SOIL MOISTURE SENSORS: ARE THEY A NEGLECTED TOOL

The Experience In Boulder, CO

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INTRODUCTION

The City of Boulder, CO began studying Soil Moisture Sensors as a method of conserving outdoor use water in 1992. At considerable expense, the Office of Water Conservation and Department of Public Works installed and monitored over 50 Watermark™ Soil Moisture Sensors and Electronic Modules on existing irrigation systems throughout the City. These were installed on private homes, association common areas, and public street medians and parks. To date, a total of four project reports, three papers and one master thesis have been prepared on the studies. In all cases the sensors were installed on standard clock driven sprinkler systems which had been programmed for daily maximum applications, and the sensors were used to prevent system operations whenever soil moisture levels exceeded the target point. The irrigation systems equipped with Watermark™ sensors were found to track both season and short term irrigation requirements without human intervention. They prevented irrigation during rainy periods and kept it off until the soil was dry enough to require water. Application rates matched the overall seasonal requirement to an average of 80% of theoretical ET.

Despite the documented technical success of the soil moisture sensors their acceptance by the irrigation professionals has be less than enthusiastic. As evidence of this consider that in 1996 a local irrigation supply house stocked 50 sensor units in conjunction with the City of Boulder’s rebate program. Despite the offer of a rebate from the City, less than five of these sensors have been sold in two years.

In the Fall of 1996 a meeting was held with the Soil Sensor Users Group: the City Water Conservation Specialist, the Consultant, the Property Managers, and Irrigation Contractors to discuss the results and try to determine the source of the resistance to use of sensors. That meeting prompted the City to fund the latest study, which is the subject of this paper.

REASONS FOR USING SENSORS

The Users Group agreed that there are several attractive reasons for use of soil moisture sensors as part of standard irrigation systems. These reasons are summarized below

- Sensors provide weather based control to clock driven irritation.
- Sensors can save water in systems which have been over-irrigating.
- By preventing over irrigation sensors can increase turf health .
- Since should save labor by eliminating the need for re-programming and temporary rain shut-offs.
- Sensors should be able to reduce water and labor costs for owners.

CONCERNS ABOUT SOIL SENSORS

Soil moisture sensors seem to be views by contractors as devices which may work in the laboratory or in controlled pilot studies, but which are still too unreliable for field use. This impression was reinforced by the many "war stories" from bad experiences with early sensor products. During the soil sensor users group meeting a number of concerns were raised about the use of soil sensors for control of irrigation systems. These concerns came primarily from the system maintenance personnel. The identified concerns were:

- Can sensors really be trusted to govern irrigation application?
- How long will sensors last in the field use?
- How much labor is require to operate systems using sensors?
- How frequently will sensors need repair and replacement?
- How can the system operator receive feed-back about system performance?
- Given the answers to the above, is use of sensors cost effective for actual field applications?

SCOPE OF THE 1997 STUDY

Despite the concerns of the contractors there is still a strong incentive to automate irrigation scheduling. From the perspective of water conservation officials sensors are relatively inexpensive devices which could provide ET based control to the thousands of systems which are currently operating off of clocks. After all, it makes as little sense to attempt to schedule irrigation using a clock as it does to schedule heating and cooling using a clock. From the owners perspective, the sensors could reduce costs. The contractors felt that if they had more information they could justify use of sensors more easily.

The 1997 study was designs to gather information needed to address the concerns with use of soil sensors raised by the Boulder Users Group. Since their concerns are probably shared by users across the county, the authors believe that this paper should be of interest to anyone involved with landscape irrigation and water conservation.

There were five main tasks established for the 1997 Field Study:

- To determine how well the soil sensors were operating after having been in the field for several years
- To obtain accurate information on the frequency and severity of problems which occurred in the sensor systems.
- To determine what remedial actions were required
- To track the time and cost required to operate a system of sensors
- To develop a simple feed back system.

REVIEW OF SENSOR OPERATION

Detailed descriptions of the operation of the Watermark™ soil moisture sensors have been provided in previous papers. To summarize, though: the Watermark ™ sensor is essentially an improved gypsum block. It uses simple electrical resistance across the sensor electrodes to estimate soil moisture levels. The sensors contain stainless steel electrodes encased in gypsum in the head of the sensor. A layer of silica sand is then added. The sand and gypsum are encased by a filter cloth and the entire unit is enclosed in a mesh of galvanized steel, which holds the unit together securely. The sensor is sometimes referred to as a granular media sensor.

The sensor can be read directly using a separate electronic device calibrated to read out in centibars of soil moisture. In use with an irrigation clock, however, the sensor is connected to a switching unit, referred to as the Watermark Electronic Module™ (WEM). The WEM is an adjustable switching module which can be set to a range of soil moisture target levels usingm an adjusting knob. It can also be set to a by-pass setting, which will enable irrigation irrespective of soil moisture levels. The WEM operates by opening the common line circuit, preventing irrigation, whenever the resistance measured through the sensors show the soil moisture exceeds the target.

The typical arrangement of the sensor system is shown schematically in Figure 1. A single pair of sensors are placed in the middle of a turf zone which is close to the clock. In heavy clay soils our experience has shown that it may be advantageous to bed the sensors in planting mix. This allows them to respond quickly to changes in soil moisture in the top 2 inches of the soil while still being buired at the 3-5 inch depth necessary to protect them from aeration equipment.

A pair of wires is run back to the clock and attached to the WEM sensor wires. (If extra zone wires are available they can be used for the sensors). The WEM is then wired to the pump start or master valve terminal on the clock which powers it up at the start of each irrigation schedule. The final connection is to the common wire, which is run into the WEM from the clock and out to the field common. A typical installation can be complete in less than 1 hour and much less if extra field wires are available which minimizes the amount of trenching.

The final step in the installation is to program the clock. In our work we have always programmed the clocks for daily operation, and to apply the maximum day allotment of water over three or four start times. For example, we might program a clock to irrigate every day but the mowing day, and to use three cycles of 0.1inch per cycle. This allows the system to apply from 0 to 0.3 inches of water per day depending on soil moisture conditions.

STUDY PROCEDURES

To conduct this study a graduate student from the University of Colorado at Boulder was hired. The student would conduct the research under the direction of his advisor, Professor Russel Qualls and the Aquacraft project manager, William DeOreo. The data collect for the project would then be used for Masters of Science Thesis.

A comprehensive list was prepared of all of the sensor installations conducted by the City of Boulder from 1992 until 1996. As many of these sites which could be contacted at random and brought into the study were used as the study group. A total of 23 sensors were able to be included. No attempt was made to screen sensors for inclusion based on prior performance of the sensors. Table 1 shows a list of the sites.

Each site was visited with the owner or manager to determine what, if any repairs were required to make the system operational. Any required repairs were made and records were kept of time and materials used. The locations of all water meters were determined so that accurate water use data could be collected. The irrigated areas of each system were also determined so that irrigation applications could be expressed in terms of inches or gallons per square feet.

During the season each site was visited on a weekly basis to check for problems and read the water meters. Weather data were also collected so that the theoretical irrigation requirements could be calculated.

The results from the study were tabulated for both hydrologic and time and cost parameters and a project report was prepared.

WATER BUDGET MODEL

The theoretical irrigation requirement for the sites was based on the modified Blaney Criddle procedure using daily temperature and precipitation data from a local weather station. This model showed that daily net ET requirements for 1997 ranged from zero to a maximum of 0.36 inches. Figure 2 shows a graph of the daily net ET for the period from April 1 to October 15, 1997. During this period the total theoretical requirement was 28.2 inches or 17.6 gallons per square foot of irrigated area. It is important to note from Figure 2 the highly variable nature of daily net ET. There were 15 instances when net ET dropped to zero during the season. Furthermore, the length of time that net ET remained at zero varied from 1 to several days. It is this variability and unpredictability of the ET which is the reason why some sort of weather based control system is so necessary.

FIELD VISITS

Initially each of the sites was visitted once per week to obtain water meter readings and check for system errors. As the study progressed the period between visits was lengthened to two weeks because the systems were found to be performing reliably.

The key data obtained during the field visits were the water meter readings. This allowed us to determine the volume and depth of irrigation as the season progressed. We also checked to see that the irrigation program had not been modified and that the WEM settings were the same. Any changes were noted and the original programs were restored, if necessary. In most cases the programs and settings were not modified, but one of the irrigation contractors did make some changes which needed to be corrected.

One of the most the most important functions of the field visits was to communicate the system performance to the participants. Most of these individuals had a hard time determining whether the system was performing properly on a day to day basis. They could see that the lawns were green, but did not know precisely how much water had been applied, or whether the system had prevented irrigation after the last rain storm. This led one of our contractors to turn the irrigation clocks off during a rainy period. He believed that the sensors had failed, allowing the irrigation systems to water, so he turned all of the clocks on the project off. When we discovered this and showed him the water meter readings--which showed that, in fact, the systems had not run--he allowed the clocks to be turned back on.

This experience with the doubtful contractor demonstrated the need for a simple procedure for tracking system performance and led to the development of the one page irrigation scheduling worksheet discussed below.

As the season progressed the data on water use and time were taken and tabulated so that the actual verses theoretical application rates could be compared.

RESULTS OF THE 1997 STUDY

The results of this study were quite encouraging from the standpoint of both irrigation efficiency and cost effectiveness. On a seasonal basis, the systems limited applications to an average of 76% of theoretical requirement when all sites are combined. Table 2 shows how the individual results varied. It can be seen that the ratio of the actual to theoretical application ranged from a low of 52% to a high of 124%. Figure 3 shows a histogram of applications. Most of the data fell between 50 and 60% and between 70 and 80% of ET. Only 5 of the sites had applications equal to or greater than the theoretical requirements. None of the participants complained about having too dry a landscape, which we found surprising given the high number of system applying just over half of the requirement.

The results on a short term basis were also quite good. Figure 4 shows the application curves for all 23 sites over the entire season. The top line represents the theoretical requirement and the bottom line the actual application. This shows that during the early seasons when conditions were wet, the actual application rates were low and as the season heated up the application rates increased. At the end of the season there was a tendency for the applications to lag farther behind the theoretical requirement. This indicates that one thing to watch out for in these systems is *under* irrigation towards the end of the season.

Figure 5 shows the application curve for the largest user. This site applied 124% of the theoretical requirement, or 36 inches of water. Inspection of the curve, however, shows that the system really tracked ET well, but that in this case the late season drop off in application did not occur. This may have been due to an adjustment of the WEM by the owner. It is important to note that an application of 124% of theoretical is well within an acceptable range of applications, and doesn't represent a failure of the system. Remember, these clocks were programmed to apply over 10 inches of water per month, so in the event that the sensors failed, and the failure went undetected, applications for the season would have exceeded 70 inches.

The other extreme in application pattern is shown in Figure 6. In this case the sensors had a tendency to under irrigate, applying just over 15 inches of water. This site was a single family residence whose owner never complained about the performance of the system or appearance of his lawn. We believe that this is due to the fact that this neighborhood (the Heatherwood neighborhood) has been used as a study area for residential water use and the home was one of the study homes. Consequently, the owner had a higher level of awareness of water conservation and was pleased by the performance of the system. If higher applications had been desired a simple adjustment of the WEM to a higher moisture setting would have accomplished this.

IRRIGATION SCHEDULING WORKSHEET

Our experience indicates clearly that the number one obstacle to wider spread use of soil moisture sensors is the lack of a clear cut feed back mechanism between the irrigation system and the user. Without this, the user is never quite certain whether the irrigation system is on target with respect to applications.

To address this problem we designed a very simple, one page work sheet which the irrigation manager can fill out and then use to track applications. A copy of the worksheet and instructions are provided in Table 3. The key to this scheduling approach is to develop a factor which converts between thousands of gallons of water use, as read on the meter, to inches of application on the landscape. This is done by dividing the irrigated area (in square feet) into the constant 1604. This results in a site specific constant, called the Irrigation Factor, having the units of Inches/Thousand Gallons. This can be used to determine the required water use in TG at the water meter each month necessary to match the actual applications to the theoretical.

The use of the Irrigation Scheduling Table gives the irrigation manager a strategy for managing water use which does not require excessive amounts of data or labor. It also leads the manager to obtain the critical operational data of irrigated area and water use, and to convert the water data from a volume to depth of application. The manager can then compare the water use at each site to the target application which is based on average conditions. Whenever the manager wants to check on system performance the system leads him to read the water meter and determine the current actual application depths. This is the key information which is needed, and will tell the manager that either the system is on target and there is no need for concern, or that it needs adjustment.

TIME REQUIREMENTS

During the course of the study records were kept of all time spent for familiarization , routine field checks and repairs. All costs for repairs were recorded as well. At the start of the year there were some repairs necessary, but not of the sensors needed to be replaced. One WEM had been stolen (along with the irrigation controller) and was replaced. This was the major repair. The initial visits for familiarization with the system required an average of 12 minutes per site. The period visits for meter reading and field checks took an average of 6 minutes per site. The total cost for repairs and replacement of the WEM were $270. We estimate that a budget of $12 per controller per year be used for repair and replacements.

CONCLUSIONS

Soil moisture sensors are without a doubt a water conservation tool with a great deal of unrealized potential. The data collected in this study have shown that sensor based system perform reliably, and that the anxiety over their use, and potential failure, by irrigation managers is unwarranted.

This study is the latest in a series sponsored by the City of Boulder, Office of Water Conservation dating back to 1994. All of these studies have involved the use and reliability of one brand of soil moisture sensors, Watermark ™ sensors and Watermark ™ Electronic Modules. The data collected as part of these studies represents from three to five years of field experience with a single group of study sites.

The previous studies have shown that the Watermark ™ soil moisture sensor can and do successfully automate irrigation scheduling in standard clock driven irrigation systems when they are installed and operated according to the manufacturer's instructions.

Despite the previous work, lingering doubts remained in the mind of the owners and contractors who were involved with the Boulder studies. These involved the long term reliability and time requirements to operate a system which includes soil moisture sensors.

This study has shown that even after five years in the field the sensors continue to successfully match irrigation applications to requirements with the seasonal applications during 1997 ranging from 52% to 124% of the theoretical, and the average application equaling 76% of the theoretical requirement.

If anything, the sensors have a tendency to under irrigate, so users should be ready to make mid-season adjustments to a slightly wetter setting, if the landscape appears too dry.

To successfully use sensors it is essential to track the actual applications by filling out the Irrigation Scheduling Table, which is attached to this paper. This worksheet requires determining the location of all water meters serving the system and the areas irrigated by each. Once that is done the operator can accurately track applications in inches by simply reading the water meters and making adjustments for any non-irrigation use going through the meter. This system provides the manager with confidence that the proper amount of water is being applied to the landscape. It also gives the manager the ability to control the system by making needed adjustments and then observing how the system responds.

The time required to monitor the soil sensors was inconsequential (6 minutes per visit). During the 1997 season we had no sensor or WEM failures, and at start up only one WEM needed replacement, but this was due to theft rather than failure of the WEM.

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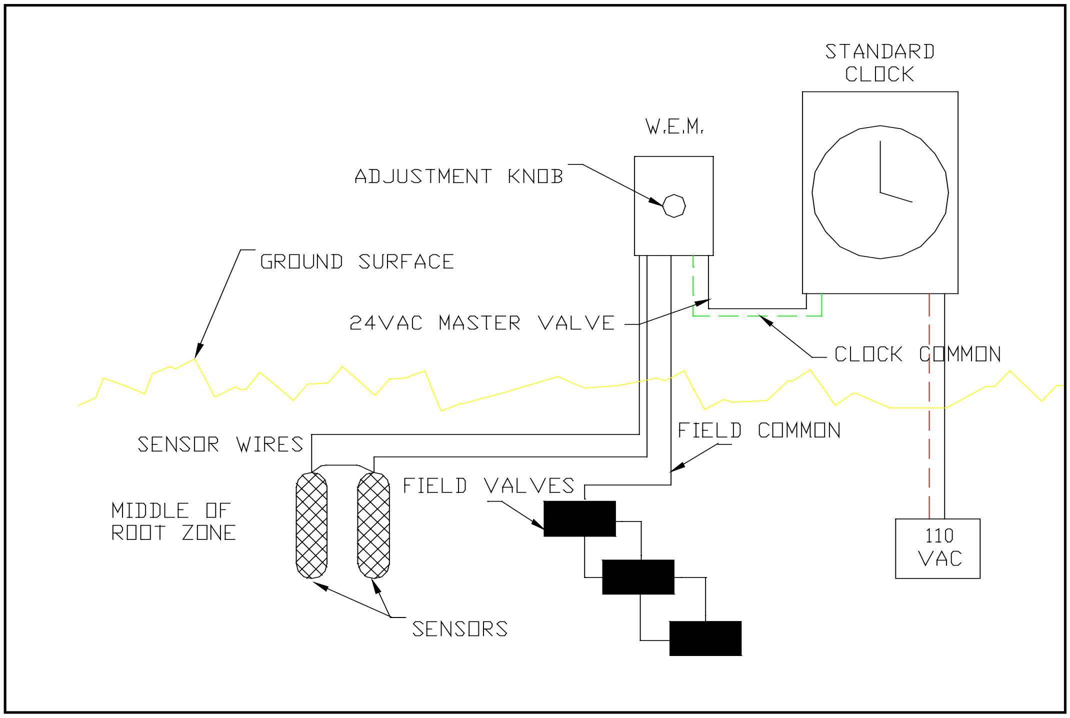

Figure 1: Sensor Installation

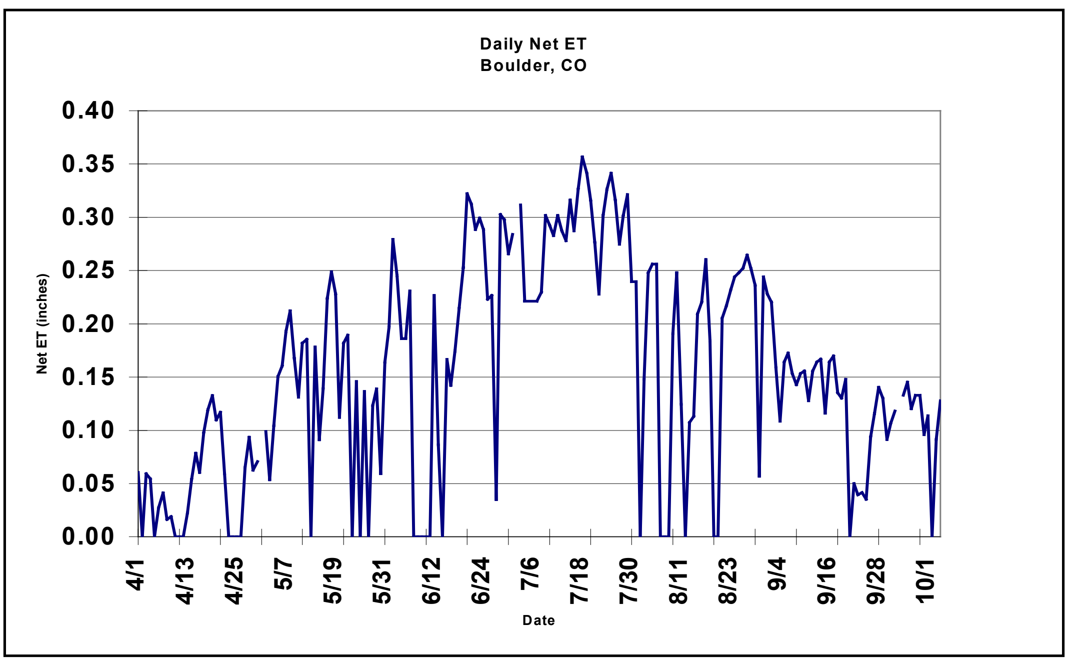

Figure 2 : Daily Net ET in Boulder, CO 1997

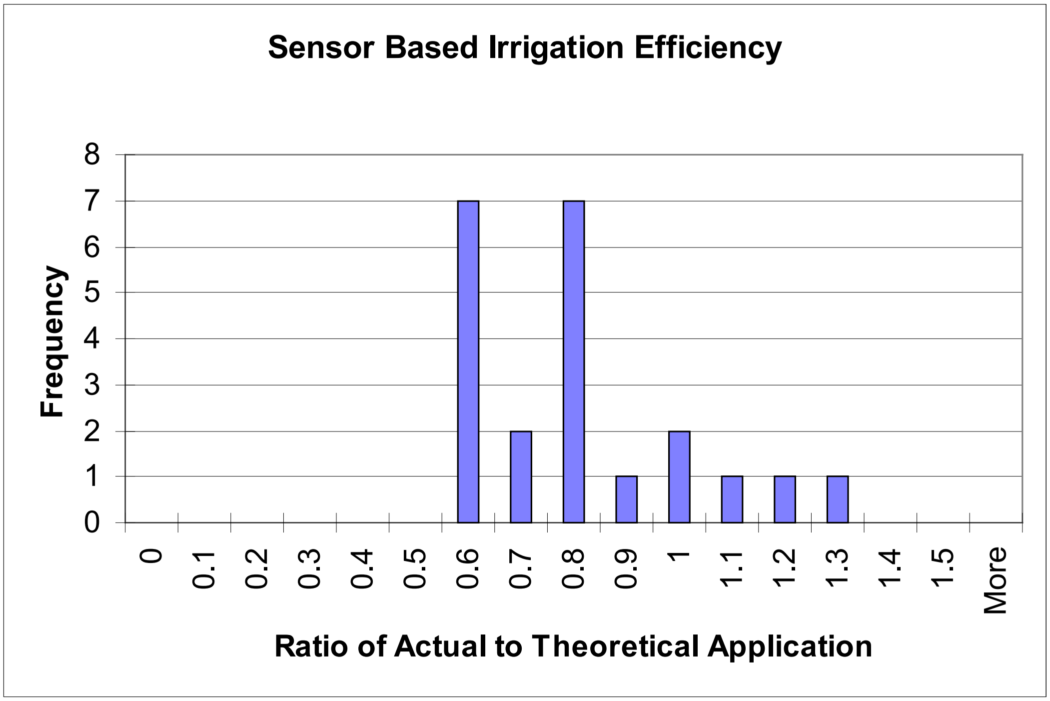

Figure 3: Distribution of Seasonal Application Rates

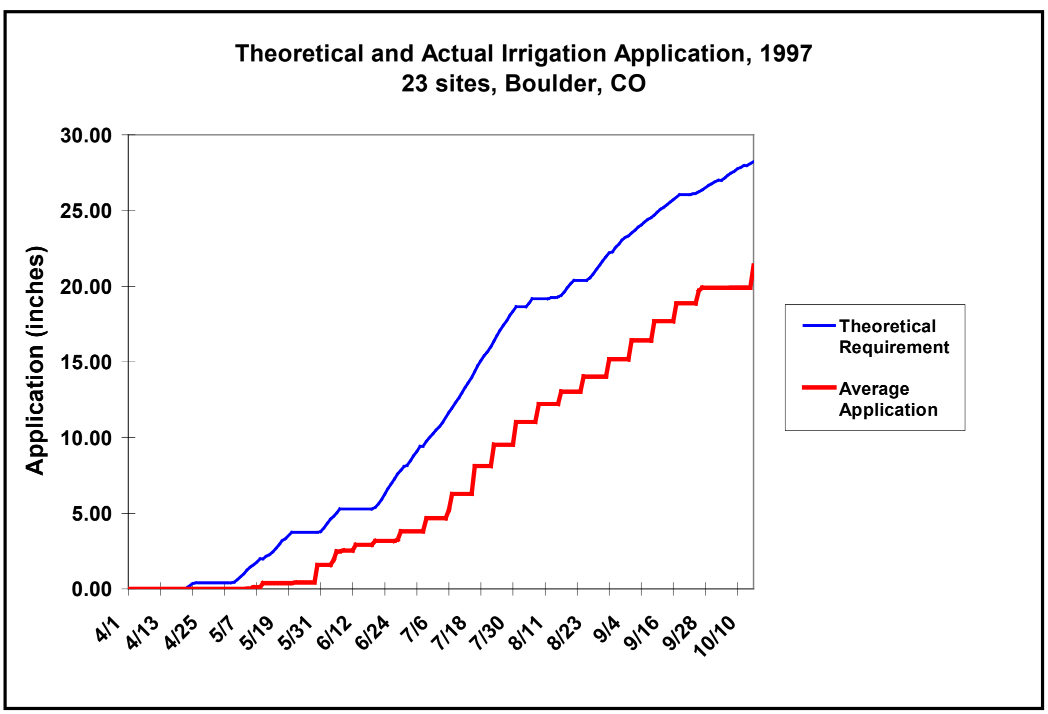

Figure 4: Average Application Curve for All Sites

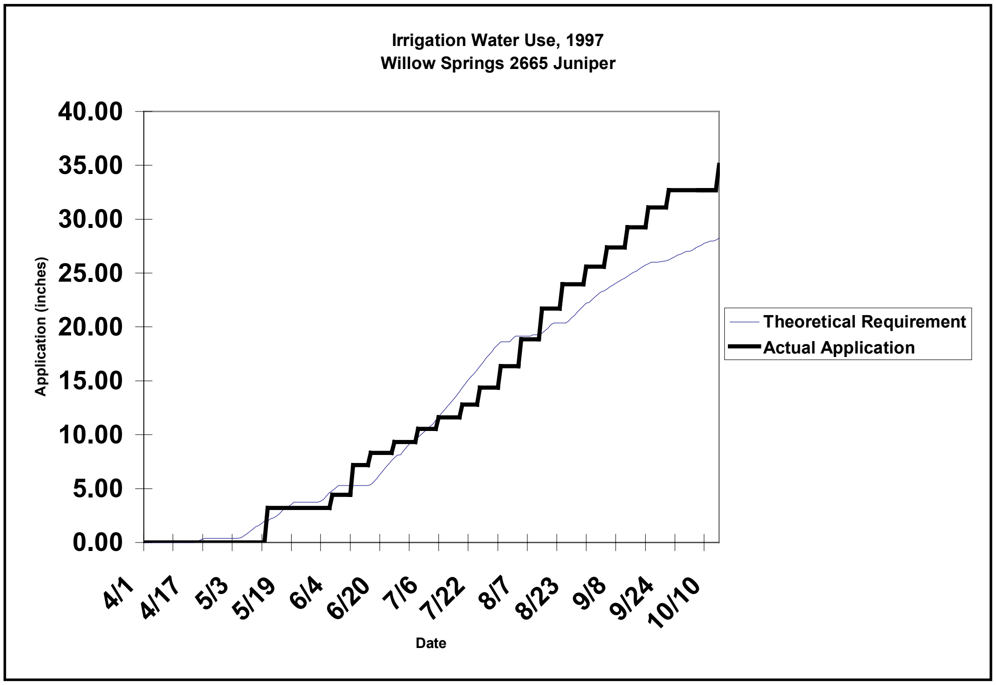

Figure 5: Application Curve for Highest User

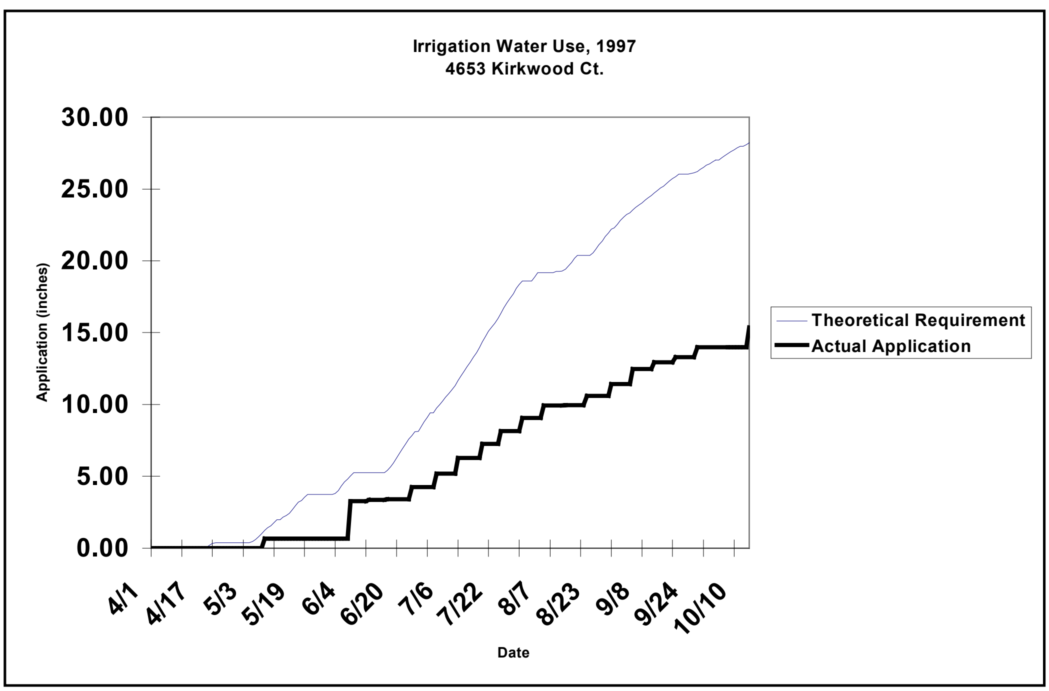

Figure 6: Application Curve for Lowest User

Table 1: List of Study Participants

	Address of Installation	Year Installed	Irrigated Area (ft2)	Type of Irrigation Clock	Managed/Maintained By
Resident	4653 Kirkwood Ct.	1994	7120.8	Lawn Gene	Homeowner
	4736 Harwich St.	1994	11241	Richdel R416	Homeowner
	711 Alpine	1994	5929	Toro Freedom Four	Homeowner
	4313 Apple Wy.	1994	10466	Rainbird ESP 12	Homeowner
City	Elm Street Park	1992	10000	Rainbird ESP 6	City of Boulder - Streets
	Table Mesa Site	1992	1000	Richdel R414	City of Boulder - Streets
Willow Springs	2623 Juniper	1994	3341	Rainbird RC-7A	Contractor A
	2625 Juniper	1994	16913	Rainbird RC-7A	Contractor A
	2615 Juniper	1994		Buckner MT8	Contractor A
	2665 Juniper	1994	9005	Imperial Valet Timer	Contractor A
	2683 Juniper	1994	5691	Imperial Valet Timer	Contractor A
	2676 Juniper	1994	19690	Imperial Valet Timer	Contractor A
	2640 Juniper	1994	34618	Buckner MT8	Contractor A
Winding Trail Village	3877 Birchwood Ct.	1994	17487	Rainbird ESP 4	Contractor B
	3699 Roundtree Ct. (Top clock)	1994	15325	Imperial Valet Timer	Contractor B
	3699 Roundtree Ct. (Bottom clock)	1994	27718	Imperial Valet Timer	Contractor B
	3640 Roundtree Ct.	1994	9487	Rainbird ESP 4	Contractor B
	3753 Birchwood Dr.	1994	73000	Raindial	Contractor B
	3818 Northbrook Dr.	1994	84919	Imperial Valet Timer	Contractor B
	3834 Northbrook Dr.	1994	9226	Rainbird RC-7A	Contractor B
	3856 Northbrook Dr.	1994	29095	Buckner MT12	Contractor B
	2755 Winding Trail Dr.	1994	83035	Richdel 512FR	Contractor B
	2696 Winding Trail Dr.	1994	16796	Buckner MT12	Contractor B

Table 2: Hydrologic Performance of Sensors

	Address of Installation	Theoretical Requirement (inches)	Actual Application (inches)	% of Theoreical Requirement
Resident	4653 Kirkwood Ct.	28.23	15.35	54.39%
	4736 Harwich St.	28.23	16.09	57.01%
	711 Alpine	28.23	18.60	65.89%
	4313 Apple Wy.	28.23	23.64	83.76%
City	Elm Street Park	28.23	16.23	57.51%
	Table Mesa Site	28.23	19.52	69.14%
Willow Springs	2623 Juniper	28.23	21.00	74.40%
	2625 & 2615 Juniper	28.23	20.27	71.83%
	2665 Juniper	28.23	35.03	124.09%
	2683 Juniper	28.23	28.00	99.21%
	2676 Juniper	28.23	22.53	79.83%
	2640 Juniper	28.23	30.42	107.79%
Winding Trail Village	3877 Birchwood Ct.	28.23	14.73	52.18%
	3699 Roundtree Ct. (Top Clock)	28.23	15.63	55.38%
	3699 Roundtree Ct. (Bottom Clock)	28.23	27.83	98.60%
	3640 Roundtree Ct.	28.23	15.83	56.07%
	3753 Birchwood Dr.	28.23	14.68	52.01%
	3818 Northbrook Dr.	28.23	20.50	72.61%
	3834 Northbrook Dr.	28.23	19.80	70.16%
	3856 Northbrook Dr.	28.23	21.54	76.30%
	2755 Winding Trail Dr.	28.23	21.16	74.95%
	2696 Winding Trail Dr.	28.23	31.40	111.24%
	Average	28.23	21.35	75.65%

Table 3 : Irrigation Scheduling Worksheet

MONTHLY IRRIGATION SCHEDULING TABLE

Name of Property:____

Address:____ Year:_________________________

Name of Manager:____ Meter Location:___________________________

Water Meter Number:____________________ Irrigation Factor:___________________________(in/TG)

Irrigated Area:_________________________(sf) =1604 / Irrigated Area

Month	Average Monthly Rainfall (in)	Target Application (inches)	Target Application (tg)	Starting Meter Reading	Ending Meter Reading	Actual Application (tg)	Actual Application (inches)
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
April	2.34	1.0					
May	2.91	2.8					
June	2.12	5.9					
July	1.92	7.4					
August	1.46	6.2					
September	1.79	2.9					
Total (gal)	12.54	26.2					
Total (gsf)		16					

Instructions 1. Identify all irrigation clocks fed by the water meter.

2. Determine the total area (sf) irrigated by all of the systems which are fed from the meter.

3. Record the location and serial number of the water meter.

4. Calculate the Irrigation Factor by dividing the magic number (1604) by the irrigated area in sqare feet.

5. Divide the Target Application from Column [2] by the Irrigation Factor; record the result in Column [3]. This will be your target application to the landscape in thousands of gallons.

6. Read the water meter on the first of the month from April through October and record the readings in Col [4] and [5].

7. Determine the total water use by subtracting Col [4] from [5]; record the results in Col [6]

8. Multiply the value in Col [6] by the Irrigation Factor and record the actual inches of application in Col [7]

9. Compare your actual applications to the target applications to see how well the system is performing.

10. Note that the target values are based on average rainfall conditions in Boulder, CO, shown in Col [1]. Application should vary based on actual annual weather patterns for the year

Useful Conversion Factors:	
1 Acre = 43,560 ft^2	1 Acre-ft = 325,851 gallons
1 ft^3=7.48 gallons	1 Million Gallons = 3.07 af
1 in = 0.623 gal/ft^2	