitation rate to fill an adequate amount of water in the catchments.

Results of Audit:

NOZZLE TYPE	PRECIPITATION RATE (PR)	DISTRIBUTION UNIFORMITY (DU)
15' Sprays	1.64"/hour	34%
MSMT Nozzles set to 15'	.50"/hour	**74%**

Table 3

By increasing the Distribution Uniformity and lowering the overall Precipitation Rate, this zone is more evenly applying the irrigation water and at a rate which the soil is capable of absorbing. Distribution Uniformity as seen in Table 3 shows the significant increase from 34% to 74%. The MSMT nozzles will save just this one zone over 50% on water consumption.

Application of Water to Soil Infiltration Rate

MSMT nozzles have precipitation rates (PR) similar to single stream rotors that more closely match typical soil infiltration rates. By applying water at rates less than that of the soil infiltration rate, runoff is greatly reduced. Often misunderstood, soil infiltration rates across the country are usually .5"/hour or less. If water is applied at a higher rate, runoff occurs shortly after the irrigation cycle begins. This is seen in almost all traditional spray installations.

One of the greatest challenges with MSMT nozzles is education and creating the similarity with single stream rotors. It is all too often that the comparison is done with conventional sprays which create additional confusion due to increased run times because of lower precipitation rates. Table 4 is taken from the Irrigation Association's Landscape Irrigation Auditor course book on soil holding capacities. It is a good idea to make the comparison between the precipitation rate of the sprinkler one will be installing and the basic intake rate (soil infiltration rate) of the soil to be irrigated. Once this has been accomplished, the irrigation installer can now make better decisions on run times for scheduling.

Soil Infiltration Rates	
Soil Texture Class	Basic Intake Rate In./hr.
Clay	**0.10**
Silty Clay	**0.15**
Clay Loam	**0.20**
Loam	**0.35**
Sandy Loam	**0.40**
Loamy Sand	**0.50**
Sand	**0.60**

Table 4

Soil infiltration rate is a measurement of how quickly water will be absorbed into certain soils. Compaction, thatch buildup, and slopes will have a negative effect and reduce the absorption rate. It can be easily seen that if areas are irrigated with traditional sprays with PR's of over 1 ½"/hr. that water will pool and begin to runoff soon after the system is turned on. Most of the soils in the United States fall somewhere in the Sandy Loam and Loamy Sand profile. Even if .6"/hr. is used for a given rate, it becomes evident that regardless of the spray that is used, it will result in an over watering scenario leading to runoff. Excessive watering has been and continues to be the most widely used method of irrigating with spray nozzles. The only way to successfully manage traditional sprays is to use the cycle and soak method of scheduling where short, more frequent cycles of irrigating are used. This method is not widely used due to water window issues and overall length of time required to apply correct amount of water. MSMT nozzles have various PR's, but most fall with .6"/hr. or less. If the Soil Infiltration Rate of a particular soil can be matched, wasteful runoff can virtually be eliminated. Additionally, this lower PR allows for continuous watering, affording the water to be absorbed at the rate it is put down. This does come at an expense to the contractor who is designing the system in the form of longer run times for a particular irrigation cycle when compared with traditional spray nozzle schedules. The math is quite simple, if a certain infiltration rate is to be matched, the water must be put down at a lower rate. If the emission device has a low PR, the runtime must be longer. The benefit however, will result in less water consumption.

Matched Precipitation

MSMT nozzles deliver water at a much higher efficiency Distribution Uniformity (DU) due to unique streams that are dedicated to placing water to precise locations rather than having one spray pattern. In addition to high DU's, MSMT nozzles have low precipitation rates that more closely match soil absorption rates. Most manufacturers' offerings have matched precipitation rates where regardless of the arc or radius chosen, the same amount of water will be delivered over a given area. This is an important feature because most traditional spray nozzles have varying PR's and therefore cause over and under watering within a single spray zone. By having matched PR’s, the installer is ensured the correct amount of water will be applied.

Wind Effects on Application Performance

Poor spray performance in light wind conditions is a problem that every landscape irrigation contractor has faced at one time or another. Traditional sprays emit water from one orifice at a given trajectory. Because of this one orifice, water tends to atomize more readily and is subject to drifting further distances than intended, in many cases off the desired landscape. MSMT nozzles emit water from various trajectories with individual streams that slowly rotate. These streams have higher energy than spray nozzles and can combat light wind applications much easier.

In a test to compare loss of irrigation water in light wind application, it was discovered that traditional spray nozzles accounted for approx. 8.5 times more loss than MSMT nozzles (Kumar 2009). Figure 5 shows the difference in overall loss of gallons due to wind drift. Note the runtime for the Spray Nozzles was significantly less than the MSMT nozzles.

NOZZLE TYPE	RUNTIME (min)	WIND DRIFT (gal)	AVGERAGE WIND SPEED (mph)
Spray Nozzle	19	3.66	2
MSMT Nozzle	30	0.43	1.5

Table 5

Labor and Installation cost savings

Additional benefits of installing MSMT nozzles include installation and labor cost savings. In today’s competitive market, providing contractors with the ability to reduce labor costs and materials for a job can be the difference between breaking even and making a profit. The benefit of installing a nozzle with low PR’s means the contractor can increase the number of heads per zone thereby reducing the amount of total zones per job. MSMT nozzles also offer greater distance performance (increased radius) compared to spray nozzles, allowing the designer and installer to increase the distance between heads. This gives the contractor the ability to increase the size of the zone to cover more area. Accomplishing all of this can result in a significant reduction compared to traditional sprays, and may also afford the designer and installer the opportunity to reduce the size of the controller, further driving down the cost of overall installation. Figure 2 provides an example of a typical installation utilizing a conventional spray system. Micro zones and climates were not taken into consideration as they would be the same for each application. The goal was to design a system that would successfully grow turf. Figure 3 represents the same site with an irrigation system designed to utilize MSMT nozzles.

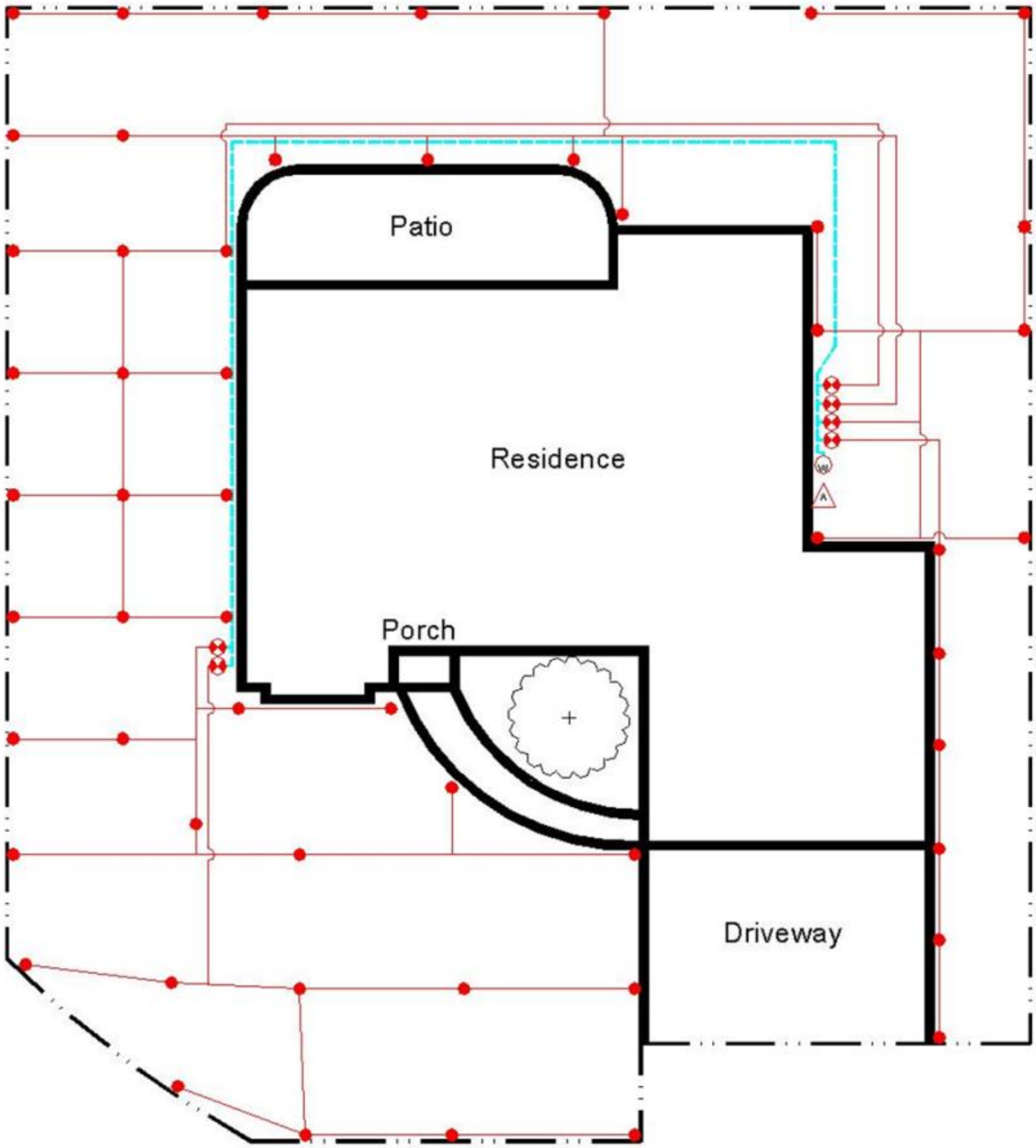

Figure 2
Designed with traditional spray nozzles

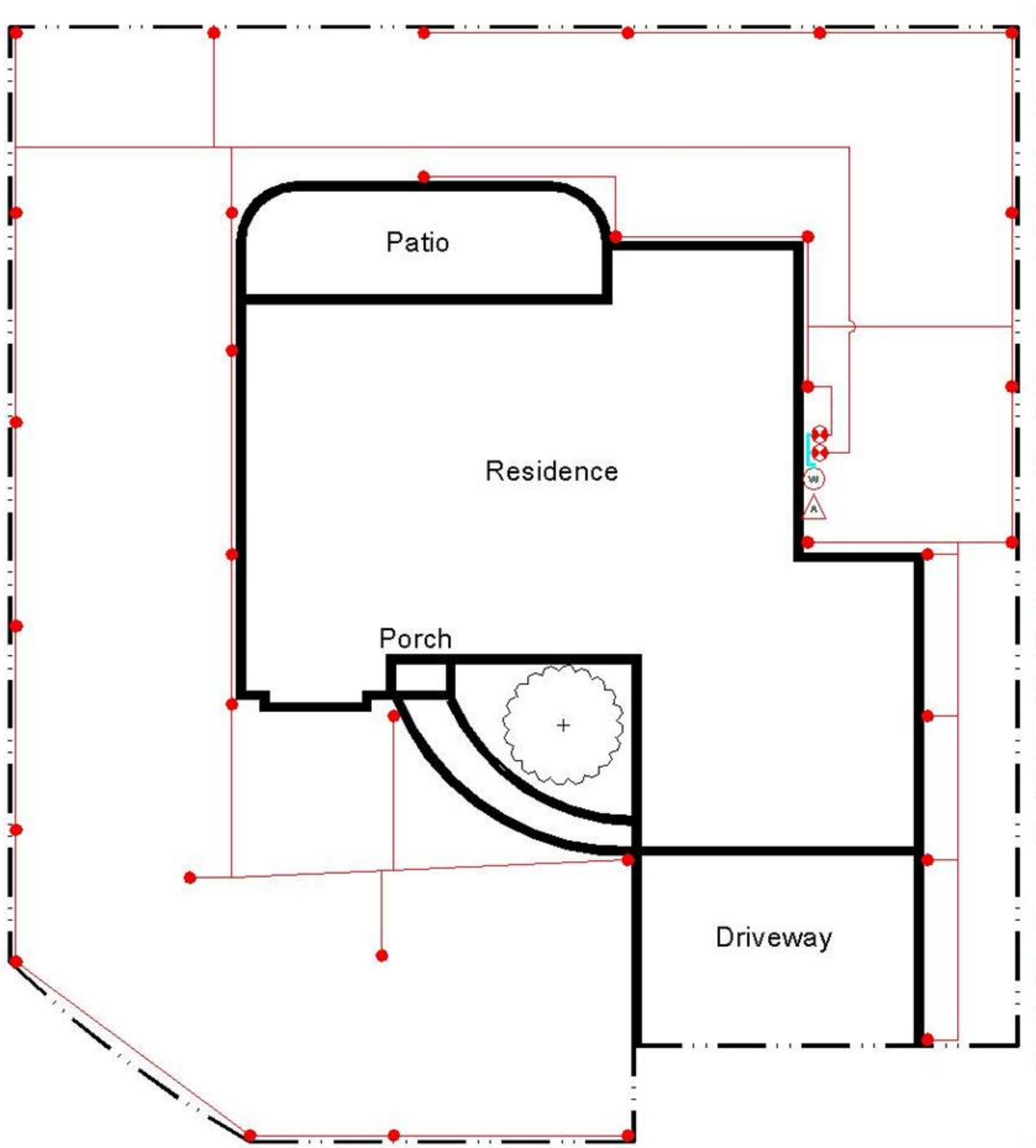

Figure 3
Designed with Multi-Stream, Multi-Trajectory rotating nozzles

When making comparisons to the two designs, the MSMT nozzle design shows how many fewer heads are needed due to the longer radius and lower flow per head option. Additionally, fewer valves were needed in order to accomplish the same coverage. Table 6 provides a simple cost comparison of the two installations:

MSMT nozzles			
	No.	**Price per unit**	**Cost**
Valves:	2	$225.00	$450.00
Mainline	15 feet	$2.50/ft.	$37.50
Laterals:	600 feet	$1.50/ft.	$900.00
Sprinklers:	34	$18.00/sprinkler	$612.00
Controller:	3 Station	$225.00	$225.00
Wire:	20 feet	$0.12/ft.	$2.40
		Bid Price:	**$2,226.90**
Water Consumption:		**21.3**	**GPM**
		% Savings on Bid:	**45%**

SPRAYS			
	No.	**Price per unit**	**Cost**
Valves:	6	$225.00	$1,350.00
Mainline	150 feet	$2.50/ft.	$375.00
Laterals:	800 feet	$1.50/ft.	$1,200.00
Sprinklers:	55	$15.00/sprinkler	$825.00
Controller:	6 Station	$275.00	$275.00
Wire:	175 feet	$0.12/ft.	$21.00
		Bid Price:	**$4,046.00**
Water Consumption:		**77.4**	**GPM**

Table 6

The amount of overall material and labor to install the conventional spray system is considerably more costly to the contractor bidding on this job. With some education on the benefits of designing with MSMT nozzles, a contractor can apply that knowledge to improve profitability and competitiveness.

Contractors have identified the benefit of selling their existing customers on MSMT nozzles and retro-fit their already installed systems. Designed so that they can be installed on spray risers, MSMT nozzles make it easy for contractors to improve irrigation system efficiency just by replacing spray nozzles with MSMT nozzles. By conducting simple system tune ups and replacing existing spray nozzles with MSMT nozzles, property owners are able to see immediate savings on their water consumption.

Conclusion

Water conservation is at the forefront of our industry and having Multi-Stream, Multi-Trajectory nozzles as a product offering, allows the gap to be bridged from wasteful spray nozzles to a more efficient method of irrigating. Education continues to be an integral part of promoting this new technology. As regulation forces the residential/commercial irrigation industry to move in the direction of water conservation, low precipitation rate nozzles and higher distribution uniformities will be called upon for future installations. Contractors adopting this new technology have the opportunity to not only install the most water conservative products but can profit from doing so as well. Installing the most efficient product offered in the market place while saving on overall labor and materials costs, the MSMT nozzle category is a winning combination for professional irrigation installers hands down.

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GPS Mapping Irrigation Systems for

Better Communication and Management

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Abstract: GIS and GPS technologies are still fairly new and are not widely used in the irrigation industry. These technologies can provide detailed mapping solutions, which many related industries have already begun to benefit from. Current research from recent surveys of landscape professionals shows their current solution to mapping irrigation systems is inadequate and there is an apparent need for better application of technology. Applying GIS and GPS technologies when designing, building and mapping irrigation systems will aid in the management of irrigation systems and promote water conservation.

Key Words: irrigation mapping, irrigation management, water conservation, GPS, GIS, irrigation “as builts”, irrigation documentation, and landscape mapping.

Introduction:

Beautiful landscapes and green open spaces are a valuable asset in a world where growth and resource management are an ever growing concern. Knowledge of the newest and most advanced technology is often the key to success in any field, especially the irrigation and landscape maintenance fields in today’s economy. The combination of educated management, skilled employees and using advanced tools make it possible to do better irrigation construction, maintenance, and communication.

Geographic Information Systems (GIS) and Global Positioning Systems (GPS) technologies are creating new methodologies and tools for documenting, mapping and managing today’s landscapes more effectively than ever. Routine maintenance and conservation become more straightforward and easy to achieve in a timely and cost-effective manner. Related industries have been harnessing the power of GIS and GPS for a number of years and their examples provide valuable insight to the irrigation industry.

Looking under the hood at GIS/GPS Technology:

Geographic Information Systems is essentially computer modeling of the earth's surface. Various map types, boundaries, built improvements (roads, water lines, etc) and limitless other elements of our environment can be modeled with this technology. A GIS map is an interactive computer generated image consisting of: layers, features/surfaces, values, locations, data, map projection and map display.

Layers are essentially single maps or specific data layered on top of each other (such as rivers, cities, and political boundaries).

Features represent the data layers and are made up of points, lines and polygons. A surface often consists of elevation data such as topography or an aerial image. With features or surfaces each point, line, polygon or raster square has values or data assigned to them. What makes GIS different than historic maps is that various components of any map can be combined, separated or even analyzed with the click of a button.

A projection represents the manner in which the data is draped over the earth's surface or projected. GIS has become the vehicle for understanding complex systems such as city infrastructure, large plant ecosystems, and thousands of other systems (Ormsby, 2010).

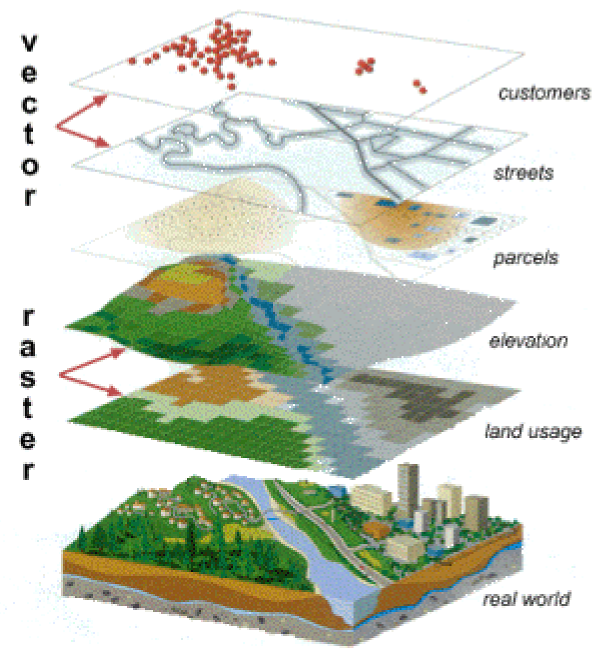

Figure 1 Diagram of GIS Layers (GIS, 2011).

The source of GPS signals is a network of satellites orbiting the globe twice a day. Through triangulation, satellites send signals to a GPS receiver which then determines the location of the user. With three satellites a 2D latitude and longitude point is determined, but with four satellites a 3D elevation point can be determined. The greater number of satellites connecting to your receiver the stronger the signal or more accurate the data (to a degree). The signal lets the receiver or GPS device know its exact location (or point), tracking speed, direction and other useful information. Depending on the type of GPS hand-held equipment used; the accuracy of data can be between 30 feet to less than 1 foot. Other factors can also affect GPS accuracy in the landscape industry including: location of satellites at time of mapping, building height, user distance from building(s), tree canopy and location, and type of GPS mapping device used.

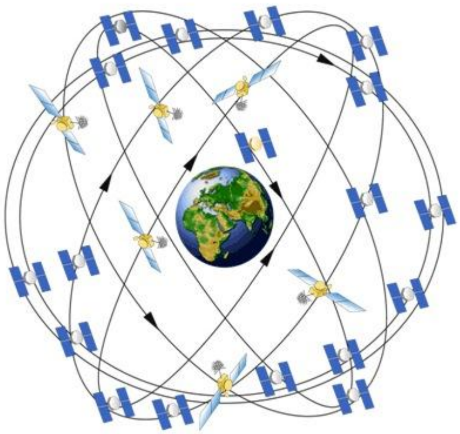

Figure 2 GPS Satellite Constellation (Delaware and High, 2011)

GIS/GPS Technology in Related Industries:

The City of Nashua New Hampshire is in the process of acquiring a water company which serves approximately 120,000 people. The city is planning and preparing for the future by using GIS to manage the water system. Nashua relies on GIS, *"technology to plan future improvements to their water delivery systems, quickly spot leaks, and uncover hard-to-find fire hydrants. They use it to track the dates when old pipes last received any maintenance. They rely on GIS to target which pipes or valves may next need a visit from the city or district maintenance staff"* (Rafter, 2011). GIS is helping Nashua conserve water through fixing leaks faster and maximizing the systems efficiency this also applies to smaller systems of water such as irrigation systems.

The city manages its water system by doing an in-depth inventory of assets. The inventory of assets helps in the day to day management, but is crucial when senior employees with long-term institutional knowledge of the system retire and that information could be lost. If the system has been mapped correctly and the knowledge of the supervisor is in the data and maps then as management changes over time this important institutional knowledge is available to the next generation of management and workers (Rafter, 2011).

Figure 3 Water Provider Systems Mapped (Rafter, 2011)

"Better maintenance is another important benefit of GIS technology, Brennan says. GIS allows utilities to better track past maintenance work. It also allows them to be more proactive when it comes to maintaining the health of their systems. Staffers may discover that water pipes are breaking across the city. Through the use of GIS and computerized maintenance management systems, staffers can target areas of the water system that should be repaired next to avoid future breaks. It's usually cheaper to maintain a pipe then it is to repair one that's already broken" (Rafter, 2011).

GIS technology allows professionals to see the system as a whole or zoom in on specific details. This same approach of managing large water districts or water providers is beneficial to irrigation maintenance companies, property managers, and agencies which are responsible for managing irrigation systems and water. **Knowing where your irrigation lines and parts are located is the first step in managing a system proactively.** Similarly institutional information of irrigation systems and property can be mapped and made available for all those involved in the long-term maintenance (Rafter, 2011).

Maricopa County Arizona has a population of more than four million. The growth patterns have largely been sprawling development and the county maintains more than 650 miles of road. The county was over burdened with tracking and managing the cleaning and sweeping of streets.

"To lower costs and improve business processes, the county decided to install GPS units on sweeper trucks that broadcast data when brooms are lowered for sweeping… As the sweeper truck drives down the street, the rotating brushes sweep road debris into the vacuum and off the street. Information is transmitted at 30-second intervals, providing the speed and location of the sweeper. The automated process replaces manual inspection and provides verification of work completed against work invoiced, ensures that speed limits are enforced, and provides support in litigation." (Akuoko 2011).

The GPS/GIS technology is now allowing the county to track: sweeping vehicles assigned to routes, identification of driver on vehicle per day, speed threshold, virtual inspection, and comparison of bills assessed (Akuoko, 2011).

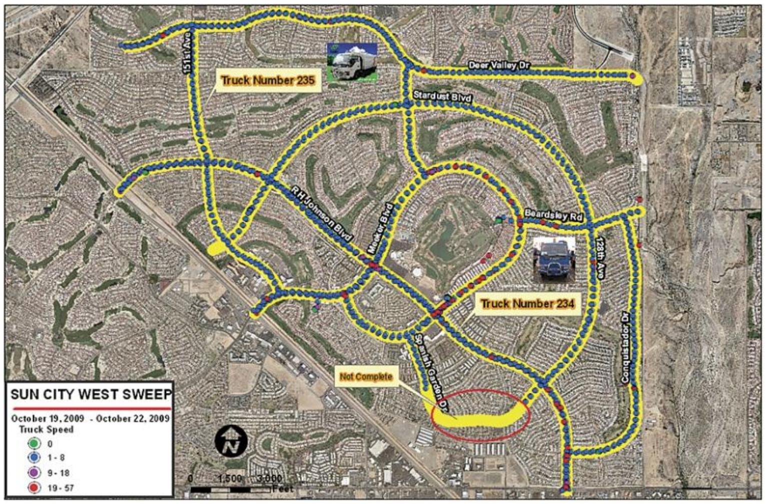

Figure 4 Map of Streets Swept (Akuoko, 2011)

"The objective of this program is to provide the tools necessary to effectively manage the sweeping contract with 100 percent accountability while reducing inspection costs" (Akuoko, 2011). The collection of GIS data while running sweeping vehicles makes it possible for the county managers to analyze and improve the maintenance of a large network of streets. **Likewise mapping and tracking large irrigation systems can also assist in creating greater accountability and effectiveness.**

Surveying the Field of Irrigation Mapping:

Irrigation mapping is the documentation or creation of "as built" diagrams or drawings of previously installed irrigation systems. In 2010 a survey was conducted of 37 irrigation/landscape professionals relating to irrigation mapping or documentation. The survey is the beginning of understanding how companies and organizations are documenting and mapping irrigation systems. The survey was conducted in December of 2010 (Benson, 2010). At this point in time limited research data is available in how irrigation professionals as a whole document previously installed irrigation systems.

As GIS/GPS technology evolves the application and use of the technology in the landscape and irrigation industries will also advance. The diagrams below show the results of the 2010 survey.

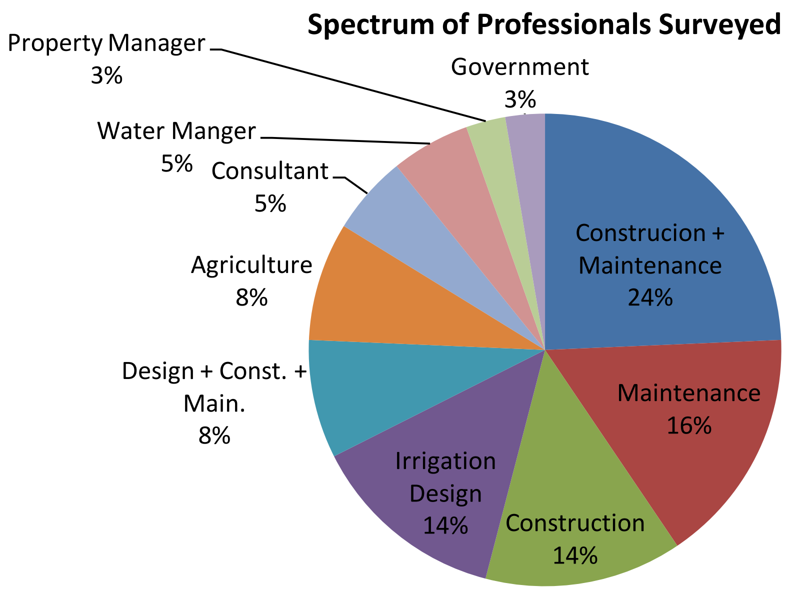

Figure 5 (Benson, 2010)

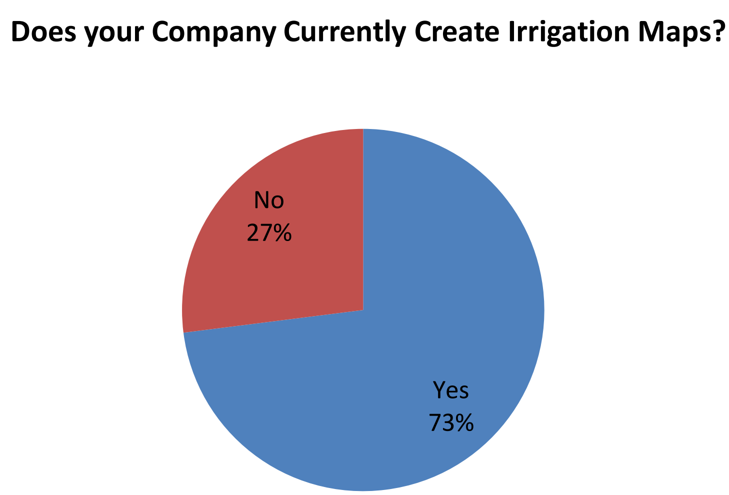

Figure 6 (Benson, 2010)

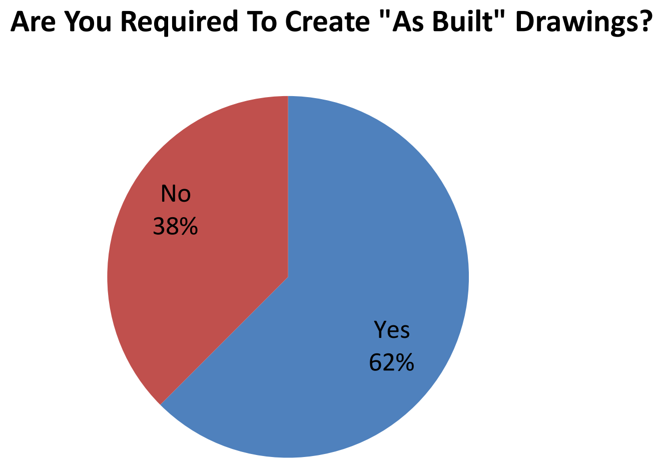

Figure 7 (Benson, 2010)

The majority of the group (73%) regularly creates irrigation maps as part of their work, but only 62% are required to create irrigation maps per mandate or specification. Most organizations involved with irrigation understand that it is essential to have maps or as builts of irrigation systems to communicate the tasks of maintenance and repairs with employees.

The study shows that the majority of **landscape professionals still use old methods for creating irrigation maps** such as hand drawing or measuring in the field and then drawing on CAD. The problems with hand drawn irrigation plans is that often they are not drawn to scale, parts shown on plan do not show or correspond to the site, they are hard to read because of handwriting, and overall less effective.

The methodologies for creating irrigation maps will improve and advance in the coming decade as irrigation professionals have more educational opportunities and technology advances. From the 1980s to the 1990s the architecture and design industry underwent a major change as the technology of CAD (computer aided drafting/design) developed and became the prevailing method for designing buildings. Likewise technology advancement can assist irrigation professionals in managing the systems and water through accurate mapping.

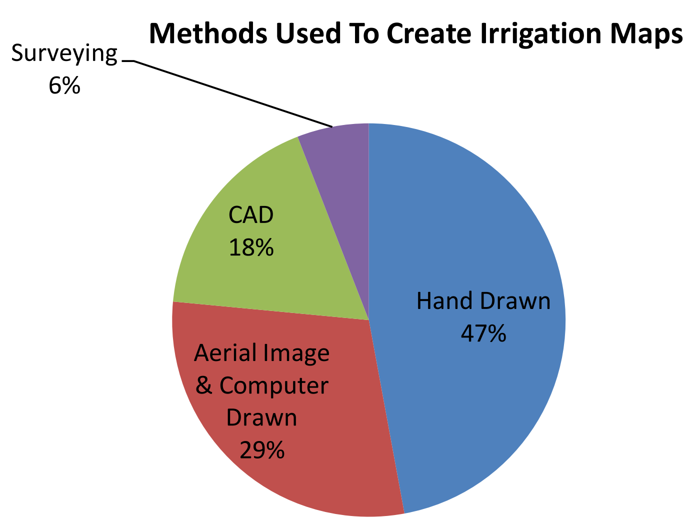

Figure 8 (Benson, 2010)

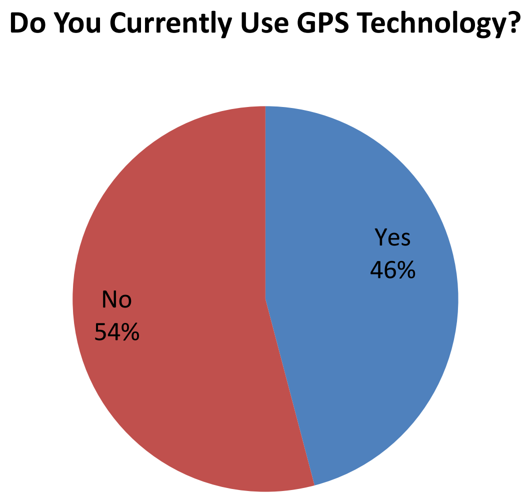

Figure 9 (Benson, 2010)

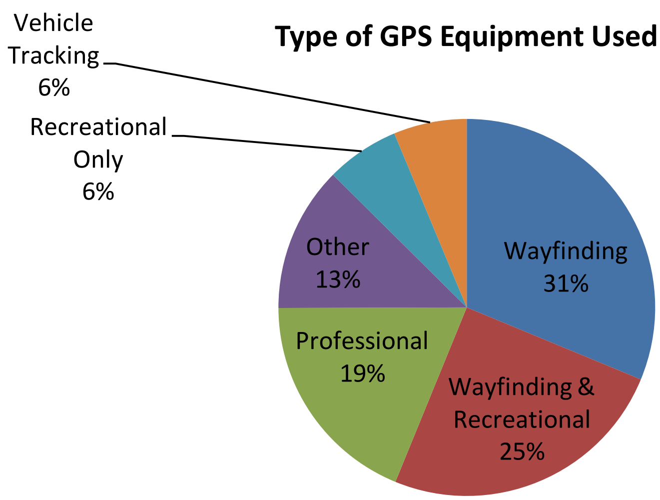

Figure 10 (Benson, 2010)

Figure 9 shows that less than half of the survey group was currently using GPS technology. This number will increase as technology and understanding increases. Figure 10 shows that many irrigation/landscape professionals are using common day to day applications of GPS. These applications include finding addresses, mapping points with basic recreational GPS devices. Only a few are using professional GPS equipment. With professional equipment you can collect GPS data for creating specific maps (such as irrigation valves, lines, trees and etc). The data is then imported into a GIS type program and a useable map is generated. Recreational GPS devices mostly track basic points, distances, and speed. Professional GPS equipment has higher accuracy and greater durability.

A group of 10 irrigation/landscape companies were surveyed in 2011. These irrigation/landscape companies have started using GPS technology for less than six months to map and document irrigation systems and landscapes. Prior to 2011 the majority of the companies involved in the study used hand measuring or survey equipment to get field measurements. Most of the map creation was done by hand, while some of the companies were using CAD for drawing (Benson, 2011).

The companies selected were spread out geographically including the following regions: Alberta, California, Texas, Utah, Ohio, Washington DC, Florida and elsewhere. In the irrigation industry work practices can vary according to climate and region. GPS mapping for irrigation systems was relevant and valuable no matter the geographic location.

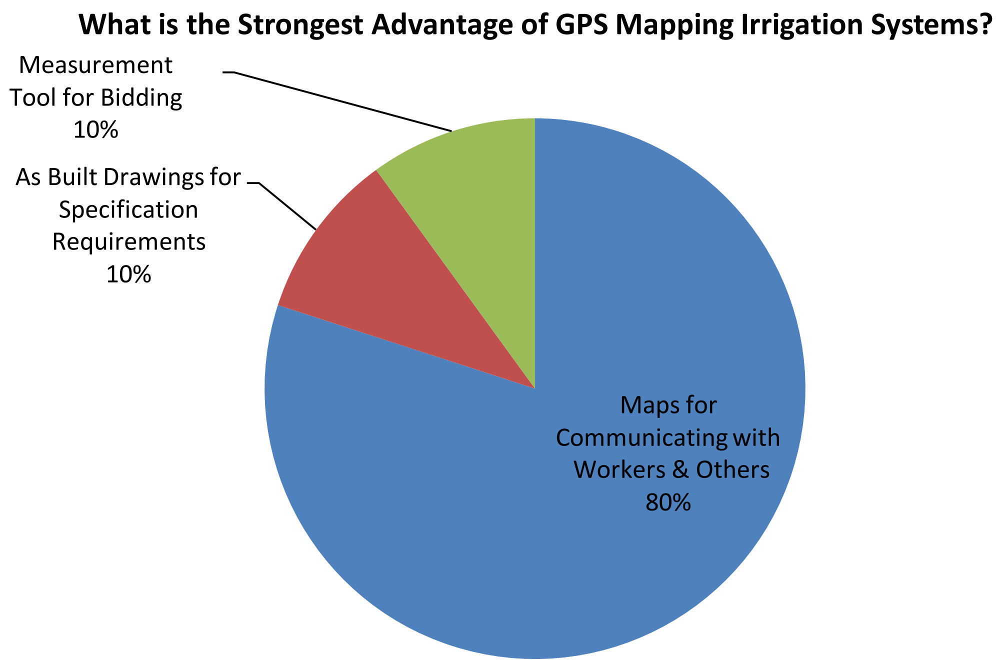

Figure 11 (Benson, 2011)

The question was asked "What are the strongest advantages of GPS mapping irrigation systems?" The provided answers included: Water Conservation, Measuring Tool for Bidding, Communication Maps for Workers and Others, Irrigation System Management, and Additional Source for Increased Revenue. **The greatest of value offered from irrigation maps is the communication tool between employees, managers and customers which provides a more effective service (figure 11).**

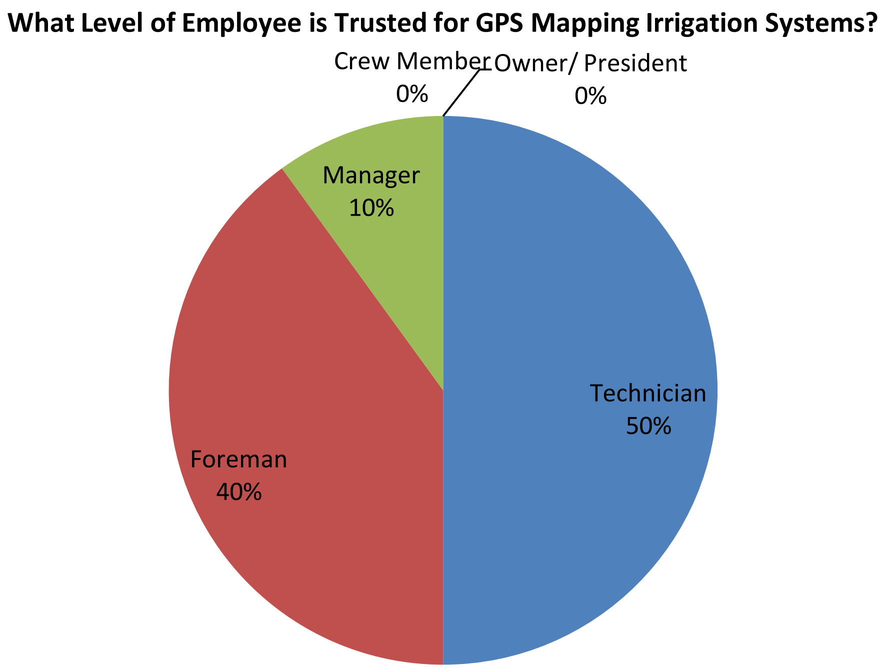

Figure 12 (Benson, 2011)

Historically GIS/GPS mapping has been done by professionals with higher education degrees in Geographic Information Systems or professionals who have received months of training. This advanced education was necessary to understand the science, run the applications and analyze the data. Technology used to create GIS maps for professional work is becoming more user friendly (even for non GIS professionals). As shown in figure **12 trained foreman and technicians are doing the GPS mapping (not GIS professionals or upper management)**. Depending of the needs of each individual company, and the importance of their GIS maps, the employee's knowledge level and training time will differ. This is an important achievement for the irrigation/landscape industry to bring the cost level down and allow more organizations to offer this service.

Basic Steps to Irrigation Mapping:

There are many strategies to mapping and documenting irrigation systems. There are also various options for software such as generic GPS mapping or more industry specific. Some basic steps for irrigation mapping may include:

1. Prepare hand-held GPS for field. While it's not necessary, you may want to load aerial images, base map, setting parameters or projections.

2. Stand over parts and equipment in the field and take points or collect data. Common parts mapped include: controllers, backflow, shut of valve, remote control valves, main lines, lateral, spigots and other misc. landscape items (such as fire hydrants, trees, and electrical boxes). **It is recommended to add information regarding part sizes, manufacturer, model number, and condition of parts** (if it needs repairs or maintenance). **This information will be valuable when doing repairs or maintenance is needed later on**. Mapping in areas with buildings or extensive tree canopy can be challenging, you may have to move away from buildings/trees and take the points (to be adjusted on the desktop). While mapping you can turn on valves to map water coverage, to better understand the efficiency of the irrigation system and learn what is needed to improve water conservation.
3. The last part to irrigation mapping is loading the data onto the computer and creating maps. Maps can be large and complex or simple in nature. It is beneficial to have a site background such as a drawing of the site (if it's new) or an aerial image (if available). **Quality map creation usually requires some basic editing** (correcting exact location of part) or cleaning up maps to be readable. GPS technology is not perfect and like other professional work it requires adaptation at times.

Figure 13 shows one valve and its spray heads which were GPS mapped. This one valve and heads took approximately 5-7 minutes to map in the field. Measuring the distances in the field and drawing the same valve and heads in CAD or by hand would take two to three times longer. When mapping much larger or complex systems; such as 20-100 valves, multiple main lines, multiple clocks, and multiple points of connection is when GPS mapping becomes an incredibly valuable time saver.

Conclusion:

GIS and GPS technology is invaluable and is ever growing in its simplicity to use. The technology has been proven in related industries such as large water system providers and infrastructure management as shown in the examples from New Hampshire and Arizona. Currently the majority of irrigation companies are creating irrigation maps, but many are doing it with obsolete technologies or methodologies. Irrigation mapping techniques will improve as technology evolves and irrigation professionals are trained how to use them.

In the past GIS/GPS mapping methods required advanced education and a few weeks or months of training to learn how to collect data and create maps. Now irrigation mapping is becoming user friendly with easy to use systems and GPS technology designed for technicians**. Irrigation professionals should consider GPS mapping systems to improve service performance for their customers and manage irrigation systems for water conservation.**

The advantages of GPS mapping irrigation systems include:

- Accurate location of irrigation parts and system mapped
- Ability to find previously mapped parts and system (i.e. buried valve boxes)
- Ability to map or track parts that need maintenance or repair
- Maps can be customized according to points, features and layers (such as valves, lines, etc)
- Areas or parts can be mapped for bidding purposes
- Photos of parts can be geo-tagged (to add location of where the photo was taken on-site)
- Coverage of water distribution by heads can be mapped to show efficiency
- Maps and data of irrigation systems can be created for communicating work procedures to employees

Figure 13 Irrigation Head & Valve Map (Young, 2011)

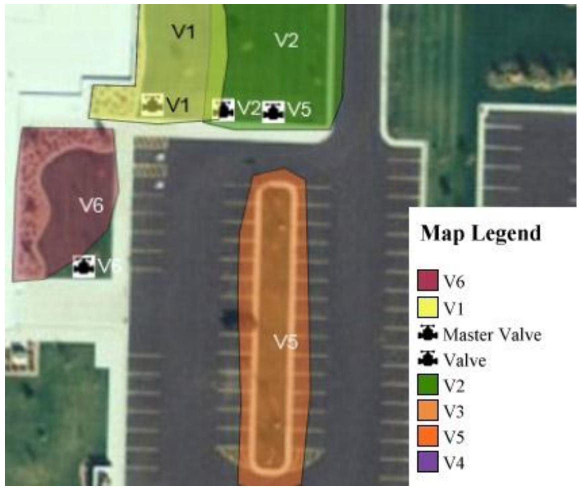

Figure 14 Irrigation Valve Coverage Map (Benson, 2011)

Irrigation maps hold the greatest value for irrigation professionals in offering better communication among employees, managers, and customers. If irrigation systems are mapped and documented it will offer organizations faster repairs, documentation of repairs, planning for improvements and create an overall better understanding of the systems. The GPS mapping and GIS management of irrigation systems **will conserve water through more timely repairs and the ability to plan for improvements**. As landscape and irrigation professionals learn and use this technology it will enhance their service to customers and assist them in creating beautiful landscapes that are sustainable and lasting.

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Best Practices in Water Conservation

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Abstract. *This topic has significant implications for all irrigation professionals. Water is a finite resource that decreases in quantity more than increasing. As populations increase, water's availability in our current delivery systems do not keep up. Collecting and reusing water that enters or passes by a site is the only way to come close to matching the rising demand. Since most rainwater is collected on rooftops, we need to look at ways to expand collection efforts to other areas such as streets, driveways, parking lots, and planters. Ultimately, all sites should be venues for collecting rainwater, treating it and supplementing irrigation with it. This involves new methods such as larger containers and innovative capture techniques. As rainwater may be contaminated due to pollutants like microscopic germs, it is often not considered suitable for drinking. However, there are many examples of rainwater being used for all purposes — including drinking — following suitable treatment. This session will address the benefits of rainwater harvesting with illustrations provided by specific Los Angeles projects such as the TreePeople project, the Westside Rainwater Park, housing developments, Elmer Ave., and the Vista Hermosa Natural Park.*

Keywords. Rainwater harvesting, permeable concrete, detention basin, bio swale, wasting water, over irrigation, HOA education, permeable parking lot, capturing drainage, stormwater harvesting, Vista Hermosa, Westside Park, Tree People

Projects for Discussion

Tree People: This is a project that encompasses a large part of what we are trying to encourage developers to embrace.

Tree People Center for Community Forestry 3 acre area located at the top of Coldwater Canyon in the Hollywood Hills, TreePeople is one of Southern California's most notable grass-roots environmental organizations. The 45-acre Coldwater Canyon Park is the home of TreePeople who's mission is to inspire the people of Southern California to take personal responsibility and participate in making the region a healthy and sustainable urban environment.

The project includes a rainwater harvest parking grove with a 216,000-gallon underground cistern, an environmental education and learning center, an urban watershed demonstration garden, TreePeople nursery operations facility and donor gardens. Bioswales collect run-off and rainwater through a streambed in the watershed demonstration garden showing how water traverses through the city fabric. This exhibit allows children and adults to interact close-up in this non-static watershed display. The new nursery provides care for trees and native plants that will be used in planting restoration programs. The parking grove is sloped to direct rainwater into drains and gravel filled trenches that is networked to the cistern for irrigation. The paving reduces the urban heat island effect by reflecting solar energy. A plant palette of drought tolerant shrubs and trees were selected and designed in a garden planned for long term growth.

Westside Rainwater Park is a unique state of the art project that utilizes storm water to irrigate the turf areas of the park. Prop O funding allowed for a system to be designed that would pump storm water out of an existing covered stormwater drainage channel. We utilized an underground irrigation system that is a gravity fed system that can flush dirty water through large orifices. The low flow allows for the planting medium (sand) to absorb the water and make it available for the turf. Irrigation water is essentially delivered from the root zone up to the surface. Excess water is cleaned by the planting medium then drains back into the storm water system. In addition to the water quality components this project will include recreational benefits for the community including new perimeter fencing, jogging paths, and a sensory garden, as an extension of the dry creek.

The Los Angeles Zoo is a facility owned by the city of Los Angeles. For many years, the parking lot has been a huge sea of asphalt with a few sycamore trees dotted about. It's proximity to the Los Angeles river has made it a target for stormwater management opportunities. A few years ago, a bioswale was constructed around the perimeter of the parking lot to capture some of the rainwater and filter it before it went into the stormdrain system and ultimately into the river. The existing parking lot at the Los Angeles Zoo has been redeveloped as a Proposition O Sustainable Project. The scope of work includes: preserving an existing perimeter bioswale, adding new bio cells to the parking lot, retrofitting the parking lot with other permeable paving systems, and planting over one hundred new trees. A new interpretive plaza will inform visitors about the link between stormwater quality and the nearby Los Angeles River. In addition to greatly enhancing stormwater management, the existing promenade between the Los Angeles Zoo and the Autry National Center of the American West will be strengthened to provide a pleasant pedestrian connection between the two important cultural institutions. Included in the project are ML+A-designed interpretive graphics to communicate the benefits of these improvements to visitors.

Vista Hermosa Park, a sustainably designed park, is an urban watershed demonstration project that accommodates community and school recreational programs, integrated with an extensive network of introduced natural features and ecosystems. The park transitions from more intense neighborhood uses, to sloping, native habitats. A range of Southern California native plant communities knit the park together, creating habitats such as oak savan-nah, coastal sage scrub, chapparral and meadows that attract a variety of wildlife species. Facilities support-ing programs ranging from nature walks to campfires under the stars include a children's discovery area, a park office, picnic areas, gathering areas and creature comforts like clean convenient restrooms and drink-ing fountains. The 30,000 gal cistern collects water from about 95% of the 10 acre park. While it is more of a demonstration scale, it provides water for a drip system along the north slope of the soccer field. Water that is not collected in the cistern is absorbed into the groundwater.

College campuses also have the opportunity to educate and save water. Pitzer College in Claremont, CA is collecting gray water from sinks and showers and storing it for underground irrigation use. The 15,000 gallon tank can hold enough water for each monthly watering cycle of the immediate building with capacity to be used on an expansion project at a later date.

Conclusion

Now is the time to start making our parks and public facilities work for us. They can provide significant amounts of water if designed appropriately to capture this valuable resource. Parks have been a major draw of maintenance dollars and it's time they start giving back or at least becoming more sustainable. The education component is key to popularize a concept that is mostly underground.

Designing a Viable Irrigation System for the National Mall
Brian E. Vinchesi

The National Mall is nestled between the US Capital and the Washington Monument in the nation's capital. This large open area of lawn and old oaks is commonly referred to as America's front lawn. Over the past several years the mall has suffered from dead turf, lack of turf, weeds and bare spots and does not look very good. It is also extremely compacted and retains water on the surface. Due to these issues, over the next few years the eight lawn panels of the mall will be going under construction to perform a major renovation to the turf areas. As part of the renovation, a new irrigation system will be installed.

The National Mall is unique in many ways and because of its uniqueness it provides many challenges to having a long term operational irrigation system. Although the mall has been irrigated in the past, the previous systems have suffered from the activities on the mall and rarely were the systems completely operational. So let's first look at a few of the obstacles to conventional irrigation that are somewhat unique to the National Mall

- 25 million visitors a year
- 3,300 permitted events per year; an unknown number of unpermitted events including baseball, softball, soccer and football
- weight, including tanks and landing and taking off of Harrier jets
- lack of sunlight for long periods of time from tents, stages and the Solar Decathlon
- vehicle traffic
- historic precedents that limit what can be done to the mall
- 1st amendment right to gather
- availability of potable water sources

All of these activities provide compaction, lots of it. The soil settles and sprinkler heads become high, low or crooked. Sprinkler heads are easily damaged by all these activities. But the most damaging aspect is tent stakes; tent stakes up to 48 inches in length that go through PVC pipe like it is not even there.

So based on the above, what are the design parameters:

1. Minimize the amount of equipment in the turf; sprinklers, valve boxes, etc.\
2. Minimize damage from tent stakes
3. Minimize potable water use
4. Provide a maximum water window of 3 days per week, 5 hours per day.
5. Do not impact the historic aspects of the mall, including the visual aspects
6. Install a central control system and weather station, however the closest place for both is over a mile away
7. Have a long lasting viable system that requires as little maintenance as possible

Some of these were easier than you might think others much more difficult.

1. Large golf rotors were used to minimize sprinklers. Luckily the lawn panels are exactly 180 feet wide the whole length of the mall. A 90 foot x 90 foot spacing pretty much covered it. So there were 3 rows of sprinklers. Two rows were preferred but it just was not possible. Valve-in-head sprinklers were used to

eliminate zone valves and their associated boxes. . Almost all valve boxes for isolation and air release are piped in and out of the walkways. To minimize wiring and wire splices a two wire system was used. Less wire and less splices will hopefully have less maintenance issues.

2. The pipe depth of cover is 60 inches to minimize stake damage. Additionally, pipe is HDPE as it has a much thicker wall at the sizes needed and without fittings. A "no stake" area of 5 feet around the sprinklers is established along each side of the mall and down the middle.
3. In order to minimize potable water use, storm water is being collected from the mall sidewalks and lawn areas. Storm water collected is stored in four 250,000 gallon cisterns buried under the mall sidewalks and is expected to provide approximately 1/3 of the annual irrigation demand. Because the water is collected and stored it also needs to be pumped. Because it is storm water it needs to be filtered and the District of Columbia regulations also require that it be disinfected. So before entering the irrigation system the water needs to be pumped, filtered and disinfected.
4. The water window dictated, quickly defined a water requirement of 1,400 gpm.
5. The historic requirement meant no controllers on the mall and no buildings. The pumping plant with its required accessories is buried in a large underground vault that houses all of the controls and logic as well as the electrical supplies for the cistern transfer pumps, drainage pumps (the mall has little elevation change) and the irrigation system.
6. The central control system had to be located off site of the mall as it cannot be in an underground pit and a weather station was not visually appealing. These are both located at the closest mall maintenance yard, about a mile away by line of site. Not usually a big issue as radio can cover that distance easily. However, no antennas are allowed as they are not part of the historic look of the mall. As you can imagine, all mall projects need to be approved by a number of entities and antennas would not be tolerated. So the system was set up with internet communication. Pump monitoring which is extensive and communication with the central controller is accomplished with dedicated ISP addresses for the pump station and the central control system interface which is the only piece of irrigation control equipment in the vault. The internet connection provides a direct link to the central computer 24/7 and from any other internet capable smart device. The weather station however communicates via radio as it is down by the maintenance yard where visual aesthetics are not an issue.
7. Maintenance is hopefully minimized by using less equipment, minimal wire and wire splices, keeping the equipment all in one place (valve-in-head), installing all wire in conduit, grounding the system more than required by the manufacturer, burying the pipe where it is mostly away from harm and getting buy in from the maintenance staff throughout the design process.

The project which started construction in September 2011 in addition to the irrigation system also replaces the soil, adds drainage, adds curbing and replaces the turf. When completed the Mall should have a more viable turf system that can better handle most of the activities being undertaken on the mall and a viable irrigation system is essential to having that occur.

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Cutting Edge Technologies for Reclaiming Water

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Abstract. *This topic has significant implications for all irrigation professionals. Water is a finite resource that decreases in quantity more than increasing. As populations increase, water's availability in our current delivery systems do not keep up. Collecting and reusing water that enters or passes by a site is the only way to come close to matching the rising demand. Since most rainwater is collected on rooftops, we need to look at ways to expand collection efforts to other areas such as streets, driveways, parking lots, and planters. Ultimately, all sites should be venues for collecting rainwater, treating it and supplementing irrigation with it. This involves new methods such as larger containers and innovative capture techniques. As rainwater may be contaminated due to pollutants like microscopic germs, it is often not considered suitable for drinking. However, there are many examples of rainwater being used for all purposes — including drinking — following suitable treatment. This session will address the benefits of rainwater harvesting with illustrations provided by specific Los Angeles projects such as the TreePeople project, the Westside Rainwater Park, housing developments, Elmer Ave., and the Vista Hermosa Natural Park.*

Keywords. Rainwater harvesting, permeable concrete, detention basin, bio swale, wasting water, over irrigation, HOA education, permeable parking lot, capturing drainage, stormwater harvesting, Vista Hermosa, Westside Park, Tree People

Projects for Discussion

Tree People: This is a project that encompasses a large part of what we are trying to encourage developers to embrace.

The Tree People Center for Community Forestry is a 3 acre site located at the top of Coldwater Canyon in Beverly Hills, TreePeople is one of Southern California's most notable grass-roots environmental organizations. The 45-acre Coldwater Canyon Park is the home of TreePeople whose mission is to inspire the people of Southern California to take personal responsibility and participate in making the region a healthy and sustainable urban environment.

The project includes a rainwater harvest parking grove with a 216,000-gallon underground cistern, an environmental education and learning center, an urban watershed demonstration garden, TreePeople nursery operations facility and donor gardens. Bioswales collect run-off and rainwater through a streambed in the watershed demonstration garden showing how water traverses through the city fabric. This exhibit allows children and adults to interact close-up in this non-static watershed display. The new nursery provides care for trees and native plants that will be used in planting restoration programs. The parking grove is sloped to direct rainwater into drains and gravel filled trenches that are networked to the cistern for irrigation. The paving reduces the urban heat island effect by reflecting solar energy. A plant palette of drought tolerant shrubs and trees were selected and designed in a garden planned for long term growth.

Westside Rainwater Park is a unique state of the art project that utilizes stormwater to irrigate the turf areas of the park. Prop O funding allowed for a system to be designed that would pump stormwater out of an existing covered stormwater drainage channel. We utilized an underground irrigation system that is a gravity fed system that can flush dirty water through large orifices. The low flow allows for the planting medium (sand) to absorb the water and make it available for the turf. Irrigation water is essentially delivered from the root zone up to the surface. Excess water is cleaned by the planting medium then drains back into the stormwater system. In addition to the water quality components this project will include recreational benefits for the community including new perimeter fencing, jogging paths, and a sensory garden, as an extension of the dry creek.

The Los Angeles Zoo is a facility owned by the city of Los Angeles. For many years, the parking lot has been a huge sea of asphalt with a few sycamore trees dotted about. It's proximity to the Los Angeles river has made it a target for stormwater management opportunities. A few years ago, a bioswale was constructed around the perimeter of the parking lot to capture some of the rainwater and filter it before it went into the stormdrain system and ultimately into the river. The existing parking lot at the Los Angeles Zoo has been redeveloped as a Proposition O Sustainable Project. The scope of work includes: preserving an existing perimeter bioswale, adding new bio cells to the parking lot, retrofitting the parking lot with other permeable paving systems, and planting over one hundred new trees. A new interpretive plaza will inform visitors about the link between stormwater quality and the nearby Los Angeles River. In addition to greatly enhancing stormwater management, the existing promenade between the Los Angeles Zoo and the Autry National Center of the American West will be strengthened to provide a pleasant pedestrian connection between the two important cultural institutions. Included in the project are ML+A-designed interpretive graphics to communicate the benefits of these improvements to visitors.

Vista Hermosa Park, a sustainably designed park, is an urban watershed demonstration project that accommodates community and school recreational programs, integrated with an extensive network of introduced natural features and ecosystems. The park transitions from more intense neighborhood uses, to sloping, native habitats. A range of Southern California native plant communities knit the park together, creating habitats such as oak savannah, coastal sage scrub, chapparral and meadows that attract a variety of wildlife species. Facilities supporting programs ranging from nature walks to campfires under the stars include a children's discovery area, a park office, picnic areas, gathering areas and creature comforts like clean convenient restrooms and drinking fountains. The 30,000 gal cistern collects water from about 95% of the 9.5 acre park. While it is more of a demonstration scale, it provides water for a drip system along the north slope of the soccer field. Water that is not collected in the cistern is absorbed into the groundwater.

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Value Landscape Engineering: Determining Lifecycle Costs of Landscape Installation and Maintenance

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Abstract. *The US Bureau of Reclamation conceptualized a process to evaluate and compare long-term costs and benefits of various landscape strategies. The process called Value Landscape Engineering (VLE) addresses the complexities associated with landscapes by breaking them down into components for evaluation. The end product of the process is a cost analysis of each component and a life-cycle financial analysis of the total landscape.*

Central Utah Water Conservancy District (CUWCD) has expanded upon the VLE concept to provide landscape professionals and homeowners a tool to determine the life-cycle impacts of not only water use and costs, but fertilizers, pesticides, labor, equipment, and fuel/electricity/energy costs as well. Additional information such as hydrocarbon output/reduction, particulate matter output/reduction, and solar heating/cooling benefits/costs are also available to the end user.

Keywords. Value Engineering, landscape water use, spreadsheet, model, cost benefit, long-term, comparison, customize, hydrocarbon output, hardscape, fuel costs, maintenance, replacement, landscape choice

Introduction

Landscape water use is top-of-the-list as a factor in consideration of western urban water supplies. In Utah, landscape water use accounts for nearly 2/3 of potable water supplies, twice the amount used indoors. Utah and other western states have come under increasing criticism for their wasteful water use practices, but indoors, their water use is generally very close to national averages.

With water supplies remaining relatively constant but populations always growing, it is not surprising that landscape water use has come in for close scrutiny as water districts, municipalities, and other water purveyors seek ways to maximize their customer numbers while keeping capital outlays to a minimum—in short, to stretch their water supplies to cover the needs of an ever-increasing public.

For engineering-focused businesses, one frequently used process for evaluating costs and benefits for proposed projects is Value Engineering. Experts are assembled to examine features proposed, material costs, anticipated maintenance and replacement costs, and expected benefits. Many public entities even require the Value Engineering step before any project is deemed "shovel-ready." So what about landscaping? Do homeowners ever seriously consider what the long-term consequences of their landscaping choices may be? And how much they will cost, labor- and money-wise? Frustrated homeowners half-joke about paving over their troublesome lawns. As landscape professionals, can you counter that suggestion with facts about the real benefits of well-chosen live landscape features? And for us as water industry professionals, can we point to hard dollar benefits of water conservation beyond the touchy-feely and altruistic?

In answer to these questions, Central Utah Water Conservancy District has sought to apply the template of Value Engineering principles to landscaping in order to enable professional water and landscape managers, as well as homeowners, to make well-informed decisions about their outdoor surroundings.

The Team

As with any Value Engineering project, Value Landscape Engineering has required an array of varied talents and expertise. Fred Liljegren, landscape architect with the US Bureau of Reclamation and Dr. Larry Rupp of Utah State University first proposed the idea at a 1997 conference, and we have been most fortunate to have them both participate in this project. Dr. David Rosenberg, Assistant Professor of Civil and Environmental Engineering, has headed a Utah State team that includes turf, woody plants, and landscape management experts. We were able to tap into Brigham Young University's Grounds management, and the owner of one of Utah's largest landscaping maintenance businesses. And to translate the results into a user-friendly web-based interface, we relied on one of CUWCD's project managers and the consulting services of CRS Engineers.

Collecting (and Crunching) the Data

After determining the pertinent resources, usage rates, and costs, compilations were made as "back-matter" for a summary that allows a user to insert his own values and generate a customized response. Below are excerpts from three of the fourteen spreadsheets that are the foundation for landscape analysis. Defaults are built in to the summary, but changes can easily be made in the "backmatter" for a truly customized result.

One interesting note: the VLE team took advantage of available information to include not only water and fuel use, but pesticide and fertilizer use, and CO_2 and particulate emissions as well. Now there is hard data to quantify the contributions (and some of the impacts) of the landscape plants in our environment.

Table 1. Water Use Analysis (Example of Backmatter)

Landscaping				UNIT	YEAR 1 WATER USE (GAL/UNIT)	YEAR 2 WATER USE (GAL/UNIT)	YEAR 3 & UP WATER USE (GAL/UNIT)
1	Trees						
		Drought tolerant		EA	168	144	0
		Drought intolerant					
			Slow growing	EA	216	168	0
			Fast growing	EA	216	168	0
			Fruit	EA	216	168	0
		Conifers		EA	216	168	0
2	Shrubs						
		Drought tolerant		EA	48	42	42
		Drought intolerant		EA			
			Hedged	EA	60	54	54
			Fast growing flowering	EA	60	54	54
			Non pruned	EA	60	54	54
3	Ground cover						
		Drought tolerant		SQ FT	13	3	3
		Drought intolerant		SQ FT	26	12	12
4	Perennials						
		Drought tolerant		SQ FT	12	3	3
		Drought intolerant		SQ FT	26	12	12
5	Annuals			SQ FT	48	48	48
6	Vegetable garden			SQ FT	48	48	48
7	Turf grass						
		Cool season		SQ FT	23	23	23
		Warm season		SQ FT	18	14	14
		Total Lifecycle Plant Water Required (gallons)					

Table 2. Replacement Costs (Example of Backmatter)

Landscaping					NUMBER OF TIMES TO REPLACE
1	Trees				
		Drought tolerant			0
		Drought intolerant			
			Slow growing		0
			Fast growing		0
			Fruit		0
			Conifers		0
2	Shrubs				
		Drought tolerant			0
		Drought intolerant			
			Hedged		0
			Fast growing flowering		0
			Non pruned		0
3	Ground cover				
		Drought tolerant			1
		Drought intolerant			1
4	Perennials				
		Drought tolerant			1
		Drought intolerant			1
5	Annuals				14
6	Vegetable garden				14
7	Turf grass				
		Cool season			0
		Warm season			0
8	Mulches				
		Organic			4
		Inorganic (around sparse shrubs)			0
9	Paving				0

Table 3. Pesticide Requirements (Example of Backmatter)

Landscaping					Insecticide (lbs Active Ingredient/UNIT/YEAR)	UNIT
1	Trees					
		Drought tolerant			0	EA
		Drought intolerant				
			Slow growing		0	EA
			Fast growing		0	EA
			Fruit		0.1132	EA
			Conifers		0	EA
8	Shrubs					
		Drought tolerant			0	EA
		Drought intolerant				
			Hedged		0	EA
			Fast growing flowering		0	EA
			Non pruned		0	EA
9	Ground cover					
		Drought tolerant			0	SQ FT
		Drought intolerant			0	SQ FT
10	Perennials					
		Drought tolerant			0.00009	SQ FT
		Drought intolerant			0.00009	SQ FT
11	Annuals				0.00009	SQ FT
12	Vegetable garden				0.00009	SQ FT
13	Turfgrass					
		Cool season			2.1875E-06	SQ FT
		Warm season			2.1875E-06	SQ FT

How Well Does It Work?

The true test of any model is how accurate it is in projecting and predicting what will actually happen. In the case of Value Landscape Engineering, the Utah State team was able to use data from a unique source: the nine-year-old Conservation Garden Park at Jordan Valley Water Conservancy District in the Salt Lake Valley. The Garden Park has been expanded dramatically over the last couple years, but the original garden was built around a neighborhood theme, with model landscapes demonstrating a variety of irrigation and planting strategies. Irrigation for each landscape is metered separately, and maintenance and planting records are also isolated for each unit. Using records from the "traditional," "perennial," and "woodland" themed yards, the Utah State team tested and verified their formulas and cost projections.

Table 4. Sample of Compared Landscapes, Jordan Valley Water Conservancy District

II.	**PLANT COVERAGE and CONFIGURATION**				JVWCD Traditional Landscape	JVWCD Perennial Landscape	JVWCD Woodland Landscape
				UNIT			
1	Total Landscaped Area			SQ FT	4,850	4,655	4,870
2	Hardscape						
		Paved or stone		% of TOTAL AREA	15%	20%	20%
		Landscape rocks		% of TOTAL AREA			
		Decking		% of TOTAL AREA			
3	Turfgrass						
		Cool season (percent of total landscaped area)		% of TOTAL AREA	45%	5%	
		Warm season (percent of total landscaped area)		% of TOTAL AREA			
4	Shrub beds						
		Drought tolerant		% of TOTAL AREA	15%		60%
		Drought intolerant					
			Hedged	% of TOTAL AREA			
			Fast growing flowering	% of TOTAL AREA			
			Non pruned	% of TOTAL AREA			
5	Perennial beds						
		Drought tolerant		% of TOTAL AREA	13%	52%	20%
		Drought intolerant		% of TOTAL AREA	8%	20%	
6	Annual beds			% of TOTAL AREA			
7	Vegetable garden			% of TOTAL AREA			
8	Ground cover						
		Drought tolerant		% of TOTAL AREA	5%	3%	
		Drought intolerant		% of TOTAL AREA			

Another interesting opportunity for testing the VLE model was on a home bought by Provo City as a redevelopment project. As is unfortunately typical for many home construction projects, no plans were made for the landscaping, even though the intention was to showcase energy and water efficiency in the remodeled home. As an afterthought, Central Utah Water was contacted to ask if their irrigation grant program could be a resource; the landscaping was ultimately funded in large part by the District, with assistance and in-kind contributions from a number of contractor partners. Two separate landscaping plans were drawn up, and their features were plugged into the VLE spreadsheets, with very interesting results.

Table 5. Excerpt from comparison of two possible Provo Redevelopment House landscapes

VI.	**REPLACEMENT COSTS**		Artistic Landscape	Simple Landscape
	Total Replacement Costs		$42,968	$31,468
	Present Value of Replacement Costs		$37,152	$27,214
VII.	**INVESTMENT ANALYSIS**			
	Year 1 Capital, Material, Purchase, Contingencies, Site Preparation, and Installation Costs		$29,222	$21,407
	Present Value of Future Costs		$42,735	$31,951
	Total Present Value of All Costs		$71,957	$53,358
VIII.	**LIFECYCLE ANALYSIS**			
	Total lifecycle financial cost	($)	$71,957	$53,358
	Total lifecycle water use	(1000 gallons)	1,485	2,476
	Total lifecycle energy	(kW-hr)	0	0
	Total lifecycle fertilizer use	(lbs N)	151	255
	Total lifecycle pesticide use	(lbs)	8	5
	Total lifecycle owner labor	(hrs)	3,834	3,222
	Total lifecycle hired labor	(hrs)	0	0
	Total lifecycle fuel	(gallons)	111	232
	Total lifecycle particulate matter	(lbs)	1	2
	Total lifecycle hydrocarbon output	(tons CO_2)	-1.4	-1.6

Findings

The Value Landscape Engineering model highlights a number of findings that can inform choices of landscape practices and composition. Among them are:

1. Landscapes require significant money, time, water, fertilizers, and other inputs over the long period that people may own a residential or commercial property.
2. Replacing cool-season turfgrass with warm-season turfgrass can substantially reduce total and annual costs, water, labor, and fertilizer use over a wide range of water and turf seed prices.
3. Replacing cool-season turf with drought-tolerant shrubs or perennials or hardscaping can significantly decrease water use and net CO_2 emissions.
4. Intensively managing a landscape can significantly increase all costs, required inputs, and impacts, but property owners can realize large savings if they follow recommended maintenance practices.[1]

[1] Rosenberg et al. (2011)

One Final Step

In order to make the VLE model most useable for the average homeowner, CRS Engineers developed a web-based version that can be readily accessed online. Visitors to the website can insert their property dimensions, the number of trees and shrubs, the dimensions of planting beds and turf, the areas of hardscape, and end up with a useful projection of what that landscape will cost in energy, water, and labor over a twenty year lifetime. They can then go back and play “what if?”: what if they plant more or fewer trees?; what if they add a patio?; what if they irrigate with drip instead of pop-ups?; what if they use less turf and more hardscape?; what if they only plan to stay in the home 5 years? The potential of this tool as an aid to more thoughtful and purposeful landscape choices is great.

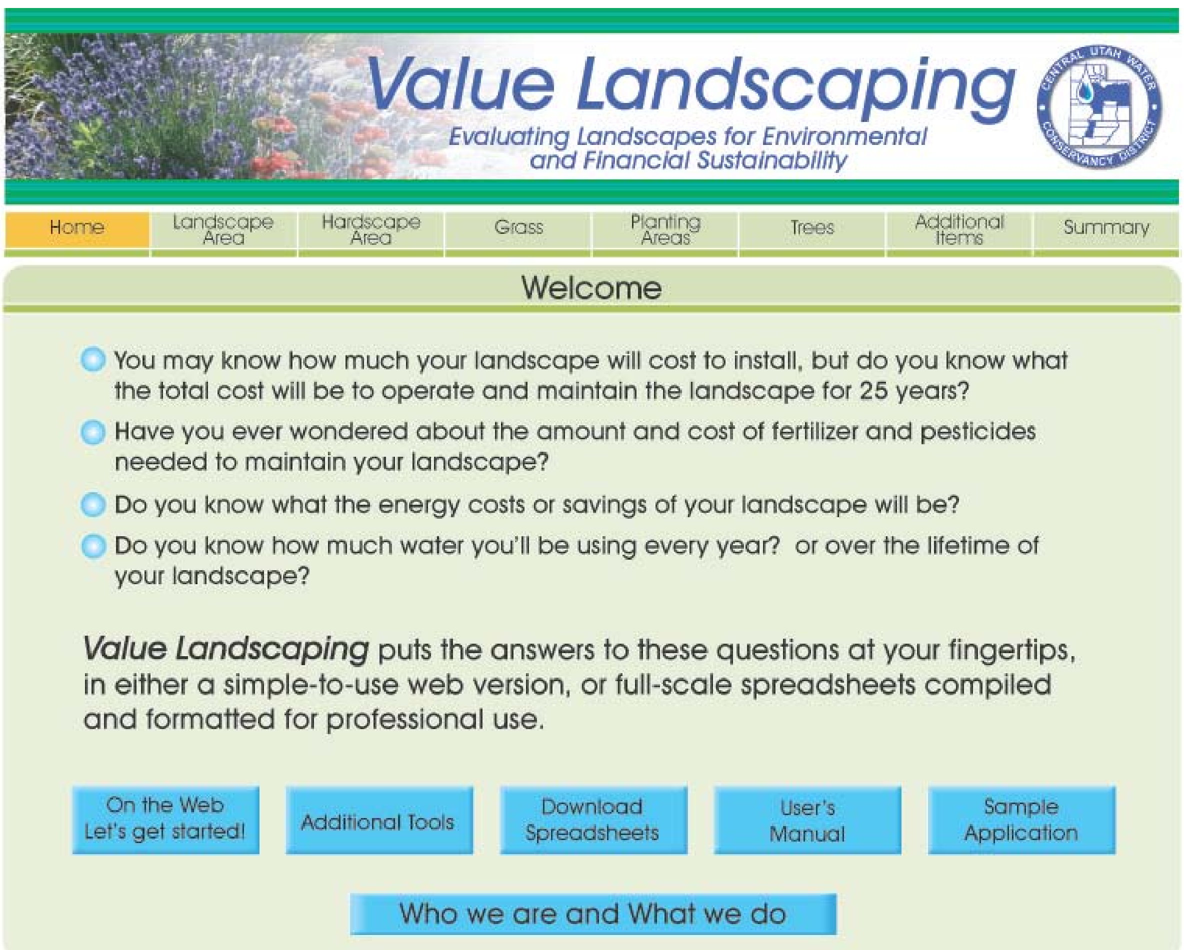

Figure 1. Welcome page for Value Landscape Engineering (Value Landscaping), accessed at vle.cuwcd.com

Figure 2. Sample input screen from vle.cuwcd.com

Expanding the Model

One of the largest landscape water users in Utah is the LDS Church. Their basic church plan calls for ___ acres of grounds plus parking lot. The Facilities Management Department of the Church has been very active in tailoring the model to different climate regions in the country and is currently testing VLE in depth in northern Utah near Utah State University. Their data and experience input to this process will be invaluable.

Conclusion

The USU team continues to collect and evaluate useful data for this project. The original spreadsheets were updated early this year and will be updated again as the need arises. Comparisons are being made with the findings of statewide landscape water audits and other research projects ongoing at Utah State University and at the State Botanical Center.

We encourage other professionals to contribute their expertise to this project as well. Homeowners, property managers, contractors, and vendors around the country are urged to review and use the model to help make decisions for their landscaping plans. The input of the real experts in the green industry will be essential to keeping this tool sharp and ready to use.

Acknowledgements

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Additional references are included and quoted extensively in the above Journal article.

Are You Up To Code?

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As state and municipal water efficiency laws become more widely adopted, irrigation professionals are now challenged to meet higher standards. With the demand and cost of water ever rising, these regulations will have a permanent impact on the work of landscape and irrigation professionals. The City of Santa Monica, a retail water agency in Southern California, has taken a leading role in addressing sustainable water practices by adopting ordinances that promote efficient water use throughout the city. The City's Water-Efficient Landscape and Irrigation Standards (WELIS) are municipal regulations based upon the Irrigation Association's Turf & Landscape Irrigation Best Management Practices and include irrigation design and installation criteria, inspections and auditing requirements, and system maintenance requirements. By following industry standards and the Irrigation Association's Turf & Landscape Irrigation Best Management Practices professionals can satisfy most state and municipal expectations and always be "up to code."

Since 1992, the City has had a "no water waste" ordinance to reduce outdoor water waste by prohibiting irrigation overspray and runoff, as well as prohibiting watering during the warmest times of the day. This law is actively enforced. The majority of landscapes in Santa Monica are designed, installed, and maintained by landscape professionals. Yet, these landscapes almost always have runoff and overspray and generally waste water. This is clear evidence that there is a lack of basic knowledge regarding irrigation best management practices and plant water needs within the landscape industry.

In order to address this issue, the City of Santa Monica took a two prong approach: provide free on-going education workshops for landscape professionals and codify landscape and irrigation best management practices. The goals of this approach are to increase the professional's ability to design, install and maintain beautiful and sustainable landscapes and save water.

In 2008, the City adopted the Green Building Ordinance (GBO) in Chapter 8.108.010 of the Santa Monica Municipal Code, which included landscape and irrigation requirements for public and private properties. In 2009, the City updated the GBO to conform to California's Model Water Efficient Landscape Ordinance. Landscapes and irrigation systems, installed according these Standards, will save on average ten to sixteen times the water as compared to using the State's landscape water budget (MAWA).

The City's Water-Efficient Landscape and Irrigation Standards (WELIS) section of the GBO has a number of different components. Much like the IA's Turf & Landscape Irrigation BMPs they address design, installation, maintenance and management. There is a plant material component, a mulch and amendment component, an irrigation component, a water feature component, and a maintenance component. These Standards are applicable to new construction, major remodels, and existing landscapes and irrigation systems for single family, multi-family, commercial projects, and public agencies.

The WELIS addresses the following critical factors for a successful and sustainable landscape: soil type, climate-appropriate plants, water-efficient irrigation, and permeability achieved by proper design, installation, and maintenance.

It is a common misconception that by merely limiting high water using plants, water conservation is achieved. We have seen climate appropriate landscapes irrigated with sprayheads and bubblers that cause runoff and end up wasting water because the irrigation device's application rates are much higher than the soil's infiltration rates, even though the plant's water requirements are low. Not to mention traditional overhead irrigation systems have poor distribution uniformity and thus tend to waste water.

To address these concerns, the WELIS requires pressure regulation for all irrigation devices. All spray irrigation must be located at least 24 inches from any impermeable hardscape, trees, fences or buildings. This will reduce runoff. This will also encourage the removal of overhead irrigation and the use of permeable pavers like decomposed granite, climate appropriate groundcovers irrigated with drip, or subsurface flow systems for turf, all of which reduce runoff and therefore lessen the impact of over-irrigation that erodes our streets and infrastructure.

Furthermore, the irrigation efficiency of systems must meet a certain requirement. All irrigation systems must be designed and installed in such a manner that a precipitation rate of 0.75 inches per hour is not exceeded in any portion of the landscape. Often soil infiltration rates are much slower than application or precipitation rates of most commonly used irrigation devices. The result of course, is runoff. In reality, this actually limits overhead irrigation to devices like multi-trajectory, multi-stream rotary nozzles, that have lower precipitation rates, less than 0.75 inches per hour. Drip irrigation devices like in-line emitters and on-line emitters with flow rates less than 2 gallons per hour meet this requirement, depending on the row spacing. Tree bubblers often have high application rates. Drip irrigation can be used for trees and/or a 'Root Watering System' can be used. This allows the tree to develop deep, strong roots, leading to less frequent watering. Trees must also be irrigated on a separate valve.

The WELIS also requires that all plants that are 1 gallon in size or larger, be irrigated with drip irrigation. Trees are an exception here. Drip irrigation is plant specific so the delivery of water is directly to the root zone, wasting less water.

Weather based irrigation controllers or WBICs that are SWAT approved and listed are required by the WELIS. These controllers use measured weather conditions from either on-site or off-site weather stations as well as historical evapotransporation rate information, species factors, and landscape site information, to calculate the irrigation needs of each zone. Soil moisture sensors could also be used in conjunction with these devices.

The installer of the irrigation system is also required to test the irrigation system. The City encourages the installers to follow CLIA guidelines for auditing, although there is a lack of clearly defined drip irrigation procedures that the City hopes will be addressed by the industry and industry educational institutions.

The WELIS does require Distribution Uniformity or Emission Uniformity calculations for each irrigation zone. A minimum of 71% is required for sprayheads, 80% for drip irrigation. For overhead irrigation systems, proper sprinkler spacing, head-to-head coverage, and reliable pressure throughout the system are essential for even uniformity.

Cross-Connection or Point of Connection equipment must be properly installed. Backflow prevention is a particular concern for public health and safety. Proper installation of an anti-siphon valve may seem perfunctory considering the design requirements of such a device. However, we have seen improper installation of these devices by "experienced professionals." As a result, these devices are closely inspected at every job site.

Check valves or anti-drain valves must also be included in any project wherever the elevation dictates it. Low head drainage is an unnecessary result of a poorly designed irrigation system and can be prevented with the installation of a check valve in, at or near the lowest head. Low head drainage wastes water.

The WELIS spell out very detailed requirements for installing irrigation systems. Specific kinds of irrigation parts like valve assemblies, filters, and pressure regulators are required. Also certain irrigation devices are prohibited by the guidelines. Of note, multi-outlet drip emitters are prohibited due to their problematic nature, as well as ¼ drips tubing, unless that tubing is being used for container plantings. There are also specifications for pipe selection and burial depth.

Fully detailed Landscape and Irrigation Plans and a Hydrozone Matrix are required for new construction and major remodel projects. The hydrozone matrix is a fill-in spreadsheet used to describe the hydrozones for the entire landscape. Included for each zone is the following: the square footage, percentage of total landscaped area, plant type, hydrozone basis, hydrozone description, exposure or micro-climate, irrigation method, irrigation devices (including manufacturer / model / number), zone pressure, precipitation rates, zone gallons per minute, and controller station number. You can insert this matrix on either plan sheet or on a separate sheet. These plans are reviewed by the Planning Department with consultation from Watershed Management Staff.

There is a website to help professionals develop these plans. Professionals can visit www.sustainablesm.org/landscape for a list of sample plans for download. Also on this website there are downloadable lists of high water using plants, lawn alternative information, lists of acceptable watering devices, charts for calculating precipitation rates, watering schedules, a hydraulic calculator and even a list of sustainable landscape professionals that have attended our workshops.

Once plans have been approved, two inspections are required. One is an open trench inspection and a final inspection. Each inspection ensures the approved plants and parts are installed properly.

The maintenance requirements of the WELIS ensure that changes made to an existing irrigation system are in compliance with these standards. Any upgrade to an existing irrigation system must follow specific requirements to ensure the optimal performance of the irrigation system. For example, all new or replaced sprinklers nozzles on heads on the same valve must have matched precipitation rates that do not exceed 0.75 inches per hour. And our Code Compliance Division is involved in making sure landscape and irrigation requirements are strictly enforced throughout the city.

In summary, a professional could meet our City's code by adhering to both industry standards and the Irrigation Association's Turf & Landscape Irrigation Best Management Practices, a series of guidelines that should be common practice and not the result of environmental regulation. If most water in the urban environment is wasted as a result of outdoor irrigation in the landscape, the prevalence of this kind of regulation will increase. And as stated in the Irrigation Association's Turf & Landscape Irrigation Best Management Practices IA, "The landscape and irrigation industry must demonstrate the ability to irrigate efficiently. The landscape industry is the most visible user of water in an urban setting…The failure to demonstrate efficient irrigation could set the stage for serious consequences to the landscape industry. A drought or perceived water shortage could provide all the impetus necessary for onerous mandates determining when and how much to irrigate as well as the type of plants a landscape can have. The ability to irrigate efficiently will help the landscape industry control its destiny." In the end, the Green Building Ordinance's Water-Efficient Landscape and Irrigation Standards will help bring about better water resource management, smarter irrigation designs, and landscapes that blend harmoniously within the local environment without causing excessive and unneeded strain on our valuable resources.

The Effect of Spray Sprinkler Spacing on Distribution Uniformity

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Abstract. *A study was conducted measuring the effect on distribution uniformity (DU) when increasing or decreasing the spacing between sprinkler spray nozzles. Six nozzles were tested; three models each in the 12' and 15' series throw. Each nozzle was operated on the same irrigation system. Spacing between nozzles was increased and decreased at 10%, 20%, and 30%, intervals beyond or below recommended 50% diameter of throw. Tests were conducted outdoors on an irrigation system regulated at 30 psi, when wind conditions were below 5 mph.*

Brands A, B and C each have optimum spacing's that improved uniformity performance when compared to other spacing's. None of the nozzles had the highest DU when operated at the recommended spacing. Each nozzle has a few distances that significantly decrease their uniformity compared to other spacings.

The mean DU values for 12' nozzles were .62 and for 15' was .60.

Keywords: Spray nozzle, Sprinkler spacing, Distribution uniformity

Introduction

The irrigation spray nozzle is one of the most widely used devices to water many types of landscapes, including turf areas, shrub areas, trees, and annual flowers. Most spray nozzles sold are used in landscapes to cover distances in increments of 5', 8', 10', 12' and 15'. In addition to multiple distances, multiple arcs of 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, and 360° of a circle are available. Ideally, the nozzles radius of throw and arc and its' spacing relative to other sprinklers in the design should result in a uniform distribution of water over an area.

Water management decisions are based on irrigation systems uniformity of application to the landscape surface (Solomon 1979). The goal is to control too little or too much watering on any portion of an area as compared to the average over the entire area.

Distribution uniformity, (DU) is a measurement of uniformity calculated using a ratio (Burt et al., 1997). Ratios are calculated from field audits with catch cans.

Distribution Uniformity is calculated with the following equation (Merriam and Keller, 1978):

$$DU_{lq} = \frac{V_{lq}}{V_{ave}}$$

where: $V_{lq} =$ The lowest quarter average of the volume of water collected

V_{avg} = the total average volume of water collected

DU_{lq} is represented as a ratio and not a percent (Burt et al 1979). The DU_{lq} value can be used to determine if an irrigation system is operating above or below a standard. A system with a .50 uniformity ratio uses twice the water than a system with a DU of 1.0. The higher the uniformity, more water saving can be achieved which the reason spray nozzle uniformity is of concern for water conservation advocates, and government agencies.

California Assembly Bill 1881, the California Model Water Ordinance enacted January 1, 2010 demonstrates the state's commitment to saving water. The ordinance's purpose is to encourage local agencies and water purveyors to use incentives that promote the efficient use of water. The ordinance applies to new construction and the remodel of existing landscapes greater than 2500 square feet requiring a landscape permit. The ordinance establishes a formula that limits the amount of water a landscape can consume annually. Local water purveyors are given the authority to penalize properties that use more than their allowance. The allowance or MAWA – Maximum Applied Water Allowance has a DU value embedded in its formula-Irrigation Efficiency. Irrigation systems can be completely uniform but not be efficient if the landscape manager over waters. Unlike DU, irrigation efficiency includes proper irrigation scheduling and extra water use such as watering in fertilizer, or establishing new plants. However, a system can never have poor uniformity and obtain high irrigation efficiency.

The Model Water Ordinance uses an irrigation efficiency of .71 which is based on certain assumptions of DU for irrigation systems. Since systems with spray nozzles typically have lower DU values than systems with rotors, it may be more difficult to design and manage a spray system to meet an irrigation efficiency of .71.

The Irrigation Association (IA) Certified Landscape Irrigation Auditor Training Manual (September 2010) has a DU quality rating for spray nozzles. The I.A. states that .65 -.75 is achievable, .55 -.65 is the target, and .45 -.55 is the historical range of DU values. When Baum conducted a study on 15' x15' outdoor plots irrigating with spray nozzles under controlled conditions their spray head DU results were .49 (Baum et al., 2005).

The study also audited residential spray landscapes with results for spray systems averaging .41 to .58. This study noted that for spray nozzles there was some relationship to sprinkler brand and pressure to their uniformity results. Low pressure had an effect of across all brands. Furthermore their test pointed to spacing as a key for good rotor performance

Materials and Methods

The purpose of this study was to determine the effects on distribution uniformity when increasing and decreasing spacing between spray nozzles for 12’ and 15’ nozzles (Table 1). An above ground irrigation system was designed and built to change spacing between nozzles from 8.4 feet to 19.5 feet, which allowed spacing to vary +/- 30% from the normal recommended spacing. The design was closed loop to keep pressure loss to a minimum. The system operated 9 spray nozzles: four quarter, four half, and one full circle nozzle in a square spacing design (Figures 1 and 2).

Table 1. Nozzle designation and recommended operating distance spacing at 30 psi.

12 A	Brand A	12 foot throw
12 B	Brand B	12 foot throw
12C	Brand C	12 foot throw
15A	Brand A	15 foot throw
15B	Brand B	15 foot throw
15C	Brand C	15 foot throw

The nozzles in this study were TORO Precision spray, Hunter Pro-Spray, and Rain Bird MPR series. These nozzles were considered representative of nozzles for use in the sprinkler spacings considered in this study.

Thirty psi is the recommended operating pressure for all nozzle brands tested. The system operated between 29 and 31 psi with variations between first and last sprinkler within 10% of operation pressure. A water meter provided a check on flow.

Figure 1 Irrigation system for testing nozzles with catch can grid.

Nozzle spacing set up

All spacing's were set at the distances listed in table 2. When a group of tests began nozzles were randomly picked from the package. Once the replications were complete at the tested spacing the nozzles were placed in a baggie and used in one more replication for a total of 10 to 12 cycles per nozzle. This ensured that the same nozzle completed a group of test, but that there was variation through the study.

Table 2. Nozzle spacing for all tests.

Nozzle	% Difference from Recommended Spacing	Spacing feet		Nozzle	% Difference from Recommended Spacing	Spacing feet
15' A,B&C	0	15		12' A,B&C	0	12
15' A,B&C	+10	16.5		12' A,B&C	+10	13.2
15' A,B&C	+20	18		12' A,B&C	+20	14.4
15' A,B&C	+30	19.5		12' A,B&C	+30	15.6
15' A,B&C	-10	13.5		12' A,B&C	-10	10.8
15' A,B&C	-20	12		12' A,B&C	-20	9.6
15 'A,B&C	-30	10.5		12' A,B&C	-30	8.4

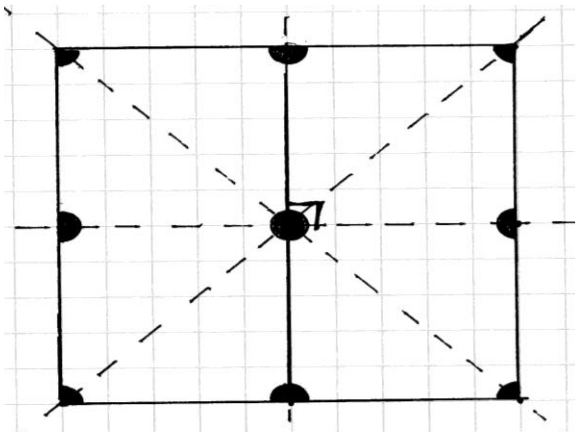

Figure 2 Sprinkler layout with four quarter, four half and one full circle nozzle.

Catch Can Placement

The catch can grid was made with 36 cups, exceeding the Irrigation Association recommendations of 24 cans. Devices were placed low enough to not obstruct the spray pattern. The grid began two feet in from the four quarter circle nozzles. There were six rows with six catch cans in each row (Figure 1).

Data collection

Brands A and C run time was 4 minutes and brand B run time was 5 minutes for each test. An average wind speed for the duration of test was recorded. If the average wind was above 5 mph testing ceased. Testing was between the hours of 9 AM to 1 PM. Pressure was checked during each test and recorded.

A test at each spacing was replicated a minimum of 5 times, sometimes six. All six brand nozzles were used for a maximum of 12 tests and retired for new nozzles. Fourteen different spacing's were tested with a total test count of 222.

Statistical Calculations

The study was designed to test two factors: spray nozzle brand and nozzles spacing on the dependant variable, distribution uniformity. An analysis of variance was performed on the main effects (nozzle brands and spacing) using PROC GLM of SAS (SAS ver. 9.2, Carey N.C.). When significant F test were observed, mean separator tests were performed with L.S.D. or L.S. means in the PROC GLM module.

Results and Discussion

There were significant differences between nozzle brands and spacings for both the 12' and 15' nozzles (Tables 3). These differences were the expected results considering differences in types of nozzles and nozzle spacings of +/- 30% from recommended spacing.

Table 3. Two Way Analysis of Variance (ANOVA) for DU of the 12’ and 15’ nozzles. Analysis of variables: nozzle, spacing, and interaction nozzle and spacing.

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nozzle Brands (12’ radius)	2	.29505586	.14752793	67.80	<.0001
Spacing	6	.038852841	.006421402	2.95	0.0112
Nozzle *Spacing	12	.25153970	.02096164	9.63	<.0001
Nozzle Brands (15’ radius)	2	.13244505	.06622252	17.58	<.0001
Spacing	6	.07479862	.01246644	3.31	.0055
Nozzle *Spacing	12	.13127273	.01093939	2.90	.0020

The mean DU for all 12’ nozzles was .62 and for 15’ nozzles the mean DU was .60. All data is based on a test configuration of four half, four quarter and one full circle nozzles arranged in a square pattern.

Between all 12’ nozzles, DU values ranged from .64 to .60 for the spacings tested (Table 4). However, there is no significant difference in DU with respect to spacing in +/-30% of recommended spacing of 12’. The seven spacings were 8.4’, 9.6’, 10.8’, 13.2’, 14.4’, and 15.6’.

Between all 15’ nozzles, DU values have no significant difference when spaced at 15’ when compared to 10.5’, 12’, 13.5’, 16.5’, and 18’ (Table 4). The 15’ nozzles placed at 19.5’ had a significantly lower DU of .55 than the DU for the recommended 15’ spacing.

Table 4. Distribution uniformity averaged across all nozzle types for various spacing. Pairwise comparisons were made using LS Means between the 15’ and 12’ nozzles at the recommended spacing and all spacing between +/- 30% of recommended spacing. N= 15 to 18 for each spacing; α=.05

12’ DU Mean .61 vs.	Spacing, Feet (% diff)	Pr>t	15’ DU Mean .61 vs.	Spacing, feet	Pr>t
.64	8.4 (-30%)	.0596	.62	10.5 (-30%)	.7923
.63	9.6 (-20%)	.1866	.63	12 (-20%)	.4486
.63	10.8 (-10%)	.1866	.62	13.5 (-10%)	.8891
.60	13.2 (+10%)	.4590	.58	16.5 (+10%)	.1276
.60	14.4 (+20%)	.4358	.58	18 (+20%)	.1202
.60	15.6 (+30%)	.3781	.55	19.5 (+30%)	.0050

The high efficiency nozzle 12B and 15B had significantly higher Mean DU values than the other two traditional spray nozzle designs which included data for all spacings 8.4 – 15.6 feet for the 12 foot nozzle, and 9.6 – 19.5 feet for the 15 foot nozzle (Tables 5 and 6).

Table 5. Comparison of distribution uniformity by nozzle brand for 12' nozzles (Critical value of LSD =.0284, α=.05)

t-grouping	Mean DU	N	Nozzle
A	.65	37	12 B
B	.64	37	12 C
C	.55	37	12A

Table 6. Comparison of distribution uniformity by nozzle brands for 15' nozzles (Critical value of LSD =.0284, α=.05)

t-grouping	Mean DU	N	Nozzle
A	.65	37	15 B
B	.58	37	15 A
B	.57	37	15C

The 12B nozzles had an overall DU mean of .65 for all spacings +/-30% of recommended spacing. The Irrigation Association (IA) would rank this DU as "achievable". This was the highest DU in the test of all nozzles. Nozzle 12A had an overall test mean of .55 and12C had an overall test mean of .64. These DU values were in "target" range of the IA ratings.

The DU results for nozzle 15B had an overall test mean of .65. 15A had an overall test mean of .58, and 15C had an overall test mean of .57. These 15' nozzles had DU values the I.A. consider in the target and achievable categories.

When spacing and nozzle interact, the results were unexpected. In the 12' nozzle category none of the nozzles performed their best when placed at the recommended spacing of 12'. 12 A's best spacing was 15.6' with a DU of .60. 12B's best spacing was the shortest tested distance, 8.4 feet, with a DU of .74. 12C's best spacing was 9.6',

In the 15' nozzle category none of the nozzles performed their best when placed at the recommended spacing of 15'. The 15' nozzle has the highest DU at the 12' spacing or shorter. 15A's best performing spacing was 10.5' with a DU of .66.

15B had the highest DU at 12'. However 15B could operate 10.5' to 18' with no significant change in DU. Similar to 12B, 15B experienced a decline in DU when the spacing was +30% of recommended spacing.

Nozzle 15C best spacing was 12'. This nozzle at 12' had DU values that were not significantly different than DU at spacings of 10.5' – 16.5'. This study demonstrates that each nozzle has a range of spacings where DU values are not significantly different.

Baum et al. study (2005) did not report high DU results; low pressure was considered the reason for poor uniformity in this study. Baum et al.(2005) test plots also reported low DU under controlled conditions, which may have occurred because only quarter nozzles were used. This study tested the DU of a system, where there is an equal representation of half and quarter sprays. Generally it is perceived that spray nozzles do not yield higher DU values than rotors. This study had higher DU averages than Latief et al. (2008) tests. The tests were very similar, but their test experienced significant pressure fluctuations. The pressure during this study remained stable between 29 psi to 31 psi, and DU values were higher compared to their results. Pressure may be more significant to DU performance than distance between nozzles or geometric spray patterns.

Precipitation Rate

Precipitation rate does not impact uniformity; however it can impact irrigation efficiency. California's Model Water Ordinance gives a water allocation based on .71 irrigation efficiency. Some water will always be applied to compensate for uniformity differences. More water may be used for other management practices such as applying fertilizer. The precipitation rate graphs (Figures 9 &10) demonstrate the closer the spacing the higher the precipitation rate. When nozzle 12 B was spaced at 8.4' its application rate doubled over that at 12'. Run times must be adjusted based on the precipitation rate to apply a correct irrigation water requirement.

Precipitation rates for both 12' and 15' foot nozzles show a decrease, as expected, as sprinkler spacing increased (Figures 3 & 4). The precipitation rates for sprinkler spacings less the recommended spacing (less than 12' or 15'), may not correspond with precipitation rates measured in the field since the radius of throw would be adjusted to prevent overspray outside the intended irrigated area. In this study, the radius of throw was not adjusted.

However, for spacings above the recommended spacing, the precipitation rates could be used to determine appropriated irrigation schedules. The measured precipitation rates in this case are reasonably close to calculated values based on nozzle flow.

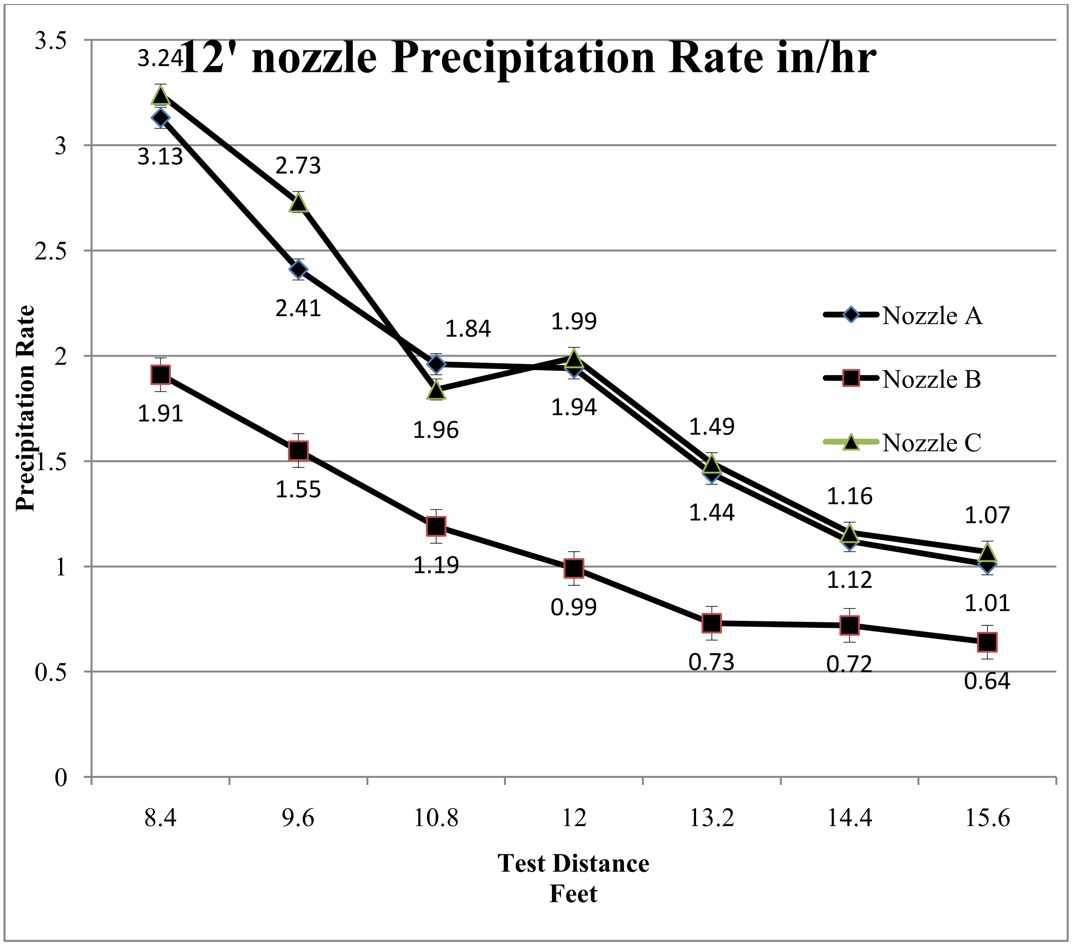

Figure 3. 12' Nozzle precipitation rate.

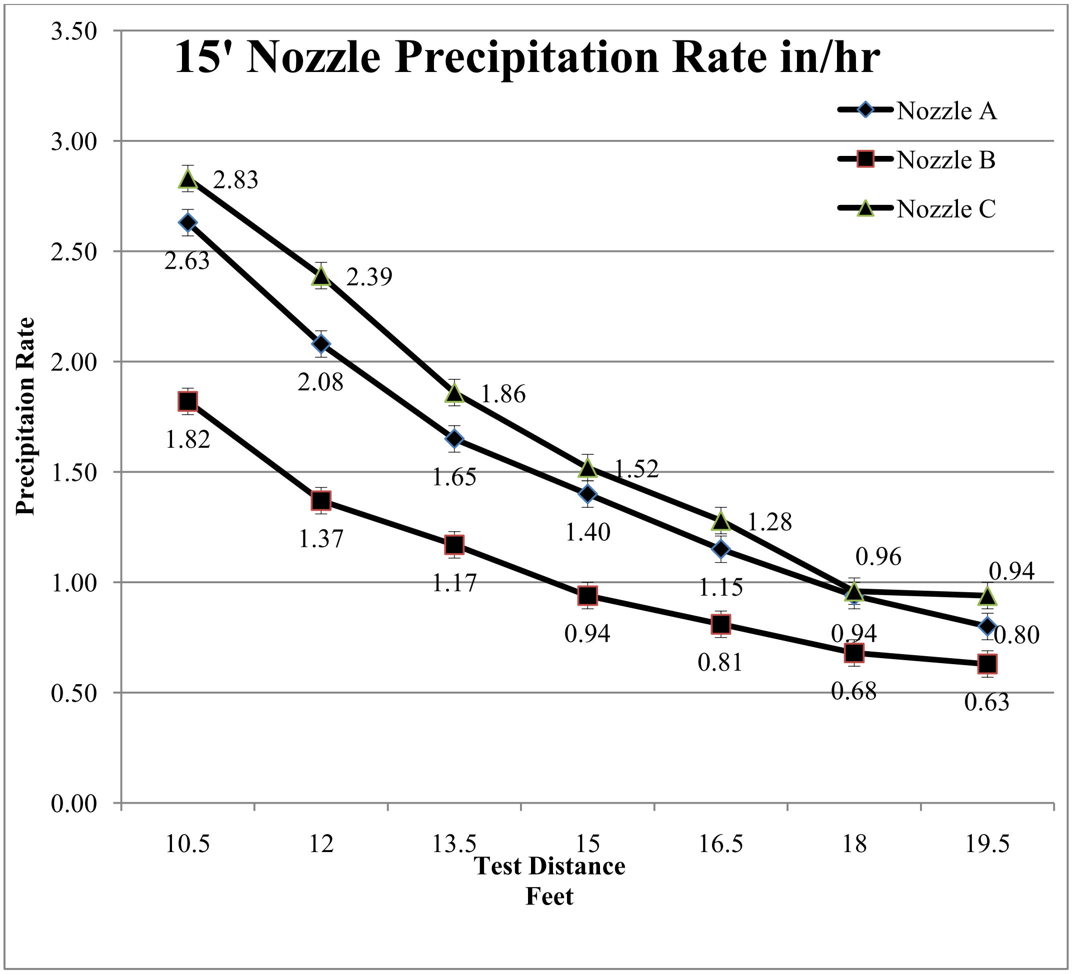

Figure 4. 15' Nozzle precipitation rate.

Conclusions

1. The mean DU for all nozzles and spacings tested was .61.
2. The mean DU for all **12'** nozzles was .62 and for 15' nozzles was .60.
3. The highest DU values for all nozzles were at spacings other than the recommended spacing.
4. There are several spacings for each nozzle where DU in not significantly different than its highest DU for that brand.
5. Brand B had higher DU values than other nozzles tested.
6. Precipitation rates change with spacing and must be accounted for in irrigation scheduling.

Recommendations for future study:

1. Determine the effect of adjusting the nozzle radius on DU.
2. Test at lower and higher pressure than manufacturers recommend pressures.

3. Test the effect of spacing above 30% of manufactures recommended throw on DU.
4. Optimum distance between nozzles should be field tested to determine if results are consistent over a range of conditions.

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Turfgrass ET from Small Weighing Lysimeters in Colorado: First Full Year Results

Mark A. Crookston[1] and Mary J. Hattendorf

Abstract. *Small weighing lysimeters were planted in 11 different turfgrass species or mixes in 2010. Only one of the selections was warm-season turfgrass, the remaining 10 were cool-season turf grasses. There are four replicates of each turfgrass. Results are compared to ETos calculated from an adjacent weather station using the standardized Penman-Monteith equation. The first full season results from 44 small weighing lysimeters are presented. Each lysimeter is centered in a 4-ft by 4-ft plot of the same grass variety. The lysimeters each consist of a PVC shell containing a 12-inch diameter, free-draining sandy loam soil core having a 20-inch rooting depth. The lysimeters are continuously weighed in-place by electronic load platforms connected to a data logger. Irrigation is applied via high uniformity sprinklers and measured through a flow meter monitored by a data logger. All turfgrasses are irrigated on the same schedule and are managed to avoid soil moisture induced stress – each is brought back to field capacity at the time of irrigation. All grasses are mowed to the same height. The purpose of the study is to quantify evapotranspiration of several varieties of turfgrass, under wel- watered conditions and with adequate fertility. The average ratio of measured turfgrass evapotranspiration to calculated ETos are graphically presented in the Summary. Quantification of turfgrass ET with increased accuracy is especially important in regards to water conservation, programming of weather-based SMART irrigation controllers, agricultural to urban water transfers, and water rights administration.*

Keywords. Turgrass ET, weighing lysimeter

Introduction and Background

Interest in different varieties of turfgrasses and their water usage has increased in recent years. Although general statements of lower water requirements are readily attached to some turfgrasses, quantitative assessments based on ETos from the standardized Penman-Monteith equation are rare. The use of lysimeters to directly measure turfgrass ET provides a defensible basis for quantifying and comparing actual water use. This information will assist in the programming of weather-based SMART controllers to account for reduced plant water use in the Spring and Fall. It can provide municipalities with information necessary in developing landscaping standards in support of efficient water use and conservation. It should also assist in more accurate quantification of irrigation return flows from urban landscapes and the in-stream flow credits claimed by Colorado municipalities under water rights administration.

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A previous paper by Crookston, et al. (2010) included an overview of several previous studies regarding turfgrass ET. Although many of these previous studies are in relatively close agreement for ET from well-irrigated cool-season turfgrass with adequate fertility, quantification of differences between cool-season turfgrasses is lacking. Additionally, the difference in mowing height and lack of reference to ETos from the standardized Penman-Monteith equation curtails their transferability from one region to another. The Northern Water lysimeter study will compare ET from turfgrasses - mowed to the same height and under the same climate conditions - to standardized Penmen-Monteith ETos at Berthoud, Colorado.

Methods

In 2009, Northern Water commenced construction and installation of a 30-ft x 30-ft study plot for turfgrass lysimeters within its Conservation Gardens at its headquarters in Berthoud, Colorado. The turfgrasses were seeded starting May 28, 2010, and finishing June 2, 2010. However frequent sprinkler irrigations for establishment of the turfgrasses continued through most of July 2010. The tops of most lysimeters were still clearly visible and the effective diameter of the lysimeters did not fill the small gap surrounding all lysimeters until after that time. Consequently, the 2011 season is the first full season for evaluation of ET from established turfgrasses.

The lysimeter plot was divided into 4-ft x 4-ft sub-plots, separated by 1-inch x 6-inch PVC plastic composite decking/edging material. This edging clearly delineates the subplots and helps prevent the spread of one grass variety into another subplot. It also provides support for foot traffic by study technicians without damage to turf or compaction of the soil. Turfgrasses were planted into 44 of the 49 sub-plots, with the four corners and center sub-plots excluded from the study, but planted to a bluegrass blend to maintain fetch. The lysimeter plot was divided into four blocks, with each block containing 11 randomized sub-plots with lysimeters, one of each turfgrass variety included in the study. Consequently, the study includes four replicates of each of the following 11 turfgrasses:

Table 1. Turfgrasses.

Blue gramma – buffalograss mix	70% - Blue Gramma 30% - Buffalograss
Drought hardy Kentucky bluegrass	33% - Rugby 33% - America 33% - Moonlight
Ephraim crested wheatgrass	
Fine fescue mix	25% - Covar Sheep 25% - Intrigue Chewings 25% - Cindy Lou Creeping Red 25% - Eureka Hard

Kentucky bluegrass blend	50% - Rampart 25% - Touchdown 25% - Orfeo
'Low Grow' mix	29% - Creeping Red fescue 27% - Canada bluegrass 24% - Sheep fescue 16% - Sandburg bluegrass
'Natures Choice' - Arkansas Valley mix	70% - Ephraim Crested wheatgrass 15% - Hard fescue 10% - Perennial ryegrass 5% - Kentucky bluegrass
Perennial ryegrass	Playmate blend
Reubens Canada bluegrass	
Tall fescue	Major League blend
Texas hybrid bluegrass blend	50% - Reveille 50% - SPF 30

Equipment

The weighing platform for each lysimeter includes a Revere PC6-100kg-C3 load cell transducer. Each load cell is connected to one of three AM 16/32 multiplexers, each connected to a Campbell Scientific CR10X data logger. Figure 1 is a diagram of the small turfgrass lysimeters and their arrangement within the lysimeter plot.

Every three seconds a measurement is taken from each load cell. These measurements are averaged every 60 seconds. This 1-minute average is time-stamped and stored in the data logger at the end of each 15-minute period. Stored data is automatically downloaded every 15 minutes to a desktop PC via an RF401 spread-spectrum radio. Differences in lysimeter weight are calculated as the difference in the measurement at the end of each hour. These hourly values are compared to calculated ETos obtained from the REF-ET software v.3.1 (http://www.kimberly.uidaho.edu/ref-et/) utilizing data from the adjacent Campbell Scientific ET-106 weather station. The weather instruments are each calibrated annually.

The weighing platforms for each lysimeter were calibrated in-place (without the lysimeter) in September 2009 over their full load range using steel weights. The platforms were again re-calibrated in-place during 2010, but only over their operational range (from dry soil to wet soil). In-place re-calibration was again performed in early March 2011. No problems were identified during the re-calibrations, and all weighing platforms were measuring lysimeter weights properly.

The entire lysimeter plot is on a single irrigation zone using MP Rotator 2000 sprinklers on 15-ft spacing. A DLJ ¾-inch x ¾-inch brass flow meter with pulse output is connected to a Campbell

Scientific data logger which measures all irrigation applications to the lysimeter plot. In addition, 15 Texas Electronics tipping bucket rain gauges are installed flush with the turf height throughout the lysimeter plot to measure net irrigation application as well as rainfall.

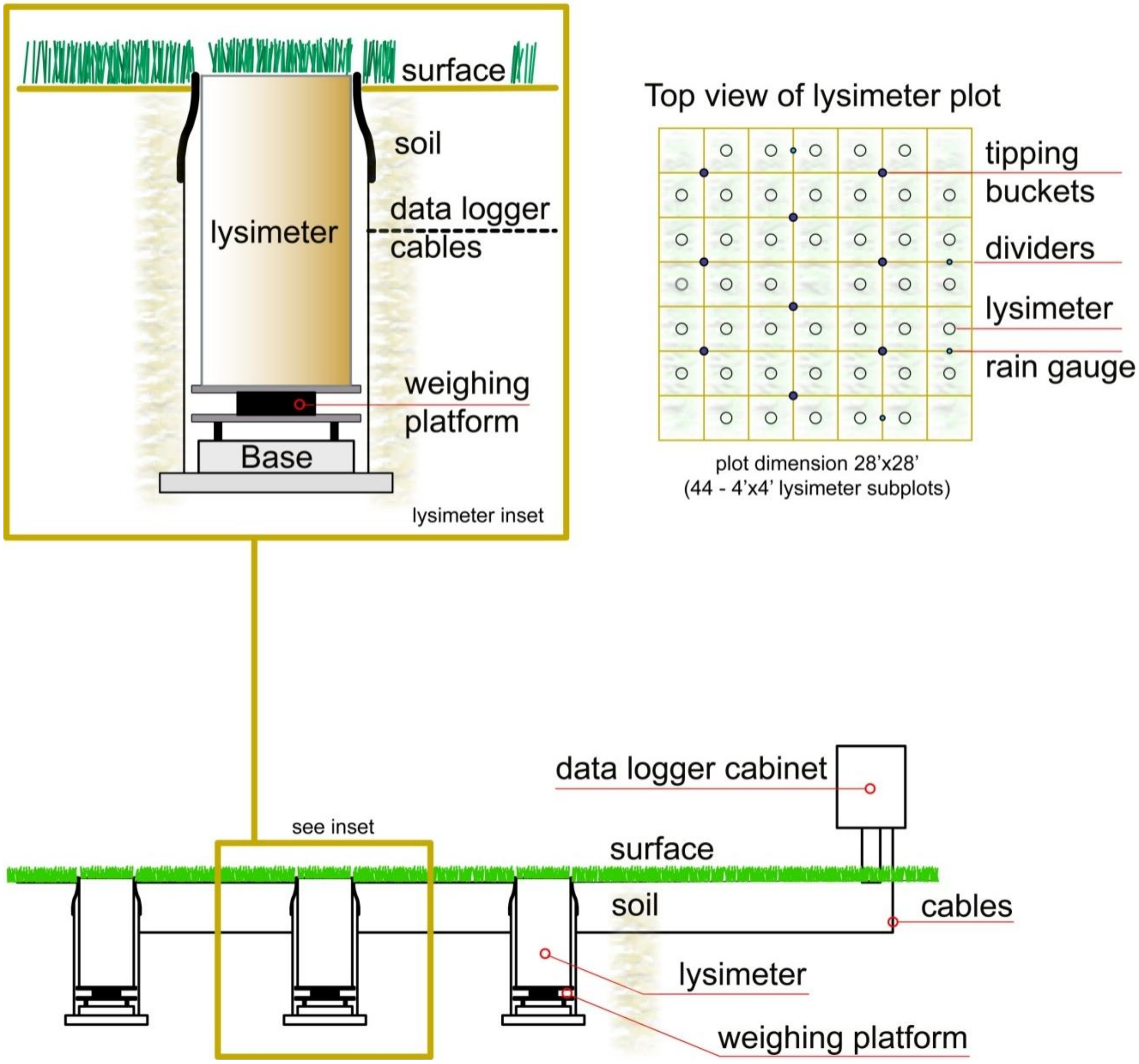

Figure 1. Diagram of Small Turfgrass Lysimeters.

A photograph of the site location, surrounding gardens, and weather station location is provided in Figure 3 at the end of this paper.

Deep Percolation Calculations

Deep percolation through the lysimeters was not directly measured. Deep percolation from irrigation was calculated as the difference between applied irrigation less the increase in lysimeter weight after free drainage. Beginning in late July 2010, all sprinkler irrigations were scheduled for after sundown and before midnight. Because the lysimeters are free-draining with sandy loam soil only 20-inches deep, any deep percolation from irrigation was generally assumed to be completed before sunrise. Turf water use during this nighttime drainage period was considered negligible. However, hand watering to bring each individual lysimeter grid up to field capacity did occur during daytime hours–either earlier the same day as the sprinkler irrigation, or the following day. The majority of the data during daytime irrigation events was excluded from the comparison to calculated ETos. Any excessive percolate that ponded below a lysimeter was removed through a manually-controlled vacuum extraction system as needed.

Deep percolation from rain was calculated similarly as for irrigation. However, special considerations were required – particularly for significant daytime rain events. Deep percolation from rain was calculated as the difference between measured rainfalls less the increase in lysimeter weight (after stabilization). A few periods of extended deep percolation were observed during 2011 following lengthy rain periods, generally in excess of 3 to 4 days. If these rainy drainage periods occurred during daytime hours, the data were generally excluded from the comparison to calculated ETos.

Results and Discussion

Figure 2 graphically presents the average ratio of measured turfgrass evapotranspiration to calculated ETos during the 2011 season for each of the 11 selected turfgrasses. As expected, these data clearly indicate reduced water use in the Spring and Fall with peak water use occurring during mid-Summer. Although some differences between different turfgrasses are evident, these data are preliminary and should not be relied upon until further seasons of data are included for evaluation.

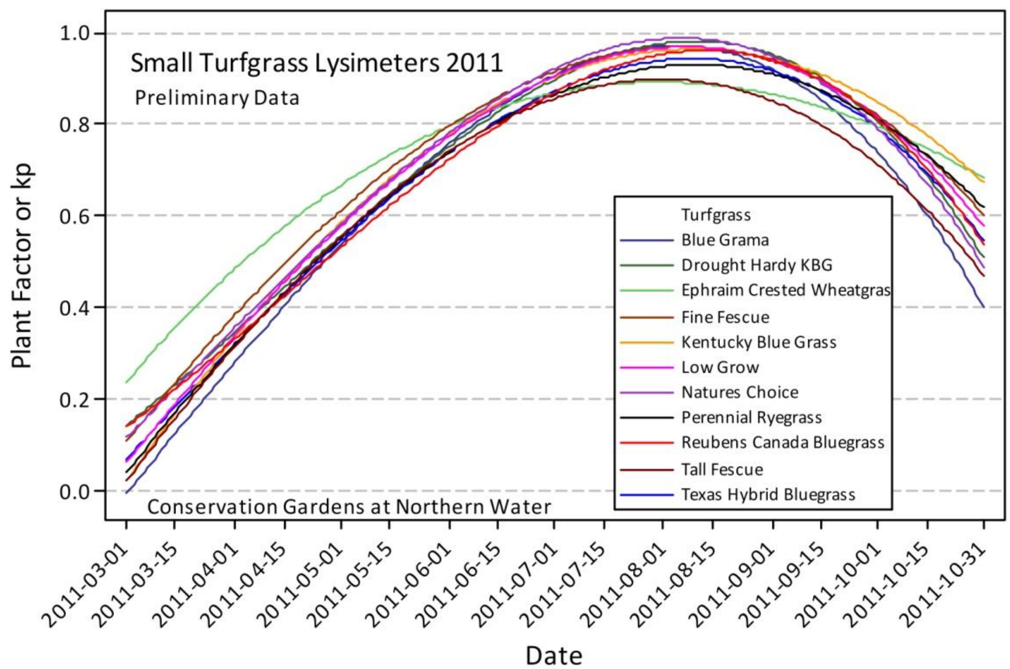

Figure 2. Small Turfgrass Lysimeters 2011 - Preliminary Data (graph of 2011 plant factors)

Conclusions

Additional seasons of data collection are necessary to fully establish the plant water use coefficients for the various turfgrasses. Future plans include study of turf water use under deficit or reduced irrigation management. It is anticipated this information will be of particular value in programming and adjusting irrigation controllers to adjust for the reduced water use of turfgrasses in Spring and Fall and to better maintain turfgrass vigor and health during the mid-summer period of greatest water need. Previous approaches utilizing a constant turfgrass coefficient all season can be readily improved, resulting in potential for increased water conservation and improved landscape appearance.

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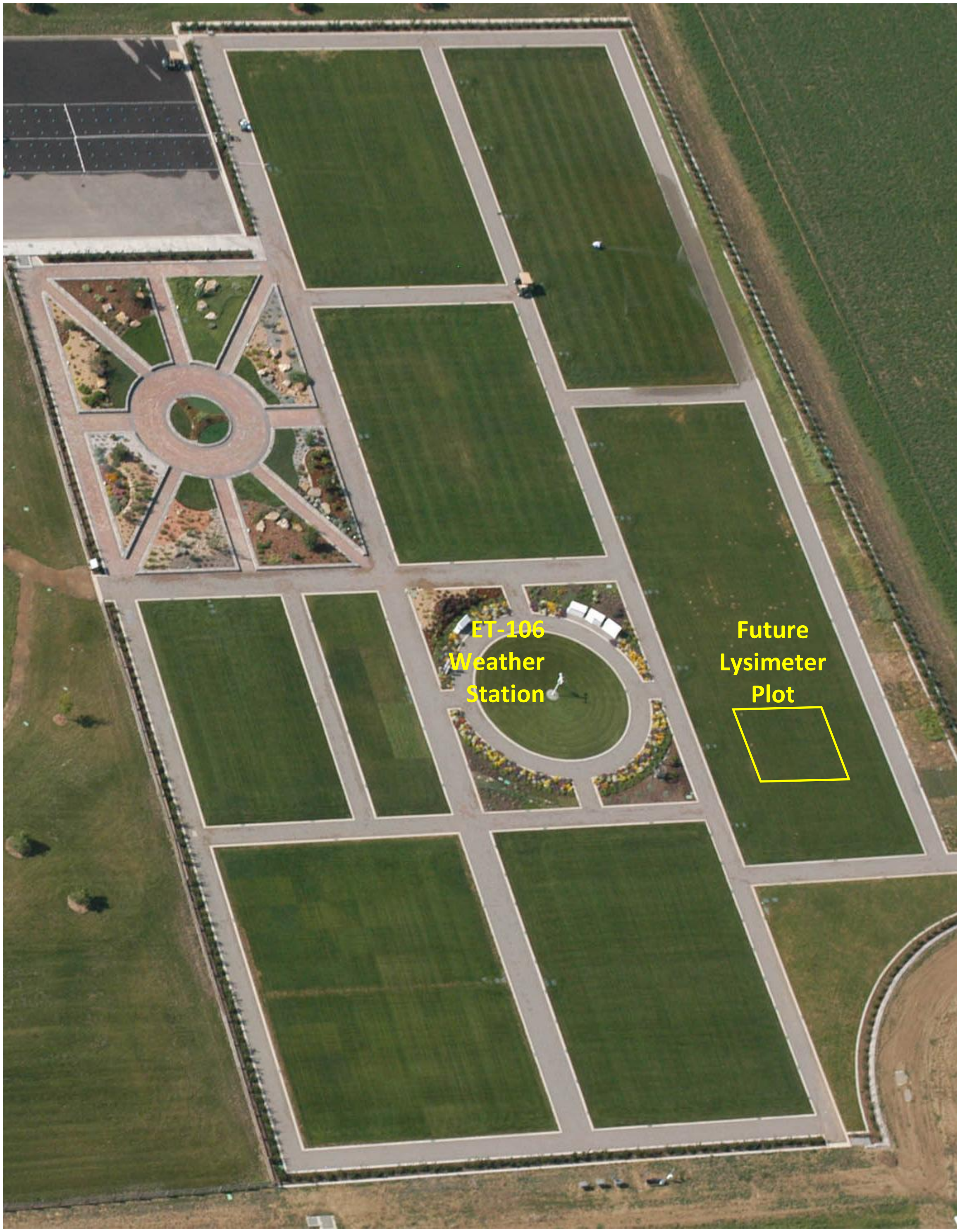

Figure 3. Aerial View of Conservation Gardens at Northern Water – before construction of lysimeter grid.

A Water Budget Calculator Created for Residential Urban Landscapes Using Novel Approaches

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Abstract. *We created a water budget web interface that allows users in Albuquerque, New Mexico to calculate their landscape water budgets using current, historical, and El Niño Southern Oscillation phases reference evapotranspiration data. Three water budget calculation methods are available at the web interface. A Modified Water Budget approach uses the total parcel landscaped area and zip code-specific mixed landscape coefficient (K_c). A Vegetation Fragmented Water Budget approach uses the total area of trees, shrubs, or grasses within the landscape and vegetation type-dependent K_cs. A Species Fragmented Water Budget uses the landscape areas of each species and specific K_cs for each species. Residents can input a specific address and digitize the parcel image of that address. Outputs from the digitizing process can be used to calculate the landscape water budget.*

Keywords. Water budget calculations, residential landscapes, spatial and temporal ET_o.

Introduction

A landscape water budget is the amount of water required to maintain the residential landscape (Bennett and Hazinski, 1993). People tend to irrigate landscapes at 50% higher than their actual water requirements (Pittenger and Shaw, 2010) even though most landscape species will perform acceptably when irrigated within 18-80% of reference evapotranspiration (ET_o) (Pittenger and Shaw, 2004). Thus, a lack of knowledge of landscape water budget leads to water waste and the depletion of states' water reservoirs (Hurd and Smith, 2005), while accurate water budgets help municipalities cope with drought (King County, 2007) and craft urban water conservation plans (Kenney et al., 2004). Developing a science-based water budget calculation program with accessibility to different users may serve to monitor landscape irrigation and promote city-wide water conservation efforts.

For uniform plant cover, a water budget may be determined by multiplying ET_o by the crop coefficient (K_c). But considering the mixed landscape plants in residential sites as a single big leaf may under- or over-estimate the residential landscape water budget. Xie (2009) cautioned against using a single K_c for landscapes, since they consist of a heterogeneous mix of vegetation with various water requirements (Costello and Jones, 2000). Another calculation method is to multiply the landscaped area by ET_o and a landscape adjustment factor (AF) (King County, 2007; White et al., 2004). This approach is simple, but the AF's are neither science-based (White et al., 2004) nor site specific.

Existing water budget calculators (City of Boulder, Colorado, 2010; The Irrigation Water Management Association, 2010; United States Environmental Protection Agency, 2009) use fixed landscape AF's and ignore the variability in plant water requirements and ET_o. Urban areas that include considerable vegetation cover, such as residential landscapes (Zmyslony and Gagnon, 1998; Richards et al., 1984), show spatial variation in evapotranspiration rates (Grimmond and Oke, 1999). For example, reference evapotranspiration rates differed significantly among zip codes of Albuquerque, NM (Al-Kofahi, 2011). Thus, using a single ET_o value to calculate water budgets on a city scale is inexact (Xie, 2009). In addition, weather anomalies lead to differences in ET_o (Meza, 2005), such as the global El Niño Southern Oscillation (ENSO) phase ET_o (Sabziparvar et al. 2010). So, using the spatial and temporal ET_o

data is potentially important for irrigation management and water resources planning on a city scale.

This research aimed to develop novel approaches to water budget calculation that would satisfy a wider range of users and exploit the spatial and temporal variability in ET_o in urban areas.

Methodology

Study Area

Albuquerque is New Mexico's largest city. It is home to 529,219 residents (U.S. Census Bureau, 2011) that represent 90% of Bernalillo County's population. The city receives around 9.05 in of annual precipitation (Earp et al., 2006), and ground water is the city's main source of water (United States Geological Survey 1996). In 2007, Per Capita Water Use (PCWU) in 2007 was 167 gallons /day (City of Albuquerque 2010).

Water Budget Calculation Approaches

Common Landscape Water Budget (CLWB) method (Eq. 1) (Xie, 2009; St. Hilaire et al., 2008; King County, 2007; White et al., 2004) contain an assumed mixed landscape coefficient (K_c) and irrigation efficiency (IE) merged into an AF (AF= K_c/IE). We eliminated the IE from our basic equations since it is variable and location-specific. We used the finest scale of residential landscape vegetation (species) and developed the Species Fragmented Water Budget approach (SFWB) to account for each species' water requirement level, coefficients, (K_c) (Eq. 2) and areas.

The complexity of accounting for all residential landscape's species' water requirements (Pittenger and Shaw, 2004), necessitated some simplification. We considered the residential landscape as subunits of different vegetation types (trees, shrubs and grasses), and we included generic vegetation coefficients for trees (0.37), shrubs (0.38), and grasses (0.53) calculated for Albuquerque (Al-Kofahi, 2011). We called this approach, the Vegetation Fragmented Water Budget approach (VFWB) (Eq. 3).

Municipalities and homeowners may require a ground-sensed quick water budget calculation approach that is applicable to all parcels in specific residential areas (i.e. zip code). To assist with this approach, we classified residential landscape vegetation components of Albuquerque zip codes into tree, shrubs, and grass cover. Four hundred and eighty parcels were selected randomly from Albuquerque's sixteen zip codes. Around thirty residential landscapes in each zip code were classified using object-based supervised classification module in ENVI EX 4.7.1 software and very high spatial resolution (0.5 foot) true color aerial photographs, captured in 2008. Error matrix was used to assess the classification accuracy.

We used the generic vegetation coefficients and the zip codes' vegetation percentages to develop a mixed K_c for each zip code (Eq. 4). In the Modified Landscape Water Budget approach (MLWB) (Eq. 5), the mixed K_c replaced the AF in the CLWB formula.

Reference Evapotranspiration (ET_o)

Five points (locations) were selected purposively in each zip code of Albuquerque using Geographic Information System and the zip code vector layer (City of Albuquerque, 2008). For each point, hourly weather data was downloaded from the National Weather Service Forecast Office and used to calculate hourly ET_o using Penman-Monteith equations (Snyder and Eching, 2002). The program calculates the daily ET_o for each point using the three weather forecasts closest to the day of interest. Each zip code's daily ET_o values were averaged and summed to determine the zip code's monthly ET_o.

We obtained historical minimum and maximum temperatures (1931-2009) and used Hargreaves equation (Allen et al. 1998) (Eq. 6) to calculate historical ET_o for Albuquerque using those data. We obtained 1931-2009 monthly ENSO signals (Climate Prediction Center, 2009) and used the historical monthly ET_o to obtain monthly and yearly historical ENSO phases ET_o.

$$ET_0 = 0.0023(T_{mean} + 17.8)(T_{\max} - T_{\min})^{0.5} Ra \qquad (6)$$

Where:

ET_0 = Reference evapotranspiration $(mm \cdot day^{-1})$;

T_{mean} = Average air temperature $(°C)$;

$T_{\max}$ = Maximum air temperature $(°C)$;

$T_{\min}$ = Minimum air temperature $(°C)$;

Ra = Extraterrestrial radiation $(MJ \cdot m^{-2} \cdot day^{-1})$.

Statistical Analysis

We assessed the differences among different ENSO phases ET_o using historical monthly ET_o estimates for each phase. Each combination of signal and month was fitted a mean using PROC AUTOREG. The analysis accounted for the autocorrelation and heterogeneity of variance. Estimated means and the estimated variance matrix were used to generate specific PROC IML tests.

Results

We developed three water budget calculation approaches (SFWB, VFWB, and MLWB) for residential landscapes in Albuquerque. The accuracy of residential vegetation classification was 89%. We calculated mixed landscape coefficients for each zip code based on the zip codes' residential vegetation proportions and vegetation generic coefficients (Eq. 4). The common water budget formula over-estimated the actual water budget (Table 1).

$$\textit{Common Landscape Water Budget } (CLWB) = ET_o \times AF \times LA \times CF \quad (1)$$

$$\textit{Species Fragmented Water Budget } (SFWB) = \sum_{i=1}^{3}\sum_{j=1}^{n} ET_o \times CF \times A_{ij} \times K_{c\,ij} \quad (2)$$

$$\textit{Vegetation Fragmented Water Budget } (VFWB) = \sum_{i=1}^{3} ET_o \times CF \times A_i \times GK_c(i) \quad (3)$$

$$\text{Zip code Mixed Landscape Coefficient } (ZK_c) = \sum_{i=1}^{3} GK_c(i) \times \frac{A_i}{TA} \quad (4)$$

$$\textit{Modified Landscape Water Budget } (MLWB) = ET_o \times ZK_c \times LA \times CF \quad (5)$$

Where:

AF= Adjustment factor;

A_i = Area of (i);

A_{ij} = Landscaped area of j^{th} Species within the i^{th} vegetation type (ft^2);

CF= Conversion factor (0.632 $gal/ft^2.in$);

ET_o = Monthly or yearly reference evapotranspiration (in);

j = Individual species;

i = 1: Trees, 2: Shrubs, and 3: Grass (ft^2);

$GK_c(i)$= Generic vegetation (i) coefficient;

$K_{c\,ij}$ = Species coefficient;

LA= Landscape area (ft^2);

TA = Total landscape area (ft^2);

ZK_c = Zip code-specific coefficient (0.38-0.42).

Albuquerque's monthly and yearly historical ET_o were 5.1 and 61.24 inches respectively. Historical monthly and yearly ET_o are commonly used to calculate water budgets. Historical ET_o is the average of the historical ET_o values regardless of ENSO phases and the frequency of each

Table 1: Annual water budget calculation of a residential landscape in Albuquerque using different water budget calculation approaches.

Approach	Historical ET_o (in)	Conversion Factor ($gal/ft^2.in$)	Coefficient used		K_c	Landscaped area (ft^2)	Water budget (gal/year)	Total water budget (gal/year)	Difference from CLWB (gal/year)
CLWB[1]	61.24	0.632	Common		0.50	2002*	38,742	38,742	0
MLWB[2]	61.24	0.632	Mixed		0.42	2002	32,544	32,544	-6,198
VFWB[3]	61.24	0.632	Generic Tree		0.37	952	13,638		
			Generic Shrub		0.38	179	2,631		
			Generic turf		0.53	871	17,861	34,131	-4,611
SFWB[4]	61.24	0.632	Species:	*Juniperus spp.*	0.20	179	1,389		
				Thuja orientalis	0.35	174	2,351		
				Prunus spp.	0.50	195	3,777		
				Punica granatum	0.20	182	1,409		
				Cupressus arizonica	0.10	191	738		
				Iris spp.	0.20	8	65		
				Rhaphiolepis indica	0.20	56	432		
				Thuja occidentalis	0.50	98	1,896		
				Salvia greggii	0.20	22	172		
				Rosa minitifolia	0.35	19	254		
				Stipa pulchra	0.20	8	59		
				Turf grass	0.53	871	17,861	30,403	-8,339

[1]CLWB = Common water budget formula; [2]MLWB = Modified water budget formula; [3]VFWB = Vegetation fragmented water budget formula; [4]SFWB = Species fragmented water budget formula; *2002 ft^2 is the average landscaped area of Albuquerque average parcel size of 8008 ft^2.

signal. Monthly ET_o of El Niño signal was significantly lower than that of Neutral (p=0.0002) and La Niña (p=0.0006) signals. In addition, the frequencies of ENSO phases along the 78 years examined were not equal (Table 2). The overall monthly historical ET_o was higher than monthly historical El Niño ET_o and lower than La Niña and Neutral ET_o in most of the months (Fig. 1).

Table 2: Historical El Niño Southern Oscillation (ENSO) signals ET_o over all months.

Signals[1]	Average Monthly ET_o (in)	Standard Errors	Frequency
El Niño	4.967 b[2]	0.039	21.4%
La Niña	5.129 a	0.040	20.2%
Neutral	5.123 a	0.023	58.4%

[1]Signals ET_o averages were based on 78 years of record; [2]Averages with different letters are significantly different.

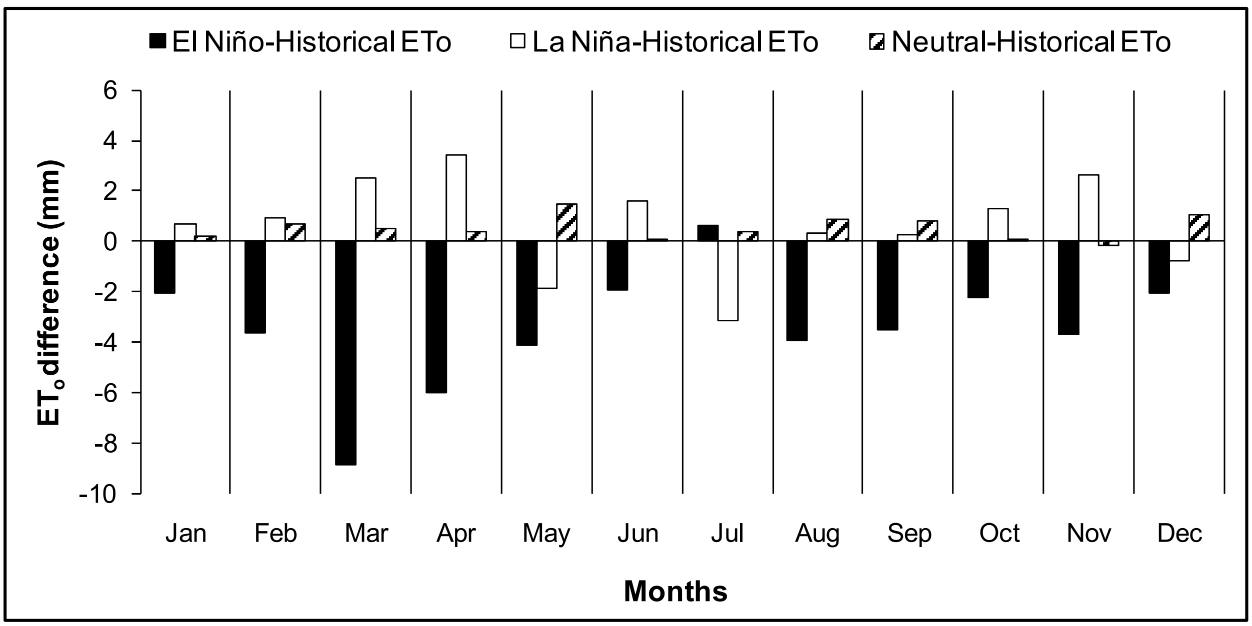

Figure 1: Monthly historical El Niño Southern Oscillation (ENSO) signals ET_o subtracted from the overall historical ET_o; mm=0.03937 in.

The three water budget calculation approaches were incorporated in an interface that allows Albuquerque users access and usage by inputting an address and browsing its top-view from Google Maps imagery. Imagery could be digitized to calculate the total landscape area, vegetation areas or species areas. Historical ET_o, spatial current, and temporal ET_o (ENSO phases) were provided to calculate the landscape water budget.

Discussion

For multiple reasons, residential landscape irrigation consumes a considerable portion of states' water resources (Hurd and Smith, 2005). First, the landscape represents a major component of urban vegetation (Larsen and Harlan, 2006). Second, 40 to 70% of household water-use in the United States goes to landscape irrigation (Ferguson, 1987). Third, people tend to over-irrigate residential landscapes (Pittenger and Shaw, 2010). To address these situations, we developed science-based water budget approaches with accessibility to users of differing levels of sophistication. Unlike other approaches, our method estimates the water budget using ground-proofed vegetation components data and considers species' water requirements. Furthermore, our approaches showed potential reductions in water budget estimates compared to the methods researchers commonly use (City of Roseville 2010; Pittenger et al. 2010; King County 2007; Pittenger and Shaw 2004; White et al. 2004). For example, water budget calculations of the SFWB, VFWB, and MLWB showed reductions of 21%, 12%, and 16% of the water budget, respectively, relative to those based on the common formula (Table 1). Our research indicates that the methods commonly used for estimating landscape water budgets need fine-tuning, whereas, the new calculation methods can potentially generate huge water savings, especially on a city scale.

The SFWB approach is considered the most accurate approach because it accommodates all residential landscape species and addresses speciess differences. Plant water requirements range from low to high (Bennett and Hazinski, 1993), a simple fact that must be accounted for in estimating water budgets. Pittenger and Shaw (2004) reported that it is difficult to calculate residential landscape water budgets while accounting for species water requirements. However, the inclusion of landscape plant species lists, their K_cs, and generic K_cs for unknown or unlisted species on the interface overcomes that limitation.

The VFWB and MLWB are simple approaches that incorporate some generic science-based coefficients to help homeowners and residents easily estimate residential landscape water budgets. A simple, but accurate water budget calculation approach is critical to water conservation efforts. For example, the City of Albuquerque is targeting a PCWU of 155 gallons/day by 2024 (City of Albuquerque 2010) and residents' participation will be crucial to reaching that goal. If homeowners participate in the water conservation through efficient residential landscape irrigation, then water conservation efforts are more likely to succeed (Grisham and Fleming, 1989).

Residential landscape styles tend to resemble each other within spatially close areas, but as the area becomes larger, they become varied (Zmyslony and Gagnon, 1998). For the MLWB, we used a specific mixed K_c for each zip code. That mixed K_c was calculated based on each zip code's vegetation component. This approach could allow municipalities to assess residential landscape water use before issuing building permits, and determine whether high water use of parcels reflects outdoor or indoor activities.

The water budget approaches, landscape coefficients, and evapotranspiration data were incorporated into a user-friendly interface, accessible at www.nmclimate.nmsu.edu/wb. The interface includes a step-by-step help tool, previews of the residential landscape image based on the address, and digitization tools that allow areas of residential landscape features to be calculated. For example, the digitization tools can be used to obtain total landscaped areas, vegetation types, species or water body areas in a parcel. All data can be inputs for water budget calculation.

The interface offers different sources of ET_o to satisfy multiple users' goals and objectives. For example, landscape planners, decision makers, and municipalities often use historical ET_o for water budget calculations in long term plans, simulations, and water use projections. However, global weather anomalies might impact some water budget calculation inputs, and such potential changes need to be considered (Meza, 2005). For example, global land evapotranspiration rates showed an increasing trend from 1982 to 1997 that stopped from 1998 to 2008; that period (1998-2008) was synchronized with the major global El Niño event (Jung et al., 2010). In Maipo River Basin, Chile, ENSO phases influenced ET_o values and consequently lead to differences in plant water requirements during the prevalence of different ENSO signals (Meza, 2005). Hence, using historical ENSO phases ET_o may ensure that the required amount of irrigation water is applied without over-estimation during El Niño phase. On the other hand, using the historical ET_o to estimate water budgets during La Niño and Neutral phases may jeopardize the landscape because of the under-estimation of plant water requirements.

The interface provides the monthly (January-December) historical ET_o for each ENSO signal as our ENSO phases ET_o data confirm the variability of ET_o values among different signals (times) for Albuquerque. However, ET_o varies spatially, and that variability has hydrological, horticultural, and ecological implications for urban areas (Grimmond and Oke, 1999). Current ET_o values were spatially variable within locations in Albuquerque. To account for this, we included the current ET_o values for each zip code.

Conclusion

We developed new water budget calculation approaches (SFWB, VFWB, and MLWB) to facilitate the estimation of residential landscapes' water budgets, improve their accuracy, and support water conservation efforts. These approaches accounted for the vegetation types and water requirements variability. Landscape plant species K_cs, generic vegetation-type K_cs, and zip code-specific mixed K_cs were used. The CLWB approach showed over-estimation in the water budget compared to the new calculations methods. The three calculation approaches, current, historical, and ENSO phases ET_o data were incorporated in to a web interface to allow users access to estimate their residential landscape water budget. Reference evapotranspiration varied among spatial scales (locations) and temporal scales (ENSO phases) within Albuquerque. We also accounted for this in our water budget calculator web interface.

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Keeping Water in the Pipes through Irrigation Auditing

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Abstract: *The purpose of this paper and ensuing presentation is to demonstrate what can and cannot be accomplished through irrigation auditing. Irrigation Auditing is frequently misunderstood and often undervalued. In our region the value of outdoor auditing often gets lost when compared to the barrage of indoor water audits and toilet replacement programs to save water. This paper seeks to illuminate what an irrigation audit can provide and present sound rationale for investing in an irrigation auditing program. Creating more informed end users and painting a more complete picture of the positive impacts of irrigation auditing will result in greater investment in the process. Experience both in the field and with clients will be presented to create the business case for irrigation auditing. Audit information from institutional green spaces will be included to show the water savings available as recommendations are implemented. For anyone living where potable water is still the prevalent source for irrigation, being able to keep more water in the pipes is a particularly powerful tool.*

Keywords: Irrigation auditing, irrigation efficiency, sustainability

<u>Introduction</u>

Irrigation Auditing is a powerful tool that when utilized correctly can lead to dramatic water conservation results through improvements in the efficiency of irrigation systems. Achieving this goal will occur as awareness increases around irrigation auditing and what can be accomplished.

In our short time together we are going to look at -

1. WHAT information is obtainable through irrigation auditing and how that data can help with irrigation responsibilities;

2. WHY implement an irrigation auditing program. Determining return on investment;

3. WHO are the end users; some specific findings and impacts.

You may be wondering about the other two “W’s” from the list; the when and the where. These are implied in all you will hear today. If it isn’t happening already, make it happen now; in your sports fields, parks and as far as you can reach.

1. WHAT information is obtainable through irrigation auditing and how that data can help with irrigation responsibilities?

Those interested in this topic will be irrigation auditors or end users or both. You will likely have experienced the disconnect that can happen at the very beginning of the irrigation auditing process where what the audit can provide and what the client wants to see are not aligned. Both parties end up unhappy and irrigation auditing loses credibility.

Ever done the employment evaluations where you complete a questionnaire about yourself and then your supervisor completes the same one? Then you compare and look at the differences. Seems pretty straightforward; both answering the same questions. Then why the different responses? We see things differently and certainly have differing motivations.

Determine specifically what type of information the client is looking for and work with them to understand that investing in the audit is step 1 of a two step process.
What is the second step? Investing in the implementation of recommendations.

An irrigation audit DOES PROVIDE VALUABLE INFORMATION including:

- Site specific precipitation rates
- Site specific distribution uniformity (often referred to as efficiency)
- Irrigation equipment deficiencies and/or safety concerns
- Irrigation design and/or installation deficiencies
- Insight into the volume of water being wasted on the site
- Observations with respect to the health of plant material
- Informed recommendations to improve the system performance

An irrigation audit DOES NOT EQUAL WATER SAVINGS.
Step Two, the implementation phase, is where the quantifiable impacts will be felt.

When a Certified Landscape Irrigation Auditor steps onto a site, to bring the maximum value to the client, they should bring with them a background in irrigation and making good irrigation water use decisions. She or he will have a broad base of irrigation experience and years of industry involvement to assist in providing valuable insights. A strong auditor will quickly identify areas of concern and before even setting out the catch cans, they begin imparting valuable water saving, plant improving knowledge to their client.

As for creating the report, the client will often want the list of recommendations for changes prioritized. The more we as auditors simplify the steps to success, the better the chances that some or all of the changes will occur. Too much information is as detrimental as not enough and if the client feels overwhelmed they are not inspired to action. There are too many audit report binders sitting on shelves collecting dust.

Irrigation System Efficiency

Before moving on and because it comes up frequently in irrigation auditing, I would like to address irrigation system efficiency. The word efficiency is too often used interchangeably with uniformity when talking about irrigation system performance. It is a misconception that a system found to have a Distribution Uniformity of 70% is a system that will operate at 70% efficiency. Efficiency is bigger than the DU alone and how the system is scheduled and maintained moving forward must be considered.

> *Efficient system performance means that water is applied as uniformly as possible. It is the result of appropriate design, installation, operation and maintenance of the system.* [1]
>
> Irrigation Association Golf Irrigation Auditor manual; 2006

2. WHY implement an irrigation auditing program? Determining return on investment.

Finding the motivation to conduct audits and encourage change is not difficult if you have an environmental consciousness. Since I took the course and wrote the exam five years ago I have been espousing the *do the right thing philosophy*, as I'm sure have many of you. The reality is that argument doesn't always create the necessary motivation. However there are now many more reasons to invest in an Irrigation Auditing Program from financial to legal to accountability.

A) Landscape irrigation improvements make the same investment sense as replacing toilets

Many of you will have had discussions with potential clients about the merits of what irrigation auditors do and in particular, how our audits compare to the indoor water use audits that are so prevalent. When presenting to commercial clients we have often heard "doesn't it make more sense to replace all the toilets to save water?". This is a valid question as water conservation is a business and those of us in it are competing for funds. For many, creating and implementing an outdoor based water conservation program can be daunting while replacing an old toilet seems rather simple. The process of finding appropriate irrigation industry partners for the program can be intimidating as well. Having said all that, a strong return on investment is possible as demonstrated by the two options in the following scenario:

Option A: Replace old toilets

Government building with 100 employees and 10 older toilets.

Replace the 3.5 gallon flush toilets with 1.6 gallon flush toilets at a cost of $6000 for new toilets, installation, removal and disposal of old toilets.

Annual water savings: 337,500 gallons [2]

Investment per gallon saved: 6,000 / 337,500 = .02 /gallon

Option B: Improve the irrigation system of the soccer field adjacent to the building.
Soccer field on a 2 acres site with an irrigation system operating at 40% uniformity.
Improve the irrigation system to 75% at a cost of $35,000 for audit, labour and materials.
Annual water savings: 1,750,000 gallons
Investment per gallon saved: 35,000 / 1,750,000 = .02 / gallon

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B) Water pricing structures are changing…
In our part of the world there is the appearance of an endless supply of freshwater that has led to low water prices and low levels of concern for water waste. This has paved the way for subpar irrigation systems and subpar performance. So long as the grass and plants look green, don't worry about the water running down the road into the storm sewers. The following excerpt from a paper by Steven Renzetti puts the situation in perspective and shows the less than progressive situation we are in.

Different water pricing structures
There is considerable diversity in the forms of water pricing that exist across Canada. A 2004 report from Environment Canada sketched the national pattern as follows:

37% of Canadian households pay a **flat rate** for water, irrespective of the quantity they use.
62% have some kind of **volumetric pricing**, based on the volume of water consumed.

Volumetric pricing breaks down into three general categories:
o 39% pay for the quantity of water they consume at a **constant** unit price.
o 13% pay for water used at a rate that **decreases** as the volume they consume rises.
o 10% pay water prices that **increase** with the amount consumed, thus promoting conservation. [3]

Municipalities are formulating and implementing strategies that are more financially sound including metering. The caveat to metering is that without correct pricing strategies it may not have a lasting effect. However for those of us in the irrigation auditing arena, meters are a welcome addition to any site. In the best case scenario, the pricing is high enough to be a key factor in the return on investment for auditing and making changes. But even where pricing does not have a significant impact, knowing what is being used on a site allows us to benchmark and document results.

C) Government policies and laws being introduced for better use of water resources
In the United States, the Energy and Water Integration Act 2011 is a very recent example of this type of legislation. This bill calls for investigations into the many ways that water and energy are connected and demonstrates how we must move to a better position with respect to the efficiency of water use. It draws attention to the water-energy nexus and the importance of

using less water not only because of the long standing argument of conservation but also because it is an integral part of energy production as well as every aspect of the economy. At last check the bill had been placed on the Senate Legislative Calendar under General Orders. Calendar No. 102 [4].

In our backyard, the provincial government in British Columbia has introduced their Water Smart Plan. Like many government initiatives it is slow in coming with a seemingly unending stream of facilitated input sessions from community stakeholders. There are many vague statements regarding water conservation concepts but there is one mandate in particular within that plan stands to have a significant impact.

Fifty percent of new municipal water needs will be acquired through conservation by 2020. [5]

That is a powerful statement. Consider a small city like Kelowna at 119,000 people.
The population is projected to grow at an annual rate of 1.88% until 2015 and then 1.58% until 2020 [6], adding 22,666 people with increased residential, business and agricultural water demands. The city currently uses approximately 15.8 million cubic meters for its 119,000 residents which is 132m3 per person. Looking at projected population growth and per capita consumption for Kelowna, by 2020 the water requirement for new municipal needs would be 2.99 million cubic meters. Half that volume, 1.5M cubic meters, must be acquired through conservation from 2020 onwards.

The City of Vancouver, also facing the same conservation challenge and estimated to be using 542 liters per capita per day [7] (198m3 per resident annually). The city is projected to grow by 71,800 people by 2021.[8] That equates to requiring an additional 14M cubic meters to keep pace with anticipated growth; half of which must be "found water".

D) Energy saving initiatives have become standard practice and saving water saves power

It is rare these days to find an organization of any magnitude that does not have some form of an Energy Management Plan. Potable water is still the most prevalent irrigation water source and potable water systems consume a lot of energy, from the pumping system to the treatment facility to the stormwater/sewer system. As a result there is significant support for organizations with large power bills to hire Energy Efficiency Managers -

BC Hydro's Community Energy Manager Program will provide $50,000 of the $100,000 cost of creating the full-time position. After the first two years, the city will explore other financing options to keep the energy manager for an additional three years. [9]

Reducing potable water used for irrigation purposes will result in energy savings.

Continuing with the soccer field example, what might be the related energy savings?
The example shows a saving 2.68M (US) gallons of water. That equates to 10,145 cubic meters; our billable unit in Canada.

For the delivery of these 10,145 cubic meters, we will assume there is a pump station involved as well as a reservoir and/or a booster station. Also consider the energy for treatment of the water by UV or whichever method is employed.

Estimated consumption	1.75kWh/m3.
	10,145m3 x 1.75kWh = 17,754 kilowatt hours
	17,754kWh x $.0864kWh[10] = **$1,534 annual savings**

Notes: Energy costs vary dramatically depending on the sources of that energy. Hydroelectric being the predominant source in British Columbia, costs on both sides of the border for this type of energy were looked at and found to be similar. A US source for the kWh cost was used for the calculations.
1 cubic meter = approximately 35 cubic feet or 265 US gallons

E) It costs less to save water than to find, treat and deliver more water.

Large municipalities across North America have recognized that keeping water in the pipes for future use makes good business sense. In fact, water efficiency costs between 20% and 50% less than traditional infrastructure expansion. [11]
Some examples of this:

- $11 million dollar water efficiency program 42% more cost effective than new infrastructure (City of Guelph, 118,000 people)
- $10.1 million capital budget for a six year program versus new infrastructure costs of $40 million (York Region)
- Seattle's Saving Water Partnership achieves long term water saving of 10 million gallons (38 million litres) and defers **indefinitely** $70 million new infrastructure. Program cost over 10 years; 3.8 million per year.[11]

The Federation of Canadian Municipalities (FCM) has calculated that an investment of at least $31 billion is needed to maintain and repair water infrastructure across Canada [12]. These types of calculations are done assuming that the demand on those water systems will continue at a particular rate based on historical data. With each successful irrigation auditing experience, we are reducing that overall cost and prolonging the life of the water systems, many of which are nearing their anticipated life expectancy.

F) Green marketing

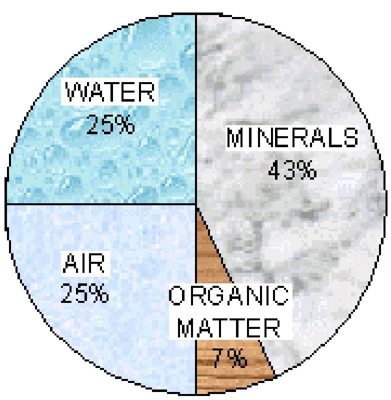
Worth mentioning but difficult to quantify is the marketability of making inroads in outdoor water conservation. Along with energy saving initiatives, many organizations will have ongoing sustainability projects like high profile Water Smart programs. Where large green spaces are managed, an irrigation audit process is ideally suited and highly marketable.

3. WHO are the end users; some specific findings and impacts.

Once we have connected with a client and have determined that the information we can provide will address their needs, we are presented with opportunities to evaluate various green spaces. Public organizations often charged with maintaining large amounts of green space have afforded the most volume and variety of opportunity in our area. Where central control systems are involved but not maximized, irrigation auditing and related processes are the best option to realize the system potential. Private companies, also managing significant plant material will commit to the process recognizing the opportunity to not only improve plant health but to incorporate the process into the marketing of their "green" initiatives.

The following are highlights from three sites evaluated and audited over the past year. Each site presented some distinct issues but in each case the condition of the growing medium (soil) either mitigated system concerns or exacerbated them. Too often the plant material and the irrigation manager are at a disadvantage regardless of the uniformity of the irrigation system or how well it is managed. It is the foundation for the health of these sites and when it is healthy and of sufficient depth it is powerful in its ability to offset system inefficiencies.

Healthy Soil is made up of 4 components necessary for plant growth:
43% Minerals
7% Organic Matter
25% Air
25% Water



Source: Chatham-Kent Organic Epicentre, http://ckorganic.ca/soilhealth.html

Site One

This is a high profile site with that was constructed approximately 20 years ago. Some system renovations have occurred as necessary however no improvement strategy existed.

Client concerns:

- excessive water consumption
- mainline breaks becoming more frequent
- visible runoff resulting in standing water

Client goals:

- reduce water consumption
- investigate mainline breaks
- improve site aesthetics / public perception.

For this site the client also requested a GPS as-built to assist with site management including scheduling.

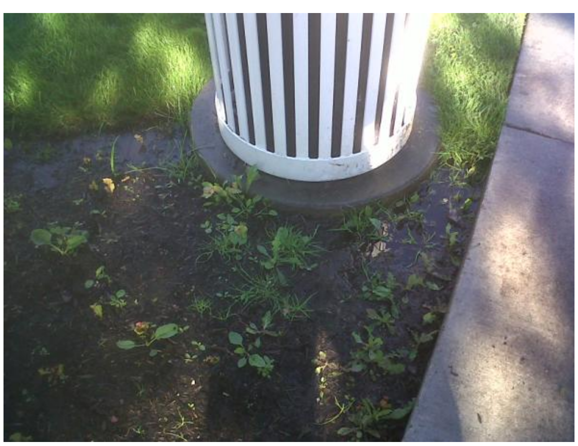
Audit process revealed the following:

- Site DU of 59%
- Overwatering in combination with no check valves leading to runoff
- Original irrigation design failed to incorporate topographical challenges and calculations for maintaining safe velocities were incorrect
- Scheduling not based on site information and not seasonally adjusted
- Healthy soil in some areas compensating for low uniformity

Improvements Overview:

Projected annual savings with improvements: Over 500,000 gallons

Within the first week, the findings of mixed product and product without check valves were addressed immediately, reducing runoff and improving appearance. Spring will begin improvements to scheduling to further reduce water use and assist in reducing velocities which are likely contributing to the mainline breaks. Total system renovation was not a possibility but the smaller changes will have a significant impact.



Standing water as a result of overwatering and low head drainage.

Site Two (Sections A and B)

This site has been touted as the most photographed place in its city due to its natural features and convenient location making it another high profile location. It also presented a unique opportunity in that it was likely going to be renovated in two sections providing a comparison between the existing system and a new system.

Client concerns:

- excessive water consumption
- significant overspray onto hardscapes
- visible signs of incorrect system function (ie: runoff and mushy areas)
- past irrigation installation experiences less than favourable

Client goals:

- reduce water consumption
- reduce or eliminate water onto hardscapes
- improve site aesthetics / public perception
- have a project consultant manage an installation and assess the outcome

For this site the client also requested a GPS as-built to assist with site management including scheduling.

Audit process revealed the following:

Section A -

- **Site DU of 39%**
- Stretched spacing on hillside resulted in overwatering to compensate for dry areas with excessive saturation and runoff for other areas
- Scheduling not based on site information and not seasonally adjusted
- Healthy soil in some areas compensating for low uniformity

Improvements Overview:

Projected annual savings with improvements: 1,200,000 gallons

The size of the site and extent of the spacing challenges indicate that a system renovation is required and feasible.

Note that the second section was renovated that same season following a researched and peer reviewed design, new irrigation technology and hands on project management. Due to a product delay, correct nozzles were not installed in approximately 25% of the heads at the time of the second audit which had to be completed by a specific deadline. However the findings are still impressive and had the desired result of gaining support to continue renovating additional sites.

Section B –

- **Site DU of 73.5%**

Site Three

This site was at a state-of-the-art school where the building was created to achieve high environmental standards and yet the surrounding fields were not performing well.

Client concerns:

- excessive water consumption
- field condition substandard; patches of brown, sunken areas, hardpan sections and complaints as to the playability of the fields
- irrigation equipment difficult to locate and service

Client goals:

- reduce water consumption
- determine the cause(s) of the concerns
- improve site aesthetics / public perception
- explore how to avoid these failures in future

For this site the client also requested a GPS as-built to assist with site management including scheduling.

Audit process revealed the following:

- Site DU of 47%
- Point of Connection pressure different from what the client was told would be there
- Stretched spacing now exacerbated by the pressure drop
- Scheduling not based on site information and not seasonally adjusted
- Unhealthy soil, tested and found to be very high in potassium and very low (unreadable amount) in nitrogen

Improvements Overview:

Projected annual savings with improvements: 1,800,000 gallons

The key factor for improving system performance on this site is to increase site pressure. Following the audit the client began discussions with the water purveyor who had assured the installer a certain pressure and size of POC but had subsequently altered those parameters. If the purveyor does not cooperate then the next choice would be a booster pump installation which is a significant investment.

A soil amendment program has also been initiated which includes aeration and the addition of nitrogen. Improvements in the appearance of the plant material were noted but it is an involved process as nitrogen must be closely managed and runoff remains a concern on this site.

Interesting note:

An audit conducted on another school with a much older system (still primarily hydraulic) found the DU to be 67.5%. This generated discussion around assessing contractor qualifications for new installation and overall management of the installation process for new locations.

Conclusion

After embarking on an irrigation auditing program, an organization will often diversify its outdoor water conservation efforts. The audit process is initiated with the recognition of system concerns such as excessive water use and system failures. Frequently during the investigation, other unexpected issues may come to light that prompt expanded activities. Questions are asked such as "How was the installation of this irrigation system managed?" and "What is the knowledge base of the irrigation personnel who maintain the site?".

It comes back to the concept of system efficiency. While conducting irrigation audits and implementing recommendations will enhance the performance of a system, there are other efforts required to achieve system efficiency. Working with clients to improve the installation process and supporting their efforts to create knowledgeable irrigation teams are just two of the many activities that irrigation auditors can also assist with. Experience has shown that expanding our roles as auditors is critical in keeping more water in the pipes.

Acknowledgements:

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Stewardship Coefficient: Measuring the Impact of Best Practices

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Abstract

With an improved understanding of sprinkler system performance come better decisions regarding optimum parameters such as sprinkler selection, layout, operation and adjustment. Overlapping sprinklers, extended runtimes and unmatched precipitation rates severely increase the amount of water used to irrigate a turf area. By calculating the amount of overwatering done and comparing it to the amount of under-watering, a more complete picture of the sprinkler system performance can be achieved. Catch can data is analyzed and compared to theoretical results, providing a solid basis for using the stewardship coefficient. This added perspective enriches the audit outcome and computes the true impact of current best practices without requiring additional data. By calculating the true cost of best practices, a more complete picture of a sprinkler system performance can be achieved. Only by highlighting areas in need of improvement can changes be made that enable comprehensive landscape stewardship.

Keywords

conformal irrigation, intelligent precipitation, audit, uniformity, catch can, best practices, stewardship coefficient,

Introduction

An ever increasing focus on outdoor water conservation requires continuously improving management of limited water resources. Having a better understanding of how a sprinkler system is performing empowers the turf manager to make better decisions regarding optimum parameters such as sprinkler selection, layout, operation and adjustment. This process of improvement typically begins with a thorough audit of the site to measure the sprinkler systems ability to deliver the correct amount of water in the right places within the bounds of the turf area. This whitepaper outlines an additional perspective in order to enrich the audit outcome as well as computing the true impact of current best practices. No additional audit data is collected, rather two additional performance parameters are defined and demonstrated that can better illustrate the tradeoffs occurring in each hydrozone at a particular site.

Turf health and quality are very important objectives for all landscaped areas. Aside from the environmental benefits (Zoldoske, 2008), the visual appeal of a healthy, lush lawn is the primary reason turf is installed in the vast majority of landscapes. A lush, green, healthy, properly maintained lawn resonates with a large majority of turf owners. At issue is the amount of water required to properly care for a lawn. Currently, irrigation audits are performed to determine both the amount and distribution of water applied to the turf area. Calculating uniformity from catch can data commonly gives insight into the areas of the lawn that are receiving the least amount of water. This is an aid for evaluating the risk to turf health and quality since the driest areas of the lawn are more prone to disease, wilt and browning.

Overcoming these dry areas usually requires running the zone longer in order to apply more water to the driest fraction. Naturally, when runtime is extended, the remaining majority of the turf area is overwatered. Overwatering causes its own set of turf health issues in addition to the obvious impact on the water budget. Thus, in an effort to reduce the effects of under-watering in the driest 25% of the turf area, overwatering the other 75% is a commonly accepted practice. This conflict between health and conservation naturally raises these questions:

> Could an auditor use additional information to better understand the health/conservation tradeoff for all hydrozones?
>
> Could improved visibility of the overwatered areas highlight design issues that should be addressed to maximize water savings?

By calculating the amount of overwatering done and comparing it to the amount of under-watering being done, a more balanced picture of the sprinkler system performance can be achieved.

Method

The Irrigation Association describes Distribution Uniformity (DU) as the evenness with which a sprinkler system deposits water over a hydrozone (IA, 2007). It is a ratio of the average volume of water deposited over the driest areas to the average volume of water over the entire hydrozone. By using catch can data from the driest 25% of the hydrozone, the Lower Quartile Distribution Uniformity (DUlq) can be calculated. Since the lower quartile represent the driest areas of the hydrozone, the wettest areas can be similarly represented by the highest 25% of the same catch can data. Thus the calculation for the Higher Quartile Distribution Uniformity (DUhq) is performed in a similar manner and is defined as:

$$DUhq = \frac{Average\ Catch\ Volume\ in\ Highest\ Quarter}{Average\ Catch\ Volume\ in\ Zone}$$

Notice that the auditor does not require additional catch can data from the site. The calculation of DUhq is derived from the same method as for DUlq. After DUhq has been calculated, the amount of overwatering in the wettest quarter of the turf area is readily apparent since this value will never be less than 1. Now with both DUlq and DUhq calculated, a more balanced picture of overall zone performance can be seen.

The most straightforward method to compare these two uniformity values is to form a ratio. This provides a general indication of the tradeoff between the wettest and driest areas within the zone with very little effort. Because turf health and water use are both strongly related to under-watering and overwatering respectively, this ratio is also an overall indicator of the lawn health to water savings potential for the zone. This ratio, called the stewardship coefficient (Cs), calculates the ratio of under-watering to overwatering in the zone. This coefficient is defined as:

$$Cs = \frac{DUlq}{DUhq}$$

As Cs increases, approaching the limiting value of one, the zone is becoming more balanced between lawn health and water conservation. A zone with Cs less than one indicates a stewardship imbalance, meaning the zone is either severely under-watered, over-watered or both. Now armed with a more complete toolkit to evaluate the overall balance between health and water use, the effect of two well known irrigation best practices can be evaluated.

Today, the majority of gear drive rotors have single leg or stream DUs ranging from 0.50 to 0.80 as reported by manufacturers. When the DU of an individual sprinkler head is less than 1.0, dry fractions in the zone will automatically occur. The common remedy is extending zone run time to sufficiently water the driest fraction. Additional runtime is often calculated from a Run Time Multiplier (RTM). The multiplier is calculated based on the DU values obtained from the catch can data for the zone. The lowest 50% or 25% of the catch can data are commonly used and are referred to as the lower half (lh) and lower quartile (lq) respectively. These represent the driest areas in the hydrozone. A value proportional to the reciprocal of the selected DU value is used to multiply the current zone run time in an effort to provide additional water to the driest fraction in the zone. For example, the RTM when using DUlq is given as:

$$\mathrm{RTM} = \frac{1}{0.4+(0.006 \times DUlq)}$$

According to the Golf Irrigation Auditor handbook, most properly designed irrigation systems have average DUlq's between 0.55 and 0.75. This means the run time multiplier will range between 1.38 and 1.18. A field report by Mecham, et al. (2004) in which 6800 audits revealed an average measured DUlq of 0.58 or less. Thus an RTM of 1.35 accurately represents what is in use in the field today.

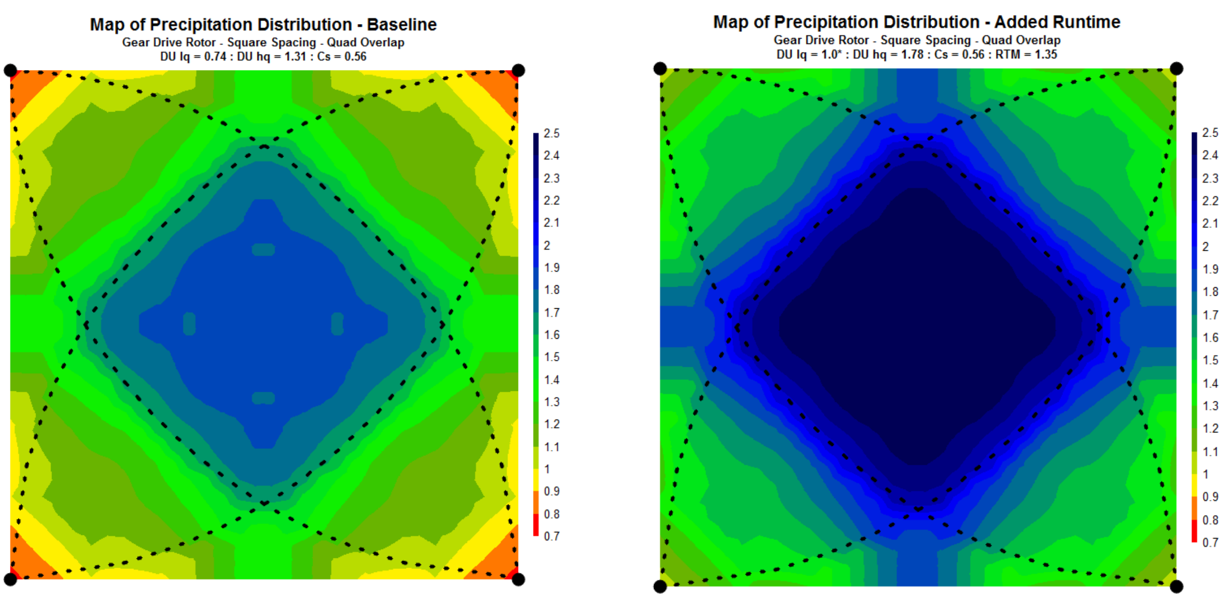
The other best practice is the head to head (H2H) paradigm. This requires that the spacing between sprinkler heads does not exceed the rated throw of the head for a given pressure. This insures that the area close in to the head is sufficiently watered by adjacent heads. This requirement also insures that the individual spray patterns provide overlapping coverage within the zone. The amount of overlap varies from layout to layout but areas with 3X and 4X overlap are common.

In order to calculate the true cost of these best practices, a virtual turf test area was created that will predict the water use for a given sprinkler layout. For this study, the test area is a 32 ft square turf area with one gear driven rotor in each corner each rotating thru 90° of arc resulting in a square spacing and quadruple overlap. The sprinkler profile data was obtained from the Center for Irrigation Technology (CIT, Fresno, CA) in the form of .prf files. These single leg profile data records were input into Catch3D, a personal computer program from Utah State University designed to visualize sprinkler distribution.

A full 360° pattern was generated for a given rotor. This pattern was sectioned into four equal quadrants and overlaid onto a 32x32 cell grid. The resulting, high density, square grid contains 1,024 cells with the cumulative deposition from each rotor spraying through 90°. The high density grid can be used to plot a high resolution map of the precipitation distribution, or densigram, as well as perform all of the calculations outlined in this paper. The plotting was performed using a commercial plotting package.

Results

Figures 1 and 2 are densigrams for the baseline and added runtime cases, respectively. The rotor locations and radius witness lines are included for clarity. The color gradient scale shows variations in application from 70% to 250% of the required amount over the area.



Figures 1 (l) and 2 (r). Densigrams for Baseline and RTM added cases.

When viewed in high resolution, the effects of head to head overlap are immediately clear. The areas with 3X and 4X overlap are clearly evident. Approximately 90% of the test area receives more water than the required amount. The baseline application ranges from 76% to 180% of the required amount. The lowest quartile is dry enough to warrant the use of a Run Time Multiplier (RTM) to ensure adequate watering of the driest areas. The effect of adding an RTM is evident in Figure 2. The variation is from 104% to 247% of the required amount. This is a significant increase in the volume of water used to irrigate this area. Table 1 shows the calculated results.

Condition	DU lq	DU hq	Cs	DU lh	RTM lq	RTM lh
Baseline	0.74	1.31	0.56	0.81	1.35	1.23
RTM lq	1.00	1.78	0.56	1.10	1.00	0.91
SmartRotor	0.98	1.01	0.97	-	-	-

Table 1 – Virtual Test Area Results

A more detailed way to examine the data is to look at the dryness distribution in the hydrozone. Solomon, et. al. refer to this type of plot as a Destination Diagram (Solomon, 2007). By plotting the relative amount of water deposited into each square foot of the virtual test area from least to greatest, a dryness distribution chart can be produced, as seen in Figure 3. For a given X and Y on the appropriate 'dryness' line, the plot shows that X% of the zone received less than the application amount Y.

Once the data are presented in this format, several things become clear. In the pursuit of watering the driest 25% of turf areas, a significant amount of overwatering is occurring in the remaining 75% of the area. To determine the amount of overwatering as a result of the added runtime, one can simply calculate the area between the baseline curve (blue) and the RTM added curve (red) in Figure 3. This area difference represents a 29% increase in the total water applied from the baseline.

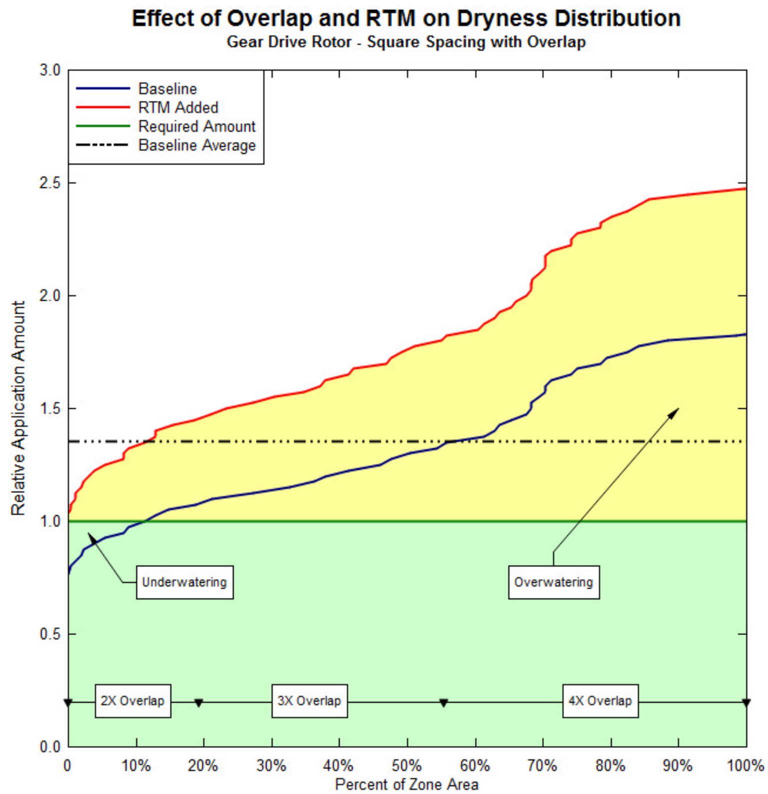


Figure 3. Dryness Distribution Curve.

To determine the amount of excess water arising from the head to head (H2H) paradigm, the area under the required amount line (green) is subtracted from the area under the baseline curve. This represents a 40% increase from the required amount. When the H2H paradigm is referenced to the all too common RTM Added case, the increase is almost double or 80% from the required amount. This is represented by the yellow highlighted area in Figure 3. Undoubtedly, there are measurable water and energy costs associated with the practice of using a Run Time Multiplier and the best practice of head to head overlap. This whitepaper has demonstrated that the overwatering associated with the using an RTM can be as high as 29% while the head to head paradigm can result in overwatering as high as 80%.

While simply relaxing the H2H requirement could easily reduce water use by 50%, today's gear drive rotor sprinklers are incapable of properly watering without the overlap condition. One solution to this predicament is conformal irrigation, which relaxes the head to head requirement, allowing the stewardship coefficient to approach unity. The result would be a significantly more uniform application, closely approximating natural rain. With conformal irrigation, water is applied in concentric bands from the head out to the outermost perimeter. This "banding" can be seen in Figure 4.

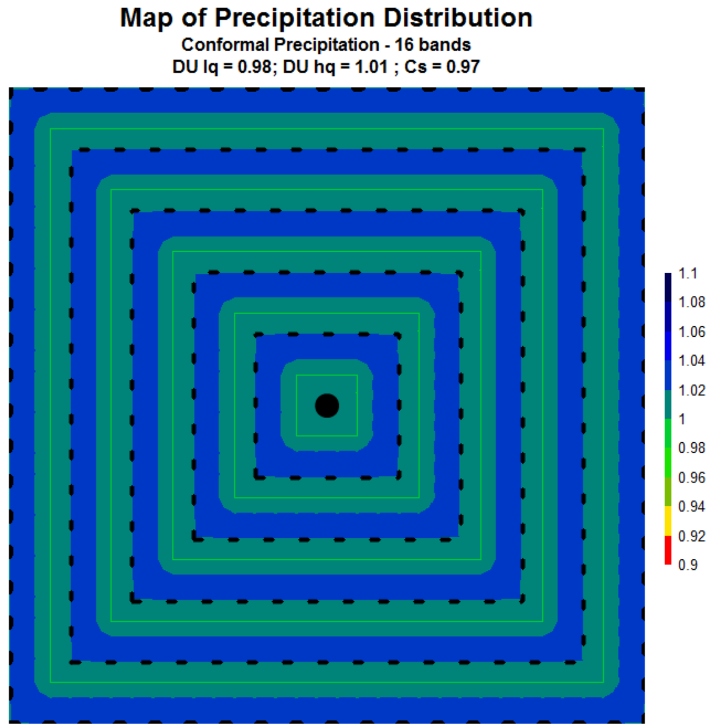


Figure 4 Densigram of Banded Watering

In order to see the variation between bands, the scale has been reduced to ± 10% of the required amount. The accumulated variation within the zone at the end of the watering cycle ranges from 100% to 103% of the required amount. The result is a stewardship coefficient of 0.97, indicating a properly balanced zone. By applying water in bands that are concentric with the outer perimeter, the gross overlap found with traditional H2H layouts can be eliminated. When this method is used, much higher DUlq and lower DUhq values are predicted. This results in a stewardship coefficient that is very close to unity for maximum water conservation and optimum turf health.

Conclusions

While the conformal paradigm can easily be visualized, it has not been realized until recently. New advances in intelligent precipitation technology (IPT) now allow water to be applied in concentric bands from a single sprinkler head. The benefits of this new technology are significant water savings while eliminating dry spots and overspray. Based on the dryness distribution plot in Figure 3, an intelligent system can reduce water use by 40% to 50% in most cases. Combined with zero overspray, water savings approaching 70% may be achieved while reducing structure damage and providing real time water use data.

Only by improving the tools used to evaluate turf watering can progress be made toward the common industry goal of reducing outdoor water use. Both the Higher Quartile Distribution Uniformity (DUhq) and the Stewardship Coefficient (Cs) are effective metrics for characterizing a hydrozone. Only by highlighting areas in need of improvement can changes be made that can enable the landscape irrigation industry to achieve these goals.

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Use of Remote Sensing to Identify Urban Landscape Water Use in Sacramento, California

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Abstract

The traditional approach to estimating evapotranspiration (ET) originating from applied irrigation water is to apply crop coefficients (Kc) to land use types and then multiply by reference ET (ETo). However, the Kc X ETo approach can be subject to significant uncertainty due various factors including land use and water management. Remote sensing, using satellite imagery and ancillary weather data combined with proven energy balance algorithms offers a new tool for estimating plant ET. Evapotranspiration estimated from remote sensing is combined with GIS coverage of land use, to determine plant factors (Kcs). Factors influencing ET are inherently accounted for in this approach. Water conservation professionals can use the information to help irrigation managers better match plant water needs with available supplies and to target irrigation system improvements. In addition, spatial and temporal coverage can be used for viewing on Google Earth.

Keywords. remote sensing, evapotranspiration, irrigation, urban landsacpe

Introduction

Urban landscape water use in the Sacramento area is thought account for over 50% of the total water consumption in the region. Recent state legislation and renewed awareness of water conservation have highlighted the need to reduce the amount of water used for landscape irrigation.

The traditional approach to estimating evapotranspiration (ET) begins by surveying land use to define the areas occupied by different types of crops or vegetation over time. Water use for each crop and land use type is then computed by multiplying reference ET (computed from weather data) by crop- and land use-specific coefficients (Kc values). These Kc values are often developed through research at small-scale controlled plots. Land use surveys are extremely labor intensive, time consuming and costly, and the ET estimates derived from them are subject to significant uncertainty due to difficulties involved with accounting for the effects of irrigation management practices, soil and water salinity, water supply adequacy, presence of shallow groundwater, and other spatially variable influences on ET. There is sufficient knowledge available in the scientific community regarding coefficients (Kc) for crops grown under pristine conditions; however, Kc values for non-pristine agricultural conditions and for non-agricultural water depletion processes are not adequately defined at this time.

Remote sensing offers a new means of estimating ET, using digital satellite imagery combined with tested processing algorithms. WaterWatch of The Netherlands (www.waterwatch.nl) has developed the Surface Energy Balance Algorithm for Land (SEBAL) to calculate the potential and actual ET of each pixel in a satellite image. The ET is calculated based on radiances recorded by digital images along with some ground based ancillary weather data and is independent of crop and land use type. SEBAL has been applied in numerous countries around the world, including the U.S. and has been independently validated for a variety of land cover types, climatic conditions and spatial scales (Bastiaanssen, et. al., 2005). In California, SEBAL (www.sebal.us) has been applied to improve ET estimates for several agricultural areas (Wijsman, 2005); however, use in an urban area has not been examined.

Combining GIS coverage (e.g. landuse, water and irrigation districts and agencies boundaries) with ET estimates from SEBAL allows water managers to view and understand the spatial and temporal distributions of actual ET and Kcs values to support water management decisions. Also, exporting data to a viewer such as Google Earth allows for better visualization. Additionally, data can be exported to spreadsheets for combination with metered water use for analysis.

Data and Methods

Data required for this project include detailed land use information in a GIS format, monthly water delivery data for various connection types, meteorological data from California Irrigation Management Information System (CIMIS, www.cimis.water.ca.gov) and satellite imagery in visible, near-infrared and thermal spectrum from LANDSAT (http://glovis.usgs.gov). Satellite images were processed, using SEBAL, to calculate the residual energy of incoming solar radiation after accounting for atmospheric absorption and transference, outgoing and reflected radiation, heat to the soil and heat to the air. The LANDSAT imagery utilized has a 30m resolution in visible and near-infrared bands and 120m (resampled to 60m) for the thermal band. The major SEBAL model outputs include ET actual, (ETa), crop coefficients (Kc & Ks), and normalized difference vegetation index (NDVI) at 30m resolution. Reference ET was also estimated within SEBAL using spatially distributed weather data from CIMIS.

LANDSAT Images and SEBAL

Eight LANDSAT satellite images from 2007 covering Sacramento County (Row 33.5 and Path 44, shifted scene) were utilized (Table 1). Each image was processed using SEBAL to compute actual ET for each pixel in each image set. The individual image results were used to develop period estimates of ETa that were summed to obtain a seasonal total ETa covering the period March 16 through September 30, 2007.

Table 1. Periods represented by Each LANDSAT image date.

Image Date	Period Represented	Total No. of Days
March 31st , 2007	March 16th – March 31st	16
April 16th , 2007	April 1st – April 30th	30
May 10th , 2007	May 1st – May 31st	31
June 19th , 2007	June 1st – June 30th	30
July 5th , 2007	July 1st – July 15th	15
July 21st , 2007	July 16th – July 31st	16
August 22nd , 2007	August 1st – August 31st	31
September 7th , 2007	September 1st – September 30th	30

Land use GIS coverage for the greater Sacramento region was combined with the ETa determined with SEBAL to obtain period and seasonal ETa values for each land use type. Additional outputs included, Kc, Ks, and NDVI, and biomass production for each pixel in the study area for each image date. An ESRI shapefile containing points located at the center of each satellite pixel within the study area was generated for extracting ET and other spatial data. The extracted spatial data was exported and stored in a database (Table 2).

Table 2. Format of database with pixel-Scale SEBAL daily and periodic results.

Parameter or Data Field	Units	Data Type
Pixel x-coordinate	m	float
Pixel y-coordinate	m	float
Field or Polygon ID	-	integer
Water Purveyor	-	text
Land Use Type	-	text
Image Date	-	date
Period Represented	-	text
Daily ETa, Kc, Ks & NDVI	mm	float
Period ETa Kc, Ks & NDVI	mm	float

Land Use Shape files

Land use shape files were collected from water suppliers and other governmental agencies with land use planning responsibilities. Specific land use types were available for golf courses, cemeteries, regional parks, agricultural areas, and political boundaries. For some entities political boundaries include residential sub-divisions or neighborhoods, industrial zones etc. National Agricultural Statistics Service (NASS) Landuse grid for 2007 was used to delineate agricultural land use type. All the land use data were in an ESRI polygon shapefile format except the NASS data which were in a grid format with a spatial resolution of 30m x 30m. The NASS data utilized in the present study was developed by US Department of Agriculture using Landsat images for the growing season of 2007.

CIMIS Data

Measurements of incoming solar radiation, air temperature, relative humidity, and wind speed were used in the SEBAL analysis. These meteorological data were analyzed at instantaneous (time of the satellite overpass), daily (average for the image date), and periodic (average for the period represented by an individual image date) time steps. These parameters were obtained from twenty-five CIMIS stations within or surrounding the Landsat scene (DWR, 2011).

Weather data from each station were reviewed and corrected when necessary, following accepted, procedures (Allen, et al 1998 and Allen et al., 2005). Weather observations from ground stations represent point measurements that may be representative of the surrounding area; however, in many cases, particularly for heterogeneous regions, the point data may not be suitable to represent weather conditions of the surrounding area. To overcome this limitation, spatially distributed weather grids were developed using MeteoLook (Voogt, M.P., 2006). This model interpolates point weather observations based on the knowledge of surface and terrain characteristics coupled with physically-based models. Processes that influence surface weather conditions such as elevation, surface roughness, albedo, incoming radiation, land wetness, and distance to water bodies are included in MeteoLook.

Reference ET (ETo) was estimated from spatially distributed weather data using the ASCE Standardized Penman–Monteith grass reference equation (Allen et al., 2005). The actual crop water use coefficients were then developed using the spatially distributed ETa and ETo data. For the ETa analysis, and for specifying water use budgets, the spatially distributed reference ET (ETo) data was used to develop crop water use coefficients. ETo for the analysis period, represented by the Fair Oaks CIMIS station, totaled 41.2 inches (Table 3). Rainfall for the same period totaled 2.72 inches.

Table 3. Rainfall and reference evapotranspiration form the Fair Oaks CIMIS station, Fair Oaks CA.

Period Represented	Rain	Reference ET (ETo)
	inches	
March 1-15*	0.04	1.54
March 16-31	0.53	2.13
April 1-30	1.73	4.88
May 1-31	0.39	6.99
June 1-30	0	7.71
July 1-15	0	3.9
July 16-31	0	3.79
August 1-31	0	7.14
September 1-30	0.07	4.66
Total	2.72	41.2

*Not used in the analysis or included in the totals.

Sample Output

Sample output was prepared for several different land use applications; residential neighborhoods, a golf course, and a park. Output includes figures that show the type of data available along with spatial and temporal out.

Google Earth Overlay

Images exported from the GIS can be imported as overlays in Google Earth (Figure 1). This output can be used to navigate an area to look for high water use area which is particularly important in areas without meters (Figure 2). A qualitative comparison between Figures 1 & 2 indicates that there is considerable more ET in Figure 2, a neighborhood without meters to residential connections. A noticeable difference in the two developments is the density of tree canopy.

EvapoTranspiration and Plant Factor (Crop) Coefficients

Temporal and spatial output of both ET and Kcs are available. Eight time periods (Table 1) of ETa were analyzed, with each image date representing between 15 and 31 days. The initial time period (March 16-31) represents leaf out for trees in the region whereas subsequent images are considered to be at full leaf out. ETa for the individual periods were added spatially to obtain a seasonal total representing a period of March 16 – September 30, 2007. The Kcs were estimated for the each of the respective image dates (Table 1).

The data presented in Figure 3 are the same that are shown in Figures 1 and 2 but are put on a scale of area. The metered neighborhood had a greater percent the total area with lower ETa than the neighborhood without meters. Also shown in Figure 3 is the distribution of seasonal ETa from a riparian forest located at the confluence of two drainages in the southern section of Sacramento County. The average ETa in the metered neighborhood is 25.3 inches and 39.3 inches in the unmetered neighborhood. ETa of the riparian forest is 43.2 inches. Data can also be plotted by period (Fig. 4). The utility of plotting data in this manner is that the ETa variability is evident and a user can compare the consumptive use against CIMIS.

Actual plant mix coefficients are the ratio of ETa to ETo, where ETo is estimated within SEBAL using spatially distributed CIMIS weather data. Figure 5 is Google Earth output of a public park. The top portion shows the land use in the park and the bottom has the Kcs values from the September 7, 2007 image date. In a small park such as this, the 30 m -120m resolution of the input data results in overlaps that combine mixed uses. For example, the tennis courts in the image show up as having Kc values around 0.6-0.8 but this is a result of the trees surrounding the tennis courts. The lower baseball field is large enough for several measurements but without viewing the outline of the pixels it is unknown if the measurement can be considered reliable because they may contain portions of the houses, the ball field or the road. Figure 6 presents Kcs distribution (for the area shown in Figure 4) for 9/7/07 plotted along with the range of values that the State published in their guidance documents (Costello, 2000). The minimum Kc value is 0.57 and the maximum is 1.3.

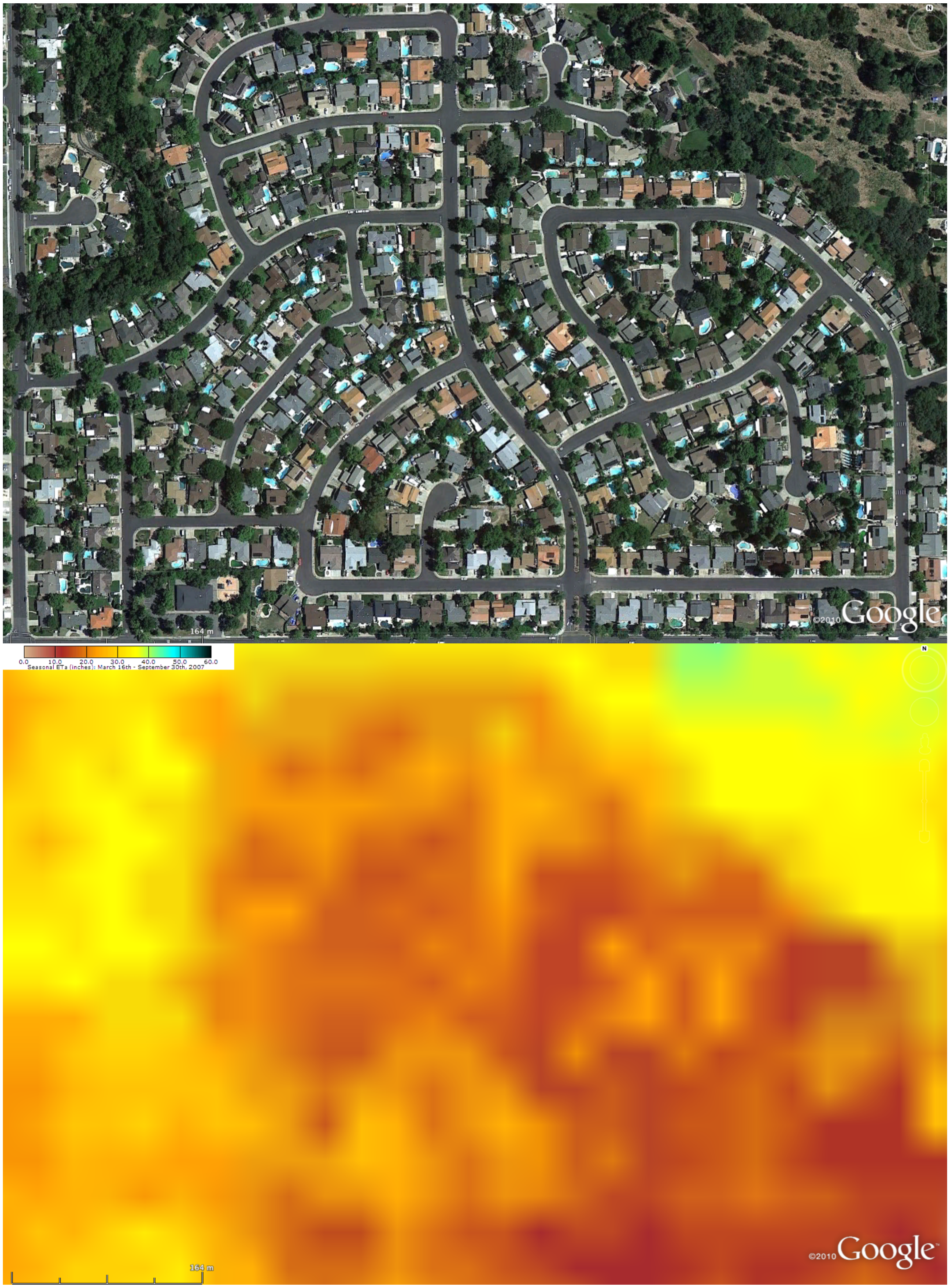

Figure 1. Google Earth with SEBAL based seasonal ETa from a metered residential neighborhood in the greater Sacramento region. Average ETa for the analysis period is 25.3 inches. The average age of homes in the area is about seventy years.

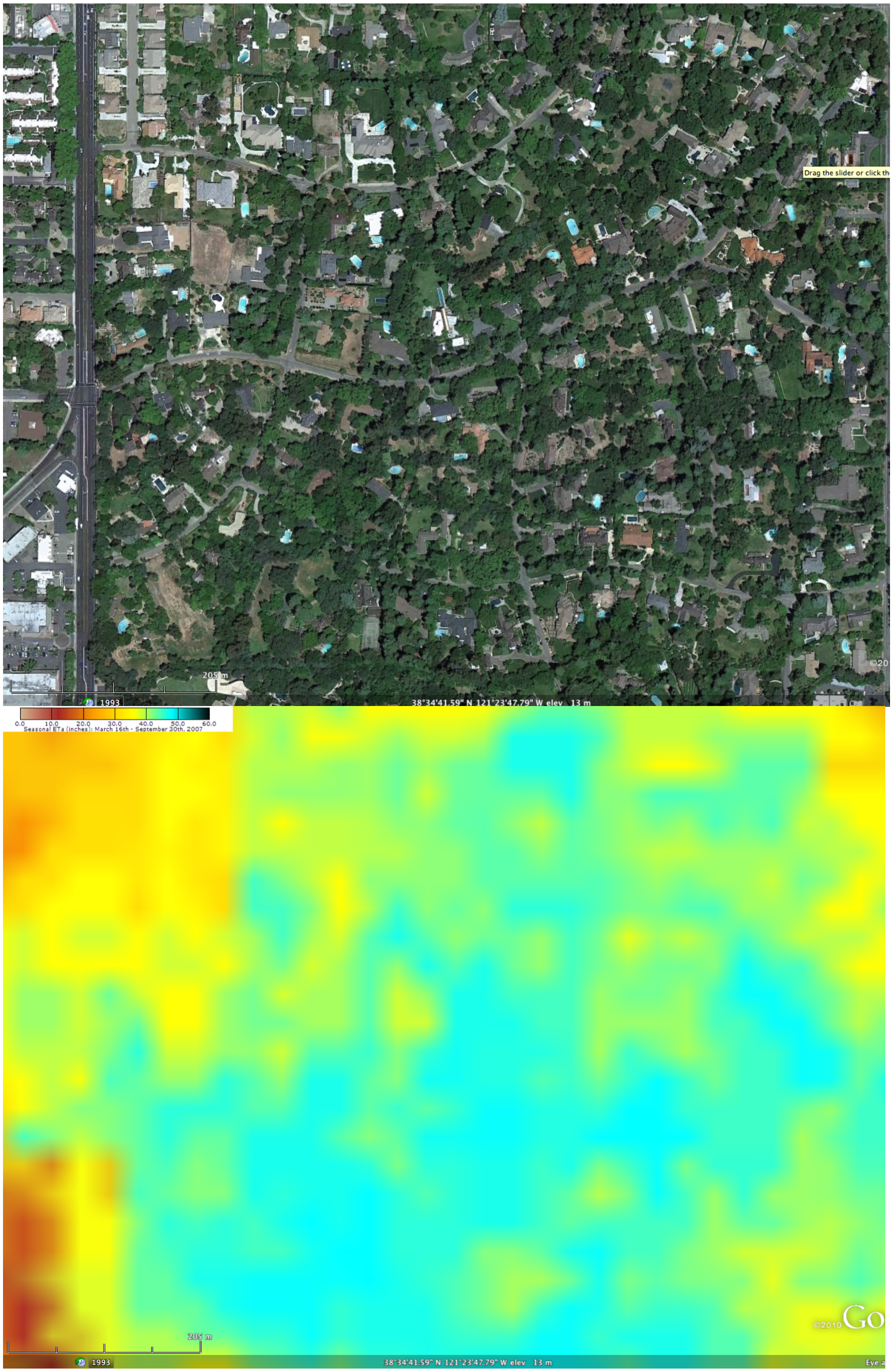

Figure 2. Google Earth with SEBAL based seasonal ETa from a non-metered residential neighborhood in the greater Sacramento region. Average ETa is 39.3 inches. The average age of homes in the area is about forty years.

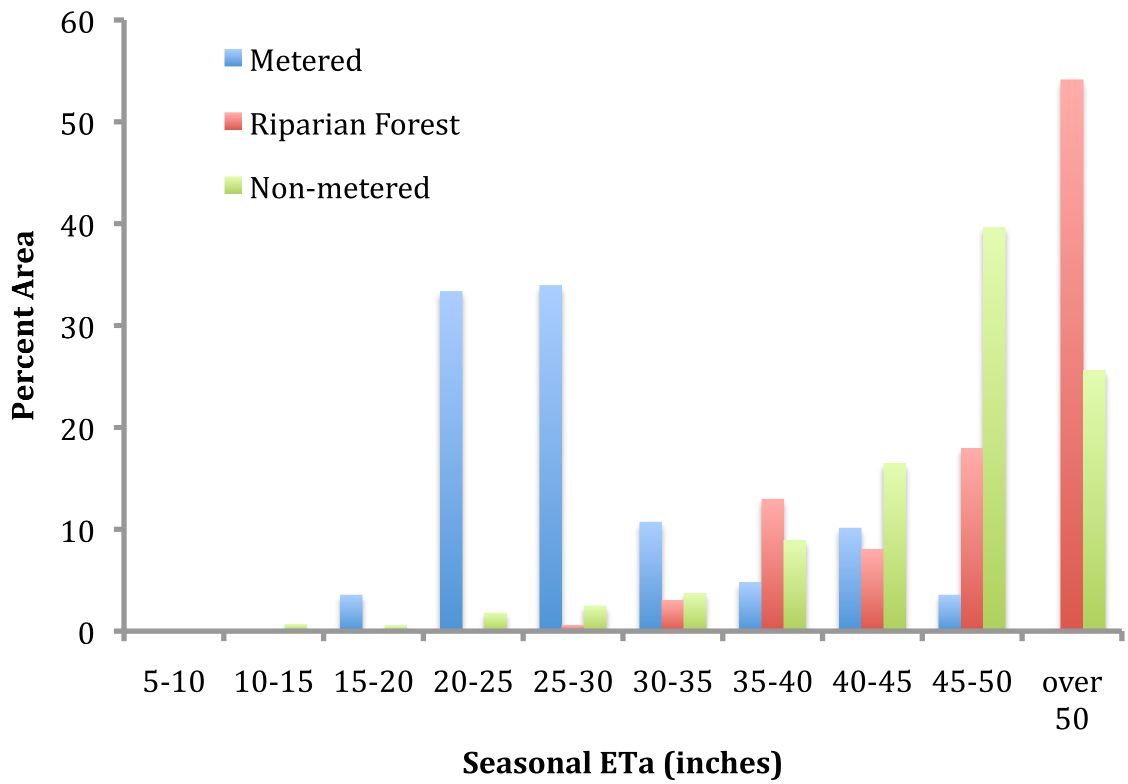

Figure 3. Distribution of seasonal ETa from a metered and an unmetered neighborhood. As a comparison, the ETa for a riparian forest in southern Sacramento County is also shown.

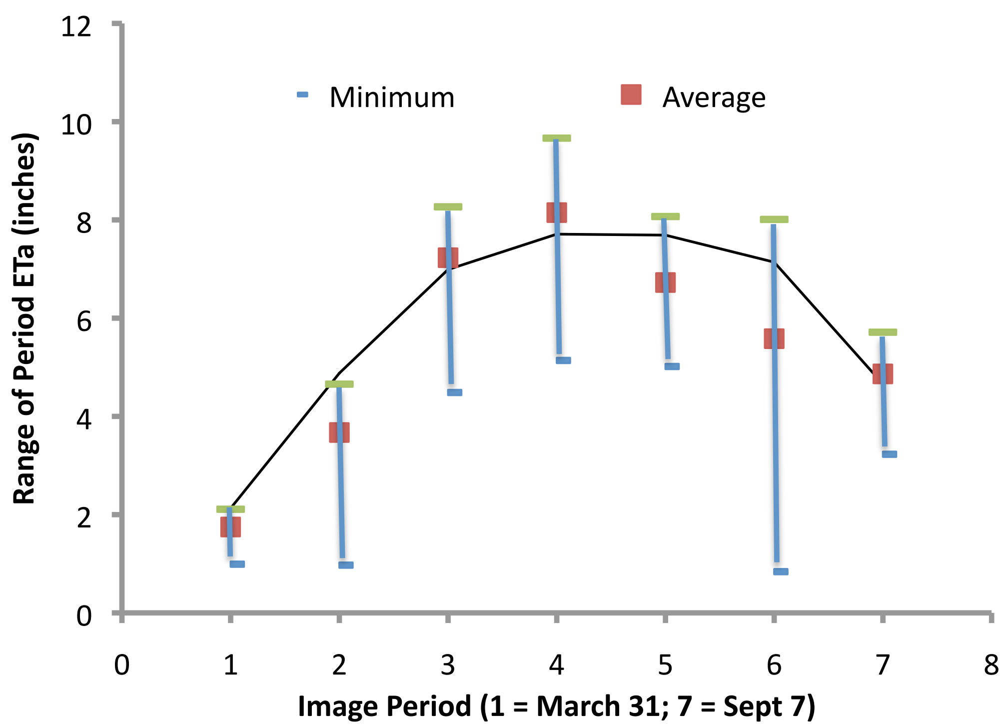

Figure 4. Range of period data and CIMIS data.

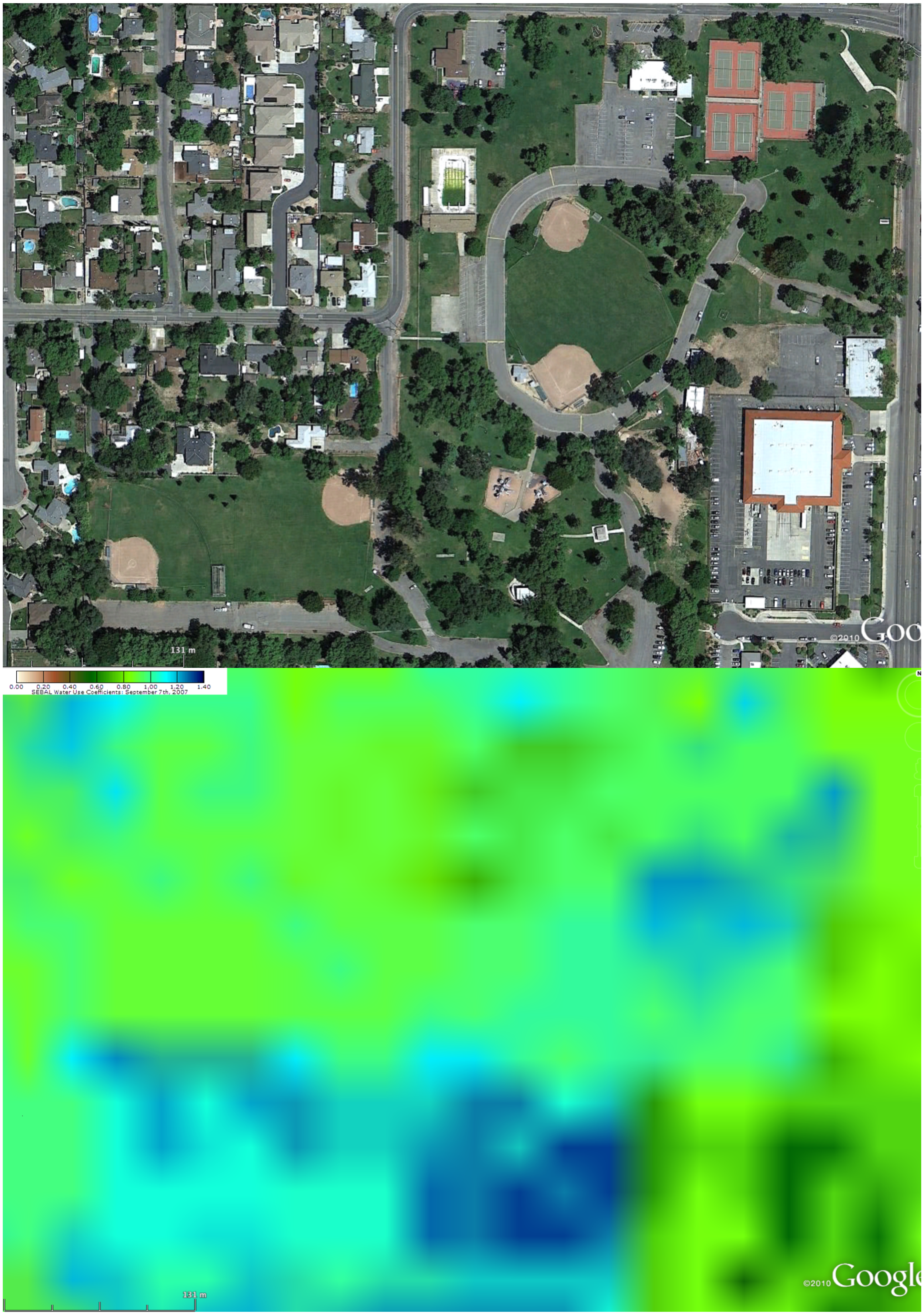

Figure 5. Google Earth with SEBAL based Kcs for the September 7, 2007 image from a public park. This park has mixed use areas.

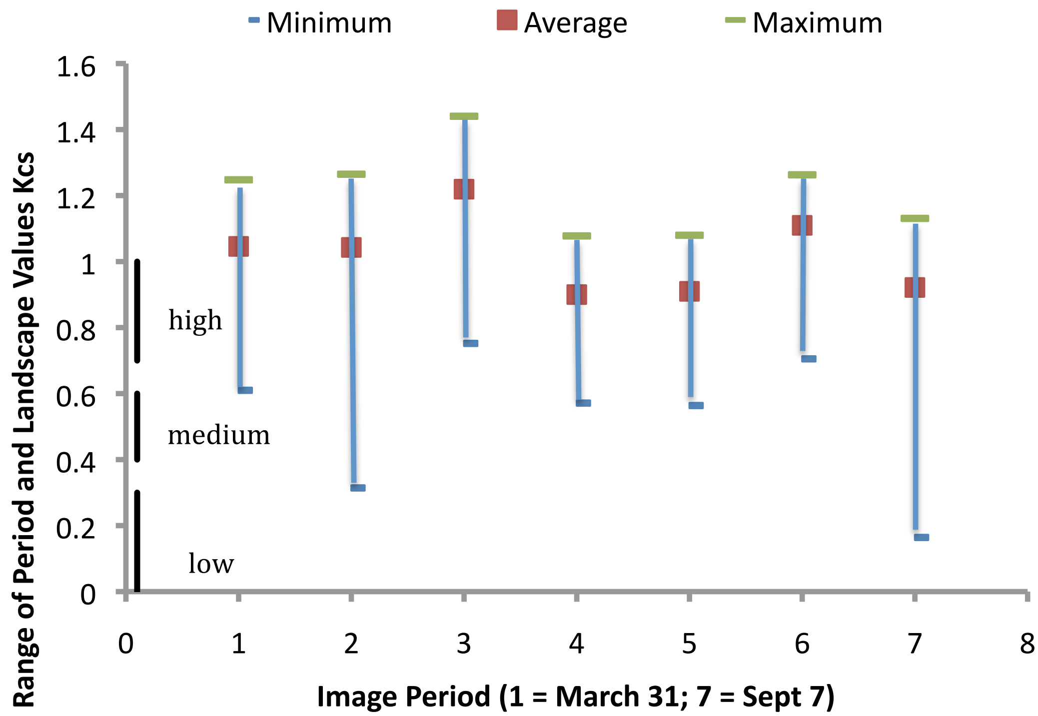

Figure 6. Range of Kcs values for September 7, 2007 from a public park. This park has mixed use areas that include sports fields, tennis courts, and picnic areas.

Conclusion

Remote sensing provides temporal and spatial ET information that is not available through other means. The level of resolution used in this analysis is adequate for large landscapes but not for smaller parks but can be used to evaluate the ET rates of larger landscape areas in urban settings. In unmetered areas, remote sensing allows for analysis of outdoor water use and for agencies to target outreach and education services.

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WaterSense Label Offers Opportunities for Irrigation Controllers

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Abstract. *The U.S. Environmental Protection Agency's WaterSense program is gearing up to label weather-based irrigation controllers. EPA is partnering with manufacturers, retailers, and distributors, and is collaborating with water utilities and irrigation professionals, to bring the first WaterSense labeled irrigation products to the marketplace. Learn the five essential things that will help you successfully leverage the WaterSense label. Attend this session to:*

1. *Understand the key weather-based irrigation controller specification criteria;*
2. *Find out what the WaterSense label represents and how manufacturers should use it;*
3. *Explore the advantages of using the label and hear examples of labeling success stories;*
4. *Learn how partners can get more out of using the WaterSense label through activities such as product promotion and collaboration with other partners; and*
5. *Learn how the product certification and labeling process benefits the irrigation industry.*

Keywords. WaterSense, water-efficient, weather-based irrigation controllers, certification

There are more than 13.5 million irrigation systems currently installed in the United States. Replacing existing standard clock timer controllers or installing new WaterSense labeled weather-based irrigation controllers could offer a significant water-saving opportunity for homeowners and organizations that use irrigation systems.

On November 3, 2011, the U.S. Environmental Protection Agency's (EPA's) WaterSense® program announced the release of the final WaterSense Specification for Weather-Based Irrigation Controllers. EPA's goal is to recognize and label weather-based irrigation controllers that can deliver a high level of performance and that will help guide the landscape irrigation industry toward improved water efficiency.

The release of this final specification is the result of more than four years of collaboration between EPA and controller manufacturers, water utilities, irrigation industry representatives, and other stakeholders. Since the release of a Notification of Intent to develop this specification in 2007, EPA has held several public meetings, gathered various working groups, conducted independent research, and worked with numerous experts to determine appropriate performance characteristics to ensure that labeled products provide efficient irrigation.

In November 2009, WaterSense released its initial draft specification for public comment. It was followed by a revised specification, released in January 2011. In the months since, EPA has carefully considered input from a wide variety of stakeholders with varying view points. This final specification represents a culmination of research, collaboration, and compromise that balances the needs and interests of WaterSense stakeholders.

The final specification sets performance criteria in terms of irrigation adequacy and irrigation excess. In addition, the specification includes supplemental capability requirements, which provide another level of performance to product users. The specification also informs stakeholders about testing configuration and labeling.

A Label with Integrity

By using water-efficient products, consumers save natural resources, reduce water consumption, and save money. In order to realize these savings, consumers need to be able to identify products that not only use less water but also achieve the level of performance they expect. EPA created the WaterSense label to make it easy for consumers to find these water-efficient products and have confidence that they will perform to their needs.

To help consumers and contractors identify WaterSense labeled products, the WaterSense label is required to be printed on the product packaging of all labeled products. It may also be directly adhered to the product or used in manufacturer literature, advertising, and websites, as long as it is used directly in conjunction with the certified product. Only products independently certified to meet a WaterSense specification can bear the label and only an approved licensed certifying body can issue the label. Manufacturers can provide the label artwork to retailers, distributors, and wholesalers for promotional purposes, including fliers, in-store displays, and websites. Consumers and contractors can visit the WaterSense website (www.epa.gov/watersense) to see the current listing of all WaterSense labeled products.

WaterSense Partners Provide Support

Certification programs for irrigation professionals were the first entities to earn the WaterSense label. Irrigation designers, installation/maintenance professionals, or auditors who are certified through a WaterSense labeled certification program are eligible to become a WaterSense irrigation partner. WaterSense has partnered with more than 1,100 irrigation professionals across the country who are committed to water efficiency and certified on their knowledge of water-efficient irrigation practices. In fact, many of these partners already incorporate weather-based irrigation controllers into their irrigation system designs.

The WaterSense label first appeared on products in 2007, with the release of the WaterSense Specification for Tank-Type Toilets. Since then, bathroom sink faucets, showerheads, and urinals have joined the ranks of WaterSense labeled products and are transforming the market for water-efficient plumbing. More than 4,000 different models of plumbing products have earned the WaterSense label to date, helping consumers save a cumulative 125 billion gallons of water and $2 billion in water and energy bills.

Partnering with WaterSense demonstrates commitment to water efficiency and provides a way for companies to distinguish themselves from their competitors. WaterSense partners have access to free tools and resources to help promote the WaterSense labeled products they sell and have increased exposure by being listed as a WaterSense partner on the program website. In the five years since the program's inception WaterSense manufacturer partners have shipped more than 50 million products with the label.

The success of WaterSense in the plumbing industry has brought with it increasing consumer awareness and support from manufacturers across the industry. As Marie-Helene Pernin, Marketing Manager at NEOPERL, Inc. explains, "The label has brought a great awareness to water conservation at the consumer level." Plumbing manufacturer Caroma Industries, a 2010 WaterSense excellence award winner, has capitalized on that WaterSense brand recognition. The company estimates that 99 percent of its toilet sales in 2009 in the United States was WaterSense labeled models. With the release of the final WaterSense Specification for Weather-Based Irrigation Controllers, irrigation product manufacturers can now join this community of manufacturers who have benefitted from WaterSense brand recognition.

WaterSense also partners with retailers and distributors to promote WaterSense labeled products. Lowe's, a two-time WaterSense partner of the year, uses online training to educate its more than 238,000 employees on WaterSense messaging and encourages employees to try labeled products for themselves in order to integrate WaterSense throughout its stores. Lowe's and The Home Depot publicize WaterSense in national and local television spots, circulars, magazine ads, and online.

Speaking at the Annual Association of Home Appliance manufacturers meeting in 2008, John Kasberger, senior vice president and general merchandising manager for kitchen and bath at Lowe's, explained how the retailer works with vendors to get water-saving products on their shelves as soon as they earn the WaterSense label: "Lowe's is going to give WaterSense [labeled product] suppliers preference when selecting new products and programs," he said. "We want to be a leader when it comes to helping customers save water."

Ferguson, one of the country's largest wholesale distributors of plumbing supplies, and a 2007 WaterSense partner of the year, has sold thousands of WaterSense labeled products to contractors, plumbers, builders, and a rising number of homeowners and remodelers. To help drive consumer traffic toward water-efficient fixtures, the company uses point of purchase displays and has made an effort to work with municipalities to stay abreast of rebate programs. Ferguson educated its staff of 22,000 associates in 1,400 service centers located in all 50 states about the benefits of water efficiency and WaterSense labeled products. To help educate local contractors, Ferguson hosts in-store events where contractors can view demonstrations of WaterSense labeled products and have their questions answered by Ferguson staff and manufacturer representatives.

WaterSense also partners with utilities, water districts, state and local governments, trade associations, and nonprofit organizations to promote water efficiency and the value of the WaterSense label. Many of these partners offer rebates or other promotions to encourage local consumers to buy WaterSense labeled products. In 2010 alone, WaterSense partners reported that they issued more than half a million incentives for water-efficient products.

"We are now basing our programs/rebates off of [WaterSense labeled] products," said Lisa Brown, Water Conservation Administrator for the City of Roseville, California. "The more products certified… the more we can incentivize."

WaterSense partner Cascade Water Alliance, a nonprofit organization of eight municipalities in the Puget Sound area in Washington, which provides water to 370,000 residents and 22,000 businesses, has implemented several water-efficiency programs including a toilet rebate program. Cascade offers $100 rebates for residential or commercial customers who replace older, inefficient tank-type toilets with any WaterSense labeled toilet. In order to increase consumer awareness, Cascade met with local retailers and plumbers to train sales staff and provide free point-of-purchase promotional materials. Some retailers estimated that, thanks to Cascade's rebate program, 75 to 90 percent of their toilet sales are now WaterSense labeled toilets. Additionally, 94 percent of customers surveyed by Cascade said their new toilets perform as well as or better than their previous models, affirming EPA's performance criteria for WaterSense labeled products.

In addition to providing all of its partners with branded marketing tools to promote WaterSense labeled products, in 2010, WaterSense launched We're for Water, a social marketing campaign to encourage consumers to make simple changes to save water. The We're for Water campaign seeks to foster a community of organizations and individuals who care about saving water for future generations. The cornerstone of the campaign is a series of print public service announcements that encourage consumers to try WaterSense labeled products and practice other water-saving behaviors.

Certified Green Value

With the introduction of the first WaterSense labeled irrigation product, EPA hopes to provide a significant step toward increasing water efficiency in the landscape irrigation sector. Third-party product certification backed by the credibility of EPA can transform an industry and create opportunities for new business. In the plumbing sector, for example, problems with first-generation "low flow" toilets were infamous in the early 1990s. Almost everyone remembers toilets that clogged and showers with no power. Although later generations of products resolved these issues, misconceptions persisted and kept many consumers from saving both water and money. WaterSense has been able to help the plumbing industry overcome the poor reputation of "low flow" products by including performance requirements in its specifications. Consumers know the WaterSense label signifies both efficiency and performance, taking the risk out of buying a water-saving product.

Product certification also offers the advantage of allowing WaterSense labeled products to be recognized by other green programs. The U.S. Building Council's Leadership in Energy and Environmental Design (LEED), Green Globes' Green Building Initiative, National Association of Home Builders' National Green Building Standard, and International Code Council's International Green Construction Code have all incorporated WaterSense labeled products in their green building standards. Some states and municipalities have also turned to WaterSense to green their local building codes. In Miami-Dade County, new construction is required to install water-efficient plumbing fixtures using the WaterSense specifications as a reference. Inclusion in these requirements has lead to increased demand for WaterSense labeled products from builders and contractors.

A Bright Future for Labeled Irrigation Controllers

WaterSense owes its success to the dedication and enthusiasm of the more than 2,000 utilities, government entities, nonprofit organizations, manufacturers, retailers, distributors, builders, and certified irrigation professionals who have partnered with WaterSense to help promote the WaterSense label and spread the word about the importance of water efficiency. With the release of the final WaterSense Specification for Weather-Based Irrigation Controllers, EPA is excited to have new opportunities work together to increase water-efficiency in the irrigation products industry.

For more information about WaterSense labeled weather-based irrigation controllers and partnership opportunities with WaterSense, please visit the WaterSense website at www.epa.gov/watersense.

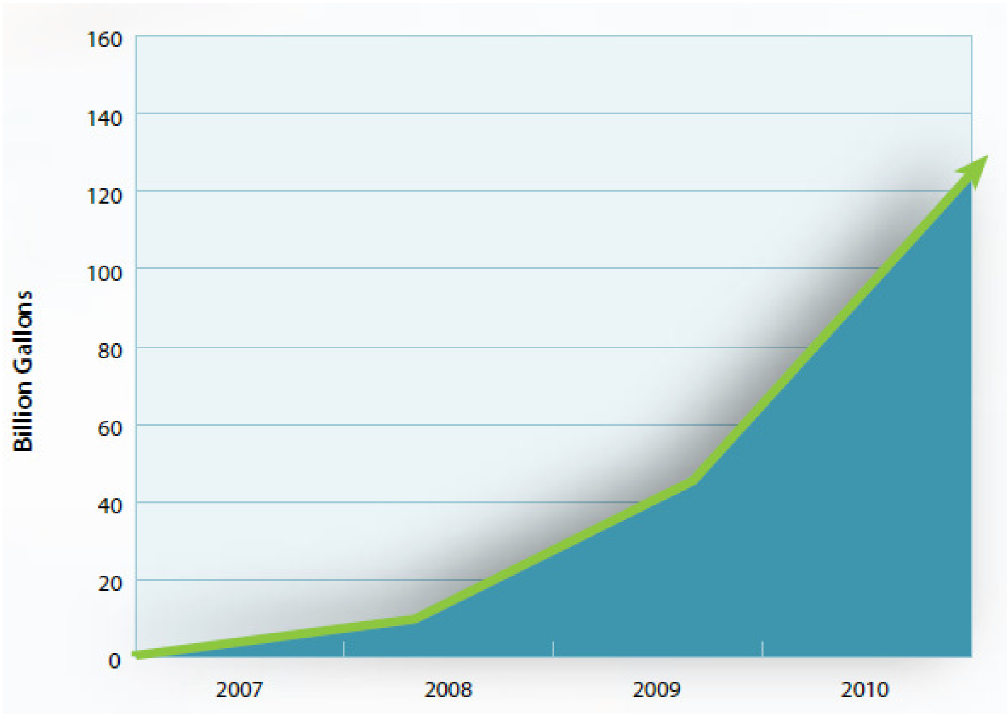

Figure 1. Cumulative water savings associated with WaterSense labeled products.

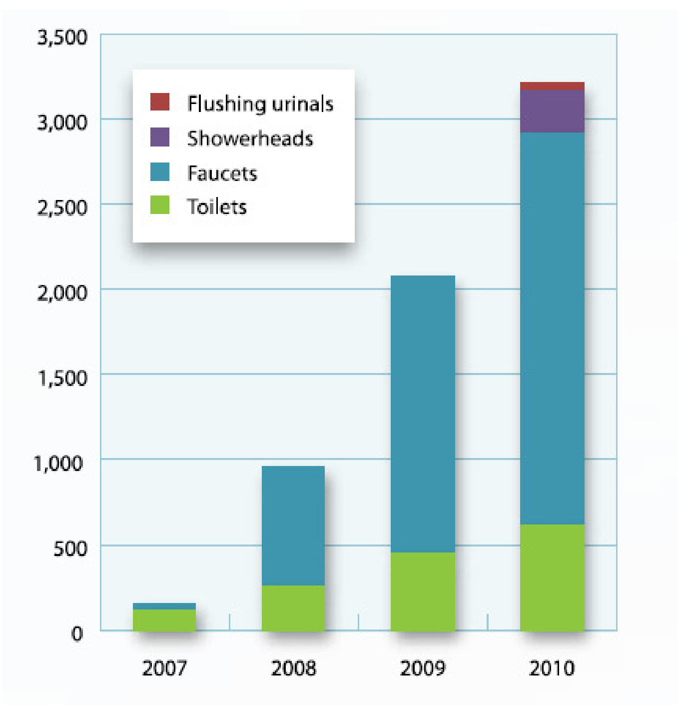

Figure 2. Total number of WaterSense labeled models (2007-2010).

Evaluation of ET Based "Smart" Controllers

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Abstract. *A smart controller testing facility was established by the Irrigation Technology Center at Texas A&M University in College Station in 2008. The objectives were to (1) evaluate smart controller testing methodology and to (2) determine their performance and reliability under Texas conditions from an "end-user" point of view. The "end-user" is considered to be the landscape or irrigation professional (such as the Licensed Irrigator in Texas) installing the controller. This report summaries the performance of eight smart controllers over an eight month (238 day) growing season in 2010. Controllers were programmed based on a virtual landscape that evaluated controller performance using multiple plant types (flowers, turf, groundcover, small and large shrubs), soil types (sand, loam and clay), root zone depths (3 to 20 inches) and other site specific characteristics. Controllers were divided into 2 categories, those which utilize on-site sensors to calculate or adjust ET or runtimes; and those which ET values are sent via cellular, radio or the internet. Controller performance was compared to total ETo, plant water requirement (ETc) and the weekly irrigation recommendation of the TexasET Network (http://TexasET.tamu.edu). Results so far indicate that controllers using on-site sensors for calculating irrigation water requirements produced lower water requirements and were more often within the irrigation recommendations of the TexasET Network. Significant seasonal differences in controller performance were also found. Results also indicate problems in quantifying effective rainfall, particularly when using a rain sensor. Continued evaluation of ET based controllers is needed to identify the causes of inconsistency among controllers.*

Keywords. *Landscape Irrigation, Irrigation Scheduling, Smart Controllers, Evapotranspiration, Water Conservation*

INTRODUCTION

The term smart irrigation controller is commonly used to refer to various types of controllers that have the capability to calculate and implement irrigation schedules automatically and without human intervention. Ideally, smart controllers are designed to use site specific information to produce irrigation schedules that closely match the day-to-day water use of plants and landscapes. In recent years, manufacturers have introduced a new generation of smart controllers which are being promoted for use in both residential and commercial landscape applications.

However, many questions exist about the performance, dependability and water savings benefits of smart controllers. Of particular concern in Texas is the complication imposed by rainfall. Average rainfall in the State varies from 56 inches in the southeast to less than eight inches in the western desert. In much of the State, significant rainfall commonly occurs during the primary landscape irrigation seasons. Some Texas cities and water purveyors are now mandating smart controllers. If these controllers are to become requirements across the state, then it is important that they be evaluated formally under Texas conditions.

CLASSIFICATION OF SMART CONTROLLERS

Smart controllers may be defined as irrigation system controllers that determine runtimes for individual stations (or “hydrozones”) based on historic or real-time ETo and/or additional site specific data. We classify smart controllers into four (4) types (see Table 1): Historic ET, Sensor-based, ET, and Central Control.

Many controllers use ETo (potential evapotranspiration) as a basis for computing irrigation schedules in combination with a root-zone water balance. Various methods, climatic data and site factors are used to calculate this water balance. The parameters most commonly used include:

- ET (actual plant evapotranspiration)
- Rainfall
- Site properties (soil texture, root zone depth, water holding capacity)
- MAD (managed allowable depletion)

The IA SWAT committee has proposed an equation for calculating this water balance (SWAT 2011).

Table 1. Classification of smart controllers by the method used to determine plant water requirements in the calculation of runtimes.	
Historic ET	Uses historical ET data from data stored in the controller
Sensor-Based	Uses one or more sensors (usually temperature and/or solar radiation) to adjust or to calculate ETo using an approximate method
ET	Real-time ETo (usually determined using a form of the Penman equation) is transmitted to the controller daily. Alternatively, the runtimes are calculated centrally based on ETo and then transmitted to the controller.
On-Site Weather Station (Central Control)	A controller or a computer which is connected to an on-site weather station equipped with sensors that record temperature, relative humidity (or dew point temperature) wind speed and solar radiation for use in calculating ETo with a form of the Penman equation.

MATERIALS AND METHODS

Testing Equipment and Procedures

Two smart controller testing facilities have been established by the ITC at Texas A&M University in College Station: an indoor lab for testing ET-type controllers and an outdoor lab for sensor-based controllers. Basically, the controllers are connected to a data logger which records the start and stop times for each irrigation event and station (or hydrozone). This information is transferred to a database and used to determine total runtime and irrigation volume for each irrigation event.

Smart Controllers

Eight (8) controllers were provided by manufacturers for the Year 2010 evaluations (Table 2). Each controller was assigned an ID for reporting purposes. Table 2 lists each controller's classification, communication method and on-site sensors, as applicable. The controllers were grouped by type for testing purposes. The ET controllers (A & B) were tested indoors, and the sensor-based controllers C-H were tested outdoors.

Table 2. The controller name, type, communication method, and sensors attached of the controllers evaluated in this study. All controllers were connected to a rain shut off device unless equipped with a rain gauge.

Controller ID	Controller Name	Type	Communication Method	Sensors
A	ET Water	ET	Pager	None
B	Rainbird ET Manager	ET	Pager	Tipping Bucket Rain Gauge
C	Accurate WeatherSet	Sensor Based	None	Pyranometer
D	Weathermatic Smartline	Sensor Based	None	Temperature
E	Hunter ET System	Sensor Based	None	Tipping Bucket Rain Gauge, Pyranometer, Temperature/ RH
F	Hunter Solar Sync	Sensor Based	None	Pyranometer
G	Rainbird ESP SMT	Sensor Based	None	Tipping Bucket Rain Gauge, Temperature
H	Toro Intellisense	ET	Pager	None

Definition of Stations (Zones) for Testing

Each controller was assigned six stations, each station representing a virtual landscaped zone (Table 3). These zones are designed to represent the range in site conditions commonly found in Texas, and provide a range in soil conditions designed to evaluate controller performance in shallow and deep root zones (and low/high water holding capacities). Since we do not recommend that schedules be adjusted for the DU (distribution uniformity), the efficiency was set to 100% if allowed by the controller.

Programing the smart controllers according to these virtual landscapes proved to be problematical; as only 2 controllers had programming options to set all the parameters defining the virtual landscape (see Table 4). In addition, it was impossible to see the actual values that two controllers used for each parameter or to determine how closely these followed the values of the virtual landscape.

One example of programming difficulty was entering root zone depth. Only five of the 8 controllers in the study allowed the user to enter the root zone depth (soil depth). Another example is entering landscapes plant information. Three of the controllers did not provide the user the ability to see and adjust the actual coefficient (0.6, 0.8, etc) that corresponds to the selected plant material (i.e., fescue, cool season grass, etc.).

Thus, we programmed the controllers to match the virtual landscape as closely as was possible. Manufacturers were given the opportunity to review the programming, which two did. Four of the remaining manufacturers provided to us written recommendations/instructions for station programming, and one manufacturer trusted our judgment in controller programming.

Table 3. The Virtual Landscape which is representative of conditions commonly found in Texas.

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Plant Type	Flowers	Turf	Turf	Groundcover	Small Shrubs	Large Shrubs
Plant Coefficient (Kc)	0.8	0.6	0.6	0.5	0.5	0.3
Root Zone Depth (in)	3	4	4	6	12	20
Soil Type	Sand	Loam	Clay	Sand	Loam	Clay
MAD (%)	50	50	50	50	50	50
Adjustment Factor (Af)	1.0	0.8	0.6	0.5	0.7	0.5
Precipitation Rate (in/hr)	0.2	0.85	1.40	0.5	0.35	1.25
Slope (%)	0-1	0-1	0-1	0-1	0-1	0-1

Table 4. The parameters which the end user could set in each controller DIRECTLY identified by the letter "x."

Controller	Soil Type	Root Zone Depth	MAD	Plant Type	Adjustment Factor	Precipitation Rate	Zip Code or Location	Runtime
A	X	X	X	X		X	X	
B[1]	-	-	-	X	X	-	X	X
C				X				X
D	X			X	X	X	X	
E	X			X	X	X		
F[2]							X	X
G	X	X		X	X	X		
H	X	X	X	X	X	X	X	

[1] Irrigation amount was set in controller based on runtime using soil type, root zone depth, MAD and precipitation rate.
[2] Controller was programmed for runtime and frequency at peak water demand (July).

Testing Period

The controllers were set up and allowed to run for a 34 week (238 day) period from March 29 to November 22, 2010. Due to the length of the study, controller performance was reported over the entire testing period and on a seasonal basis as well. For the purposes of this study, seasons were defined as follows:

- Spring-March 29 to May 30 (62 Days),
- Summer-May 31 to August 30 (92 Days),
- Fall-August 31-November 22 (84 Days).

ETo and Recommended Irrigation

ETo was computed from weather parameters measured at the Texas A&M University Golf Course in College Station, TX which is a part of the TexasET Network (http://TexasET.tamu.edu). The weather parameters were measured with a standard agricultural weather station which records temperature, solar radiation, wind and relative humidity. ETo was computed using the standardized Penman-Monteith method. During the evaluation period, the total ETo was 41.5 inches with a total of about 18 inches of rainfall (see Table 8).

TexasET and the Plant Water Requirement Calculator

In this report, smart controller irrigation volumes are compared to the recommendations of the TexasET Network and Website generated using the Landscape Plant Water Requirement Calculator (http://TexasET.tamu.edu) based on a weekly water balance. This is the method that is used in the weekly irrigation recommendations generated by TexasET for users that sign-up for automatic emails. The calculation uses the standard equation:

$$ETc = (ETo \times Kc \times Af) - Re \qquad \text{(Equation 1)}$$

where:

- ETc = irrigation requirement
- ETo = reference evapotranspiration
- Kc = crop coefficient
- Af = adjustment factor
- Re = effective rainfall

Recommended Kc for warm season turf is 0.6 and cool season 0.8. Due to the lack of scientifically derived crop coefficients for most landscape plants, we suggest that users classify plants into one of three categories based on their need for or ability to survive with frequent watering, occasional watering and natural rainfall. Suggested crop coefficients for each are shown in Table 5.

In addition to a Plant Coefficient, users have the option of applying an Adjustment Factor. This can be used to adjust the crop coefficient for various site specific factors such as microclimates, allowable stress, or desired plant quality. For most home sites, a Normal Adjustment Factor (0.6) is recommended in order to promote water conservation, while an adjustment factor of 1.0 is recommended for sports athletic turf. Table 6 gives the adjustment factor in terms of a plant quality factor.

A weekly irrigation recommendation was produced using equation (1) following the methodology discussed above. The Af used in this year's are shown in Table 3. Effective rainfall was calculated using the relationships shown in Table 7.

Table 5. Landscape Plant Water Requirements Calculator Coefficients		
Plant Coefficients		Example Plant Types
Warm Season Turf	0.6	Bermuda, St Augustine, Buffalo, Zoysia, etc.
Cool Season Turf	0.8	Fescue, Rye, etc.
Frequent Watering	0.8	Annual Flowers
Occasional Watering	0.5	Perennial Flowers, Groundcover, Tender Woody Shrubs and Vines
Natural Rainfall	0.3	Tough Woody Shrubs and Vines and non-fruit Trees

Table 6. Adjustment Factors in terms of "Plant Quality Factors."	
Maximum	1.0
High	0.8
Normal	0.6
Low	0.5
Minimum	0.4

Table 7. TexasET Effective Rainfall Calculator	
Rainfall Increment	**% Effective**
0.0" to 0.1"	0%
0.1" to 1.0"	100%
1.0" to 2.0"	67%
Greater than 2"	0%

RESULTS AND DISCUSSION

Results from the Year 2010 evaluations are summarized in Table 8 which shows the total irrigation volumes for each controller and station (zone). In Tables 9, 10 and 11, irrigation volumes are listed per season. Table 12 shows total irrigation volume over the entire study year in inches and as a percentage of ETo and ETc.

When looking at total irrigation amounts over the entire evaluation period:

- One (1) controller had five stations that were within +/- 20% of the recommendations of the TexasET Network
- One (1) controller had four stations within +/- 20% of the recommendations of the TexasET Network
- One (1) controller did not produce any stations within +/- 20% of the recommendations of the TexasET Network

Controller performance during the Spring evaluation period (March 29-May 30, 62 days) was generally poor.

- Two (2) controllers produced irrigation volumes in excess of ETc
- One (1) controller had irrigation volumes in excess of ETo.
- In total, 54% of the stations had excessive runtimes for the period even though 4.27 inches of rainfall fell, eliminating the need for irrigation for most stations for four of the nine weeks.

Performance during the Summer evaluation period (May 31-August 30, 92 days) showed an improvement.

- One (1) controller had 5 stations within +/- 20% the irrigation recommendations of TexasET.
- Two (2) controllers produced irrigation runtimes in excess of ETc, including one which irrigated in excess of ETo.
- Over nine inches of rainfall fell during this time frame meaning no controllers should have irrigated in excess of ETc.

Controller performance during the Fall evaluation period (August 31-November 22, 84 days) was poor.

- Four controllers produced station runtimes in excess of ETc, including one station in excess of ETo.
- One (1) controller had 4 stations within +/- 20% the irrigation recommendations of TexasET.
- For this time frame, 67% (32 out of 48) of the stations irrigation amounts were between the recommendations of the TexasET Network and that of calculated ETc (excluding rainfall).

Table 8. Total irrigation volumes over the entire testing period: Mar 29 - Nov 22, 2010. Also shown are the total ETo and Rainfall recorded during the evaluation period.

	Station 1	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
Plant Type	Flowers	Turf	Turf	Groundcover	Small Shrubs	Large Shrubs
A	26.93	20.83	14.37	12.48	13.13	9.17
B	35.48	19.61	14.43	10.31	10.92	0
C	16.59	18.37	14.88	5.6	8.97	5.8
D	16.96	7.87	6.26	3.84	5.31	2.9
E	14.07	7.22	4.82	4.07	4.91	1.66
F	20.93	12.69	9.82	6.3	3.58	3
G	27.4	15.8	8.58	5.32	8.04	0
H	46.1	16.29	11.78	7.34	12.47	5.04
TexasET Recommendation	23.61	13.47	9.67	6.33	9.40	3.64
ETc (ETo x Kc)[1]	33.22	24.92	24.92	20.77	20.77	12.46
ETo[2]	41.53					
Rainfall	17.98					

[1] Rainfall is not included in calculation

[2] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Golf Course, College Station, Texas.

Shading denotes values within +/- 20% of TexasET Recommendation

Table 9. Spring irrigation volumes, Mar 29 - May 30, 2010 (62 Days)						
Controller ID	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
A	6.30	6.55	4.10	3.03	3.68	2.50
B	10.0	5.46	4.04	2.89	3.19	0
C	5.93	6.52	5.22	1.72	2.72	1.73
D	4.87	2.25	1.79	0.75	1.52	0.72
E	4.96	2.76	2.20	1.53	1.87	1.12
F	6.61	3.91	3.03	1.80	0.72	0.70
G	7.82	4.15	1.99	1.29	1.47	0
H	12.32	4.64	3.28	2.15	3.62	1.45
Total ETo[1]	11.10					
Total Rainfall[2]	4.27					
TexasET Recommendation	6.14	3.30	2.23	1.31	1.93	0.75
Total ETc[3]	8.88	6.66	6.66	5.55	5.55	3.33

[1] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Golf Course, College Station, Texas.
[2] Total Rainfall collected from TexasET Network Weather Station "TAMU Golf Course"
[3] Rainfall not included in this calculation
Shading denotes values within +/- 20% of TexasET Recommendation

Table 10. Summer irrigation volumes, May 31 - Aug 30, 2010 (92 Days)						
Controller ID	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
A	13.14	10.11	7.28	6.33	6.30	4.17
B	15.90	8.96	6.64	4.74	4.55	0
C	3.35	3.15	2.57	1.15	1.83	1.17
D	4.17	1.70	1.35	0.94	1.15	0.73
E	2.45	1.72	0.76	0.83	1.20	0
F	3.80	2.08	1.66	1.18	0.27	0.13
G	10.66	6.59	3.44	2.32	4.19	0
H	20.87	6.82	4.97	3.01	5.20	2.13
Total ETo[1]	19.18					
Total Rainfall[2]	9.12					
TexasET Recommendation	11.57	6.63	4.78	3.17	4.64	1.78
Total ETc[3]	15.34	11.51	11.51	9.59	9.59	5.75

[1] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Golf Course, College Station, Texas.
[2] Total Rainfall collected from TexasET Network Weather Station “TAMU Golf Course”
[3] Rainfall not included in this calculation
Shading denotes values within +/- 20% of TexasET Recommendation

Table 11. Fall irrigation volumes, Aug 31 - Nov 22, 2010 (84 Days)						
Controller ID	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
A	7.49	4.17	2.99	3.12	3.15	2.50
B	9.58	5.19	3.75	2.68	3.18	0
C	7.31	8.70	7.09	2.73	4.42	2.90
D	7.92	3.92	3.12	2.15	2.64	1.45
E	6.66	2.74	1.86	1.71	1.84	0.54
F	10.52	6.70	5.13	3.32	2.59	2.17
G	8.92	5.06	3.15	1.71	2.38	0
H	12.91	4.83	3.53	2.18	3.65	1.46
Total ETo[1]	11.25					
Total Rainfall[2]	4.59					
TexasET Recommendation	5.90	3.54	2.66	1.85	2.83	1.11
Total ETc[3]	9.00	6.75	6.75	5.63	5.63	3.38

[1] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Golf Course, College Station, Texas.
[2] Total Rainfall collected from TexasET Network Weather Station "TAMU Golf Course"
[3] Rainfall not included in this calculation
Shading denotes values within +/- 20% of TexasET Recommendation

Table 12. Comparison of total volumes (inches) of each controller to plant water requirements and Eto over the entire evaluation period.								
Total	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Irrigation Applied, in	96.91	90.75	70.21	43.14	36.75	56.32	65.14	99.02
% ETc	71%	66%	51%	31%	27%	41%	48%	72%
% ETo	39%	37%	28%	17%	15%	23%	26%	40%
TexasET Rec.	66.12							
ETc (ETo x Kc)[1]	137.06							
ETo	249.18							
Rainfall	17.98							

[1] effective rainfall not subtracted

CONCLUSIONS AND FUTURE PLANS

Over the past five years since we started our "end-user" evaluation of smart controllers, we have seen improvement in their performance. The communication and software failures that were evident in our field surveys conducted in San Antonio in 2006 (Fipps, 2008) are no longer a problem. In the past four years of bench tesiting, we have seen some reduction in excessive irrigation charactaristic of a few controllers.

Our emphais continues to be an "end-user" evaluation, how controllers preform as installed in the field. The "end-user" is defined as the landscape or irrigation contractor (such as a licensed irrigator in Texas) who installs and programs the controller.

Although the general performance of the controllers has gradually increased over the last four years, we continue to oberserve controllers irrigating in excess of ETc. Since ETc is defined as the reference plant evapotranspiration (ETo) times a plant coefficient, this should be the greatest amount of water a plant should need over any time frame if no rainfall occurs. However three controllers consistently irrigated in excess of ETc even though over 17 inches of rainfall fell during this typical irrigation season.

The factors that could cause this over irrigation are improper ETo calculation/aquisition and insufficient accounting for rainfall. Of the eight (8) smart controllers in the study, three (3) were equiped with "tipping-bucket" type rain gauges which actually measure rainfall, while the other five (5) controllers were equiped with rainfall shutoff sensors as required by Texas law. Rainfall shutoff sensors only detected the presense of rainfall and interrup the irrigation event. Of the three controllers which used "tipping-bucket" gauges, two were consitently among the top 3 performing smart controllers, especially during the summer period when the greatest amount of rainfall occured.

Generally, controllers with on-site sensors, performed better and more often irrigated closer to the recommendations of the TexasET Network than those controllers which have ET sent to the controller.

While water savings shows promise through the use of some smart irrigation controllers, excessive irrigation is still occuring under some landscape scenerios. Continued evaluation and work with the manufacturers is needed to fine tune these controllers even more to achieve as much water savings as possible.

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Implementation of Smart Controllers in Orange County, Florida

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Abstract. *Water agencies are continually looking for better ways to help households reduce their outdoor water use without sacrificing landscape quality of their constituents. The main objective of this study was to evaluate two types of smart controllers to determine whether they can reduce irrigation application of high water users located in unincorporated Orange County. A total of 154 participants were recruited where 61 Rain Bird ESP-SMT ET controllers and 61 Baseline Watertec S100 soil moisture sensors were installed on single-family residential properties grouped in eight locations throughout Orange County, FL. Half of the participants receiving smart technologies also participated in a personal, on-site training session about their smart controller provided by the University of Florida. The on-site visit included optimization of program settings and additional educational materials to supplement the user manual. The results will include the participant selection, installation, and education phases of the study with preliminary data collection summaries.*

Keywords. Evapotranspiration, irrigation, maintenance, scheduling, smart controllers, soil moisture

Introduction

Smart irrigation controller technologies are becoming more popular in Florida based on their increasing implementation in the western United States. Some water agencies in California have mandated smart controllers for new irrigation systems or have provided rebates for water customers that chose to replace their current timer with a smart controller. Due to increasing popularity, it is important to determine if these technologies can be implemented widely in Florida to provide ta reduction in potable water demand.

Irrigation has been shown to account for 64% of average total household water use in central Florida (Haley et al., 2007). Irrigation scheduling based on evapotranspiration (ET_O) (Davis et al., 2009) or soil moisture (McCready et al., 2009) can reduce irrigation application by as much as half during dry periods compared to a recommended time based schedule. As a result, water agencies are looking toward these technologies to help households reduce their outdoor water use without sacrificing landscape quality.

The main objective of this study is to evaluate two types of smart controllers to determine whether they can reduce irrigation application of high water users located in unincorporated Orange County. This paper describes the participant selection, installation, and education phases of the study with preliminary data collection summaries.

Materials and Methods

Study Design

This study was designed to evaluate high water users located within eight location clusters in Orange County where half of the location clusters were considered to have flatwoods soils and the other half were considered sandy. Each location cluster contains five treatments replicated four times thus requiring twenty cooperators per location.

The smart irrigation technologies selected for this study are the ESP-SMT (Rain Bird, Azusa, CA) ET controller and the Watertec S100 (Baseline, Inc., Meridian, ID) soil moisture sensor. The ESP-SMT is an on-site ET controller that measures temperature and relative humidity to calculate ET_O. This ET controller directly measures rainfall using a tipping bucket rain gauge and is programmed with landscape characteristics for each zone to schedule irrigation based on ET_O and rainfall. The Watertec S100 measures volumetric water content through time-domain-transmissometry (TDT) technology. The sensor is buried in the irrigated area and wired to a solenoid valve. The sensor controller is wired to the existing timer and bypasses scheduled irrigation events when the measured soil moisture is greater than the threshold.

Half of the participants receiving smart technologies also participated in a personal, on-site training session about their smart controller provided by the University of Florida. The on-site visit included optimization of program settings and additional educational materials to supplement the user manual. Cooperators were encouraged to ask questions during this time and were directed toward contact information for additional questions or concerns. Prior to the on-site visit, cooperators that received a technology were given exemptions from watering restrictions and were programmed to allow irrigation daily.

For the ET controllers, general programming changes made during the on-site visit included limiting irrigation to 3 days per week and customizing application rates and plant types. For example, plant types for turfgrass zones were updated from default values of 3 inch root zones and monthly fluctuating crop coefficients to 8 inch root zones and a crop coefficient of 0.6. Ideally, fluctuating crop coefficients would have been maintained as a program setting but was not a selectable option when customizing the root zone depth.

Cooperators that received soil moisture sensors, regardless of receiving on-site training by the University of Florida, were re-programmed by the installer to irrigate every day for 20 minutes if the zone is primarily spray heads or 45 minutes if the zone is primarily rotors. The soil moisture sensors for the cooperators who did not receive an on-site visit were installed using the methodology selected by the installer that included loosely packing the soil around the sensor in a hole at a 6 inch depth. Cooperators that participated in the on-site training session received updated timer settings to apply 0.25 inches of irrigation, twice per day, three days per week, unless bypassed by the sensor. Additionally, the installer was asked to bury the sensor by inserting into the soil column at a 3 inch depth for all cooperators selected as receiving the on-site visit.

Homeowner Selection Process

This study was designed to target homeowners that were deemed high water users within the Orange County Utilities service area. Homeowners were selected for initial recruitment by comparing their monthly historical irrigation habits, collected from billing data, to monthly predicted gross irrigation requirement. The irrigation requirement was calculated using a daily soil water balance where local ET_O and rainfall information was collected from a publically available weather station. Monthly ratios of actual irrigation to a predicted irrigation requirement were calculated for all months between 2003 and 2009. Homeowners were considered “high” irrigation users and candidates for this study if they had at least three months per year for three years where their ratios were greater than 1.5 and less than 4. In general, this methodology would narrow recruitment to only high water users with habitual irrigation at least 1.5 times greater than the predicted requirement while eliminating outliers with extenuating circumstances (ratio > 4).

Letters were mailed to 7,407 utility customers located throughout the Orange County Utilities service area that met the ratio requirement described above. Within the letter, customers were asked to go to a University of Florida webpage. This webpage was set up to direct the customer to a link for the survey website as a part of the program sign-up process. Using the survey website, customers answered questions related to their irrigation scheduling habits, irrigation maintenance habits, irrigation knowledge and terminology, etc. There were 843 respondents to the survey.

Customers were immediately removed as potential participants if they did not meet the following requirements:

- Utilized automatic time clock for irrigation
- Irrigation connected to potable water supply (not reclaimed)
- Lived in home for more than 2 years (2008 - 2009)
- Year round resident
- Owned home (does not rent)
- Indicated automatic or manual irrigation habits

Additionally, some homeowners chose to be removed from the study citing the following reasons:

- Lack of trust in that there were no fees or products being sold
- Did not understand that there were future commitments after the questionnaire
- Decided that future commitments to the study were too much to handle

From the remaining customers that were eligible for participation, location clusters were identified to maintain continuity between treatments similar to a statistical blocking effect. Location-based effects that could affect irrigation may include localized rainfall, soil types, or other influences such as Homeowner Association (HOA) involvement. Five unique locations were identified where two were determined to be primarily of flatwoods soil type whereas the other three locations were considered a sandy soil. Within the two flatwoods locations, multiple clusters of twenty cooperators were identified thus totaling eight location clusters for evaluation.

Evaluations

Potential cooperators within the selected location clusters were contacted by the University of Florida and asked to schedule an irrigation evaluation. Each evaluation included recording their current timer schedule and running water for two minutes per zone to determine if there were any problems with the system. Additionally, square footage of the irrigated area was measured to compare and adjust property appraiser data for more accurate predicted irrigation requirement estimates. All information was recorded on carbonless copy paper so that the potential cooperator had a record of any problems with their system.

Potential cooperators that had multiple major problems with the irrigation system, where a major problem is considered a problem that results in a high volume water loss such as missing sprinkler heads and pipe leaks, were removed from the study. A major problem would also be considered as a broken solenoid or wiring issues that would result in irrigation that was different than the timer settings. Additionally, potential cooperators that had multiple minor problems such as clogged or leaking sprinklers but had good landscape quality were asked to make repairs to their system to remain in the study. To obtain enough cooperators eligible for participation, 284 evaluations were completed.

Application rates were used to predict average weekly irrigation application using the timer schedule collected for each cooperator during the irrigation evaluation. Application rates for each zone were not measured during the evaluation. However, the number and type of sprinkler heads for each zone were recorded. From this information, average application rates were selected as 1.75 in./hr. for spray heads, 0.75 in./hr. for rotor heads, and 1.25 in./hr. for zones that were mixed with spray and rotor heads. Watering restrictions mandated irrigation application to occur once per week during daylight savings time occurring from 7 November 2010 to 13 March 2011. Cooperators that were evaluated during daylight savings time and had timers that were programmed for once per week irrigation application were counted as 2 days per week to directly compare to the cooperators evaluated outside of the daylight savings time period. Additionally, cooperators that chose not to program start times for their primary irrigation schedule were counted as one start time per irrigation day.

Treatments

There were five treatments selected for each location: two treatments received ESP-SMT ET controllers and two treatments received Watertec S100 soil moisture sensors where one treatment for each technology includes an educational on-site visit. The final treatment is the comparison group that is monitoring only and did not receive a technology.

According to the study design, the study includes five treatments replicated four times (20 cooperators) at eight locations totaling 160 cooperators. Unfortunately, some cooperators in N. Tanner Rd Area allowed their landscapes to decline before treatment installation and were removed from the study. As a result, modified treatments were selected for this location so that there are two groups that received a technology with educational on-site visit and a comparison group. There are five replications of each treatment totaling 15 cooperators in this location only, ultimately resulting in 155 cooperators (Table 1). Treatments were installed from 23 March 2011 through 25 August 2011 for all locations except N. Tanner Rd Area. Installations began for the N. Tanner Rd Area on 12 September 2011 and are on-going.

Table 1. Count of cooperators selected for each treatment and for each location.

Location	ESP-SMT	*ESP-SMT + Edu*	*S100*	S100 + Edu	Comparison	Total

Hunters Creek A	4	4	4	4	4	20
Hunters Creek B	4	4	4	4	4	20
Keenes Pointe Area	4	4	4	4	3	19
N. Tanner Rd Area	0	5	0	5	5	15
Turtle Creek Area	4	4	4	4	4	20
Waterford Lakes – East	4	4	4	4	4	20
Waterford Lakes – South	4	4	4	4	4	20
Waterford Lakes – West	4	4	4	4	4	20
Total	28	33	28	33	32	154

Results and Discussion

Of the 284 evaluated homes, the average number of zones per home was 4.3 and the average area per zone was 1033 ft^2 (Table 2). Landscapes were much larger in the Keenes Pointe area where the number of zones averaged 6.0 and the average area per zone was 1267 ft^2. Both values being higher than the average indicates that the increase in number of zones was due to an increased landscape size and not arbitrarily based on design. A majority of the potential cooperators follow the day of the week watering restrictions with a maximum of 10% in violation at any one location. This suggests that following watering restrictions is important to homeowners in the Orange County Utilities service area.

Table 2. Summary descriptions determined during irrigation evaluations.

Location	Number Evaluated	Average Number of Zones	Average Area per Zone (ft^2)	Irrigating on Non-watering Days (%)
Hunters Creek Area	54	4.3	967	9
Keenes Pointe Area	37	6.0	1267	3
N. Tanner Rd Area	29	4.0	896	10
Turtle Creek Area	28	4.7	1102	0
Waterford Lakes Area	96	3.7	1060	10
Not grouped	40	4.6	879	10
Total	284	4.3	1033	8

There were a total of 415 minor problems and 59 major problems found across 284 evaluated homes (Table 3). Minor problems included issues that produce low volume losses such as sprinkler leaks or clogs whereas major problems included issues that produce high volume losses, faulty wiring, or solenoid problems. Though there were some homes that did not have any problems, many homes had multiple minor problems indicating maintenance neglect. Common locations for minor problems were along high traffic areas like the roadway, sidewalk, driveway, and doorways. Though there were fewer major problems, most homes that had a major problem also had multiple minor problems. Potential cooperators that had major and minor problems that may have indicated a reluctance to fix the problems or that the problems were long term issues were removed from the study.

Table 3. Count of major and minor problems found when evaluating potential cooperators.

Location	Number Evaluated	Minor Problems	Major Problems
Hunters Creek Area	54	58	10
Keenes Pointe Area	37	54	7
N. Tanner Rd Area	29	36	8
Turtle Creek Area	28	34	2
Waterford Lakes Area	96	183	22
Not grouped	40	50	10
Total	284	415	59

Assuming no rainfall, replacing ET of a warm season turfgrass during a high irrigation demand period in Florida would result in approximately 1.75 inches per week of irrigation. Using assumed application rates, predictions of irrigation application for each cooperator could be made using the timer schedule recorded during the evaluation (Table 4). The weekly irrigation indicated that Hunters Creek A, with a majority of weekly irrigation greater than 1 inch, applied more irrigation per week than Hunters Creek B where a majority of irrigation was less than 1.5 inches per week. The distribution of weekly irrigation for the Keenes Pointe Area resembled Hunters Creek A whereas the distribution of irrigation for N. Tanner Rd Area resembled Hunters Creek B. Turtle Creek and all three Waterford Lakes areas were similarly distributed with the largest number of cooperators irrigating between 1 to 1.5 inches per week. Considering rainfall occurs frequently in Florida, the locations of Hunters Creek B and N. Tanner Rd Area have a significant amount of slightly conservative irrigators whereas the majority of cooperators in all other locations can be confirmed as high water users.

Table 4. Percentage of cooperators irrigating various weekly depths of irrigation based on timer schedules recorded during the irrigation evaluation for the cooperators participating in the study.

Location	< 0.5 in.	0.5 to 1 in.	1 to 1.5 in.	1.5 to 2 in.	> 2 in.
Hunters Creek A	0	25	20	30	25
Hunters Creek B	12	47	24	6	12
Keenes Pointe Area	0	20	20	40	20
N. Tanner Rd Area	0	38	31	23	8
Turtle Creek	0	16	37	21	26
Waterford Lakes – East	0	16	52	16	16
Waterford Lakes – South	5	15	35	15	30
Waterford Lakes - West	0	15	40	30	15

Conclusion

Overall, the selection methodology to determine high water users was effective in finding irrigators who generally schedule large amounts of irrigation. Though using the methodology of calculating a ratio of irrigation application to predicted irrigation requirement for every billing customer in Orange County Utilities service area was expansive on a short term basis, targeting the more appropriate customers will increase the likelihood of success of the project thus helping to reach long term goals.

Improper maintenance of irrigation systems such as neglect of broken sprinkler heads or pipe leaks can significantly increase average household water consumption over time. There was significantly more maintenance issues found during irrigation evaluations than was expected. Many homeowners would benefit from regular maintenance on an annual or semi-annual basis.

Future research will include comparisons of irrigation application between treatments to determine differences between the technologies, educational interaction, and technology performance characteristics over time. Irrigation application during the study period will also be compared to the predicted irrigation requirement and historical average irrigation application.

Acknowledgements

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Irrigation Challenges and Opportunities Created by Modern Day Synthetic Turf Sports Field Surfaces

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ABSTRACT

Turf managers charged with maintaining natural turf on sports field complexes can work wonders given they are provided with adequate staff, equipment and budget. This is true even at high-use sports facilities. However, near constant field usage coupled with decreasing field maintenance budgets have made it almost impossible to maintain high quality natural turf for many turf managers. Modern day "infill" synthetic turf surfaces resolve many of the issues associated with high-use sports field facilities. While installing synthetic turf serves to resolve the playing surface quality issues, it presents new challenges for both the player and those charged with field maintenance. Most notable of these concerns is the need to reduce the high heat generated when these surfaces are exposed to sunlight. Synthetic turf was once considered a negative to the irrigation industry. Today, irrigation has become one solution towards resolving this high heat concern. The opportunity of irrigating synthetic turf presents new and unique challenges for the irrigation specifier, contractor and end user. Once understood, these challenges are easily overcome and will lead to ongoing irrigation opportunities for our industry.

KEYWORDS

Synthetic turf, artificial turf, sports field irrigation, irrigation challenges, irrigation opportunities, high heat, high temperatures, cooling turf.

INTRODUCTION

While it is clear that most everyone would prefer the aesthetic beauty and playability of a well maintained natural turf sports field, the reality is this is not always the most practical solution. This is particularly true at high-use sports field facilities where near constant play on the field coupled with decreasing field maintenance budgets have made it all but impossible to maintain quality turf. Given this dilemma, field & facility managers can be faced with the difficult choice of either keeping the natural turf, which might in fact be unsightly and unsafe for the players or, explore fund-raising activities towards converting the field to a synthetic turf surface.

Fortunately, modern-day synthetic turf surfaces have evolved to become an acceptable alternative for these high-use facilities. Current generation "infill" type fields resolve virtually all of the past concerns that were associated with synthetic surfaces. In fact, researchers have found that infill systems are softer, less abrasive, and generally exhibit better traction qualities than traditional Astroturf™ (McNitt, Petrunak, 2007). As a result, growth in new synthetic turf installations and the retro-fitting of existing sports fields to synthetic turf have skyrocketed in recent years throughout the US and around the world. Demand has grown to the point where there are now more than 6,000 multi-use synthetic turf sports fields installed in North American schools, colleges, parks and professional sports stadiums with consistent robust double-digit growth over the last several years (Synthetic Turf Council, 2011).

Of course, for the irrigation industry this trend has been disturbing to say the least. In fact most sales pitches received by sports turf managers in the early years from the synthetic turf industry included the end-user benefits of completely eliminating irrigation equipment and the costs of water. These presentations also included the elimination of nearly all field maintenance costs as well. However, these claims and selling tactics have in large part become a part of the past as a result of ongoing university and industry research yielding data to the contrary (McNitt, Petrunak, 2008).

While installing synthetic turf can resolve the aesthetic and playing surface quality issues on high use fields, it presents new challenges for both the player and those charged with field maintenance. Most notable of these concerns is the need to reduce the high heat generated when these surfaces are exposed to sunlight and in particular during summer's peak high temperature hours. One study noted that three things were apparent from these summer observations: 1) Natural turf surfaces are much cooler than non-irrigated synthetic surfaces; 2) non-irrigated synthetic surface temperatures can be as high as 177°F (80°C); and 3) surface temperature of synthetic fields can be reduced by 33 percent with proper use of irrigation cycling (Minner, 2004). Other research confirms this phenomenon with data revealing that field surface temperatures can reach as high as 199°F (93°C) with ambient temperatures of 99°F (37°C) (Brakeman, 2004).

This author personally experienced the concern as an assistant Pop Warner football coach. At 11 AM one Saturday southern California morning the ambient temperature was 95°F (35°C) and a temperature gun was used to measure the field surface temperature. We were amazed to hear that the field was at 160°F (71°C). By the time our kids hit the field at 2:00 PM they could barely keep their hands on the turf while in stance on the line. This of course dictated plenty of hydration, a lot of substitutions and raised concern about the safety of the team members in this environment.

Once considered a negative to the irrigation industry, irrigation has emerged as the most effective solution to date towards resolving this high heat concern on synthetic surfaces. Through research activities we can see that applications of water will dramatically reduce field temperatures. The graph in Fig 1 shows the average temperature of 8 different manufacturer's synthetic surface test plots measured on June 30th, 2004 after a single irrigation cycle (McNitt, Petrunak, 2008). While the effects of this single irrigation cycle do not last the entire day, it is clear the benefit of irrigation is one solution towards minimizing this concern. It should also be noted that it is this author's opinion the research shows there is a correlation between the ambient temperature and the effectiveness of a single irrigation cycle. At higher ambient temperatures the effectiveness of irrigation is diminished as indicated by a more rapid increase in surface temperatures after irrigation.

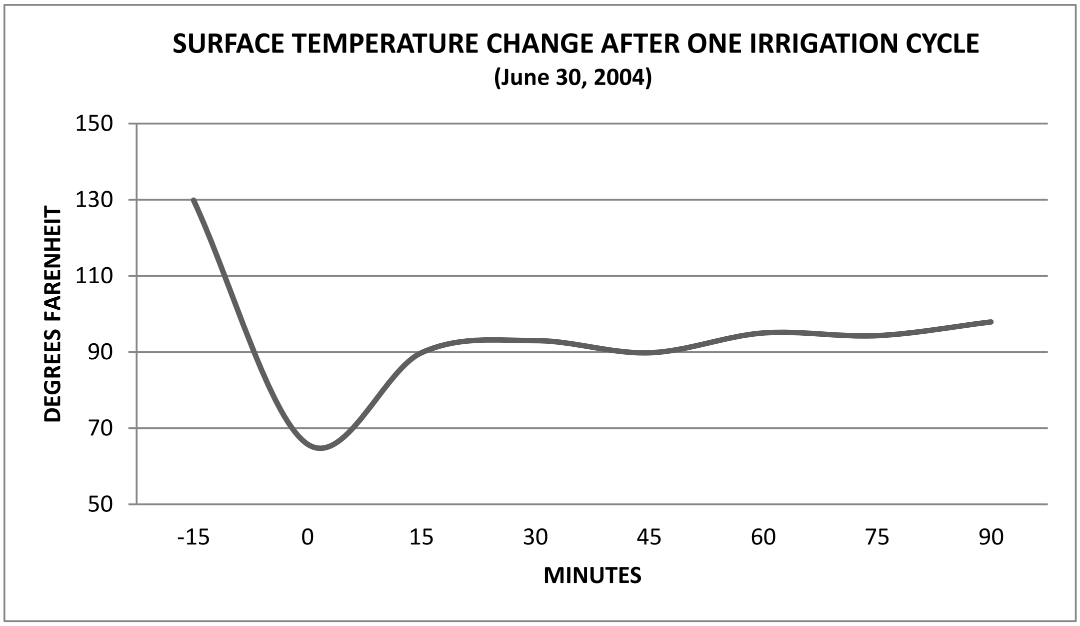

Fig. 1

Research continues at Pennsylvania State and other universities. Once believed to be a viable target towards reducing heat, it has become clear that changes to the infill material color and/or the color of the turf fibers themselves make very little difference in reducing the temperatures of synthetic surfaces (Serensits, 2011)

One area of research that appears to show promise is exploring the means to retain more water within the infill material. The intent here is to make the cooling effects of irrigation longer lasting. These experiments have shown that current day infill media are largely hydrophobic with a strong tendency towards shedding water instead of retaining it. This water then quickly disappears along with its cooling effects as it percolates through the field's extensive drainage network (McNitt, Petrunak, 2007).

PURPOSE

First and foremost, this is not a document whose purpose is to get in the middle of the active controversy between the natural turf and synthetic turf industries. Each have their benefits, each have their set of concerns and each are adamant about which is best. This document is not the forum for this discussion. This document is also specific to sports turf related synthetic turf irrigation systems. It does not tackle the emergence in recent years of infill type synthetic turf surfaces in the residential market. And, there is no intent towards justifying whether or not irrigation of synthetic turf is required other than to present informational research in the introduction above. The sole purpose of this document is, given the existence of synthetic turf projects, to convey the challenges and resulting opportunities associated with irrigating these surfaces.

One thing is clear, too often the approach to irrigating synthetic turf comes from a natural turf mindset. This is understandable given the long history of irrigating natural turf. However, this approach can create serious mistakes that will ultimately lead to a disappointed synthetic turf end-user customer.

SPECIFIER, CONTRACTOR and END-USER CONSIDERATIONS

As with any irrigation project, the irrigation specifier is the gatekeeper who is not only charged with providing a high quality site appropriate design but also with selecting equipment that protects the interests of both the contractor and end-user. The contractor is charged with providing a quality installation for the customer. At the same time, the contractor has a vested interest in making sure the installation goes as smooth and as easy as possible. The end-user customer wants it all to come together and be provided with a reliable & long-lasting system. If and when maintenance is required, the end-user expects that these repairs be simple and easy to make. In these ways, synthetic turf irrigation projects are no different than natural turf projects. However, with synthetic turf irrigation there are additional and perhaps extraordinary factors that must also be considered.

***Sprinklers* -** In the earlier years of synthetic turf irrigation, the most common product and configuration was a riser-mounted long barrel vertical impact Ag sprinkler. These so called big gun impacts were the only products that could achieve the long radius requirements needed for synthetic turf. While still used in systems today, the emergence of pop-up long-range sprinklers created a new market trend. Today, the most prevalent design is one that includes some type of pop-up product. In large part this is due to the aesthetic appeal of being able to hide the sprinklers when they are not in operation.

In the few short years since becoming an integral part of the new era synthetic surfaces, irrigation has evolved to encompass two basic segments. These include sprinklers with radius capabilities up to 125 feet and those with much higher radius capabilities up to 160 feet and beyond.

***Sprinkler Distribution Uniformity* -** Contrary to traditional natural turf irrigation, nozzle efficiency and distribution uniformity are not normally a prime factor when considering the irrigation system layout and design. This is due to several factors as will be explained. One contributing factor is that sprinklers are not typically placed within the playing surface on synthetic fields. The reasoning for this is certainly based in the fact that these sprinklers have relatively large exposed surface areas and there is a need to provide a safe playing surface for the athlete. But this is not the only reason. Another important factor is the forced sprinkler spacings dictated by the field's subsurface composition.

For all intents and purposes, the synthetic surface should be considered a non-serviceable surface as it relates to irrigation. This is because the end-user can't simply cut into the "carpet" and dig-in to make irrigation repairs. There is much more to consider. Beneath the typical approximate 2½" pile of turf fibers and the 1¾" of layered sand and rubberized infill material there is a finely orchestrated system of gradient layers designed to provide optimum support and drainage for the field (Figs. 2 & 3).

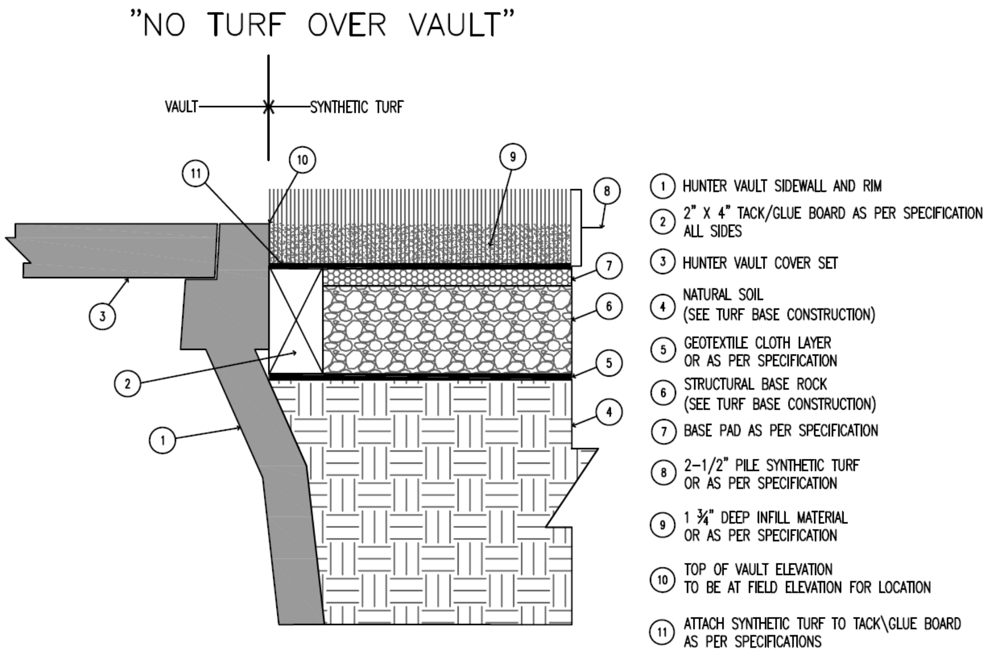

Fig. 2

Beneath the perforated carpet backing is also a perforated pad about 1" thick that not only provides drainage but also additional cushioning to protect the athlete. Beneath this pad layer is another layer or varying layers comprised of specific & specified aggregate sizes designed to provide a solid base for everything above while still allowing percolation for drainage. Further down still is a layer of geotextile cloth and/or a drainage system grid under the entire field. Some fields employ an asphalt type base with drainage provided by flowing the percolated water from the field's elevated crown along this surface to a peripheral field drainage system.

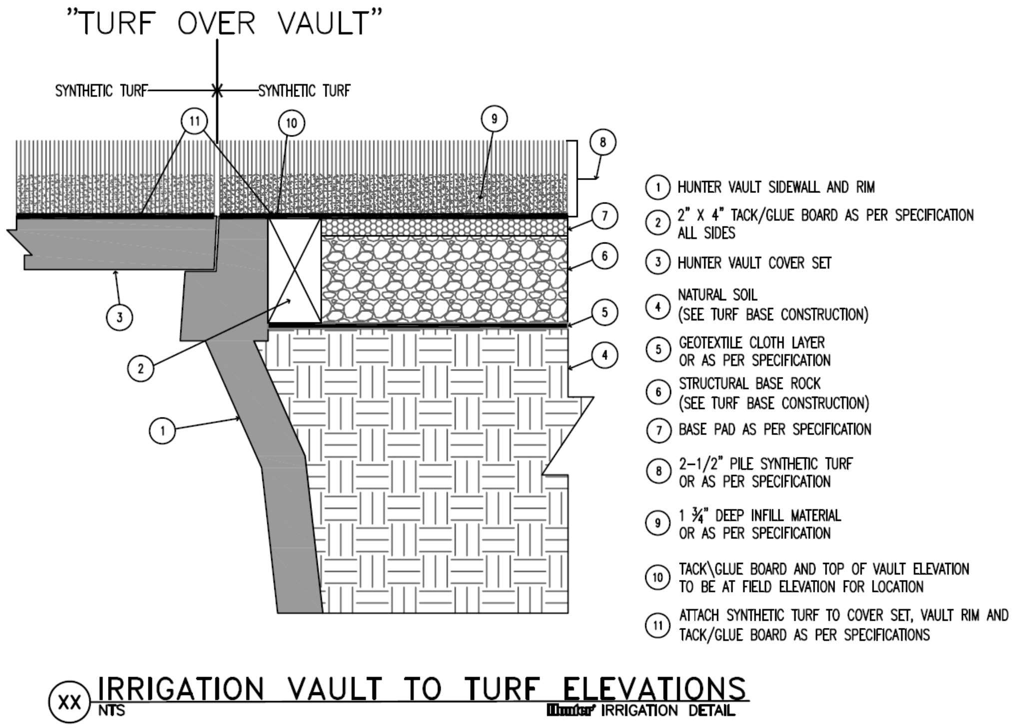

Fig. 3

Even if one assumes the excavation and subsequent backfilling after repairs can restore this gradient to its original intended profile, the next challenge is to restore the turf itself to a safe and playable surface. In order to do so, specialized equipment and techniques are required that provide appropriate hot gluing and/or stitching of the surface together.

So in consideration of the factors above, most all irrigation designs for synthetic sports turf place the sprinklers at or near the perimeter of the field. This not only keeps all irrigation plumbing away from the all-important game playing surface but also minimizes the amount of irrigation piping beneath the surface while simplifying access should repairs be required.

With sprinklers limited to the perimeter of the field, by default the challenge is not to optimize uniformity but to simply provide adequate coverage over the field in order to cool the turf. The reason is that most long range sprinklers do not have the capacity to reach all the way across the field to the one on the opposing side. Many times the sprinkler's radius only provides something that is incrementally greater than what is often called "tip to tip" coverage. This is due to the fact that there is usually more to the synthetic surface than just the primary playing field. There is usually also the peripheral sideline area to be considered as well.

As an example, an American football field with a running track around the perimeter has a distance of approximately 190 to 200 feet from the inside track edge across the field to the opposite inside track edge. For international football (soccer) the playing surface alone can reach up to 240 feet across on the largest fields with peripheral sideline & player areas beyond.

Another factor that diminishes the need for synthetic turf sprinklers to have traditional high levels of uniformity is the need to minimize or even eliminate the water close to the sprinkler. Creating the normal and sought after wedged-shaped profile requires water close to the sprinkler head. If equipped with a short-range nozzle directed close to the head, these high-flow/high-pressure sprinklers could easily blast away the infill material from the surface area adjacent to the sprinklers. The net result would be a visibly different looking and unsafe variation in the synthetic turf around the sprinklers.

Wind – Nighttime and very early AM watering are the established norms for irrigating natural turf. Less evaporation, higher available water pressures and exposure to less radius & uniformity robbing wind are some of the key reasons for this practice. To the contrary, synthetic turf irrigation can and does happen at any time of the day. This includes the afternoon hours when many areas experience their highest winds of the day. Long radius sprinklers directed into the wind will experience substantial radius reductions. Of course, with sprinklers surrounding the field, some will realize the down-wind benefit of the wind pushing the radius longer. Regardless, the point is that wind should at least be placed in consideration with every synthetic turf irrigation design.

Another point to at least consider - - - given that synthetic turf irrigation can happen at any time of the day and during those times it can be windy and during those times there are usually people in close proximity, is the use of reclaimed water appropriate? I'm sure that many would say absolutely yes given the water has been treated sufficiently. However, there are also those that would at the very least question this practice.

Operating Pressure and System Costs – The two categories of synthetic turf sprinklers each have different operating pressure requirements. The category of sprinkler with up to 125 feet radiuses require approximately 130 psi minimum at the pump station in order to maximize the radius potential and achieve the desired results at the sprinkler. Individual sprinkler flows in this category run from approximately 90 gpm up to 120 gpm. Of course, these higher pressures & flows require pump station sizing that will accommodate this demand. These relatively higher pump station and operating costs are in part offset by the lower cost of this category sprinkler. Typical list prices in this category run from a low of $300 up to $800 for individual block-type sprinklers.

The 160 feet plus category sprinkler has a much broader range of radius and operating pressures to choose from. As an example, on the lower end of the spectrum these sprinklers can fit the narrower field requirements with a 115 feet radius and 75 psi at the sprinkler with a flow of 108 gpm. At the opposite extreme these sprinklers can achieve 160 feet radius but the pressure jumps to again requiring a minimum 130 psi at the pump station and the flows at this level approach 300 gpm. A notable exception is the long-barrel vertical impact sprinkler where longer radiuses can be achieved at sub 100 psi pressures. Of course there is a price to be paid for this flexibility and capacity. To achieve the maximum performance on these larger sprinklers the pump station will need to be upsized considerably. The block type sprinklers in this category are also upsized in list price from a low of $1300 up to $3,000.

Flow Capacity and Runtime – Most customers with synthetic turf irrigation systems would prefer to minimize the total runtime required to cool the entire sports field. This is in part due to the time constraints that exist on game day. In severe temperature conditions the end-user may want to run an irrigation cycle between games and even during the halftime of a game. This can obviously place severe constraints on the system design.

Consider the following as an example scenario: Each field typically has 6, 8 or even 10 sprinklers. A gear-driven sprinkler might have a 4 minute or more full-circle speed of rotation (2 minutes for a ½ circle). The most cost-effective way to minimize the total runtime is running two sprinklers at one time. So if the user has 8 heads, runs two at a time, with ½ circle arc settings and applies a single pass per sprinkler this would require a minimum of 8 minutes of runtime. If two passes are desired then it will take 16 minutes. In many current installations either through calculation errors or construction cost constraints, the customer can only run one sprinkler at a time. This again results in a minimum of 16 minutes total runtime. With only 12 to 15 minutes in a typical halftime this can be problematic. It should be noted that some sprinklers like impact type sprinklers have a faster speed of rotation. However, the application rate per pass of faster rotating sprinklers will be less so more passes would be required.

Valve Configurations – Three different valve configurations are typically used when designing irrigation systems for synthetic turf sports fields. The three are remotely located valve Block type systems, Valve-In-Head type systems (VIH) and Valve-Adjacent-to-Head type systems (VAH).

Block systems are considered by some to be the most pragmatic approach to accommodating the need. This faction feels very strongly that highly pressurized mainlines should not exist beneath the unserviceable synthetic turf surface. Their concerns are strongly rooted in understanding the high costs and disruption associated with repairing irrigation system leaks under these surfaces (Fig. 4).

TYPICAL BLOCK SYSTEM INSTALLATION

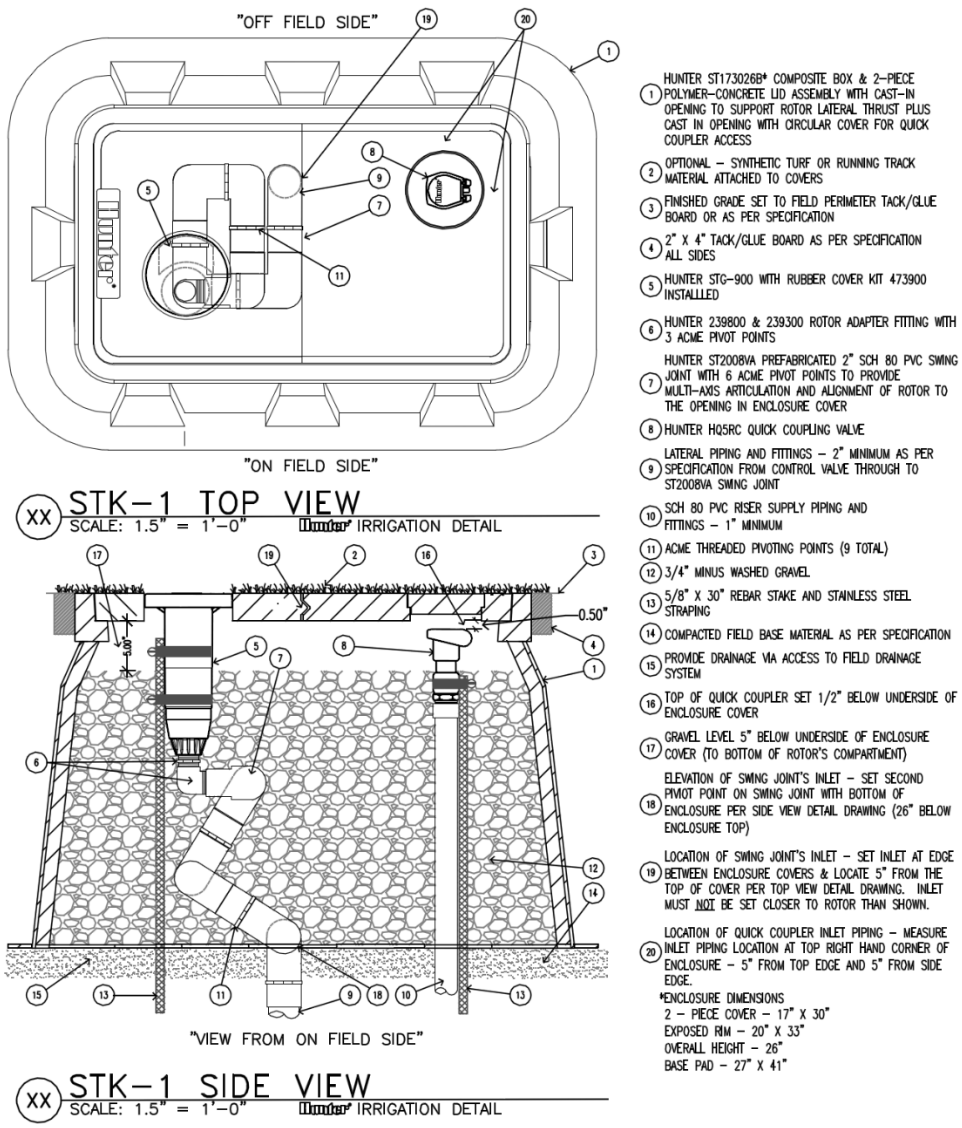

Fig. 4

Of course there can be shortcomings with this type of valving as well. Many times there is simply no suitable place for the valves and valve boxes adjacent to the field. If there is a good location then this location might be within or surrounded by hundreds of square feet of concrete or asphalt thus defeating in many ways the original intent. This approach might also require running multiple lateral piping sleeves under a running track to supply the sprinklers. The designer is also faced with the decision of where to place the pressurized quick coupler system. If under the synthetic surface then perhaps an isolation valve might be used to depressurize them when not in use. Or, quick couplers might be placed outside the perimeter of the field if logistically a possibility.

While in recent years the trend has been moving strongly towards pop-up type sprinklers in Block type synthetic irrigation systems, there is still a viable market and application for the riser-mounted sprinkler configurations. Some irrigation designers and customers prefer to place these high flow and high pressure sprinklers in an elevated position well above those that might be passing by while the system is in operation. These might be mounted against the front of the grandstands or perimeter fencing in a position that does not obstruct the grandstand view of the field. Or, they are sometimes even mounted on very tall polls as high as 20 feet tall. The riser mounted sprinkler option might also be the most appropriate and cost-effective solution for the retro-fitting of an existing synthetic turf field to irrigation. This allows all irrigation piping and gear to be installed without disrupting the existing synthetic turf surface.

VIH systems are popular and used extensively especially in the up to 125 feet category of sprinklers. This configuration offers a somewhat simple design and convenient installation for the contractor. They also offer top serviceability of the sprinkler's internal components without cutting into the synthetic surface.

The concerns with the VIH configuration are two-fold. First, they are most often used within the synthetic surface as detailed in the Block system discussion above so therefore all mainlines will exist there as well. Second, at these higher flows & pressures the valves within these VIH sprinklers are stretched well beyond their original design intent. These valves were designed for normal and acceptable pressure losses in the up to 60 gpm flow range. When attempting to push 90 to 120 gpm across these valves the pressure losses can easily exceed 25 to 65 psi (Fig. 4). The net result is a severe reduction of the pressure and flow to the sprinkler's nozzle with a commensurate reduction in the sprinkler's performance relative to the printed nozzle chart data. Also and as discussed later in this document, a directly buried VIH sprinkler's external components or its body case or the attached swing joint cannot be serviced without excavation of the synthetic surface.

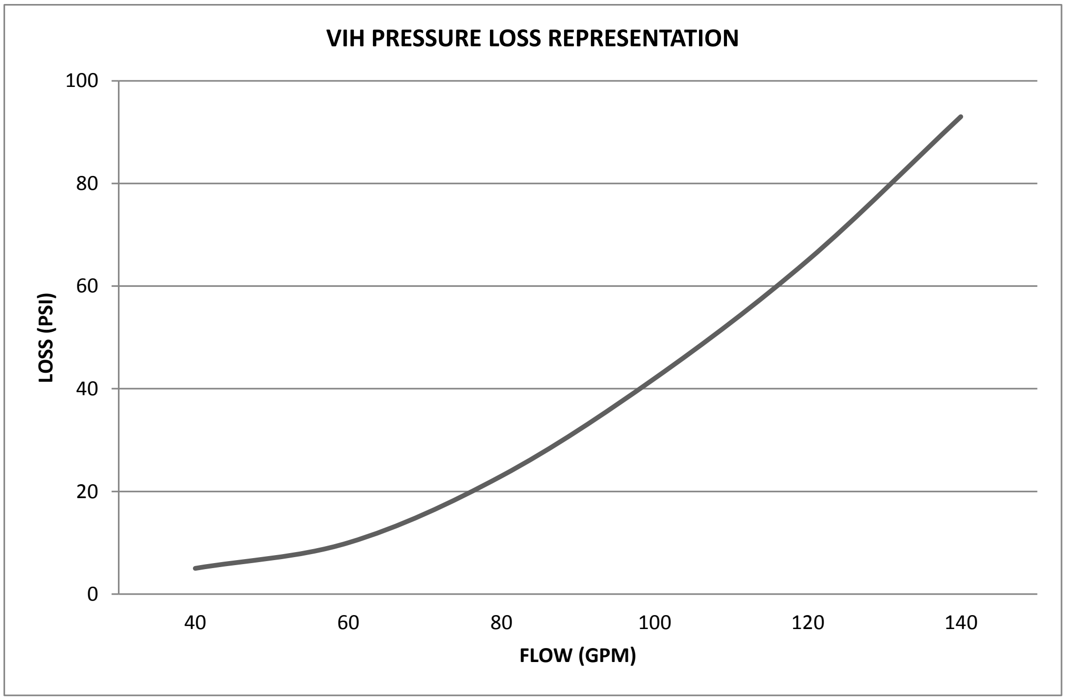

Fig. 4

VAH type valving is used in many larger radius category installations and is increasingly being used in the shorter radius category as well. This is because larger and more flow-appropriate valves can be coupled to the sprinklers with very low pressure losses realized as a result. The sprinklers and valves in this configuration are usually housed within a subsurface vault installed either within the peripheral of the synthetic surface or beyond the perimeter of the field. Ideally these vaults provide as much top access as possible to the irrigation components attached to the mainline.

Like VIH systems, the VAH systems installed within the synthetic surface will include high-pressure mainlines under the synthetic surface. Special installation care is also required to ensure the transition from the synthetic turf surface to vault is smooth (Figs. 2 & 3). VAH system vaults are typically larger in size especially when the vault provides access to not only the sprinkler & valve but also to the swing joint's point of connection to the mainline or sub-main.

TYPICAL VAH SYSTEM INSTALLATION

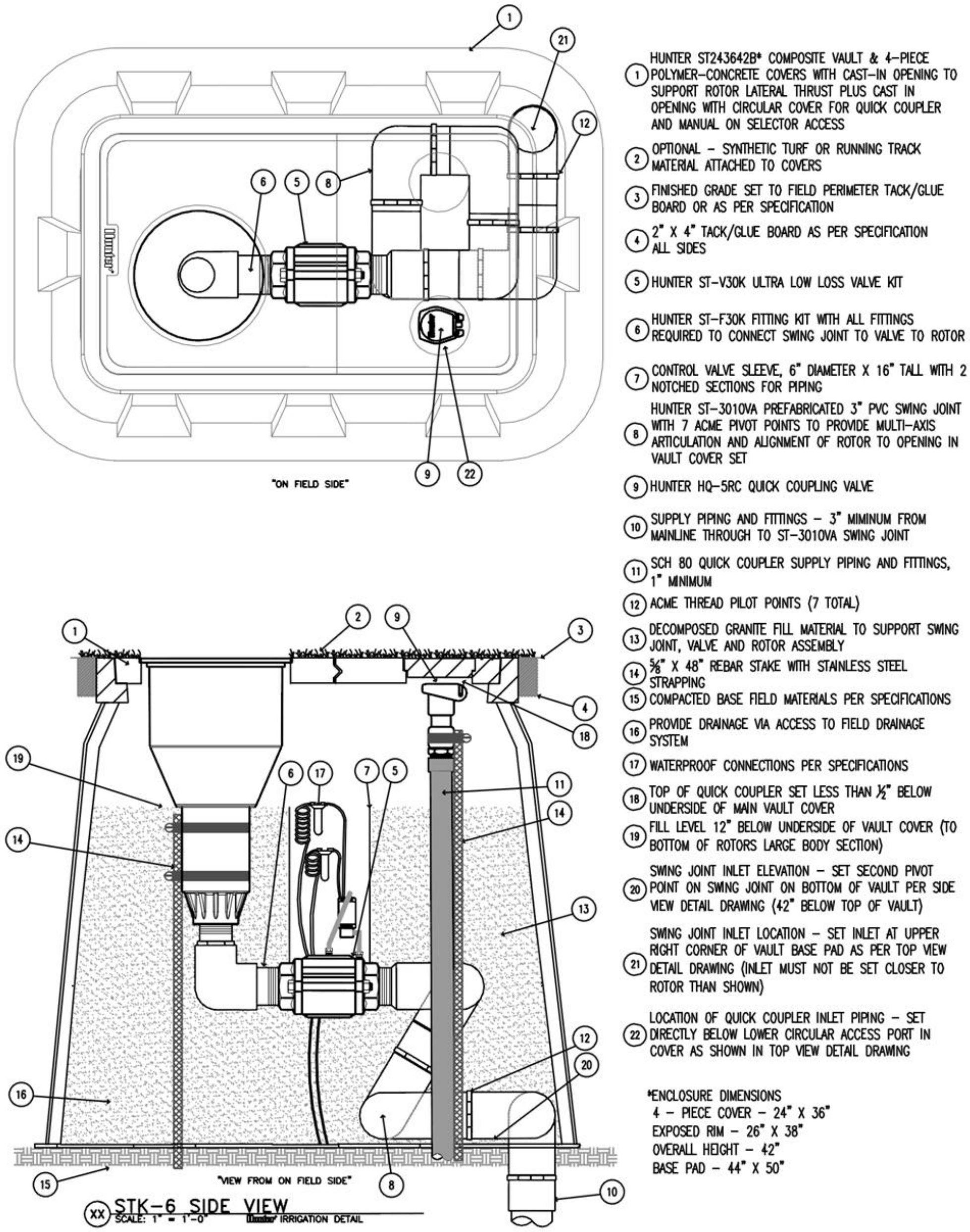

Fig. 5

Component Accessibility – For the end-user, one of the prime considerations is long-term serviceability of the irrigation system's components. This of course requires access to those components should repair or replacement be needed. Access to an exposed riser-mounted sprinkler is straight-forward to say the least. Ideally, access to pop-up type sprinklers should be easy as well.

Direct burial of a pop-up sprinkler is intuitive to those in our industry. As a result, some synthetic turf irrigation systems with pop-up sprinklers have been installed directly within the synthetic surface. These have been both block and VIH type sprinklers with either jar-top (threaded) or snap-ring/fastener access to the components within the sprinkler. The concern with this type of installation is the lack of total access. A jar-top sprinkler would require cutting into the synthetic surface even for the simplest of repairs. And of course, traditional VIH sprinklers with top serviceability of limited components and even newer generation models with total top serviceability of all components offer generous access. However, resealing of the body's threaded connection or replacement of a complete sprinkler, a sprinkler body or even the swing joint might be needed at some point in the life of the system. A sprinkler that is directly buried dictates excavation of the synthetic surface for these repairs.

The most common way to solve this dilemma is to place as many of the irrigation components as possible within subsurface vaults. This allows the service technician total access without excavation and disruption of the surface. Ideally these vaults are large enough to allow access to the sprinkler, the valve and also to the swing joint's point of connection to the main or sub-main. These vaults are usually covered with the synthetic turf carpet and the infill material is worked in at the same time as the rest of the field. This creates a seamless and safe transition over the installed vaults (Figs. 2 & 3).

If and when needed, the vault covers can be removed to service the components within. The clean transition can easily be restored once the covers are replaced using normal field maintenance grooming techniques and equipment. Unlike other enclosures that surround a field like those needed for electrical and public address needs, access to the irrigation vaults should be extremely rare. As a result there is no need for specialized barriers on the vault covers to prevent infill migration. Some end-users prefer to leave the synthetic turf off the covers altogether. The thought in these instances is to make them visible so a player running towards them can see them and take evasive action.

Sprinkler Support and Elevation to Grade – Whether riser-mounted or pop-up, these high-flow, high-pressure sprinklers create a tremendous amount of lateral thrust. Support for the riser-mounted sprinkler must come from robust free-standing metal risers and/or brackets attached to structures. For the pop-up within a vault, it is the vault's cover that must provide the lateral thrust support. Typical installations will have a properly sized hole created in the cover for the sprinkler to fit within.

With a swing joint mounted below the sprinkler, it is possible for the sprinkler to move up or down slightly over time. For this reason it is critical for the vault's cover to be adequately thick in order to maintain ongoing support if the sprinkler moves a little. Metal plate type covers will not work properly unless a support ring is created & welded to the underside. A more common option is a concrete or polymer-concrete cover which is usually two or three inches thick. The hole in a standard concrete cover can be created in the field with a properly sized circular hole saw. However, once the hole is created the standard concrete cover may be more prone to breakage due to the narrowed wall sections about the perimeter of the cover. On the other hand, polymer-concrete covers are much stronger & considerably more durable with the sprinkler hole section removed. The down side is the material is so strong and durable that cutting the hole is near impossible in the field. As a result, pre-casting polymer-concrete covers with the hole in the correct location is highly desirable.

Setting the sprinkler to proper grade and at the same time perfectly within the hole in the cover can be extremely challenging. This is due the fact that during this process the sprinkler is raised & lowered while attached to the swing joint in order to set the proper elevation to grade. The problem is that this movement also moves the sprinkler's relative position within the vault. So the installer is faced with two options.

One option is to set the elevation of the sprinkler first and then brace & lock it into position with rebar and stainless steel strapping. Once the sprinkler is in place the hole is cut into the cover to match the sprinkler's location. This option works well with the only downside being the time required to create the cover openings in the field and, the net result that every cover has a customize hole location. Replacement covers would require that this custom location to be recreated. A further complication might arise if the vault itself settles after installation.

The other option is to add up, down, forward, backward and side-to-side articulation to the swing joint. With a fully articulating swing joint the sprinkler can be placed perfectly within a pre-cast hole in the cover and all covers can have the hole in the same location. This configuration also makes it possible to easily adjust and correct the sprinkler's elevation to grade at any time in the future or, even replace the sprinkler with one that has a physically different body length.

***Drainage* –** Properly designed modern-day synthetic sports fields include a highly efficient drainage system. They have the ability to rapidly percolate rain or irrigation into the system in order to maintain optimum playability and to keep the infill material from being washed off the field. These systems will usually route the water to the perimeter edges of the field and into the looped main drainage line. Running tracks around fields are often design to drain to the inside edge of the track adjacent to the irrigation vaults. The designs of these drainage systems can be problematic for the irrigation vaults that surround the field. Some configurations can allow the water to enter the vault, either from above or below, and fill them up. With highly compacted soils surrounding the vault the water might remain and then stagnate. Consideration should be given as to whether this potential exposure exists. If so, the bottom of the irrigation vault needs to be connected to the drainage system such to provide draining of the vault.

***Control* Systems –** Many synthetic turf irrigation systems include some form of traditional irrigation controller and, these systems exist in both conventional and decoder control configurations. However, these controllers alone don't always satisfy the needs of the end-user that must manage the irrigation timing and cycling of these systems. This is because many times it is not the turf manager or irrigator that activates the sprinklers. Often it is someone on the coaching staff who is charged with cooling down the turf prior to practice or someone in the recreational league for a sport who is asked to take on this responsibility during Saturday games. The bottom line is these people typically have no knowledge of how to initiate a manual cycle on a controller. These people need a simple and easy means to activate the sprinklers. This is generally accomplished in three ways.

Manual Controller – sometimes the synthetic field is installed with a manual controller. This lockable pedestal or wall-mounted controller is installed off the field but close by. It is equipped with manual push buttons to activate & deactivate each valve. This approach while fairly simple requires that someone stay at the controller during all irrigation if players are on the field.

Remote Control – another option is to install a simple to use hand-held remote control for the system. This is convenient since the operator can be on the field while initiating and deactivating the sprinklers.

Manual Activation – some end-users prefer the simplicity of manually activating the sprinklers from the control valve's manual bleed feature.

The logistics of activating sprinklers while people are on the field are worth noting. Some facilities use the public address system to move people off the field in preparation for irrigations cycles. Some designs have even included a system of smaller sprinklers that activate as a warning prior to the activation of the larger sprinklers. Still others rely on simple verbal warnings and ushering of people & players away from the soon to be activated sprinklers. Regardless of how it is to be accomplished, consideration needs to be given to this important logistic. This consideration takes on particular importance with multi-field sports complexes where crowds are moving in and out at varying times as games on fields start and end.

Isolation Valves and Mainlines – Synthetic turf irrigation system designs vary considerably as it relates to mainline isolation valves. Some rely on a single shutoff valve located at the pump station. After all, they say, "it's not as if we need to maintain irrigation in other areas during repairs - - - the turf isn't going to die." Other designs include 2 or 3 isolation valves around the looped perimeter mainline for "good measure." Still others include 1 isolation valve at every vault for optimum isolation. All three seem to be plausible & appropriate solutions until you take a closer look.

An important factor to consider in synthetic turf irrigation systems using subsurface vaults to house the sprinklers is the mainline depth relative to the depth of the vault. Some vaults are as deep as 42" which means the sub-main enters the vault at a depth slightly below that. If the mainline depth is at 36" the contractor can be faced with a difficult situation during installation.

Typically the mainline is installed first and flushed with water. Sub-main access points to the vaults are then plugged with perhaps a PVC cap slipped onto the pipe stub until such time as the vaults get installed. Once vault installation begins it can be very difficult to plumb and make the solvent weld connections with an ongoing flow of water coming from the mainline. The solution to this potential problem is either placing the mainline lower than the vault's plumbing or, installing an isolation valve at each vault.

Similarly, this situation can cause problems in the future for the end-user making repairs within the vault as well. With the mainline elevation higher than the vault's plumbing the entire mainline will drain into the vault as soon as any pre-valve component is cut or removed. Again the solution is simple. Either ensure that the mainline's elevation is below the vault's plumbing or install an isolation valve at each vault.

Another important thing to consider is the mainline's physical location as it relates to the location of the vaults. The mainline should never be running directly beneath the vaults. This is because during sprinkler installation rebar staking is typically driven into the ground to facilitate banding & securing the sprinkler in place. With the mainline directly below the vault this could create an unfortunate mishap. Or, consider the end-user making repairs years down the road that has no knowledge of the mainline's location. An extra piece of rebar won't hurt - - - right?

Supplemental Water Use – Synthetic turf irrigation systems are most often used to cool the surface as discussed earlier. However, some users make use of the system to also wash down & clean the field. Infill dust and in particular bacteria removal are cited as reasons for this practice. This even though research has shown that Staphylococcus aureus, a common human bacterium, does not survive well in the higher heat and exposed U.V. conditions typically associated with synthetic turf (McNitt, 2008). Some have even suggested using injector systems to apply disinfectants across the field through the irrigation system.

A very common practice on synthetic fields, whether irrigated or not, is to have quick coupler valves positioned in at least two locations around the field. One reason is to have a potable water supply source for the team bench areas on the field. Another reason is to have a water supply source to take care of spills & associated problems that can happen anywhere on the field's surface. For this reason an emerging trend is to have multiple quick coupler valves around the field such that a 100 foot hose can reach anywhere on the surface.

Another reason for the quick couplers is to source the water for removal of water-soluble paint from the field. During special events these paints are often applied for various reasons. Lines are also painted on the synthetic surface for what are considered peripheral sports by the end-user entity. Many synthetic fields like high school football fields host multiple sporting events throughout the year. If every sport's lines and boundaries were included as part of the synthetic fibers in a field, both players and spectators could become confused during a game and - - - most agree that too many lines just doesn't look very attractive on a field.

For these reasons, many synthetic turf fields only include the lines in the turf fibers for the top 2 popular sports. The rest of the sports have the lines painted on the field only during the specific months of that sport's season. Once the season is over a water source is generally required to remove the paint.

A common mistake made during installation of the quick coupler valves is to place them too low in the vault. This is a problem because a removable cover within the vault's main cover is often used to access the quick coupler below. If the quick coupler valve is installed too low it will be impossible to attach the key to the quick coupler from above. All quick couplers need to be installed as close to the underside of the vault's cover as possible.

Installer Experience – This author is aware of synthetic turf irrigation projects that were fraught with problems. Multiple irrigation leaks and associated plumbing issues that didn't appear until well after the fields were completed and signed off. I saw one field where the whole corner of the field raised up seemingly a foot high with a bubble of water underneath the carpet. Issues like this under normal circumstances are troubling. However, add to this the complexity of the synthetic surface & sub-surface and it can be a recipe for disaster for the contractor and end-user.

Repairs to plumbing under these fields are very expensive for the contractor. In most situations the contractor is only allowed to make the actual plumbing repair yet they are responsible for paying the synthetic turf experts to restore the field to its original elevations and condition. The contactor might also be exposed to the loss-of-use costs that the end-user endures. For the proud end-user customer with their brand new synthetic field there is nothing worse than the embarrassment of problems right after spending a million dollars for the field.

The bottom line is that any contractor installing a synthetic turf irrigation system needs to be well trained, well versed and very experienced in installing large turf irrigation. No shortcuts can be taken and quality of installation is far more important that speed of installation.

CONCLUSION

Irrigating synthetic turf in order to cool the playing surface appears to be here to stay. In many ways, the irrigation systems for these synthetic fields are no different than those for natural turf irrigation. However, there are unique aspects and challenges associated with the synthetic system that must be taken into consideration during the design, installation and operational phases of these systems. Irrigating synthetic sports fields represents an ongoing and growing opportunity potential for the irrigation industry. Taking the time to fully understand the differences between natural turf and synthetic turf systems will turn this potential opportunity into a successful reality.

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Soil Moisture Sensor Irrigation Controllers Response to Different Temperatures and Salinities

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Abstract. *Soil moisture sensor systems (SMSs) have demonstrated that can reduce irrigation application in Florida. However, SMSs have not been tested under Florida soils, irrigated with reclaimed water, which contains salts that can affect the measured soil water content (SWC). The objective of this research was to test different commercially available SMSs under controlled conditions, and analyze their responses under different levels of water salinity and temperature. Three brands/models were selected for this experiment: Acclima/SCX, Baseline/WaterTec S100, and Dynamax/IL200-MC. Containers filled with a sandy soil were manufactured so that they could be saturated from the bottom to minimize entrapped air and fitted with sintered metal filters to allow vacuum application for water removal in a timely manner. The containers were installed in a controlled-temperature chamber and were saturated and dried down across three temperatures (10, 25, and 35ºC) and three electrical conductivities (0.0, 0.7, and 5.0 dS/m). Each container was placed on a platform-scale to determine soil-water loses, by weight variation over time. The scale readings were compared to the SMS readings, and calibration curves were developed through regression analysis. Preliminary outcomes show that most replications resulted in linear regressions with R^2 values higher than 0.94, indicating that all the units tested had a high precision for measuring the SWC, but calibration is necessary to achieve accurate readings. Increasing the temperature from 25ºC to 35ºC and/or the salinity from 0.0 to 0.7 dS/m neither affect the accuracy nor the precision of the different SMS systems, when SWC values below 15% were considered.*

Keywords. Reclaimed water, salinity, soil moisture sensor, soil temperature, soil water content.

Introduction

New commercially available soil moisture sensor systems (SMSs) consist of a probe inserted in the root zone and a controller that is connected to the time clock, or timer, of an automatic irrigation system. In the controller, the user can set a soil water content threshold and, therefore, the SMS will allow or bypass a scheduled irrigation cycle, depending on the soil water content at the programmed start time.

Most of these SMSs respond to electromagnetic properties of the soil, more specifically, to the dielectric permittivity. Of all the constituents of the soil, water is the only one with a high dielectric permittivity. Therefore, changes in the water content have the most significant effect on the total permittivity of the soil. These SMSs operate by sending a signal to the soil environment. This signal is distorted by the amount of dielectric permittivity, which is then translated into a specific soil water content, usually displayed in the SMS controller as volumetric soil water content (SWC). If the SWC is above the threshold set in the controller (too wet) the SMS will bypass that scheduled irrigation cycle, and vice versa.

SMSs have demonstrated that they can save irrigation water in Florida (Cardenas-Lailhacar et al., 2008 and 2010; Haley and Dukes, 2011; McCready et al., 2009). However, SMSs have not been tested under Florida soils irrigated with reclaimed water. This source of irrigation usually contains more salts than potable water, which can affect the dielectric permittivity and, hence, the readings of SMSs when measuring SWC. Likewise, temperature affects the electric properties of the soil, which can alter the accuracy of the SMS readings (Evett et al., 2006). Moreover, Cardenas-Lailhacar and Dukes (2010) tested the precision of different SMSs under field conditions, and found statistical differences between some brands, and sometimes even within replicates of a SMS brand.

The objective of this research was to test different commercially available SMSs under controlled-temperature conditions, and analyze their responses and readings under different levels of water salinity and temperature. This paper presents preliminary results.

Materials and Methods

This study was conducted in a controlled-temperature chamber at the University of Florida in Gainesville. Inside the chamber, platform scales with a resolution of 0.02 kg were set (Champ SQ base with CW-11 Indicator [Ohaus Corp., NJ]). Three SMS brands/controllers/probes were selected for this experiment: Acclima/SCX/Digital TDT (Acclima Inc., ID), Baseline/WaterTec S100/biSensor (Baseline Inc., ID), and Dynamax/IL200-MC/SM200 (Dynamax Inc., TX). The controllers of all these systems display the SWC of the sampled soil.

Plastic containers with overall dimensions of 55 x 38 x 25 cm high were packed with 28 l of air-dried soil extracted from the top 15 cm of an Arredondo fine sand (loamy, siliceous, semiactive, hyperthermic Grossarenic Paleudult) (Thomas et al., 1985; USDA 2007). The containers were built such that they could be saturated with water from the bottom (to minimize entrapped air that could affect the SMS readings) and, afterwards, to allow the free drainage of excess water. In addition, sintered metal filters were placed at the bottom of the containers to allow vacuum application for water removal in a timely manner. Each container was placed over a platform scale to determine soil water lose, by weight variation over time. The scale readings were corrected through the gravimetric method (Gardner, 1986) from soil samples cores of 52.5 mm diameter and 103.4 mm high at the end of each test. Soil bulk densities ranged from 1.35 to 1.49 g/cm3. The scale readings were transformed to SWC by mass balance, and then compared with the SMS readings. Calibration curves were then developed through regression analysis.

The containers were saturated and dried down across three temperatures: 10, 25, and 35ºC. The water applied had three levels of salinity: 0.0, 0.7, and 5.0 dS/m. Each SMS brand/controller/probe had three replicates. After developing the regression analysis for each, a contrast analysis was performed between the treatments within a brand, to evaluate if there were statistical differences when increasing the temperature and/or the salinity. These analyses were performed using the statistical analysis software (SAS, 2008) and the Statistica software (StatSoft, 2008).

Results and Discussion

Results presented here do not include all the possible combination treatments between temperature and salinity that will be conducted. This manuscript includes the combinations of 0.0 dS/m at 25ºC, 0.0 dS/m at 35ºC, and 0.7 dS/m at 35ºC.

Figures 1, 2, and 3 show examples of the SWC measured by the scales versus the Acclima, Baseline, and Dynamax sensors readings, respectively, for the combination of 0.0 dS/m at 35ºC. For each treatment, a linear regression was calculated, and the resulting equations and R^2 values are given. Table 1 summarizes the results of the regression analyses for the treatments presented here.

Linear R^2 values greater than 0.92 were obtained in every treatment, except for Dynamax at 0.0 dS/m and 35ºC, which resulted in R^2=0.81.

These values indicate that the different brands showed a high precision to estimate the SWC at the salinities and temperatures tested. Moreover, linear R^2 values greater than 0.94 were verified for every single replication (data not shown), which indicate that all the individual replications tested had a high precision for measuring the SWC. This can be visualized in Figures 1 to 3, where the curves of each individual replicate can be easily followed. Moreover, Figure 3 shows that two of the replicates from Dynamax had very similar readings, but the other replicate (even though it had an R^2 value of 0.94) had a different slope, which finally drove the combined coefficient of determination of the treatment to a lower value (0.81) compared to the R^2 values of the individual replicates.

Even when the different brands resulted in high precision readings, none of the slopes and intercepts (Table 1) matched exactly the 1:1 line (slope=1 and intercept=0), so calibration of these systems is necessary if accurate readings are required out of the box without external calibration.

Table 2 shows the contrast analyses that were performed between treatments within a brand to see if different temperature and/or salinity would produce different SMS readings. Results show that increasing the temperature from 25ºC to 35ºC and/or the salinity from 0.0 to 0.7 dS/m did not affect the accuracy nor the precision of Acclima and Baseline systems. In the case of Dynamax tested at 35ºC, however, increasing the salinity from 0.0 to 0.7 dS/m had a significant effect on the slope of the regression. These preliminary results suggest that Dynamax systems are more sensitive to changes in the salinity of the soil environment, and site-specific calibrations should be performed to achieve an adequate control of irrigation.

Because of the experimental design, the soil in the plastic boxes could retain water above the normal field capacities found in the sandy soils of Florida, which are usually below 15%. Therefore, a more detailed analysis was performed on the results below 15% of SWC, determined by the scale readings. Figures 4, 5, and 6 show, as examples, the individual replicates and the combined results of all replicates for brands Acclima, Baseline, and Dynamax, respectively; at 0.0 dS/m and 35ºC. A linear regression, and the resulting equation and R^2 value are presented below the 1:1 line. Even when the linear R^2 values for the individual replicates, in this example, were above 0.94, it is clear that the individual replicates had sigmoidal shape curves. Thus, a polynomial regression was also fitted to increase the coefficient of determination and to obtain a better calibration curve fit. The R^2 values of these examples are presented above the 1:1 line of Figures 4 to 6. It can be seen that all replicates resulted in R^2 values 0.995 or above, reaching very precise SWC readings. However, when the replicates are combined, the R^2 values tend to decrease, showing that differences exist between the units when reading the same SWC. Table 3 shows the results by treatment considering linear and a 5th order polynomial regression curves. In general, the Acclima and Baseline treatments resulted in higher linear R^2 values than Dynamax. If a fifth order polynomial regression is fitted, higher R2 values were obtained for all the treatments. If necessary, performing individual calibrations on these sensors could result in very precise and accurate readings, which is of more relevance in the Dynamax sensors. Table 4 shows the contrast analyses between treatments within a brand, for SWC values below 15%, to see if different temperature and/or salinity would produce different SMS readings. In these cases, none of the treatments resulted in significant differences (P-values>0.05). Therefore, for SWC below 15%, increasing the temperature from 25ºC to 35ºC and/or the salinity from 0.0 to 0.7 dS/m did not affect the accuracy nor the precision of the different SMS systems.

Conclusions

These results corroborate that the laboratory design is adequate for verifying the precision and accuracy of the SMSs tested over a range of salinity values, water contents, and temperatures.

Linear R^2 values of 0.94 or above were verified for every single replication, indicating that all the units tested had a high precision for measuring the SWC. However, neither the slopes values were equal to one, nor the intercepts equal to cero, so calibration of these systems is necessary to achieve an adequate control of irrigation, or if accurate readings are required.

Increasing the temperature from 25ºC to 35ºC and/or the salinity from 0.0 to 0.7 dS/m did not affect the accuracy nor the precision of the different SMS systems when SWC values below 15% were considered. For higher SWC values, the Dynamax systems tended to be more sensitive to changes in the salinity of the soil environment.

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Table 1. Regression analysis by treatment .

Brand	Treatment		Regression Analysis		
	dS/m	ºC	R^2	Slope	Intercept
Acclima	0.0	25	0.980	0.863	4.02
	0.0	35	0.981	0.982	2.41
	0.7	35	0.986	0.940	3.66
Baseline	0.0	25	0.982	0.910	-2.68
	0.0	35	0.977	1.004	-2.40
	0.7	35	0.931	0.930	0.12
Dynamax	0.0	25	N/A	N/A	N/A
	0.0	35	0.811	1.210	2.76
	0.7	35	0.921	1.083	5.00

N/A = not applicable

Table 2. Contrast analysis between treatments within a brand.

Brand	Analysis	Treatment Contrasts					P-value
		dS/m	ºC		dS/m	ºC	
Acclima	Regression	0.0	25	vs.[z]	0.0	35	0.1765
	Regression	0.0	35	vs.	0.7	35	0.1990
	Regression	0.0	25	vs.	0.7	35	0.5292
Baseline	Regression	0.0	25	vs.	0.0	35	0.8794
	Regression	0.0	35	vs.	0.7	35	0.3253
	Regression	0.0	25	vs.	0.7	35	0.2557
Dynamax	Regression						0.0004
	Intercept	0.0	35	vs.	0.7	35	0.1195
	Slope						<0.0001

[z]vs. = versus

Table 3. Linear and fifth order polynomial regression analysis by treatment, for soil water contents below 15%.

Brand	Treatment		Linear			5th order Polynomial
	dS/m	ºC	R^2	Slope	Intercept	R^2
Acclima	0.0	25	0.891	1.192	1.15	0.934
	0.0	35	0.928	1.140	1.39	0.945
	0.7	35	0.919	1.065	2.50	0.984
Baseline	0.0	25	0.967	1.142	-5.22	0.988
	0.0	35	0.953	1.383	-5.48	0.976
	0.7	35	0.885	0.955	-1.90	0.948
Dynamax	0.0	25	0.937	0.918	1.71	0.943
	0.0	35	0.777	1.677	-0.30	0.813
	0.7	35	0.751	1.450	2.19	0.795

Table 4. Contrast analysis between treatments within a brand, for soil water contents below 15%.

Brand	Analysis	Treatment Contrasts					P-value
		dS/m	ºC		dS/m	ºC	
Acclima	Regression	0.0	25	vs.	0.0	35	0.8719
	Regression	0.0	35	vs.	0.7	35	0.0520
	Regression	0.0	25	vs.	0.7	35	0.2778
Baseline	Regression	0.0	25	vs.	0.0	35	0.5778
	Regression	0.0	35	vs.	0.7	35	0.2435
	Regression	0.0	25	vs.	0.7	35	0.3671
Dynamax	Regression	0.0	35	vs.	0.7	35	0.9125

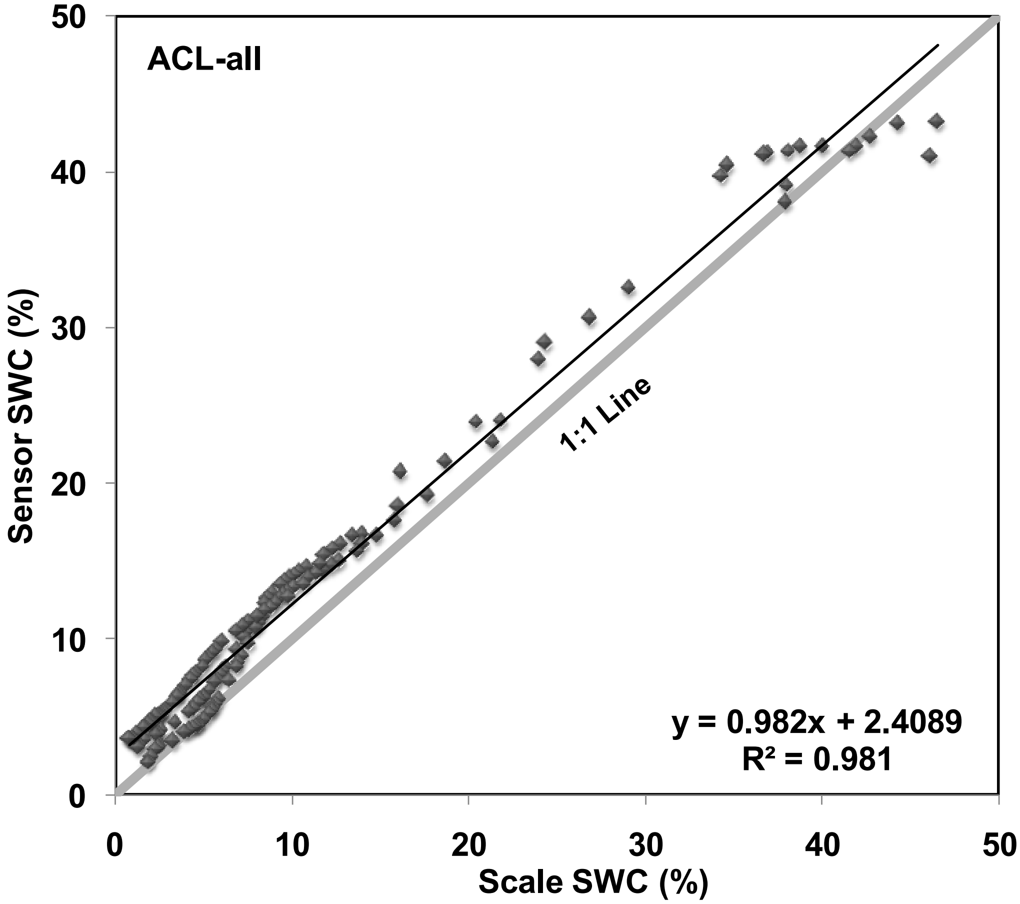

Figure 1. Acclima sensors readings versus soil water content measured by the scales at 0.0 dS/m and 35ºC. A linear regression fit is represented as a solid line, and the resulting equation and R^2 value are given.

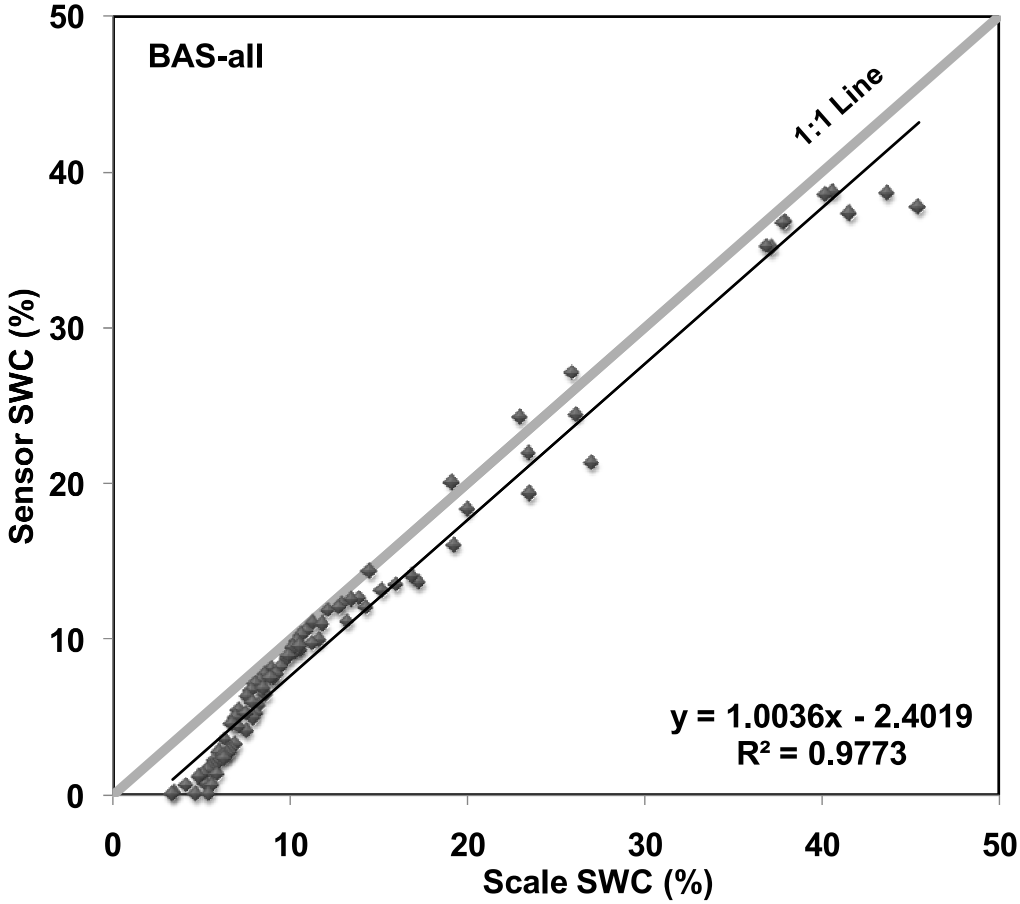

Figure 2. Baseline sensors readings versus soil water content measured by the scales at 0.0 dS/m and 35ºC. A linear regression fit is represented as a solid line, and the resulting equation and R^2 value are given.

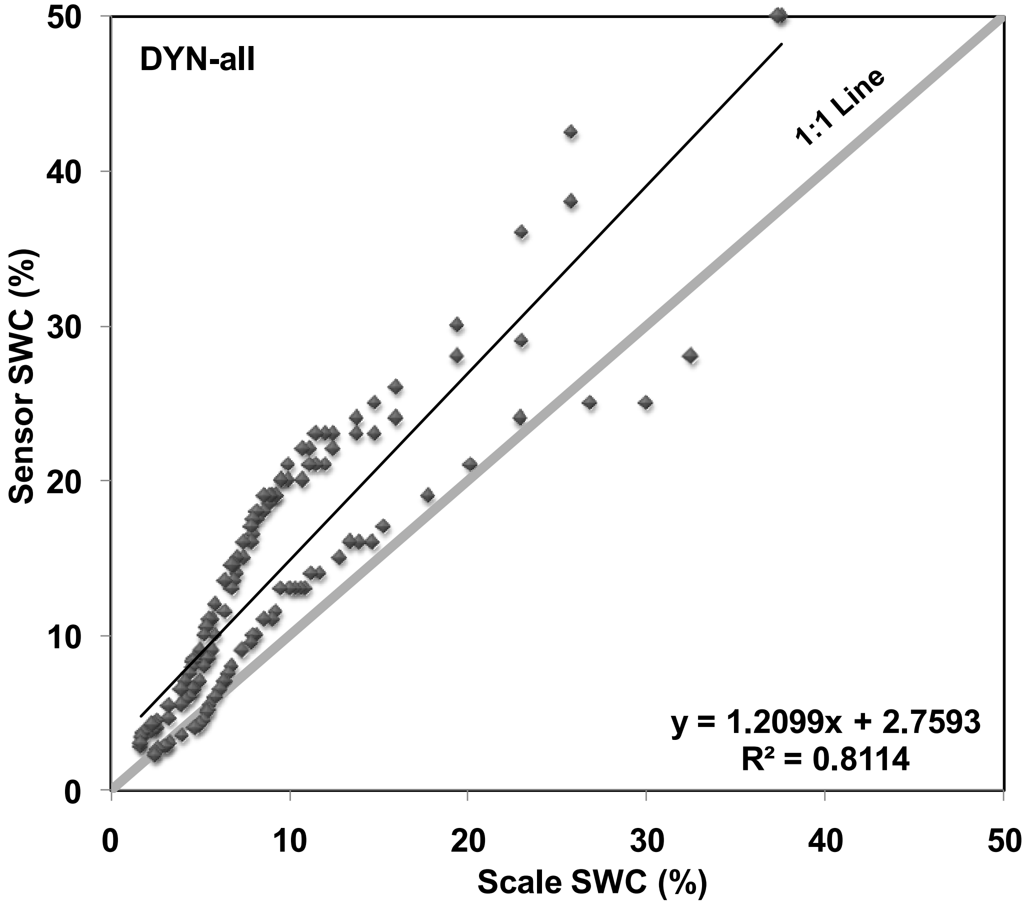

Figure 3. Dynamax sensors readings versus soil water content measured by the scales at 0.0 dS/m and 35ºC. A linear regression fit is represented as a solid line, and the resulting equation and R^2 value are given.

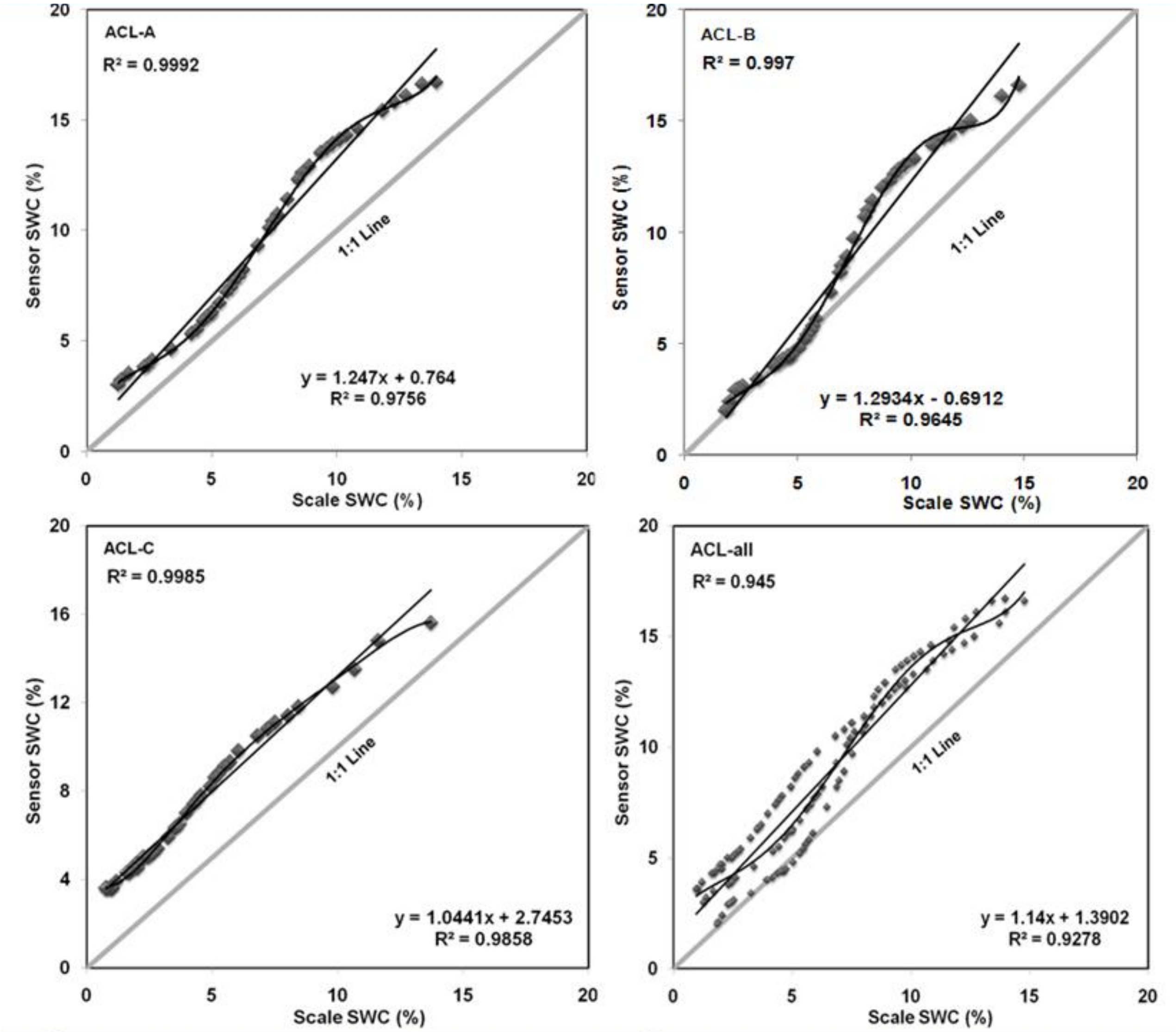

Figure 4. Soil water content below 15% as measured by the scales versus the individual replicates of the Acclima sensors (ACL-A, ACL-B, and ACL-C), and the combination of them (ACL-all), readings at 0.0 dS/m and 35ºC. A linear regression and the resulting equation and R^2 value are presented below the 1:1 line. A polynomial regression was also fitted to increase the R^2 value, which is presented above the 1:1 line.

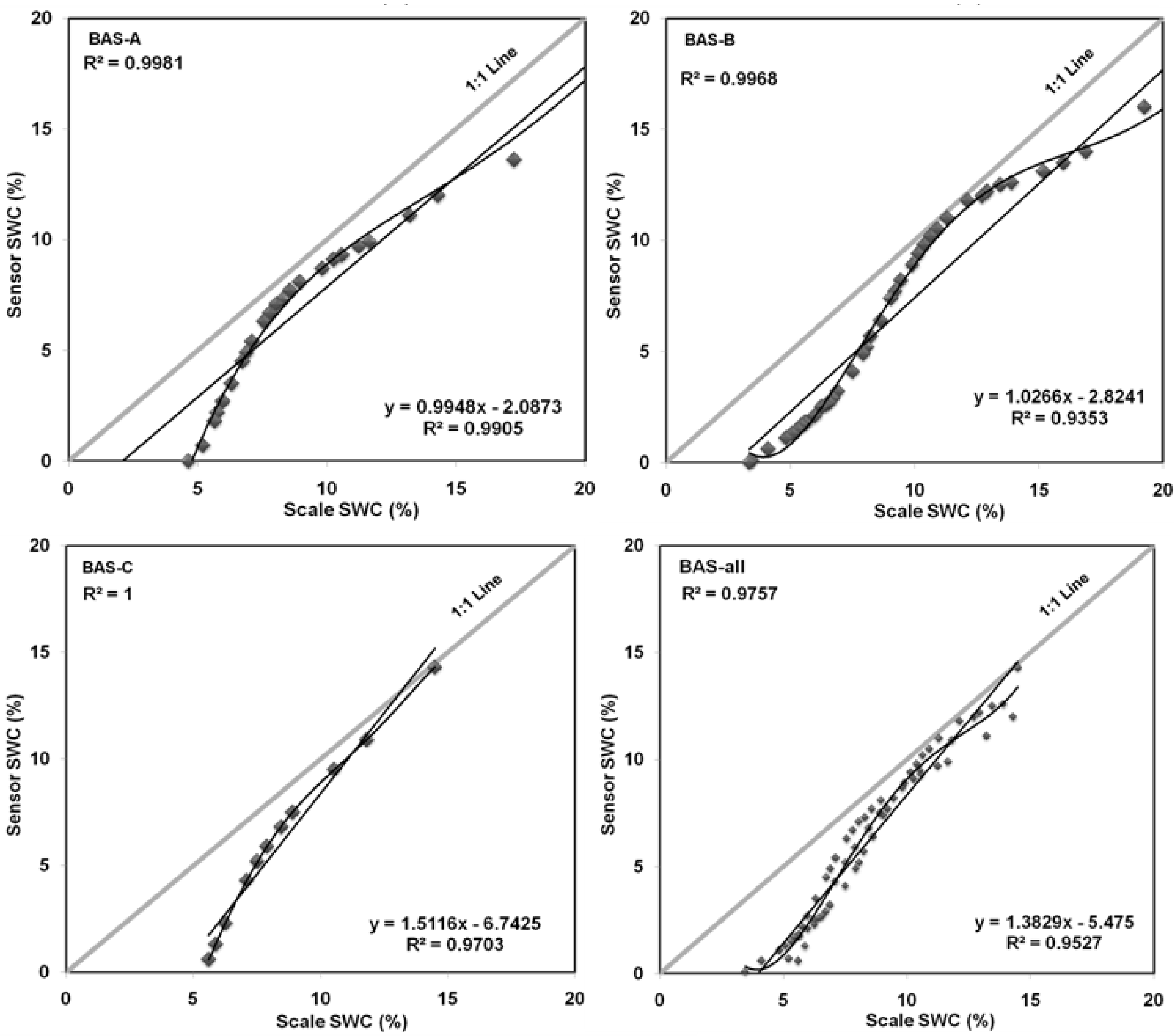

Figure 5. Soil water content below 15% as measured by the scales versus the individual replicates of the Baseline sensors (BAS-A, BAS -B, and BAS -C), and the combination of them (BAS - all), readings at 0.0 dS/m and 35ºC. A linear regression and the resulting equation and R^2 value are presented below the 1:1 line. A polynomial regression was also fitted to increase the R^2 value, which is presented above the 1:1 line.

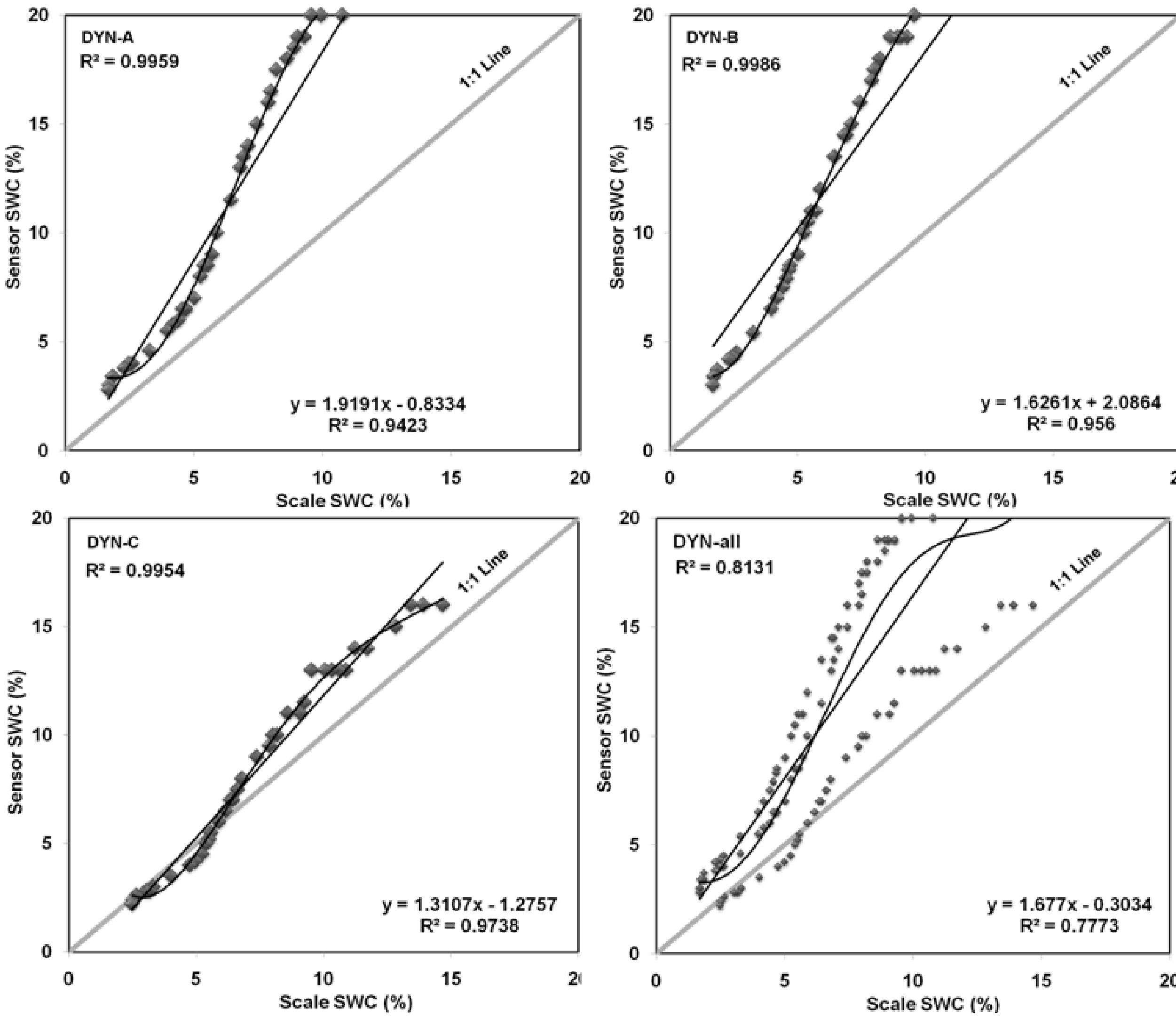

Figure 6. Soil water content below 15% as measured by the scales versus the individual replicates of the Dynamax sensors (DYN-A, DYN -B, and DYN -C), and the combination of them (DYN -all), readings at 0.0 dS/m and 35ºC. A linear regression and the resulting equation and R^2 value are presented below the 1:1 line. A polynomial regression was also fitted to increase the R^2 value, which is presented above the 1:1 line.

Catch Can Placement, Height, and Nozzle Trajectory: Effects on Distribution Uniformity

Mary J. Hattendorf[1] and Mark A. Crookston

Abstract. *Catch can audits are a critical component of irrigation system evaluations. Recent experiences with catch can height and sprinkler nozzle trajectory showed that these variables were very important factors in distribution uniformity and should be considered in irrigation system performance metrics. Lower quarter distribution uniformity (DU_{lq}) was evaluated for nozzle trajectories ranging from 20^o to 27^o and catch can heights relative to nozzles. A small (30' x 15') indoor irrigation system was used to conduct the tests using Toro Precision Series Spray Nozzles (T- Spray, 27^o trajectory), Toro Precision Series Rotating Nozzles (T-RN, 20^o trajectory), and MP Rotators (MP-R, 25^o trajectory). Horizontal catch can placement relative to nozzles followed IA audit guidelines and was not varied based on pre-test evaluations. Twenty-eight Cal-Poly catch cans were uniformly distributed throughout the test system and leveled. Riser heights were varied to simulate catch can rims at ground level (CCRG) and catch can tips at ground level (CCTG). Distribution uniformities for T-RN ranged from 70% (CCRG) to 50% (CCTG); DU_{lq} ranges for MP-R at CCRG were 81% and CCTG, 79%; $D_{lq}U$ ranges for T-Spray at CCRG and CCTR were 78% and 77%, resp. The results indicate that the true performance of the 20^o trajectory nozzle at soil level was not captured at normal catch can height and that alternate methods of performing irrigation audits on low trajectory nozzles should be explored.*

Keywords Distribution uniformity, sprinkler trajectory

Introduction

Sprinkler nozzles are designed for certain radius of throw, ranges of operating pressure, arc, and stream trajectory. The need for greater irrigation efficiency, uniformity, and better water conservation in landscape irrigation has led to many improvements in nozzle technology. One of the major improvements has been the MP Rotator nozzle, which has multiple rotating streams of water, matched precipitation rates, and typically high distribution uniformities (DU_{lq}).

Very low trajectory nozzles are useful in windy conditions or in turf areas where higher trajectory streams or spray could be blocked or adversely affect other vegetation. At Northern Water, an excellent area for a low trajectory, high uniformity nozzle is the turf under the weather station. This zone is circular and often has irrigation distribution problems. Because of

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the weather station, it is undesirable to have irrigation sprays or streams at trajectories that could directly affect instrumentation or be misted or blown into the instrumentation by wind.

However, initial experiences with a low trajectory nozzle (Toro Precision Series Rotating Nozzle, 20^{o} trajectory), showed that evaluation of these nozzles would be difficult under normal conditions in the field, as catch can rim heights are usually several inches above the ground.

This low trajectory nozzle sprayed the sides of the catch cans in our initial indoor observations regardless of the horizontal distances of the catch cans from the nozzles. A different approach was required to properly evaluate the low trajectory nozzle performance and its potential application at our weather station circle.

Methods

We evaluated the DU_{lq} of three sprinkler nozzles (Table 1) with different spray or stream trajectories (Toro Precision Series Spray Nozzles (The Toro Company, 2011a), Toro Precision Series Rotating Nozzles (The Toro Company, 2011b), and MP Rotators (Hunter Industries, 2011) using a small indoor irrigation system.

Table 1. Nozzles and part numbers.

	MP Rotator **(25^{o})**	Toro Precision Spray Nozzle **(27^{o})**	Toro Precision Rotating Nozzle **(20^{o})**
90 deg	MP-2000 Black	O-T-15-Q	PRN-TA
180 deg	MP-2000 Black	O-T-15-H	PRN-TA

The irrigation system was 30 feet by 15 feet, with a 90^{o} nozzle at each corner and a 180^{o} nozzle in the center of each 30' side (Fig. 1). The catch can stands were built to accommodate several types of catch cans, including Cal-Poly catch cans, which were used in these tests. The catch can stand heights and supports were designed to allow testing of typical sprinkler operational heights of 4" with catch can tips at the system's equivalent of ground level.

Twenty-eight Cal-Poly catch cans were uniformly distributed throughout the test system and leveled. Corner catch cans were placed two feet laterally from the corner sprinkler, then 2 feet into the lengthwise dimension (30' side) of the zone. Subsequent catch cans were spaced 4'4" apart in the lengthwise dimension, and 3'8" apart in the lateral (15') dimension.

It was logistically simpler to change the 6 riser heights than to raise and lower 28 catch can supports, so riser heights were varied to simulate catch can rims at ground level (CCRG) and catch can tips at ground level (CCTG)(Fig. 2). Cal-Poly catch can height is 5.75", so the sprinklers were raised by that amount to simulate catch can rims at ground level. (However, for simplicity, the paper will refer to the catch cans being raised and lowered, as that is the equivalence in a field setting.)

Figure 1. The indoor irrigation system set up for catch can rims at ground level. Each catch can support was shimmed so level was maintained from center to garage doors.

Figure 2. The sprinkler head set up for catch can tips at ground level.

Two runs for each nozzle at each height were conducted. All doors were kept closed during the tests, so wind was not a factor. Operating pressures for each nozzle were kept within manufacturer specifications by observing a pressure gauge installed before the valve and adjusting pressure with the pressure regulator. MP Rotators were operated at 40 psi. The Toro Precision Series Rotating Nozzles were operated at 30 psi and the Toro Precision Series Spray Nozzles were operated at 32 psi. Nozzles and heads were adjusted for proper arc and throw before each run. Runtimes were 30 minutes for MP Rotators and Toro Precision Series Rotating Nozzles. Toro Precision Series Spray Nozzles were run for 15 minutes. All runtimes exceeded Irrigation Association (Irrigation Association, 2010) guidelines for audits.

Results and Discussion

Table 2 shows the results of the 12 irrigation test runs.

Table 2. Distribution uniformity (DU_{lq}) and precipitation rate (PR) for each nozzle at CCRG and CCTG.

	MP Rotator MP 2000 (25 ^{o})		**Toro Precision Series Rotating Nozzle (20 ^{o})**		**Toro Precision Series Spray Nozzle (27 ^{o})**	
	Catch can tips at ground level					
	Run 1	**Run 2**	**Run 1**	**Run 2**	**Run 1**	**Run 2**
DU_{lq} (%)	79	80	49	50	75	77
PR (in/hr)	0.50	0.49	0.44	0.41	1.01	1.02
	Catch can rims at ground level					
	Run 1	**Run 2**	**Run 1**	**Run 2**	**Run 1**	**Run 2**
DU_{lq} (%)	81	81	70	69	78	78
PR (in/hr)	0.51	0.52	0.56	0.59	0.97	0.99

MP Rotators generally have high DU_{lq}; therefore inclusion in this test was an indication of what we could expect from this small indoor system. The MP Rotator performed very well at each catch can height, as did the Toro Precision Spray Nozzle. Trajectories of each were several degrees higher than the 20^{o} trajectory of the Toro Rotating Nozzle.

The change in catch can height from tip at ground level to rims at ground level increased the Toro Rotating Nozzle DU_{lq} from 49 and 50% to 70 and 69%, a substantial increase in performance metrics. When the riser heights simulated catch can tips at ground level, water streams continually hit the side of the catch can. Moving the catch can closer or further away did not alleviate this problem. Also, the precipitation rate was much higher when catch can rims at ground level was simulated, corroborating the visual observations.

It is possible that our indoor system at 15' wide was slightly small for the Toro Rotating Nozzle. At 30 psi, the quarter circle nozzles were specified to have a minimum 17.5' radius. The half-circle nozzles were specified to have radius of 17' at 30 psi. This irrigation system did not perform well at lower than 30 psi. Although the arc and radius were adjusted, the radius in particular was at the limits of its adjustment capabilities.

Precipitation rates of the MP rotator and the Toro Precision Spray Nozzle increased very slightly, but not substantially.

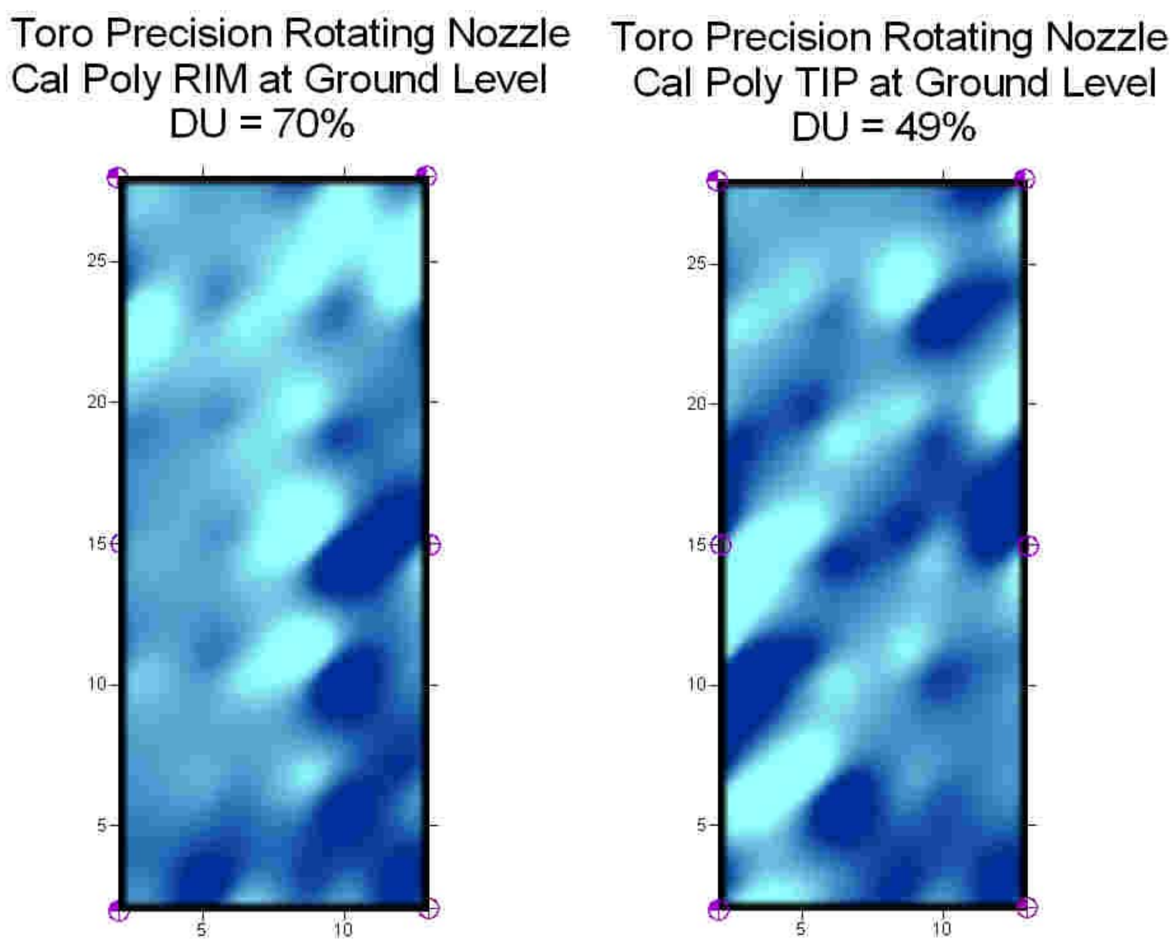

Figure 3. Shaded relief images of catch can volumes for CCRG and CCTG for the Toro Precision Rotating Nozzle.

The shaded relief images show how the Toro Precision rotating Nozzle irrigation was spatially distributed at the two catch can heights (Fig. 3). When the DU_{lq} was 70% and the catch can rim was at ground level, some areas in the lower right clearly received more water, but the rest of the area showed more uniform distribution. The catch can tip at ground level run had a much lower DU_{lq}, 49%, and the lack of uniformity was throughout the area.

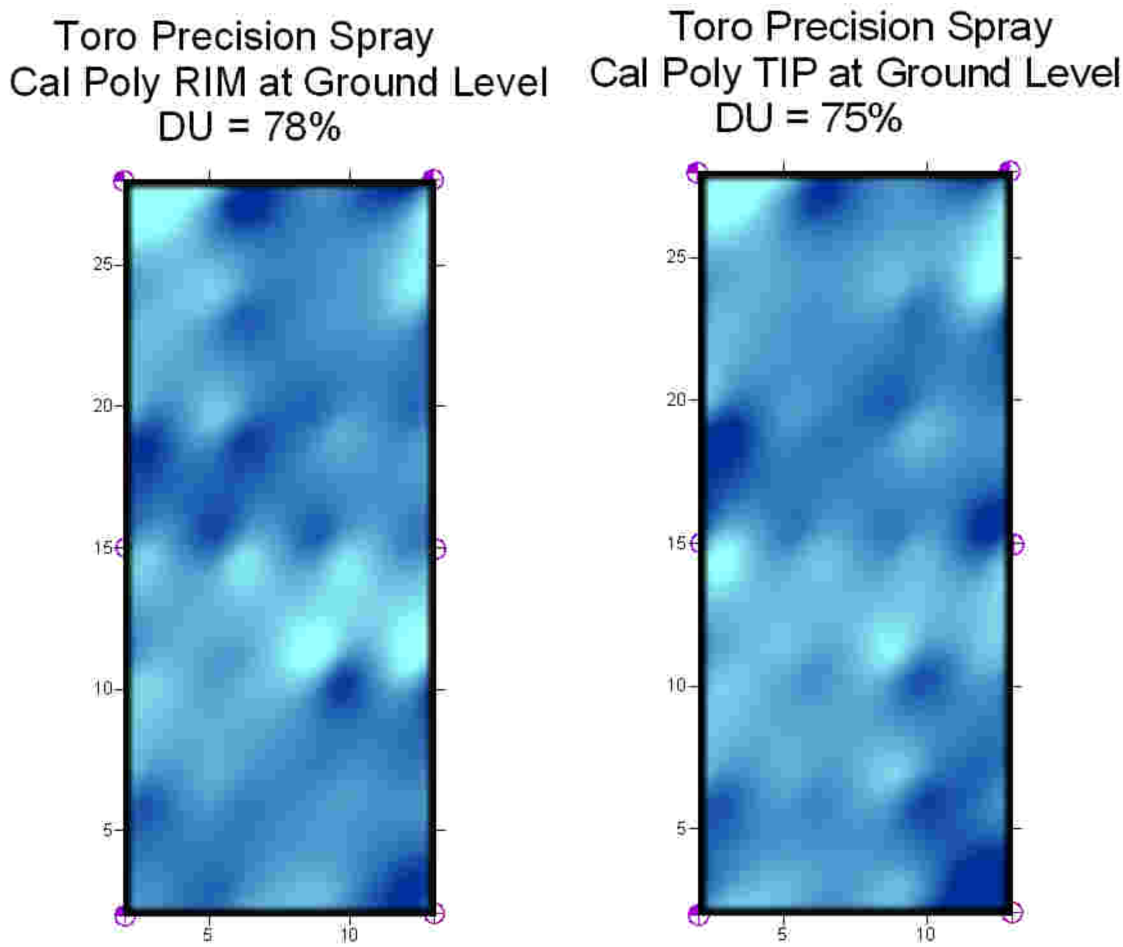

Figure 4. Shaded relief images of catch can volumes for CCRG and CCTG for the Toro Precision Spray.

The Toro Precision Spray Nozzles showed very similar spatial distributions (Fig. 4) across the irrigation zone at each catch can height. Some higher irrigation catches occurred directly in front of one or two of the heads, but otherwise did not show the wide variations that the Toro Precision Rotating Nozzle showed.

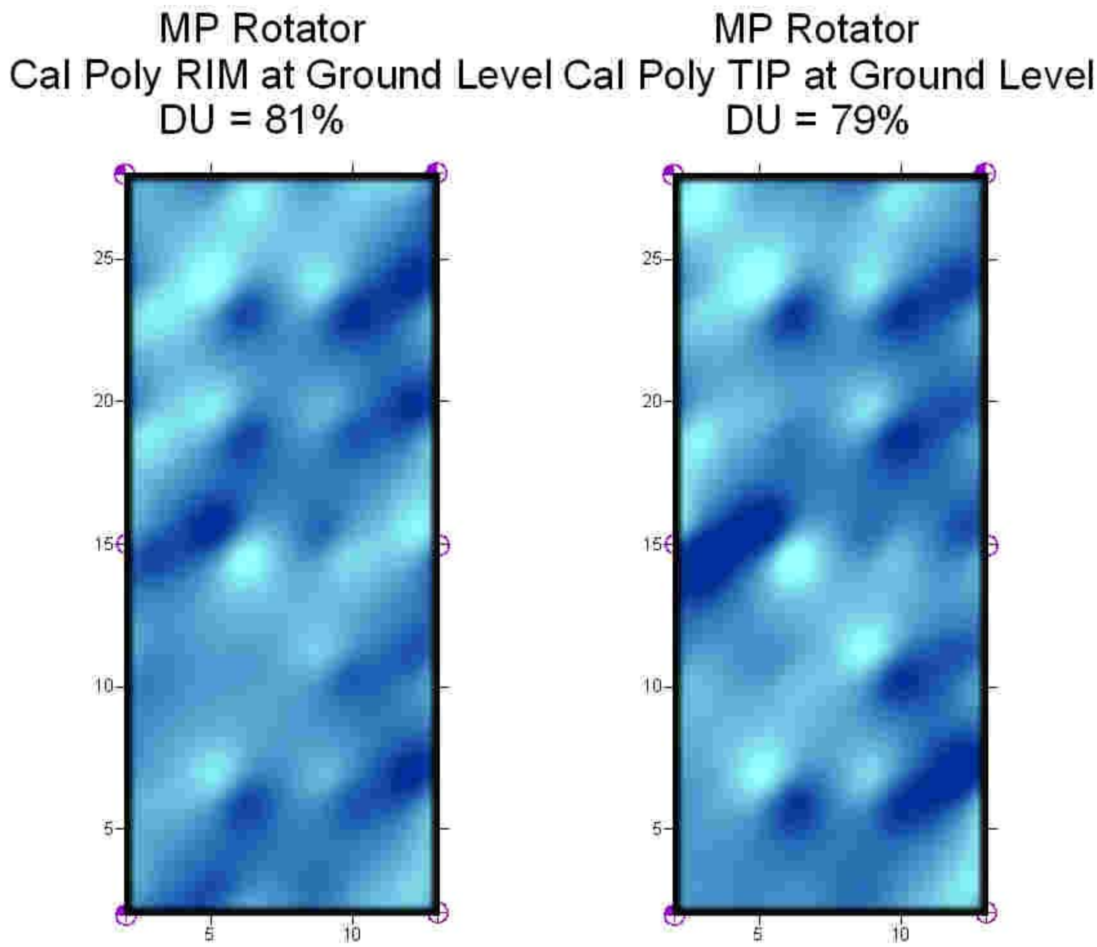

Figure 5. Shaded relief images of catch can volumes for CCRG and CCTG for the MP Rotator.

The MP 2000 DU_{lq} was high and similar for CCRG and CCTG (Fig. 5). One of the half circle heads had very high catch can amounts, but as with the Toro Precision Spray Nozzles, the rest of the area did not show the wide variations that the Toro Precision Rotating Nozzle showed.

If the 20^{o} trajectory nozzle was installed in a turf zone, an audit using standard guidelines would likely show results similar to the CCTG in our controlled study, or worse.

Possible solutions are 1) cut a hole in the turf that would allow the catch can rim to be at ground level. 2) Perform a soil moisture audit, if proper equipment is available. The ground level effect is really what counts operationally, so a soil moisture audit would take into account the droplet distribution at ground level and the soil's natural ability to laterally move soil moisture. Baum (2005) found that uniformities from soil moisture DU_{lq} were higher than those from traditional catch can audits, but raised a concern that the TDR soil moisture equipment used might not be sensitive enough to detect soil moisture redistribution.

A possible 3rd solution is to use a standard catch can such as the Cal-Poly and add sufficient height to the sprinkler head using a riser extension to simulate a CCRG condition. This would likely work for most situations.

A possible 4th solution is to design or find catch cans specifically for low trajectory nozzles. Flat, low-sided plastic bowls have successfully been at Northern Water to perform sprinkler irrigation audits. The chief drawback is that the bowls can be difficult to level in the turf; however, in a previous test using the indoor system described in this paper, the bowls performed comparably with Cal-Poly catch cans.

Conclusions

The low-trajectory nozzles are very desirable in windy irrigation zones or where high or fine spray could be detrimental to instrumentation. Practical problems exist, however, when testing performance even under controlled, indoor conditions. We tested DU_{lq} of three nozzles with different trajectories and rotating stream vs. spray output in an indoor, controlled setting. The results indicated that when catch can rims at ground level was simulated in the indoor irrigation system, DU_{lq} for a low-trajectory nozzle improved from 49% to 70%. The results of these tests indicate that a different approach to auditing low trajectory nozzles is required.

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Irrigation Association's Soil Moisture Sensor Phase II Virtual Test

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Abstract

The Irrigation Association (IA) through its Smart Water Applied Technology (SWAT) effort has been working for the last decade to develop an independent third party testing protocol designed to evaluate control systems that "automatically" adjust irrigation events using either soil moisture sensors (SMS) or climatologically-based controllers. After extensive review and public comments recently, a second testing protocol has been developed, which links SMS response curves to a controller in managing irrigation schedules for six different virtual landscape zones. This protocol is designed to provide a similar test and evaluation method as established with the "Smart" climatologically-based controllers. It is hoped that the performance results of the two different operational platforms can be compared directly. This presentation will discuss the methods and outcomes derived from utilizing the new IA protocol based on SMS response curves as well as issues of compatibility of the "computer interface" used for this test.

Introduction

The overall goal of this project was to verify the efficacy of the IA Soil Moisture Sensor Phase II-Virtual Landscape test. In particular, this project focused on the application of standardized testing protocols on soil moisture sensors operating on different principles (Phase I) and translated it for Phase II Virtual Landscape testing. The evaluation concept used accepted formulas for calculating crop evapotranspiration (ETc) and a weather station on site to estimate the moisture balance, which was used by the controller to achieve efficient irrigation while minimizing potential runoff. There are allowances in this evaluation for variability in soil properties and the inherent problems associated with trying to characterize these problems to scientific instruments.

Proposed Work and Statement of Methodology

Participating manufacturers were required to submit a controller and/or controller interface module along with a data conversion device (computer interface). The data conversion device acted as the interface that accepted the most recent moisture data from the CIT monitoring computer and converted it to a format accepted by the manufacturer's controller under test (see additional details at www.irrigationorg/gov/swat_drafts-soil/).

The Phase II-Virtual landscape included six zones to accommodate a variety of soils, water quality, plant material, slope, temperature, exposure to sun, root zone storage, precipitation rate, application efficiency, and area. The individual zones within the landscape represented a combination of the factors stated above to represent a range of agronomic conditions.

The total accumulated moisture deficit over time was used to measure adequacy while the accumulated surplus of applied water over time provided the system efficiency. Any water applied above the soil water holding capacity was characterized as runoff or deep percolation, which lowers application efficiency.

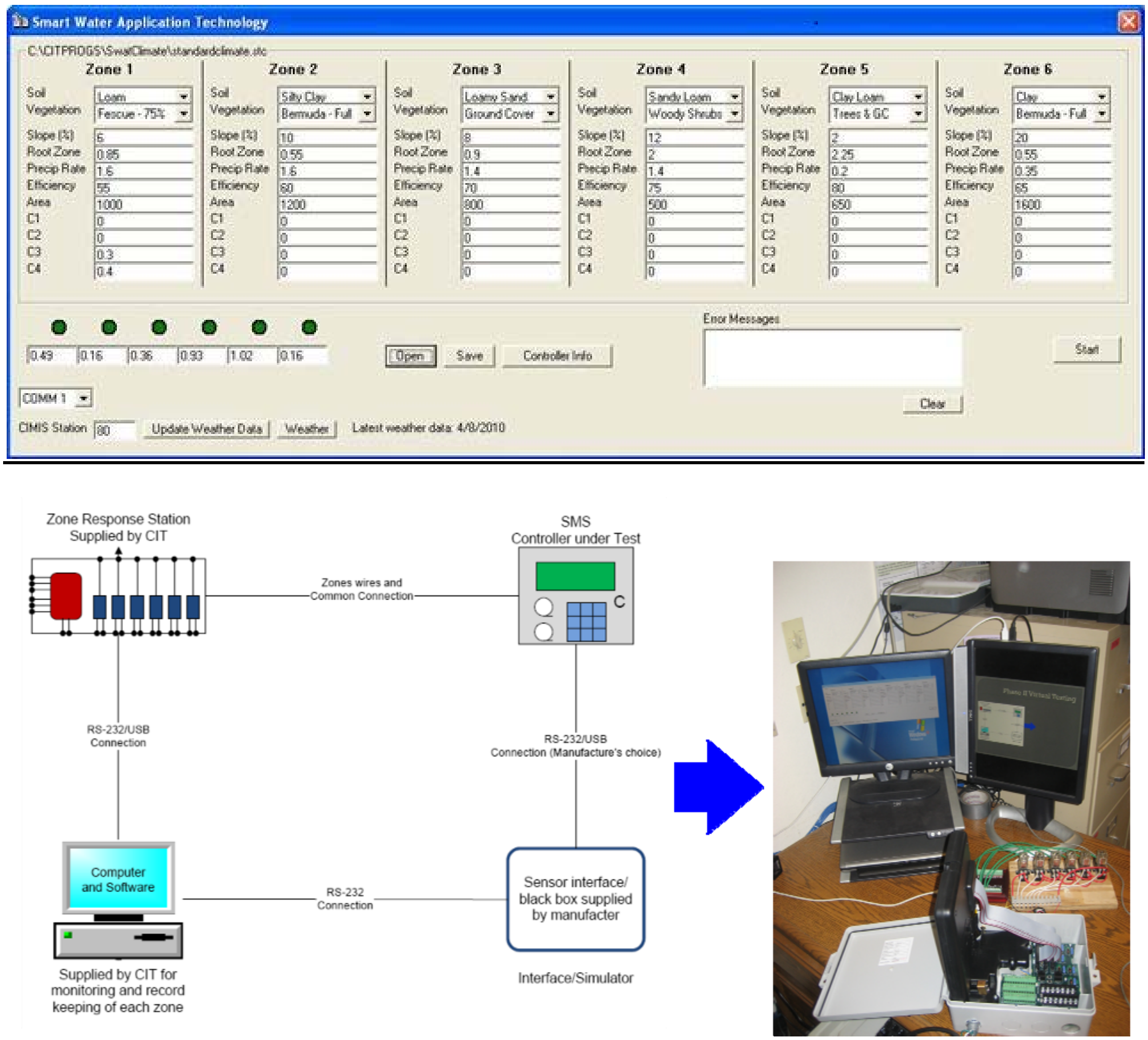

Figure 1: Schematics and layout of the Phase-II testing.

Results

Controllers from three manufacturers with different SMS operating principles were successfully tested during this beta testing phase and the following data ranges were recorded. (Given the complexities of the test development and small testing sample, it is premature to make comparisons between these beta testing results and results obtained using climatologically based controllers.)

- Irrigation Adequacy: 100 to 73.8 %
- Scheduling Efficiency: 100 to 25%
- Overall Efficiency: 100 to 70%
- Rainfall Efficiency: 100 to 80%

Irrigation Association - Smart Water Application Technology
Soil Moisture Sensor Based Controllers

International Center for Water Technology

Project Identification		
	Manufacturer	Black Box 1
	Model Number	
	Serial Number	
	Evaluated By	JO
	Date	October 1, 2010 - October 30, 2010
	Weather Station	CIMIS 80
	Reference No.	
	Comments	

Input Data	Parameter	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6
	Soil Type	Loam	Silty Clay	Loamy Sand	Sandy Loam	Clay Loam	Clay
	Vegetation	Fescue - 75%	Bermuda - Full	Ground Cover	Woody Shrubs	Trees & GC	Bermuda - Full
	Slope, %	6.0	10.0	8.0	12.0	2.0	20.0
	Root Zone Stor., in.	0.85	0.55	0.90	2.00	2.25	0.55
	Precip Rate, in./h	1.60	1.60	1.40	1.40	0.20	0.35
	Efficiency, %	55	60	70	75	80	65
	Area, SQ-Ft	1000	1200	800	500	650	1500
	Soil Intake Rate, in./h	0.35	0.15	0.50	0.40	0.20	0.10
	ASA, in.	0.25	0.16	0.26	0.24	0.26	0.10
	Max. Run Time, min.	12.0	6.6	17.3	14.4	N/A	24.0

Evaluation Summary							
	ETo, in.	3.64	3.64	3.64	3.64	3.64	3.64
	ETc, in.	1.79	2.21	1.98	1.43	2.28	2.21
	Gross Rainfall, in.	0.64	0.64	0.64	0.64	0.64	0.64
	Net Rainfall, in.	0.52	0.52	0.52	0.52	0.52	0.52
	Eff. Rainfall, in.	0.52	0.52	0.52	0.52	0.43	0.52
	Gross Irr., in.	2.82	1.84	2.59	2.03	8.05	1.69
	Direct Runoff, in.	0.00	0.00	0.00	0.00	0.00	0.00
	Soak Runoff, in.	0.05	0.06	0.07	0.07	0.00	0.05
	Effective Irr., in.	1.38	1.07	1.80	1.40	6.38	0.89
	Deficit, in.	0.00	0.46	0.00	0.00	0.00	0.58
	Surplus, in.	0.00	0.00	0.00	0.00	3.51	0.00
	Irr. Adequacy, %	100.0	79.1	100.0	100.0	100.0	73.8
	Sch. Eff., %	94.4	94.6	98.2	95.2	44.9	95.1
	Overall Eff., %	51.9	56.8	67.4	71.4	35.9	61.8
	Rainfall Eff., %	100.0	100.0	100.0	100.0	82.7	100.0
	Cur. Moist. Bal., in.	0.61	0.10	0.71	1.51	2.25	0.10

Figure 2: A typical layout of a performance report.

Conclusion

The Phase II-Virtual Landscape testing technique reduced the testing time to 30 days, or until the minimum rainfall requirement of 0.4 inches and reference ETo of 2.5 inches were met. This could potentially save a considerable amount of time and energy compared to the conventional outdoor irrigation controller tests performed using real vegetative conditions. Further, this model of testing allows for most of the conditions except for ETo and rainfall, to be replicated each time and around the year for the different controllers being tested.

During this phase of testing we were able to resolve/address all the issues related to compatibility of the computer interface and a standardized description for the computer interface and the communication protocol was finalized for future reference. Now that we have a better understanding of how the entire process works, future testing can be conducted using the latest protocol (see the full draft protocol posted at the IA website for additional details).

Author Index

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