Improving Water Application Efficiency in the Landscape through Pressure Oscillation (interim report, June 2004)

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Introduction

Water availability has become a major factor in residential landscape development. Periodic regional water shortages in recent years have caused difficulty for all segments of society, including the home gardener. As the population of California continues to grow, competition for the limited water resources will increase. This competition will lead to less available water and more costly water for the home gardener. All plant varieties in gardens require water, either at installation or throughout their life. In regional planning, however, landscape is typically considered a “soft” area. It is usually the first to be eliminated and the last to be funded in a budgetary, energy, or water crisis. California presently faces all three crisis’s.

California’s Water Conservation Act of 1990 led to the development of the Model Landscape Ordinance by the Department of Water Resources in 1992. In 1993 local agencies, cities, and counties, were required by the conservation act either to develop their own landscape water ordinance or to adopt the state model. While the state’s model ordinance does not directly apply to individual homeowners, the water conservation measures developed by local agencies have an effect on all residents, either through the required permit process for irrigation systems or through a cost per use basis. The central driver in the state’s Model Landscape Ordinance is a parameter titled “maximum applied water allowance.” Factors affecting an acceptable allowance are primarily plant species and water application efficiency. Water losses due to runoff, overspray, and deep percolation lower irrigation efficiency. This proposal pertains to runoff, which also indirectly affects deep percolation due to non-uniform water infiltration.

There are two primary types of irrigation systems available to the home gardener—sprinkler and microirrigation (also known as drip). Each system is best suited for a particular type of planting. For individual trees and shrubs, microirrigation emitters are ideal and should be the homeowner’s first preference. For planters and plants with earthen basins, microirrigation bubblers are ideal. For turf and most ground covers, sprinkler heads are most effective. Although subsurface microirrigation has been tested for grass lawns, the results have generally been disappointing.

This research project focused on runoff losses of water applied via sprinkler systems. Depending on the surface area under irrigation, homeowners generally use two types of sprinklers. For large areas, rotors are commonly used. They throw water typically from 40 ft to 80 ft, with precipitation rates ranging from 0.3 in/hr to 0.7 in/hr. Spray head sprinklers are better suited for smaller areas and are the most common water applicator in residential and commercial landscape. Spray heads typically throw water from 5 ft to 15 ft, with precipitation rates between 1.5 in/hr and 2.5 in/hr. Most soils cannot absorb all the water discharged at these high precipitation rates and runoff occurs. For example, if the ground is level with plant cover, the maximum infiltration rates for clay loam soils is about 0.20 in/hr, whereas for light sandy loam soils the rate rises to about 1.5 in/hr. These maximum infiltration rates decrease with ground slope. For a 12% slope, which is not uncommon in landscape contours, the maximum allowable precipitation rates for efficient infiltration decrease to 0.10 in/hr and 0.75 in/hr, for clay loam and light sandy loam soils, respectively. For example, soils typically found in Davis will readily absorb water at a rate of about 0.15 in/hr. Obviously, sprinkler hardware cannot apply water at such low rates. To minimize runoff, landscape personnel irrigate for very short durations, 5 min to 10 min, 4-5 times per week during the peak of the summer. This high frequency, with limited water penetration into the ground, is not ideal for many plants.

Sprinkler systems are designed to apply water very uniformly. However, if the water droplets are not absorbed where they fall, the water redistributes on the soil surface, flowing to the low depressions. The infiltrated water will therefore be relatively non-uniform. Irrigations will be made to green the dryer, higher areas and water will again accumulate in the lower elevations. Eventually, deep percolation and water loss will occur in these depressed areas. Whether irrigation water runs off the landscape onto hardscape or the water simple redistributes on the soil surface, precipitation rates exceeding the infiltration rates of the soil leads to water loss and poor irrigation efficiency.

The primary objective of this research project was to develop and demonstrate a device for minimizing surface runoff during sprinkler irrigation of landscape with conventional spray heads. The goal was to make this device suitable for either a new system installation or a retrofit situation.

Materials and Methods

Prototype fabrication

A hydraulically-driven valve device was constructed using the gearing system of a gear rotor sprinkler and machined PVC material. In the design process four prototypes were developed. Numerous options for an impeller and gearbox system were researched. This was followed by the building of impellers, ordering of gears, and purchasing rotary sprinkler heads for modification.

The design required a flow rate large enough for an average residential spray sprinkler system, about 8 - 10 gpm, so it was quickly realized that a large rotary sprinkler head was necessary to accommodate that flow. Sprinkler heads from top irrigation companies (Toro, Rainbird and Hunter) were investigated. After researching flow rates, pressures, and rotational speeds, it was decided that the Hunter I-25 Plus sprinkler head would serve the needs of this study. Information obtained from a Hunter representative indicated that the Model I-25 Plus high speed impeller's output, after being geared down, was about one revolution every two and half minutes or 0.4 rpm. Several different sprinklers were dismantled in order to better understand their operation.

Construction of the first prototype consisted of building a mold for an extension to the sprinkler head that would offset the output. Rubber tubing was used to direct water from the centered hole to the outside. The mold was prepared by spraying a mold-release formula on the edges. The cylindrical tubing was filled with epoxy and allowed to dry.

For the second prototype, Schedule 80 PVC was turned down from 5" to 1.75", the same diameter as the impeller and gearbox body. A hole was then drilled from the center outward at an angle of 75˚ with the vertical. Using special PVC to ABS plastic glue, the PVC extension was affixed to the ABS impeller and gearbox body so that the centered hole on one end of the PVC extension fit perfectly over the centered hole on the

ABS body. The valve body extension fit over the top of the original sprinkler head body and made room for the PVC extension.

Several other prototypes were designed, constructed and tested, before settling on a final design. Figures 1 and 2 show the rotor head before modification and the resulting oscillating valve following fabrication, respectively.

Figure 1. Original Rotor   Figure 2. Prototype Valve

Laboratory Phase

Laboratory experiments were conducted to determine the hydraulic characteristics of the prototype device, primarily the pressure headloss as a function of flow rate. Other tests included rotational cycle speed and evaluation of leakage. The equipment used for the laboratory testing phase are outlined in Figure 3. They included a 21X Micrologger, Halliburton Flow Analyzer (Model MC-11), Campbell Scientific Micrologger, Differential Pressure Transducer (MPX5700DP) and Absolute Pressure Transducer (MPX5700AS). An electronic storage module was used to store the data from the Micrologger and transfer it to a computer using a program called PC208W.

Pressure headloss was measured by connecting one of the ports of the differential transducer to a tapped hole on a pipe connected to the inlet side of the device and the other port to the outlet side so that the difference in pressure through the device could be measured. An absolute pressure transducers was also attached at the inlet so that the pressure at the inlet could be monitored. In order to process the results obtained from the pressure transducers a 21X Micrologger had to be used to read the voltage, which was later converted to pressure using the calibration equations derived from the graphical representations of the calibration data obtained for both transducers. In order for the Micrologger to receive signals from the pressure transducers, the transducers were soldered onto a protoboard and inserted into a socket that had 5 different wires extending out. Three of the color coded wires were then connected to the channels of the Micrologger. A program was then written specifically for the desired tests, which included, but were not limited to, the location of wires to the Micrologger, the location where the voltage outputs would be stored, and time of operation.

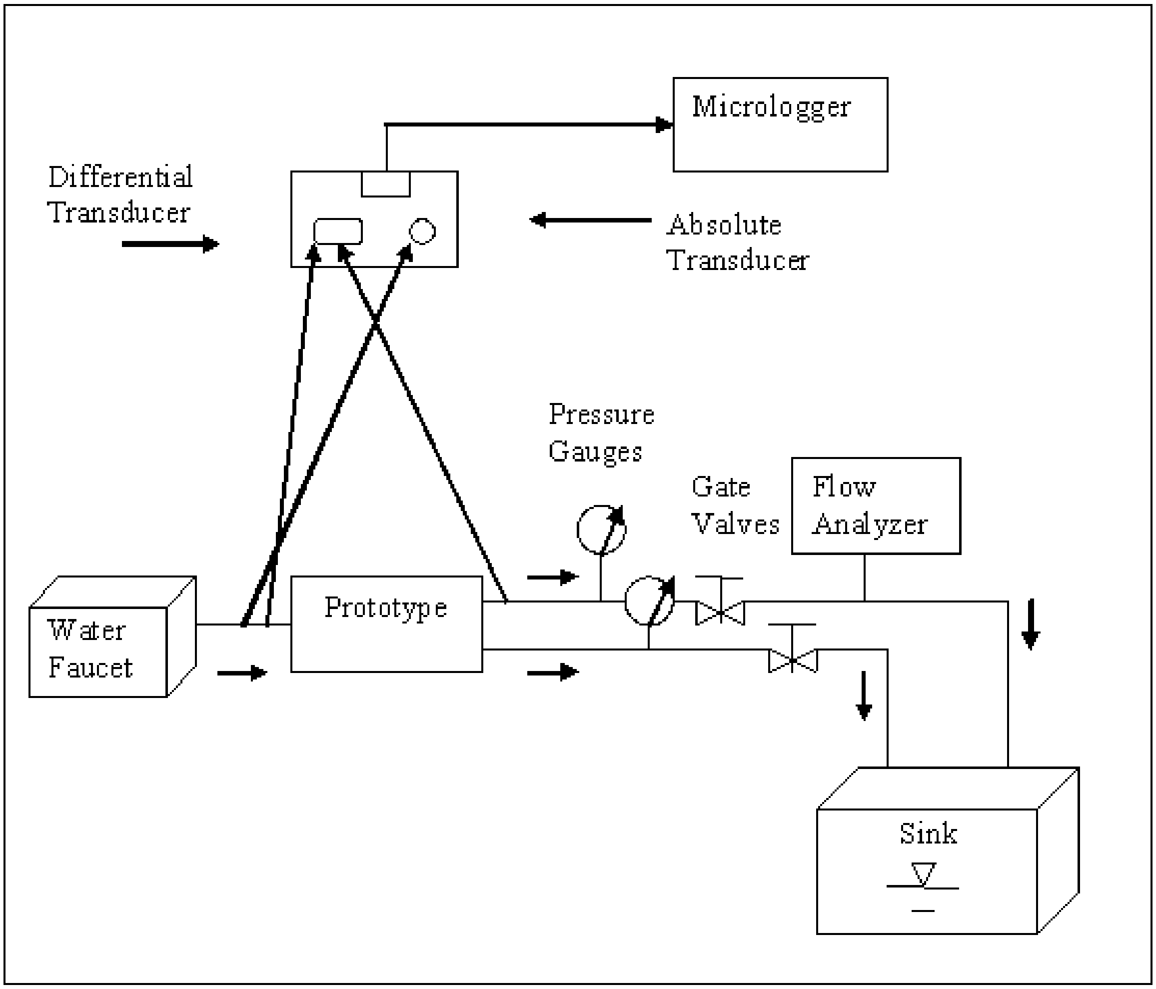

Figure 3. Schematic of laboratory testing of prototype oscillating valve.

Both transducers were initially calibrated by running tap water with a maximum pressure of 50 psi to the transducers via polypropylene tubing and back into the sink again using garden hoses. When calibrating the differential transducer, the port with the writing on the outside of the sensor was used to measure the pressure of water, while the other port with no writing remained open to atmospheric pressure. In the case of the absolute pressure transducer, the one port was used to measure the pressure of water. In order to calculate the calibration equations the voltage as seen on the Micrologger was written down at multiple pressures, usually starting out at atmospheric pressure then increasing pressure at intervals and collecting the corresponding voltages. Measurements of voltage were then continued while descending down in pressure to see if hysteresis occurred. Typical transducer data of pressure versus voltage are shown in Figure 4.

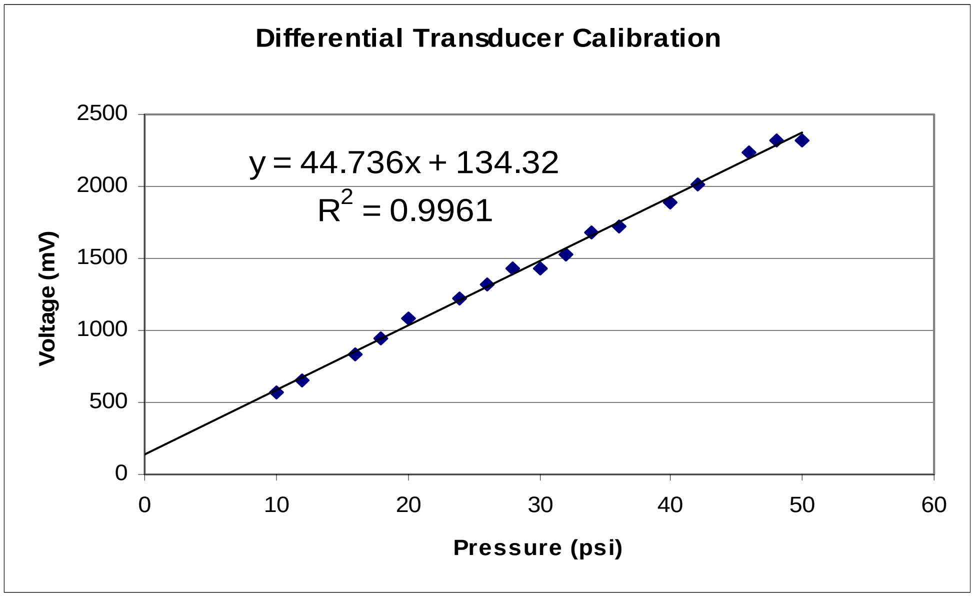

Figure 4. Trendline for calibration of the differential pressure transducer.

Following various preliminary tests, the pressure headloss observations were made for all four prototypes. Figure 5 shows the headloss data for Prototype #4. the headloss for the other prototypes were similar, but higher.

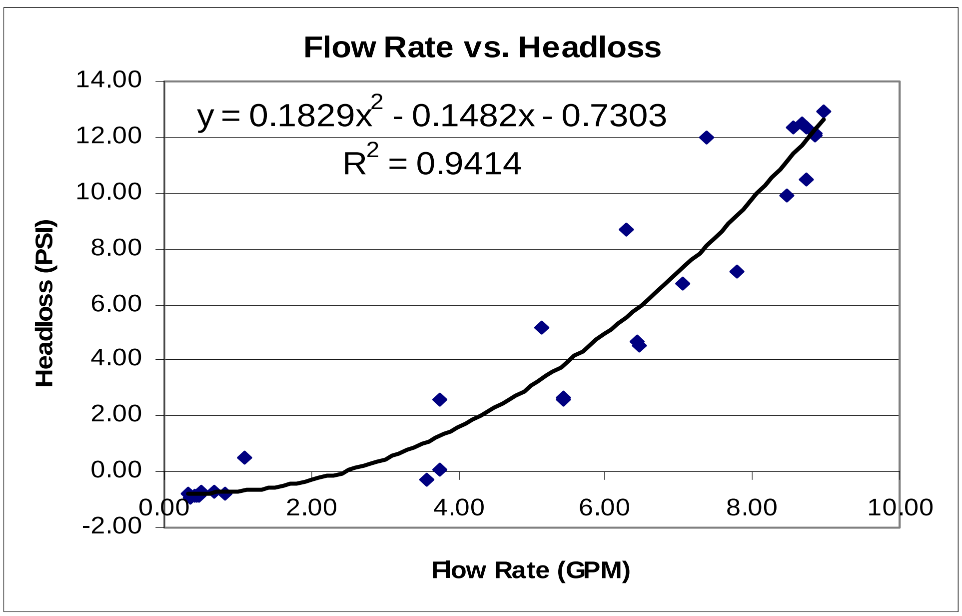

Figure 5. Pressure headloss vs. flow rate for Prototype #4. A Polynomial trendline is fitted to the data.

Field Phase

The objective of the field testing phase was to observe if the prototype would oscillate the water in a smooth fashion, as in the laboratory, but under conditions that simulate a lawn landscape with two circuits. These conditions included using backflow pressure normally created from sprinklers and the PVC pipe network. The second objective was to observe the pressure headloss of the system in actual conditions versus the headloss found in laboratory testing. Figure 6 outlines the field setup.

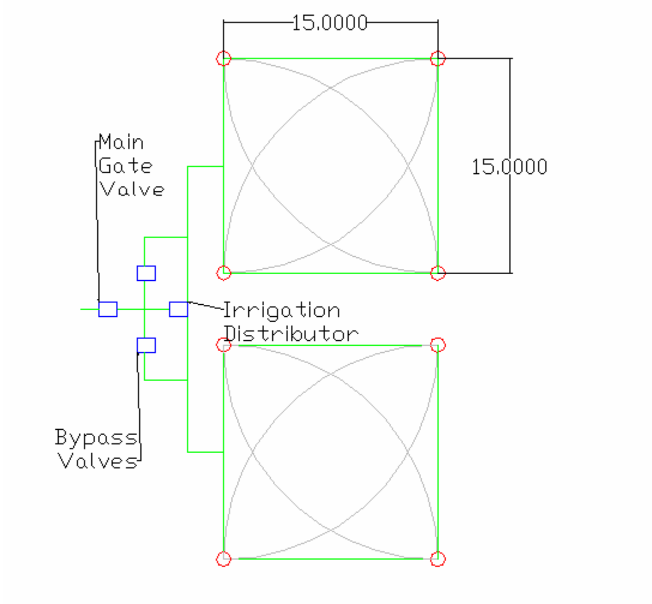

Figure 6. Evaluation field test system, showing two simple circuits, each 15 ft by 15 ft.

For part of the field testing phase prototype #4 was used and tested. As mentioned above, the first test was to examine if it would oscillate under normal field conditions. Following this test, the amount of time needed to complete a full oscillation cycle, which was defined as each side having completed a cycle within a certain timeframe, was observed and recorded. The goal was to have the oscillation match that of Figures 7a and 7b, as calculated originally as being most ideal (Hills et al., 1986).

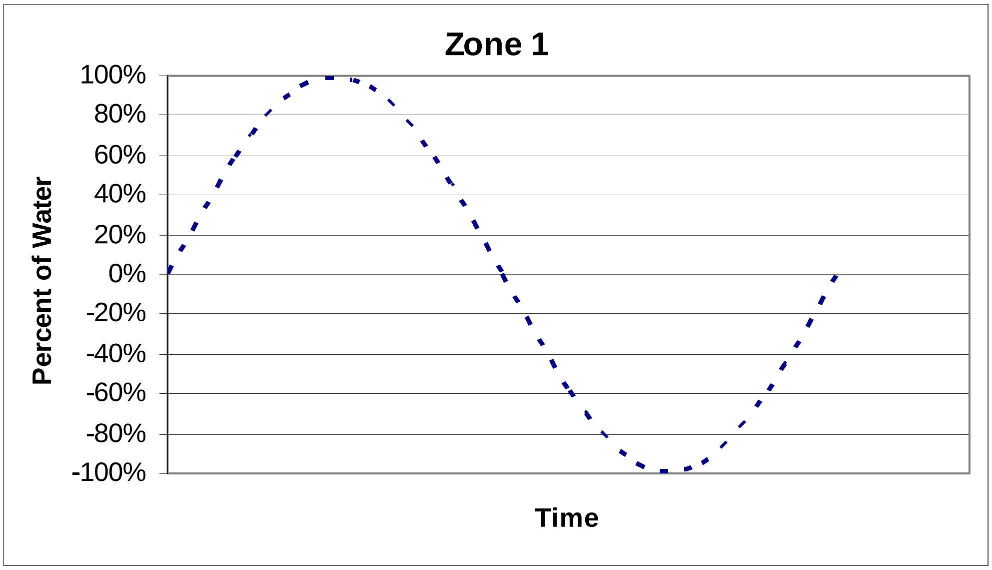

Figure 7a. Percent of water flow for Zone 1.

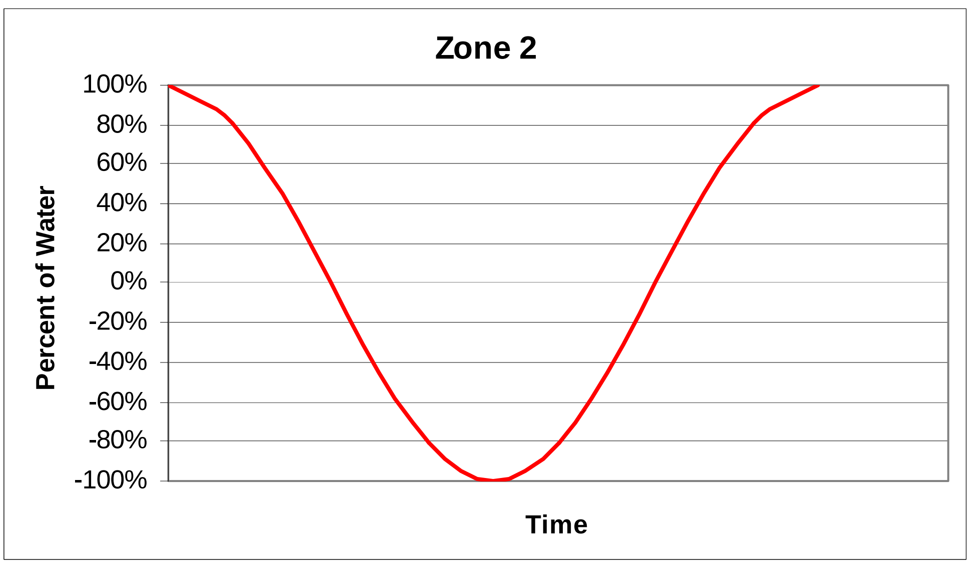

Figure 7b. Percent of water flow for Zone 2.

After recording the time for the system to complete one full cycle, the water uniformity distribution was measured. This was done by laying out 16 catch cans in each zone and performing several tests with the prototype (oscillator) in place and more tests without an oscillator (ASAE Standards, 2003). Figure 8 provides a pictorial view of the field site.

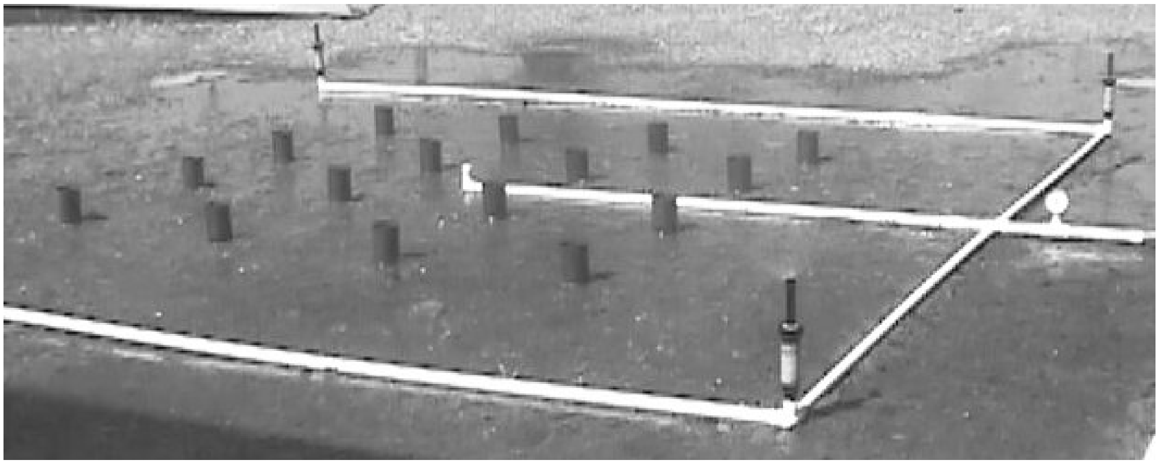

Figure 8. Left zone layout with 16 catch cans; the right zone layout was similar.

Field Results and Discussion.

Seven field tests were conducted under varying wind conditions during the month of March. Typical catch can data collected are shown in Tables 1a and 1b for the March 13 test, when the wind speed ranged between 5.0 and 8.3 mph. As noted for this one day, when the wind speed was fairly constant throughout the day, there was very little difference in the Christiansen's Coefficient of Uniformity when using and when not using the oscillator. Other information taken into consideration while viewing the distribution data, was the wind speed and direction at specific times of day. High wind velocities could possibly affect the results of the tests since sprinkler spray can be blown away from the test site or from one area to another, affecting precipitation rate values. The hourly reports of wind speed and direction data were obtained from the campus CIMIS station.

Figures 10 and 11 relate the Christiansen's Coefficient of Uniformity for all 14 tests conducted. As shown, the system with the prototype (oscillator) exhibited a similar rate of uniformity as the system without the oscillator. For any one day, a test was first conducted with the oscillator in place, which required about one hour, and then after rearranging the setup, the test without the oscillator was subsequently conducted in the next half hour. The wind speeds for all the tests were different, but were typically similar for any two tests within one day.

During the field tests it was observed that two minutes were required for a complete oscillation cycle to occur. This meant that it took one minute for the left zone to water and another minute for the right zone to water. The oscillation pattern continued as initially intended. Figures 12a to 12g pictorially illustrate an oscillation cycle of the field testing phase. These figures show the duration of time in 30 second intervals for sprinkler activation and deactivation on one of the two zones watered by the oscillator.

The average precipitation rates for all the tests with the oscillator and without the oscillator were 0.93 in/hr and 1.68 in/hr, respectively. The oscillation valve therefore dramatically reduced the precipitation rate without loss in application uniformity. Surface runoff could therefore be likely reduced in many soils.

Sample Number	Sample mark	Water Amount(ml)	Sort lower to higher	Xi-Xave	|Xi-Xave|
1	B2	116.0	73.0	3.6	3.6
2	B3	131.0	88.0	18.6	18.6
3	B4	113.0	100.0	0.6	0.6
4	B5	73.0	101.0	-39.4	39.4
5	C2	122.0	102.0	9.6	9.6
6	C3	136.0	102.0	23.6	23.6
7	C4	122.0	107.0	9.6	9.6
8	C5	100.0	113.0	-12.4	12.4
9	D2	145.0	116.0	32.6	32.6
10	D3	118.0	118.0	5.6	5.6
11	D4	102.0	122.0	-10.4	10.4
12	D5	107.0	122.0	-5.4	5.4
13	E2	123.0	123.0	10.6	10.6
14	E3	102.0	131.0	-10.4	10.4
15	E4	101.0	136.0	-11.4	11.4
16	E5	88.0	145.0	-24.4	24.4

Table 1a. Typical catch can data. Results are for the left zone without the oscillator on March 13, when wind speeds ranged between 5.0 and 7.1 mph. The resulting coefficient of uniformity was 87.3.

Sample Number	Sample mark	Water Amount(ml)	Sort lower to higher	Xi-Xave	|Xi-Xave|
1	B2	136.0	103.0	1.7	1.7
2	B3	147.0	108.0	12.7	12.7
3	B4	167.0	110.0	32.7	32.7
4	B5	148.0	112.0	13.7	13.7
5	C2	148.0	119.0	13.7	13.7
6	C3	147.0	122.0	12.7	12.7
7	C4	150.0	125.0	15.7	15.7
8	C5	125.0	136.0	-9.3	9.3
9	D2	161.0	146.0	26.7	26.7
10	D3	146.0	147.0	11.7	11.7
11	D4	112.0	147.0	-22.3	22.3
12	D5	122.0	148.0	-12.3	12.3
13	E2	103.0	148.0	-31.3	31.3
14	E3	119.0	150.0	-15.3	15.3
15	E4	108.0	161.0	-26.3	26.3
16	E5	110.0	167.0	-24.3	24.3

Table 1b. Typical catch can data. Results are for the left zone with the oscillator on March 13, when wind speeds ranged between 5.5 and 8.3 mph. The resulting coefficient of uniformity was 86.9.

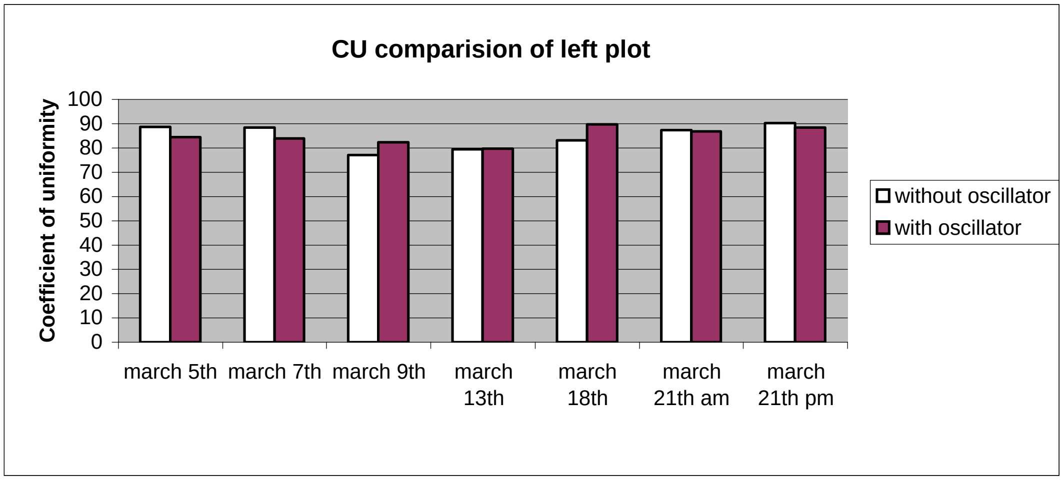

Figure 10. Christiansen's Coefficient of Uniformity of the left zone for 14 different field tests, under varying wind conditions.

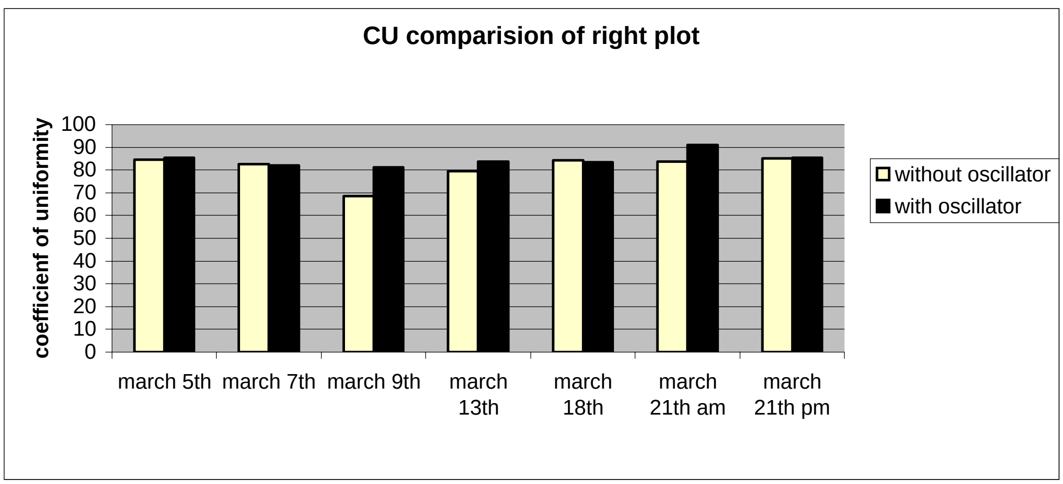

Figure 11. Christiansen's Coefficient of Uniformity of the right zone for 14 different field tests, under varying wind conditions.

Figure 12a. 0 seconds

Figure 12b. 30 seconds

Figure 12c. 1 minute

Figure 12d

Figure 12e.

Figure 12f. 1 min 30sec

Figure 12g. 2 minutes

One of the most common problems in irrigation systems is water runoff resulting from soil that has been saturated on the surface from over watering. The need for irrigation management becomes evident since water is not only wasted but leaching can take place where nutrients and salts are removed from the soil in runoff from excess watering. Leaching can result in poor water quality present in the runoff leading to pollution of water resources. Besides the importance of the rate of water application, soil permeability and infiltration rates are also important aspects to consider when attempting to prevent leaching. According to The Soil Survey (USDA, 2003), permeability is the quality of the soil that enables water to move downward through the profile. It is also measured as the number of inches per hour that water moves downward through the saturated soil. The soil type used in the field experiments was Yolo silt loam. This soil was considered to be well drained with a permeability that was moderate, meaning it could absorb water at 0.5 – 1.5 inches per hour. Indeed, no ponding that resulted in runoff was observed during the trials which incorporated the oscillator; whereas, without the oscillator water ponding was observed after a half hour irrigation. Although the land was essentially flat and no runoff was observed, if the set-up was placed on sloping ground, as is typical in urban landscape, runoff would definitely occur. Regarding other soil types, loam is described as a soil material that is 7 to 27 percent clay particles, 28 to 50 percent silt particles, and less than 52 percent sand particles. Since sand is relatively permeable its presence in the composition of this soil accounts for its ability to drain well.

Overall, the prototype oscillator performed well, and without malfunctioning. Observations made, however, suggest that modifications can be made to improve its performance. The results indicated that by increasing the diameter of the angled hole above the impeller, the flow rate increased from 6 gpm to 8 gpm. According to Figure 5, headloss increases with flow rate. For the prototype's configuration the average headloss obtained from laboratory and field testing was approximately 6 psi.

Limiting the prototype to an operational pressure of 30 psi for the actual simulation meant that the maximum head loss would be roughly 6 psi. From the field testing phase, with inlet pressure of 30 psi, it was observed that the prototype completed a full cycle oscillation in two minutes, with a 6 psi headloss

Summary

The progress made during the course of this research project sheds light on the possibility for the improvement of future designs for a hydraulically driven valve. Such a self powered, hydraulically driven valve may become a reality as a valuable irrigation system component since its operation is independent of an electrical power source making it ideal for remote areas. In addition, the lowered precipitation rate, associated with an oscillating watering cycle between two zones, shows great prospects for an irrigation system that reduces soil erosion from runoff and leaching of salts and nutrients from over watering. This project is continuing into the 2004/05 academic year, and a final report will be written in June 2005.

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