Practical Applications of Landscape Irrigation Water Management

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ABSTRACT

The goal of a landscape irrigation system is to maintain a functional and healthy landscape with the minimum required amount of supplemental water. Methods are provided that show how to achieve this goal through measurement of inefficiencies caused by distribution non-uniformity and excessive management-applied water. These measurements lead to understanding which further lead to system improvements resulting in higher distribution uniformity, higher water management efficiency, lower cost, and reduced water usage.

INTRODUCTION

How do you know if your landscape irrigation system is applying the right amount of water? How much of the water is attributable to plant need, to the equipment (as it relates to distribution uniformity), and to the extra amount applied by the water manager? How much money are you spending on each? These questions can be answered by applying some new and common sense landscape irrigation water management principles from the Irrigation Association's Turf and Landscape Irrigation Best Management Practices (reference 1). These BMPs can be downloaded from The IA's web site at www.irrigation.org.

This paper applies these principles to a real landscape. Several concepts are used; all of which are discussed in detail in the appendices of reference 1. These concepts include grass reference evapotranspiration, landscape coefficient, plant water requirement, effective rainfall, net plant water requirement, lower-quarter and lower-half distribution uniformity, run time multiplier, irrigation water requirement, overall irrigation system efficiency, and water management efficiency. See Appendix E of reference 1 on an irrigation system rating (ISR) method as it relates to water usage attributable to distribution uniformity.

BACKGROUND

The landscape test site is a commercial property located at 4646 West Sam Houston Parkway North in Houston, Texas. The landscape consists of about three irrigated acres of mostly warm-season plants including common bermudagrass, fountaingrass and Indian Hawthorns growing in full-sun conditions.

The irrigation system was installed in January 2002 and consists of 33 individual sprinkler zones controlled with an electronic controller. The irrigation system is not equipped with rain or moisture override sensors. Irrigation water is delivered by the City of Houston municipal water system and monitored through a separate two-inch meter. The cost of irrigation water for this site is $4.30 per 1000 gallons.

A weather station is located 1.2 miles south of the test site and reports daily grass reference evapotranspiration and rainfall data. This data was useful in the analysis, but was not used by the test site.

ANALYSIS AND RESULTS

Guideline for Managing Irrigation Water Use

The following steps are used to evaluate landscape irrigation water use:

1. Conduct a reasonability check to compare actual past water usage with that of a baseline "good" irrigation system. If the irrigation system uses too much or too little water as compared to the baseline system, then advance to step 2. Otherwise continue to monitor irrigation water usage and plant health on a frequent basis. Maintain desired plant health but without excess water usage.
2. Conduct an on-site audit to gather additional site data including station flow rates and distribution uniformity. This data will be used in step 3 to isolate irrigation system problems attributable to substantial over or under watering. Fix any known problems to improve distribution uniformity.
3. Re-evaluate pre-audit (i.e., past) water usage using audit results. Instead of comparing to a baseline system as in step 1, use actual distribution uniformity data to compare actual usage to expected usage. Use actual ET_o and rainfall data if possible.
4. Reschedule the irrigation controller and operate the irrigation system for a period of time. Continue to monitor irrigation water usage and plant health on a frequent basis.
5. At least monthly, re-evaluate water usage. Compare the actual water usage to the expected usage based on the previous audit results. Use actual ET_o and rainfall data if possible.

Conduct a Reasonability Check

Start by comparing actual irrigation water use with an estimate of what a "good" baseline irrigation system should use. If the month-to-month actual usage is consistently within 10 to 15 percent of the estimated requirement and the plants are healthy, the irrigation system is probably doing a good job. Otherwise additional tests and system adjustments may be warranted.

System Quality: What is a "good" irrigation system? From Appendix E of reference 1, the quality of an irrigation system can be related to its irrigation water use based on its distribution uniformity. A "good" system is one with an overall irrigation system rating (ISR) of 7 (on a scale of 1 to 10 with 10 being best). This baseline system will have an overall area-weighted average lower-quarter distribution uniformity in the range of 60 to 69 percent resulting in a run time multiplier (RTM) of 1.23 to 1.32. The overall distribution uniformity of the irrigation system may be unknown; however, by comparing actual water usage in this way, you can determine if you should spend the money to further investigate individual irrigation zones for problems.

Required Data: An initial reasonability check of irrigation water usage requires the following baseline information: 1) overall irrigated landscape area (A), 2) average landscape coefficient (K_L), 3) past monthly grass reference evapotranspiration (reference ET or ET_o), and 4) past monthly rainfall. Irrigation water usage can be derived from monthly readings of the water bill (preferred) or from knowledge of the actual schedule, runtime and flow rates of the individual stations. Use actual reference ET and rainfall data if available; otherwise use published long-term average historical data which are available for most regions. Make sure that reference ET data are referenced to grass.

Due to article space considerations, a reality check is conducted for the test irrigation system for only the most recent past month. The overall irrigated landscape area (A; sq. ft.) is 128,958 sq. ft. with an estimate of the overall average landscape coefficient (K_L) of 0.6. The actual irrigation water volume (V_{ACT}; same as V_{IWR} of the actual system; gallons) for the 28-day period May 25 through June 21, 2002, was 428,924 gallons, with historical ET_o of 7.48 inch and historical rainfall of 4.25 inch. The main question to be answered is: "Is this a reasonable amount of irrigation water usage for the period?"

Effective Rainfall: Effective rainfall (R_E; inch) is an estimate of the amount of rain (R; inch) that actually ends up in the root zone. A rainfall factor (RF) is used to convert rainfall to effective rainfall. The chosen rainfall factor depends on the intensity and frequency of rain events in a region, as well as the flatness and soil type of the landscape (among other considerations). If estimating effective rainfall from long-term historical rainfall, then dependability must also be considered. The test landscape is flat with mostly clay soil. Rain events in the Houston area in June and July can vary from slow, low volume events to heavy, short downbursts, to long intense heavy volume events. The test case uses long-term average historical rainfall; thus our best-guess estimate is that only 50% of the historical rainfall will actually be effective toward maintaining health of the plants. (If you use actual rainfall data, then your percentage could be higher for purposes of these calculations).

$$R_E = R \times (RF/100) = 4.25 \times (50/100) = 2.13 \text{ inch} \quad (1)$$

Plant Water Requirement: The plant water requirement (PWR; inch) is that amount of water needed by the landscape plants to maintain health. This requirement depends on reference evapotranspiration (ET_o; inch) over a period of time (monthly for the test case) and the plant's landscape coefficient (K_L):

$$PWR = ET_o \times K_L = 7.48 \times 0.6 = 4.49 \text{ inch} \quad (2)$$

Net Plant Water Requirement: The net plant water requirement (PWR_{NET}; inch) is the supplemental amount that must be made up by the irrigation system after subtracting out effective rainfall (R_E; inch):

$$PWR_{NET} = PWR - R_E = 4.49 - 2.13 = 2.36 \text{ inch} \quad (3)$$

The equivalent volume (V_{PWR_NET}; gallons) is:

$$V_{PWR\_NET} = PWR_{NET} \times (A / 1.6043) = 2.36 \times (128{,}958 / 1.6043) = 189{,}703 \text{ gallons} \quad (4)$$

Run Time Multiplier: The calculated values of R_E, PWR, PWR_{NET}, and V_{PWR_NET} apply to both the actual and baseline systems. The run time multiplier (RTM) is based on the lower-half distribution uniformity (DU_{LH}; %), where DU_{LH} is either calculated directly from catch-can data, or derived from lower-quarter DU_{LQ} data. The RTM from DU_{LH} data is:

$$RTM = 100 / DU_{LH} \quad (5)$$

The RTM from DU_{LQ} data (see appendices C and E of reference 1) is:

$$RTM = 1 / [0.386 + (0.614 \times DU_{LQ} / 100)] \quad (6)$$

The RTM cannot be initially calculated for the actual irrigation system because its distribution uniformity is unknown (an audit has not yet been conducted). However, from Table 1 of Appendix E of reference 1, the DU_{LQ} of a "good" baseline system with an ISR of 7 has a range of 60 to 69% for an RTM of 1.23 to 1.32, respectively, or an average RTM value of 1.27.

Irrigation Water Requirement for Distribution Non-uniformity: IWR_{DU} (inch) is that portion of the irrigation water requirement that accounts for distribution non-uniformity in delivering the water to the plant root zone:

$$IWR_{DU} = PWR_{NET} \times (RTM - 1) \quad (7)$$

The portion of irrigation water due to non-uniformity cannot be calculated for the actual system because its RTM is unknown (without the benefit of audit data). However, for the baseline irrigation system with a midpoint RTM value of 1.27:

$$IWR_{DU} = 2.36 \times (1.27 - 1) = 0.64 \text{ inch}$$

Volume due to Distribution Non-uniformity: Similarly, the equivalent volume (V_{DU}; gallons) of the baseline system related to distribution non-uniformity is:

$$V_{DU} = IWR_{DU} \times (A / 1.6043) = 0.64 \times (128{,}958 / 1.6043) = 51{,}445 \text{ gallons} \quad (8)$$

For comparison purposes, the amount of water attributable to the water manager of the baseline system (IWR_{WM}) is zero inches (for a volume V_{WM} also of zero gallons) because all of the irrigation water has already been allocated to the net plant water requirement and the distribution non-uniformity. In a real but balanced system, the water management portion may be 10 to 15 percent of the overall irrigation water requirement of the baseline system (i.e., 10 to 15 percent of [$V_{PWR\_NET} + V_{DU}$] of the baseline system).

Overall Irrigation Water Volume: The overall irrigation water volume (V_{IWR}; gallons) can be expressed as the sum of the volume required by the plants after taking effective rainfall into consideration (V_{PWR_NET}), the volume due to distribution non-uniformity (V_{DU}) and the volume applied by the water manager (V_{WM}):

$$V_{IWR} = V_{PWR\_NET} + V_{DU} + V_{WM} \quad (9)$$

For the baseline system, the total volume $V_{BASE} = V_{IWR} = 189{,}703 + 51{,}444 + 0 = 241{,}147$ gallons.

The difference (V_{DIFF}; gallons) between the actual irrigation water volume (V_{ACT}; gallons) and that of the baseline system ($V_{BASE;}$ gallons), with both using the same weather data, is the amount attributable to over or under water use. If the percent difference ($V_{\%DIFF}$; %) is more than 10 to 15 percent, then the site is being over-watered due to 1) low distribution uniformity, and/or 2) too much "extra" water being applied by the water manager. A negative percent difference indicates that the site is 1) under-watered (too dry), 2) the overall actual distribution uniformity is better than that of the baseline system, and/or 3) there was actually less evapotranspiration or more rainfall (or a combination of the two) than the historical norm.

$$V_{DIFF} = V_{ACT} - V_{BASE} = 428{,}924 - 241{,}147 = 187{,}777 \text{ gallons} \quad (10)$$

$$V_{\%DIFF} = (V_{DIFF} / V_{BASE}) \times 100 = (187{,}777 / 241{,}147) \times 100 = 78\% \quad (11)$$

Cost of Excess Water: The cost of this difference (C_{DIFF}; \$) at the water rate (W_{RATE}; \$ per 1000 gallons) of \$4.30 per 1000 gallons for the site is:

$$C_{DIFF} = V_{DIFF} \times (W_{RATE} / 1000) = 187{,}777 \times (4.30 / 1000) = \$807 \quad (12)$$

Is the extra high water use and its related cost of the actual system due to distribution non-uniformity or the water manager? Perhaps it is because no rain or moisture sensors were installed. The amount and cost of excess water use caused by not having rain or soil moisture override can be estimated by converting the amount due to effective rainfall (R_E; inch) into a volume (V_{RE}; gallons). It is this volume that could be offset by overriding the irrigation system for rain, and thus saving irrigation water and its related cost.

$$V_{RE} = R_E \times (A / 1.6043) = 2.13 \times (128{,}958 / 1.6043) = 171{,}215 \text{ gallons} \quad (13)$$

Rainfall Analysis: For May 25 - June 21, 2002, at *this* test site, the associated monthly cost of not having a rain sensor (C_{RE}), and based on the current year being the same as the long term average norm, is calculated:

$$C_{RE} = V_{RE} \times (W_{RATE} / 1000) = 171{,}215 \times 4.30 / 1000 = \$736 \quad (14)$$

Is the impact decreased if actual daily ET_o and rainfall weather data are used in the comparison? From the nearby weather station, the actual ET_o and rainfall for the 28-day period was 7.71 and 3.78 inches respectively, resulting in a C_{DIFF} of \$642 and a C_{RE} of \$653. See Figure 1 and Table 1. These costs are based on a rainfall factor (RF) of 50 % due to the nature and frequency of actual rainfall events that occurred in May and June, 2002, at the test site. In this case, the impact decreased because less actual rainfall occurred than the norm and thus less rainfall needed to be compensated by the irrigation system. In general, the rainfall factor you select will depend on your particular site and regional weather characteristics. Your confidence may be higher in the amount of *actual* rainfall that will be both effective and dependable; thus using a higher RF value.

Conduct an On-site Irrigation Audit

In mid-June, 2002, an on-site irrigation audit was performed. Audit objectives were to: 1) document the existing landscape and irrigation system design and current irrigation schedule, 2) identify and record any hardware problems that were currently wasting water, and 3) measure and record the actual performance characteristics of each station of the irrigation system. The site's overall lower-half distribution uniformity (DU_{LH}) is 74.6 percent (as derived from catch-can data) resulting in an overall run time multiplier (RTM) of 1.34, and an irrigation system rating (ISR) of 5 (fair). The irrigated area is 128,958 sq. ft. About 99.5 % of the landscape is warm-season common bermdagrass, fountaingrass, and Indian Hawthorns with a small fraction being annual flowers. Thus, an overall landscape coefficient (K_L) of 0.6 is used for the test site.

Re-evaluate the Pre-Audit (Past-Water) Use Period

Re-evaluate past water usage, but this time use the overall RTM (RTM) of 1.34 as determined from the audit. (If you have DU_{LQ} data for your site, then use equation 6 to derive your overall RTM.)

From equations 7 and 8, the actual amount of the irrigation water requirement ($IWR_{DU;}$ inch) and volume (V_{DU}; gallons) attributable to the actual distribution non-uniformity can now be calculated:

$$IWR_{DU} = PWR_{NET} \times (RTM - 1) = 2.36 \times (1.34 - 1) = 0.80 \text{ inch}$$
$$V_{DU} = IWR_{DU} \times (A / 1.6043) = 0.80 \times (128{,}958 / 1.6043) = 64{,}306 \text{ gallons}$$

Equation 12 can be written in a general form where the cost of water (C; \$) is related to the volume of water (V; gallons) used and its water rate (W_{RATE}; \$ per 1000 gallons). With this general form, the cost of water due to non-uniformity (C_{DU}; \$) can be calculated:

$$C = V \times W_{RATE} \text{ or } C_{DU} = V_{DU} \times W_{RATE} = 64{,}306 \times (\$4.30 / 1000) = \$277 \quad (15)$$

The actual volume (V_{WM}; gallons) and cost (C_{WM}; \$) of water attributable to the manager can be calculated:

$$V_{WM} = V_{IWR} - V_{PWR\_NET} - V_{DU} = 428{,}924 - 189{,}703 - 64{,}306 = 174{,}915 \text{ gallons} \quad (16)$$

$$C_{WM} = V_{WM} \times (W_{RATE} / 1000) = 174{,}915 \times (\$4.30 / 1000) = \$752 \quad (17)$$

Finally, the overall cost (C_{IWR}; \$) of the irrigation water and individual costs are:

$$C_{IWR} = V_{PWR\_NET} + V_{IWR\_DU} + V_{IWR\_WM} = \$816 + \$277 + \$752 = \$1{,}845 \quad (18)$$

See Table 1 and Figure 1 for a summary of actual irrigation water requirements, volumes and costs attributable to the net plant water requirement, irrigation system distribution non-uniformity and water management. Also see Table 1 for a description of scenarios A through E in Figure 1.

Operate the Irrigation System with an Updated Schedule

The controller schedule and station runtimes were modified and then set for the post-audit month based on long-term historical ET and rainfall data, and measured zone precipitation rates. The schedule was operated for a month (without change) while frequently observing the health of the landscape.

Evaluate Post-Audit Water Use

The final step is to evaluate monthly usage following the audit. For space limitations, this study evaluates one month of data; however, you should continue to evaluate your irrigation schedule and water usage each month. Following the methods above, the post-audit monthly *actual* water usage and cost are compared to the *predicted* amount using both predicted weather data (long-term average historical) and actual daily weather station data. For the period June 21 to July 18, 2002, if real weather conditions had actually been the same as long-term historical weather patterns, then the cost of irrigation water attributable to the net plant water requirement (C_{PWR_NET}) would have been \$812, to the distribution non-uniformity (C_{DU}) \$276, and to the water manager (C_{WM}) \$109, since the controller had been scheduled based on historic weather patterns. However, based on real weather conditions, the cost breakdown is: C_{PWR_NET} of \$52, C_{DU} of \$18, and C_{WM} of \$1127.

The plan for the site should be to reduce the C_{WM}-related cost to no more than 10 to 15 percent of the cost of the irrigation water requirement (C_{IWR}) of the baseline system. Additionally, the plan should be to reduce the C_{DU}-related cost by improving the distribution uniformity (DU) and thereby improving the overall quality of the irrigation system (as it relates to DU). For example, an increase in the actual "fair" ISR rating of 5 for the test site to a "good" ISR rating of 7, or a "very good" ISR rating of 8 will reduce the actual RTM of 1.34 (fair) to 1.27 (good) and 1.20 (very good) respectively, thereby saving water. Actual reduction of C_{DU} is achieved by close examination of individual irrigation zones in order to identify and improve those zones with low DU.

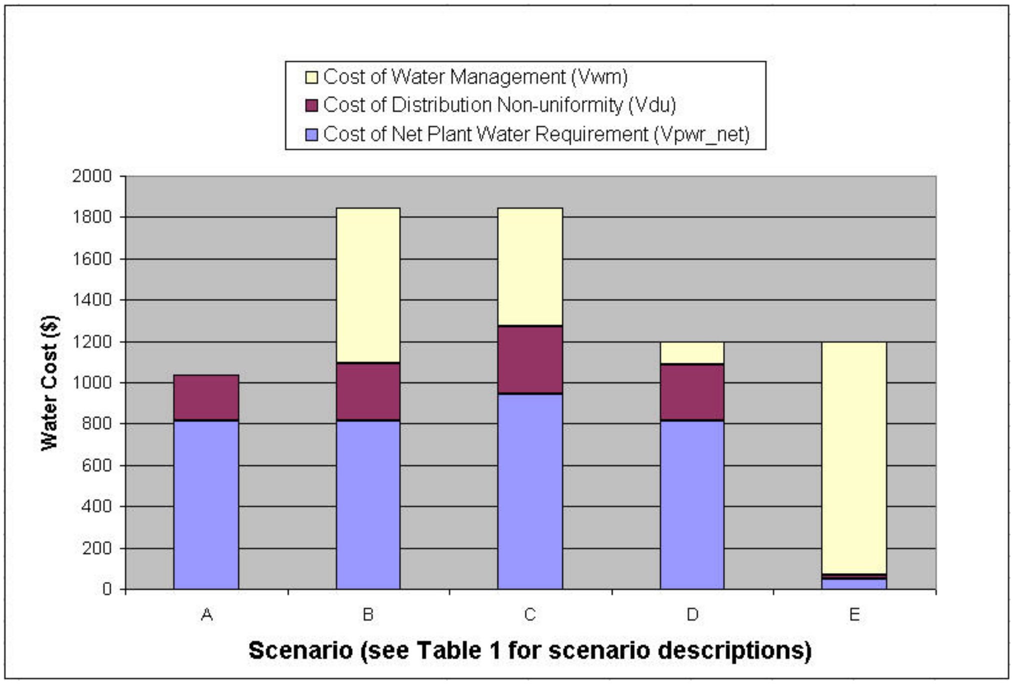
Additionally, the system can be evaluated in terms of its efficiency. Water management efficiency (E_{WM}; %) quantifies how well the irrigation manager minimizes the use of extra water needed by the landscape after accounting for irrigation non-uniformity and uncertainty in the weather. E_{WM} is the ratio of the amount of irrigation water not including management requirements to the total amount including management requirements. A good target is an E_{WM} of at least 85 to 90 percent. The E_{WM} of the *actual* irrigation system, and with *actual* weather data for the post-audit period is:

$$E_{WM} = 100 \times (RTM \times V_{PWR\_NET}) / [(RTM \times V_{PWR\_NET}) + V_{WM}] \quad (19)$$
$$= 100 \times (1.34 \times 12{,}057) / [(1.34 \times 12{,}057) + 262{,}291]$$
$$= 6\ \%$$

The overall irrigation system efficiency (E_S; %) is the percent of irrigation water that is beneficially used for plant growth. It is the ratio of the net plant water volume to the total irrigation water volume. A good target is an E_S of at least 65 percent. The E_S of the *actual* irrigation system, and with *actual* weather data is:

$$E_S = 100 \times (V_{PWR\_NET} / V_{IWR}) = 100 \times (12{,}057 / 278{,}448) = 4\ \% \quad (20)$$

FIGURE 1 - PRE AND POST AUDIT WATER COST SUMMARY



CONCLUSIONS

As competition for water resources continues to grow, the landscape irrigation industry must be equipped to meet the challenge with systematic methods and processes that quantify water usage. Actual design, performance and management of irrigation systems can be quantified in terms of needed water usage, water waste and water costs. It is important to manage irrigation systems based upon real-time weather data and utilizing water conserving devices to maximize water use efficiency.

REFERENCES

1. Turf and Landscape Irrigation Best Management Practices, The Irrigation Association, April 2002.

2. Irrigation Water Management of Commercial Landscapes, Texas Agricultural Extension Service, Texas A&M University System, July 1997.

3. Historical Data for Weather Source: Baseball USA Weather Station, May 1, 2002, to August 28, 2002.

TABLE 1 - SUMMARY OF IRRIGATION WATER USE

Scenario		A[1]	B[2]	C[3]	D[4]	E[5]
Description		Baseline	Test Site	Test Site	Test Site	Test Site
Evaluation Date[6]		Pre-audit, Historical Weather	Pre-audit, Historical Weather	Pre-audit, Actual Weather	Post-audit, Historical Weather	Post-audit, Actual Weather
ISR	--	7	5	5	5	5
A	sq. ft.	128,958	128,958	128,958	128,958	128,958
K_L	--	0.6	0.6	0.6	0.6	0.6
DU_{LQ}	%	65	64.6	64.6	64.6	64.6
DU_{LH}	%	78	74.6	74.6	74.6	74.6
RTM	--	1.27	1.34	1.34	1.34	1.34
ET_o	in.	7.48	7.48	7.71	8.08	5.20
R	in.	4.25	4.25	3.78	5.00	5.94
RF	--	50	50	50	50	50
R_E	in.	2.13	2.13	1.89	2.50	2.97
PWR	in.	4.49	4.49	4.63	4.85	3.12
PWR_{NET}	in.	2.36	2.36	2.74	2.35	0.15
$IWR_{DU,BASE}$	in.	0.64	0.64	0.74	0.64	0.04
$IWR_{WM,BASE}$	in.	0.00	0.00	0.00	0.00	0.00
IWR_{BASE}	in.	3.00	3.00	3.48	2.99	0.19
V_{RE}	gal	171,215	171,215	151,923	200,957	238,737
V_{PWR_NET}	gal	189,703	189,703	220,249	188,899	12,057
$V_{DU,BASE}$	gal	51,445	51,445	59,483	51,445	3,255
$V_{WM,BASE}$	gal	0	0	0	0	0
$V_{IWR,BASE}$	gal	241,147	241,147	279,732	240,344	15,312
$V_{DU,ACT}$	gal	51,444	64,306	74,885	64,226	4,100
$V_{WM,ACT}$	gal	0	174,915	133,790	25,323	262,291
$V_{IWR,ACT}$	gal	n/a	428,924	428,924	278,448	278,448
DIFF	gal	n/a	187,777	149,192	38,104	263,136
%DIFF	%	n/a	78	53	16	1,718
RATE	$/1000 gal	$4.30	$4.30	$4.30	$4.30	$4.30
C_{PWR_NET}	$	$ 816	$ 816	$ 947	$ 812	$ 52
C_{DU}	$	$ 220	$ 277	$ 322	$ 276	$ 18
C_{WM}	$	$ 0	$ 752	$ 575	$ 109	$1,127
C_{IWR}	$	$1,036	$1,845	$1,844	$1,197	$1,197
C_{DIFF}	$	n/a	$807	$ 642	$ 164	$1,132
C_{RE}	$	$736	$736	$ 653	$ 864	$1,027
E_{WM}	%	n/a	59	69	91	6
E_S	%	79	44	51	68	4

[1]A - Baseline "good" irrigation system, pre-audit month, historical weather patterns
[2]B - Actual irrigation system, pre-audit month, historical weather patterns, analysis used audit results
[3]C - Same as scenario B but with actual weather conditions
[4]D - Actual irrigation system, post-audit month, historical weather patterns
[5]E - Actual irrigation system, post-audit month, actual weather conditions
[6]Pre-audit date: May 18, 2002 to June 20, 2002. Post-audit date: June 20, 2002 to July 18, 2002.