Effluent Nitrogen Management for Agricultural Re-Use Applications

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Abstract
Balancing the continuous supply of domestic wastewater from effluent treatment plants with fluctuating crop water demands requires unique irrigation design strategies. A key design consideration when utilizing disinfected secondary treated city water is to maximize the re-use of effluent in winter months, when forage crop water demands are low, yet still produce minimal deep percolation. Twenty-seven center pivots in Palmdale, California required new custom-designed sprinkler packages to dispose of approximately 7,000 gallons per minute of treated wastewater. Through innovative design efforts, extensive testing and field experimentation, a standardized package has been adopted by the County Sanitation District of Los Angeles County that enables a highly efficient application of re-use city wastewater without groundwater degradation throughout the year. Many factors influenced the selection of the sprinkler package components including infiltration rates, application rates, soil moisture storage, distribution uniformity, pressure regulation, wind, and debris buildup.

Introduction
Currently in the United States, many locations use reclaimed water. Reclaimed water is treated effluent which is typically for non-potable uses, such as irrigation. Historically, treated effluent from wastewater treatment facilities was discharged directly into a stream, river, or other natural body of water. However, the continued demand for fresh water supplies has increased need for reuse of treated wastewater. Using reclaimed water for non-potable use saves potable water for drinking, since less potable water will be used for non-potable uses.

The County Sanitation District No. 20 of Los Angeles County (District) in Palmdale, California, re-uses approximately 8.5 million gallons per day (MGD) of secondary treated wastewater within the Palmdale Effluent Management Site (EMS) for irrigation. Wastewater irrigation has been proven to be a viable alternative to point source discharge of treated wastewater. However, to beneficially reuse the wastewater, an efficient and effective land application system with minimal environmental ramifications is vital. In addition, public acceptance depends upon a reliable and robust design and management strategy.

To achieve these objectives, the Palmdale EMS presently utilizes 27 center pivots providing water to over 2,000 acres of forage crops, a tree nursery, a pistachio orchard, and 11 tree barriers. A general map of the Palmdale EMS is presented in **Figure 1**.

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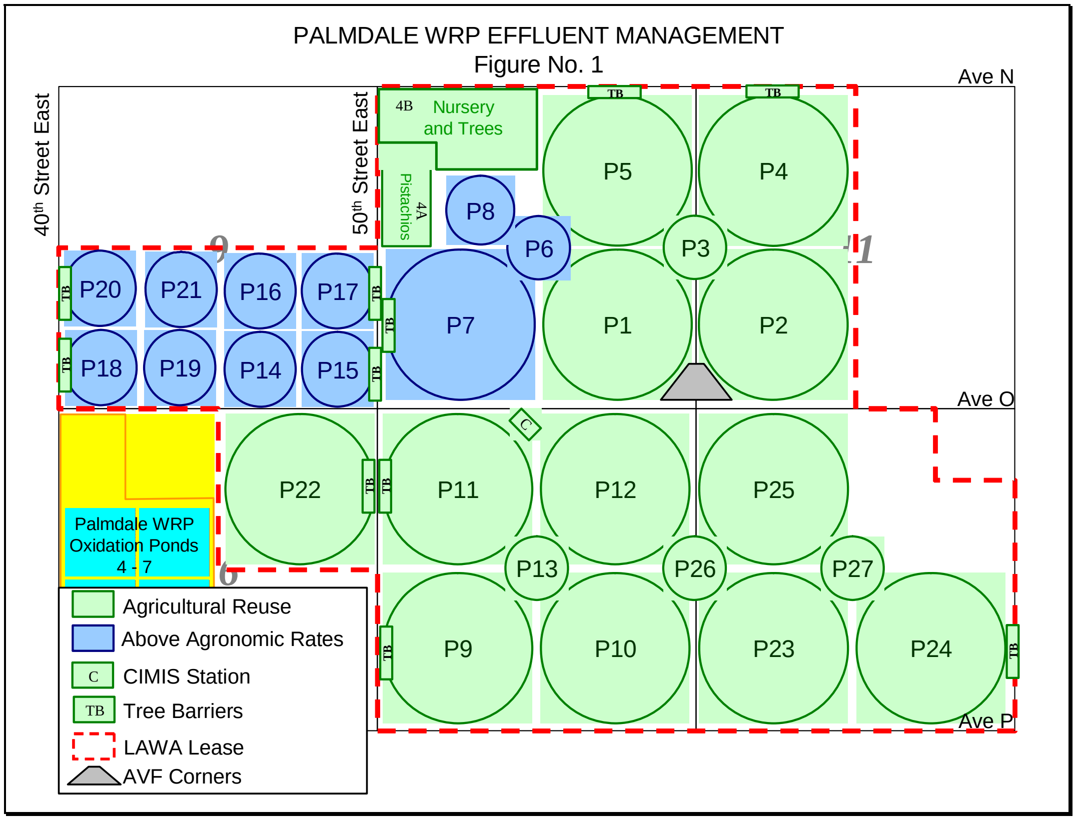

Figure 1. Palmdale center pivot layout

The District contracted with the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo, for technical assistance to improve and monitor the Palmdale EMS irrigation distribution system. One of the key objectives of the contract was to provide real-time irrigation scheduling and representative soil moisture monitoring throughout the year. This is important because irrigation demands fluctuate monthly and wastewater supply is fairly constant. Several unique aspects of irrigation scheduling and annual crop planning for the Palmdale EMS are addressed in a separate paper.

As an early part of the technical assistance program, ITRC performed two evaluations of a "representative" center pivot irrigation system within the Palmdale EMS. The first evaluation was the baseline distribution uniformity (DU), which was conducted on the representative center pivot to provide an indication of the existing performance or "as-is" performance. The second evaluation (the improved DU) was performed following a number of modifications to the representative pivot, including:

a. Raised and/or staggered sprinklers to manufacturers recommended heights
b. Installed new nozzle package
c. Cleaned the sprinkler rotators and replaced the plates
d. Replaced broken rotators and/or rotator bodies
e. Leveled tilted sprinklers

These evaluations/modifications were performed to provide the District with a practical DU that could be used in annual cropping plans. A minimum DU benchmark of 0.80 had been set forth by the California Regional Water Quality Control Board, Lahontan Region (RB), and conducting the evaluations provided a benchmark by which the District could standardize each machine to meet the RB requirements. Both evaluations were conducted with the correct design pivot inlet pressure.

This paper outlines how a single machine, with the proper hardware and adjustments, can achieve a high DU. Additionally, all center pivot packages were standardized to provide matched precipitation rates and meet all center pivot pressure requirements, in order to make operation and management simpler and more systematic.

The following sections will:

- provide background on DU
- show how the modifications to the original design packages impacted DU
- demonstrate the improvement in DU through simple modifications
- lay out the current general package for all machines and system components

This paper will focus on the physical components of the water disposal system involving center pivot design, structural modifications, and maintenance practices—all of which are highly important, because not even good irrigation scheduling and soil moisture monitoring can turn a poorly-designed irrigation system into an effective tool.

Distribution Uniformity (DU)

Distribution uniformity is a measure of the uniformity with which irrigation water is distributed to plants throughout the field. It is defined as:

$$DU_{lq} = \frac{d_{lq}}{D_{avg}} = \frac{\text{average low quarter depth}}{\text{avg depth of water accumulated in all elements}}$$

The practice of using the least-watered 25% of the area (low quarter) as the reference standard has gained wide acceptance (Burt et al., 1997). The uniformity described by DU_{lq} (and all terms involving the low quarter) leaves about $1/8^{th}$ of the area at less than the value of the numerator. If the DU_{lq} is used to compute the necessary gross application depth, this "under-irrigation" varies from zero at the $1/8^{th}$ point to the minimum depth applied at the extreme. This term can be applied to all irrigation methods.

The following are the major factors influencing center pivot DU:

1. Different application rates along the pivot length. Ideally, the sprinkler nozzles will be sized properly along the pivot to account for pipe friction, sprinkler spacing, and the area covered (the first tower covers a much smaller area than the end tower).
2. Uneven overlap of sprinkler patterns between sprinklers. This is influenced by wind, the proper angle of sprinklers, the cleanliness of the sprinkler spray mechanism, and the height of the sprinklers, all of which were considered and/or corrected as part of this evaluation.
3. Uneven application patterns in different quadrants of the field. This is primarily caused by uneven wind patterns, and is especially important if the pivot is always in the same location at the same time every day.

To accurately evaluate the DU_{lq} of the center pivots, an irrigation evaluation procedure that was designed by ITRC to work with all of these factors was used (Burt et al, 1999).

Evaluating a "Representative" Center Pivot

Pivot 2 was chosen as the "representative" center pivot because it was one of the first center pivots installed within the Palmdale Effluent Management Site (EMS) and most (if not all) of the modifications made to Pivot 2 were needed at the other center pivots. In addition, the original pivot system sprinkler chart was available and modifications fit within the operation of the EMS.

The key to effectively evaluating the specific modifications (outlined in this paper) made to Pivot 2 was ensuring that everything else (such as system flow rate, system pressure, pivot speed and wind conditions) remained constant. All of these factors are easily manipulated and controlled except for wind conditions, which can vary from minute to minute and can have large effects on uniformity.

Wind Effects on Uniformity

To make certain that the wind conditions were as uniform as possible during each of the evaluations, the Palmdale WRP CIMIS station was utilized to find any patterns in wind speed and direction that may have existed. Data from the month before the initial evaluation were analyzed and plotted to identify tendencies in the weather. Wind speed data for typical 24-hr period is shown in **Figure 2**.

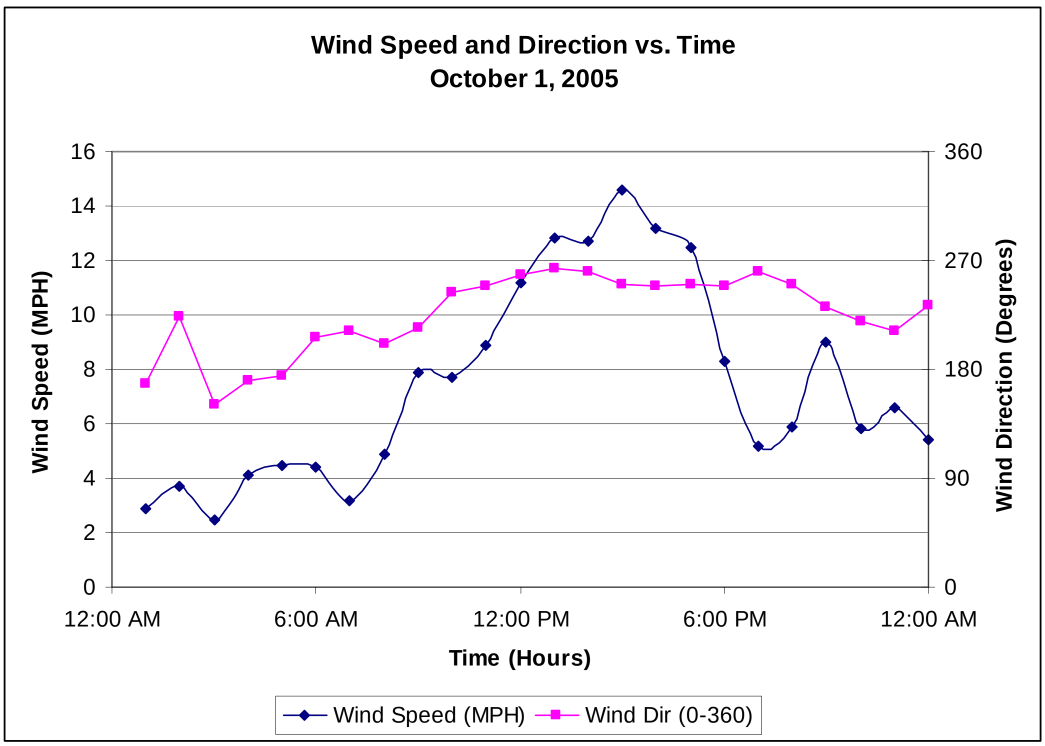

Figure 2. Graph of wind speed and direction for a typical day in October 2005

Figure 2 illustrates how the wind has a tendency to increase significantly between 9 am and 6 pm. The evaluations were conducted when the wind speed was at a 3-6 mile/hr velocity.

The tests were conducted at a 45-degree angle to the prevailing wind direction. This allows for a representative DU without having to conduct multiple evaluations on the center pivot if the wind had started blowing.

Since the center pivot rotations tend to follow a 12-hour increment and typically start at the same time every day, the effect of wind on distribution uniformity at certain points in the field will always be the same. For example, if the wind blows so that one point in the field does not receive any water, that point is likely not to receive any water on any rotation, or at least not on every other rotation.

Initial DU Evaluation

Prior to making any modifications to the “representative” center pivot a DU evaluation was conducted to verify the pivot package design in an “as-is” state. This provided a good estimate for the DU values that could be expected within the EMS. The resulting DU was 0.73. **Figure 3** illustrates the catch can volumes in relationship to the pivot center.

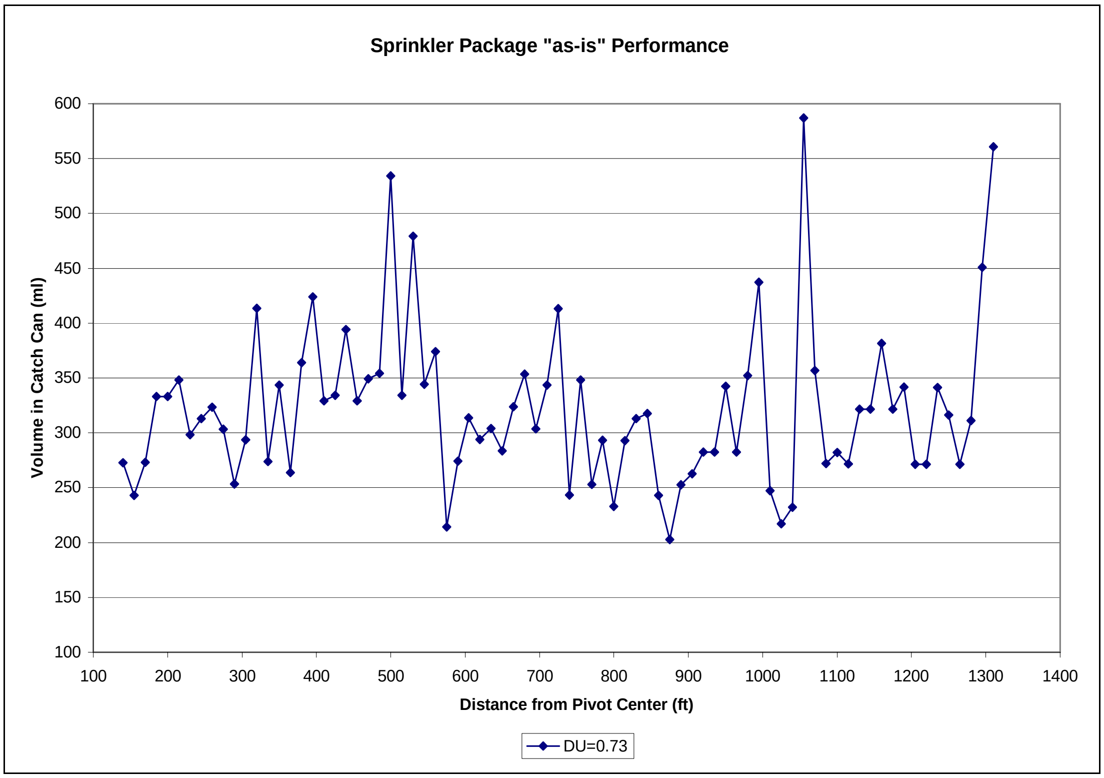

Figure 3. Catch can values along the length of the machine (non-weighted)

The pivot sprinkler package designed DU is 0.90. To achieve this goal modifications to the center pivot and sprinklers needed to be made. The improvements were selected to decrease the variations between catch cans.

Individual Center Pivot Modifications/Improvements

To provide the District with a distribution uniformity (DU) value that was obtainable and realistic, ITRC made the following modifications to Pivot 2 (listed by priority):

1. Raised the sprinklers from an average of 3.5 feet to an average of 5.5 feet
2. Staggered the heights and leveled the sprinklers to prevent water streams from colliding
3. Removed debris between the rotator and the rotator plate to allow free rotation
4. Cleaned the rotator plates to improve water trajectory
5. Replaced broken rotator bodies

6. Replaced nozzles to ensure design flow rates during the test

Points 1-3 (above) were the primary causes of the sub-par DU (of 0.73, compared to a pivot package design or target DU value of approximately 0.90).

Sprinkler Heights

Sprinkler spacing for center pivots are designed for a certain amount of overlap. This overlap ensures the proper distribution uniformity during irrigation. In previous years, the District had focused on limiting and/or preventing drift from the pivots from leaving the field by lowering many of the sprinklers (typically near the end of the machine) to an elevation just above the canopy height just before harvest (**Figure 4**). Unfortunately, this process negatively affected the DU of the pivot.

Figure 4. Original sprinkler heights – average 3.5 feet

The manufacturer of the sprinklers, Nelson Irrigation, was consulted to verify the correct mounting height for the sprinklers. The original pivot package for Pivot 2 utilized the R3000 rotator with green plates. This plate is designed to operate in a pressure range between 20-50 psi and at a height of 6 to 9 feet (Nelson Irrigation Corporation, 2005).

The sprinkler heights for the initial DU test (before modifications) ranged between 30 inches and 48 inches and had an average sprinkler height of approximately 42 inches. This limited the throw diameter and ultimately the overlapping of each sprinkler. To correct this, the sprinklers were modified so the average height was 66 inches (**Figure 5**); half at 60 inches and half at 72 inches. Prior to raising the height of the sprinklers, however, the District had mitigated drift concerns through chlorination of the secondary treated wastewater.

Figure 5. New sprinkler heights – average 5.5 feet

The R3000 rotator sprinklers were not placed as high as the manufacturer recommended because the pivot was operating at about 40 psi and wind drift is still a bit of a concern – even though the District now uses secondary treated chlorinated wastewater. In addition, maintenance of the sprinkler is more difficult at a high setting; this is discussed further in a later section.

Leveling and Staggering the Sprinklers

During the initial evaluation, adjacent sprinkler streams were commonly hitting one another, further impacting the overlap effect (**Figure 6**).

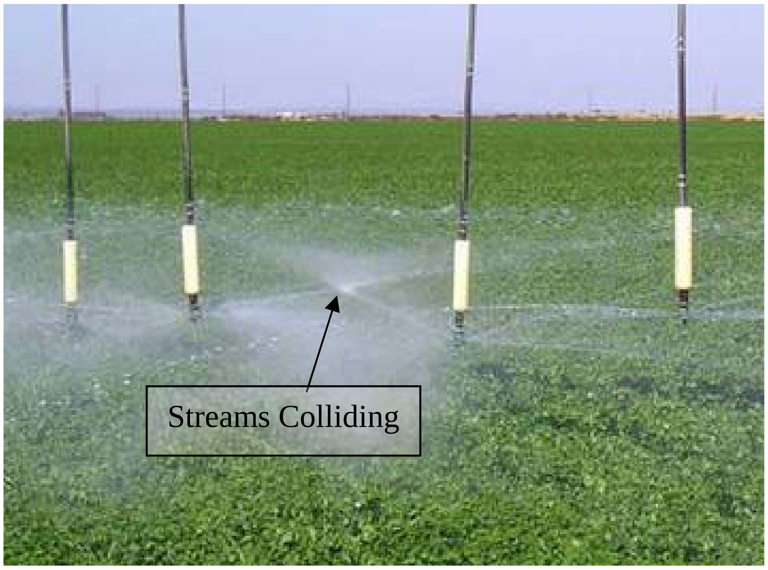

Figure 6. Sprinkler streams colliding during initial evaluation decreasing the pivot DU

In order to minimize stream collisions, drop hose heights can be staggered. For example, one sprinkler is set at 5 feet and the two adjacent sprinklers are set at 6 feet. This amount of stagger also prevents the water streams from colliding into the sprinkler weight – causing the sprinklers to swing while operating.

As part of the modifications every other sprinkler was staggered vertically by one foot to minimize the spray patterns hitting each other and to minimize sprinkler swinging (**Figure 7**).

Figure 7. Staggered sprinklers to minimize spray pattern collisions and swinging

Cleaning Debris from Sprinkler Rotators

Partial nozzle plugging and debris buildup on sprinkler nozzle plates was evident during the initial evaluation. Plastics, feathers, and algae in the irrigation water were the primary cause of this problem. Debris buildup on and under the rotator plate and nozzle plugging (even partial plugging) can have a significant negative impact on the distribution uniformity of the irrigation system. The debris impacts the nozzle spray pattern and prevents proper spinning of the rotator plates. This, in the end, results in poor application coverage. **Figure 8** illustrates an example with a rather heavy debris load.

Figure 8. Sprinklers with trash on rotator plates

As part of the modifications, each of the rotator plates was removed from the rotators and thoroughly cleaned (**Figure 9**).

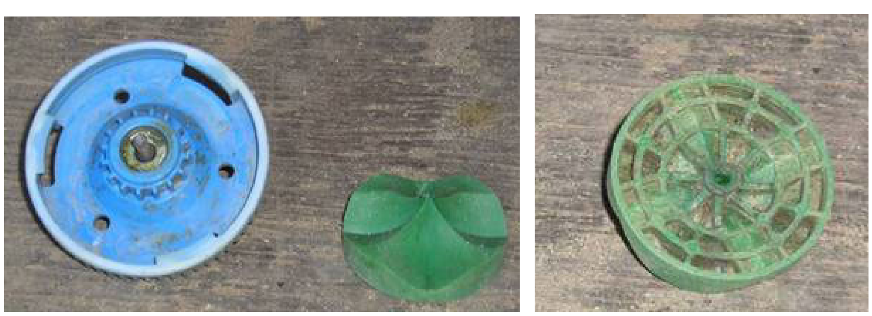

Figure 9. Clean rotators and rotator plates

Nearly all of the sprinklers had algae or debris buildup between the rotator plate and rotator. Inadequate filtration was the cause of these issues. Therefore, the District decreased the maintenance interval between servicing and cleaning the sprinklers and filters.

Replacing Rotator Bodies
Approximately 25 sprinkler bodies had to be replaced because they were either cracked, broken, or bent. The rotator body that is utilized at the Palmdale WRP is the "Trash-Buster". The open-body architecture allows for debris to pass through more easily, alleviating buildup of material on the plate and body of the sprinkler. Replacing cracked and broken rotator bodies was also part of the increased maintenance program.

A majority of the bad rotator bodies had cracked braces that support the rotator and rotator plate. This prevents the water stream from striking the rotator plate correctly. This in turn can prevent the sprinkler from operating properly, if at all (as shown in **Figure 10**).

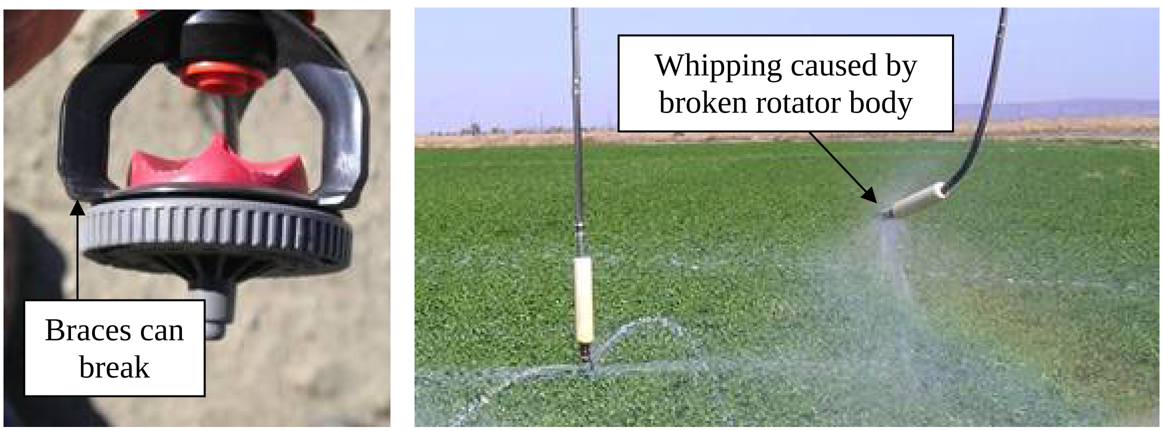

Figure 10. Non-functioning sprinkler because of broken rotator body

New Sprinkler Nozzles
The final modification made as part of the evaluation was the installation of new nozzles based on the pivot system sprinkler chart provided by Reinke Manufacturing and Rain for Rent. Each of the nozzles was removed from each sprinkler and replaced with the nozzle specified in the system sprinkler chart. The nozzles were replaced to guarantee that the proper (or design) sprinkler flow rates were being delivered at every point along the pivot and to replace any nozzles that may have any wear or plugging – reducing the DU of the system.

The original pivot sprinkler package utilized flow compensating (FC) nozzles, a plug-resistant sprinkler on the inner six spans of the pivot. The outer two spans utilize the 3TN nozzle – a fixed orifice with standard drill sizes. The FC nozzle uses a flexible orifice, which contracts as pressure increases, allowing the flow rate discharge to be held fairly constant, regardless of pressure fluctuations. The flexible nature of the rubber also allows for relaxation of the orifice at low pressure. FC nozzles are labeled by flow rate (GPM) and 3TN nozzles are labeled and color coded by drill size (in 64ths of an inch).

Flow control nozzles are NOT recommended on flexible drops because the orifice is continually adjusting/changing and the jet (or stream) of water from the nozzle may not strike the rotator plate perfectly. This could have negative implications on the system DU because of whipping as well as the life of the rotator and rotator plate. For this reason, all the FC nozzles were replaced with standard drill size 3TN nozzles per the new sprinkler package chart.

Results from the Modifications

A comparison of catch can volumes (non-weighted) before and after modifications is shown in **Figure 11**. The results were:

The initial DU = 0.73
DU with improvements = 0.89

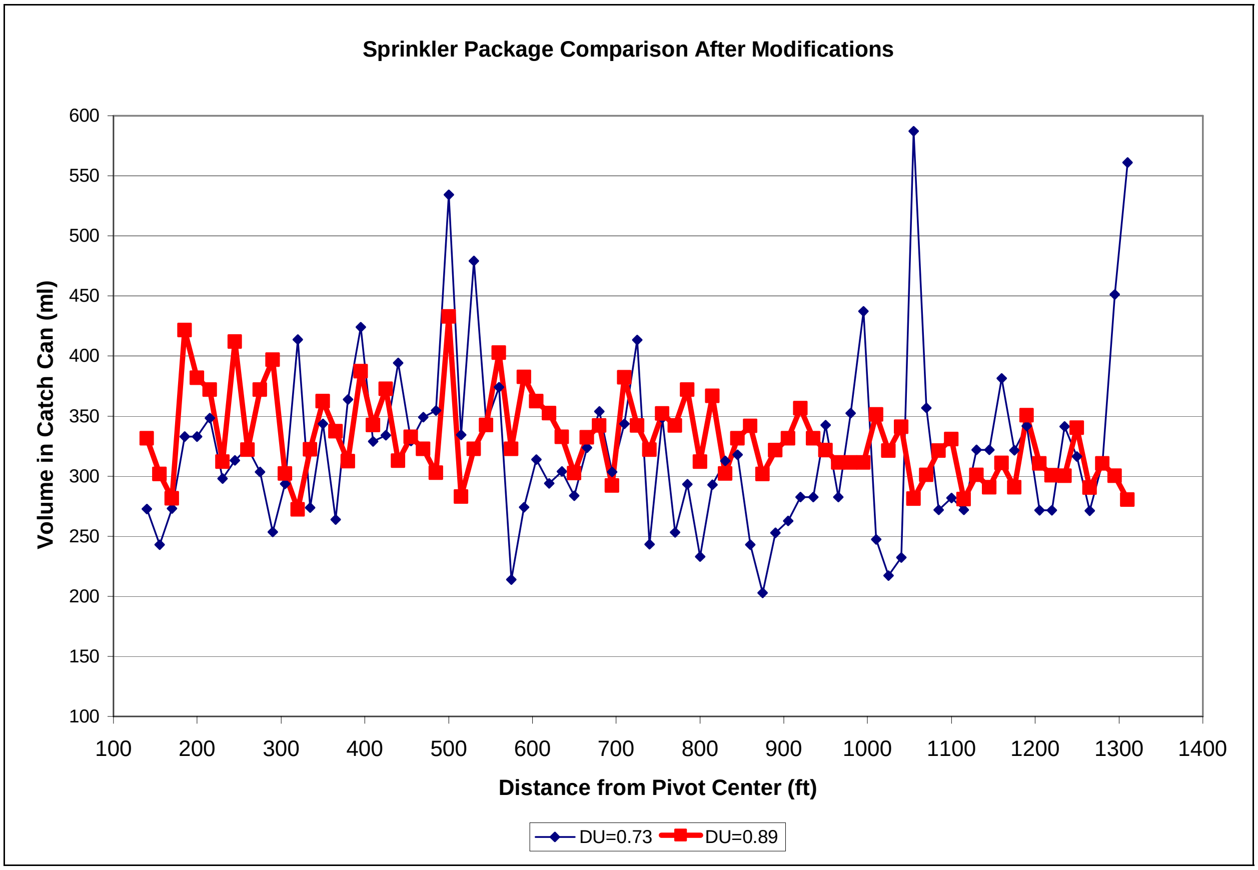

Figure 11. Catch can volumes from pivot center to edge of field (non-weighted)

Although there appears only to be some improvement between evaluations, the difference in DU is linked to the points on the right half of the figure. These points, when weighted, improve the DU because they represent a large portion of the field. For this reason, the modifications proved to be very effective at improving the DU for an individual pivot and ensuring that a majority of the pivot is representative of the entire field.

Comparing the Results of the “Representative” Center Pivot

For comparison purposes each of the points from both DU evaluations was weighted based on the location from the center of the pivot (the points farthest from the center are more important because they cover more area). These points were then plotted with a relative value of 1.0 to visually display the differences between the two evaluations.

Figure 12 illustrates that the number of points that fall within +/- 10% of the weighted average is greatly improved as the DU approaches 1.0. This equates to:

1. improved application uniformity
2. increased water efficiency (assuming good irrigation scheduling) minimizing deep percolation
3. simpler irrigation scheduling
4. an increase in representative sampling locations throughout the pivot
5. improved soil sensor reliability because its location is most likely more representative

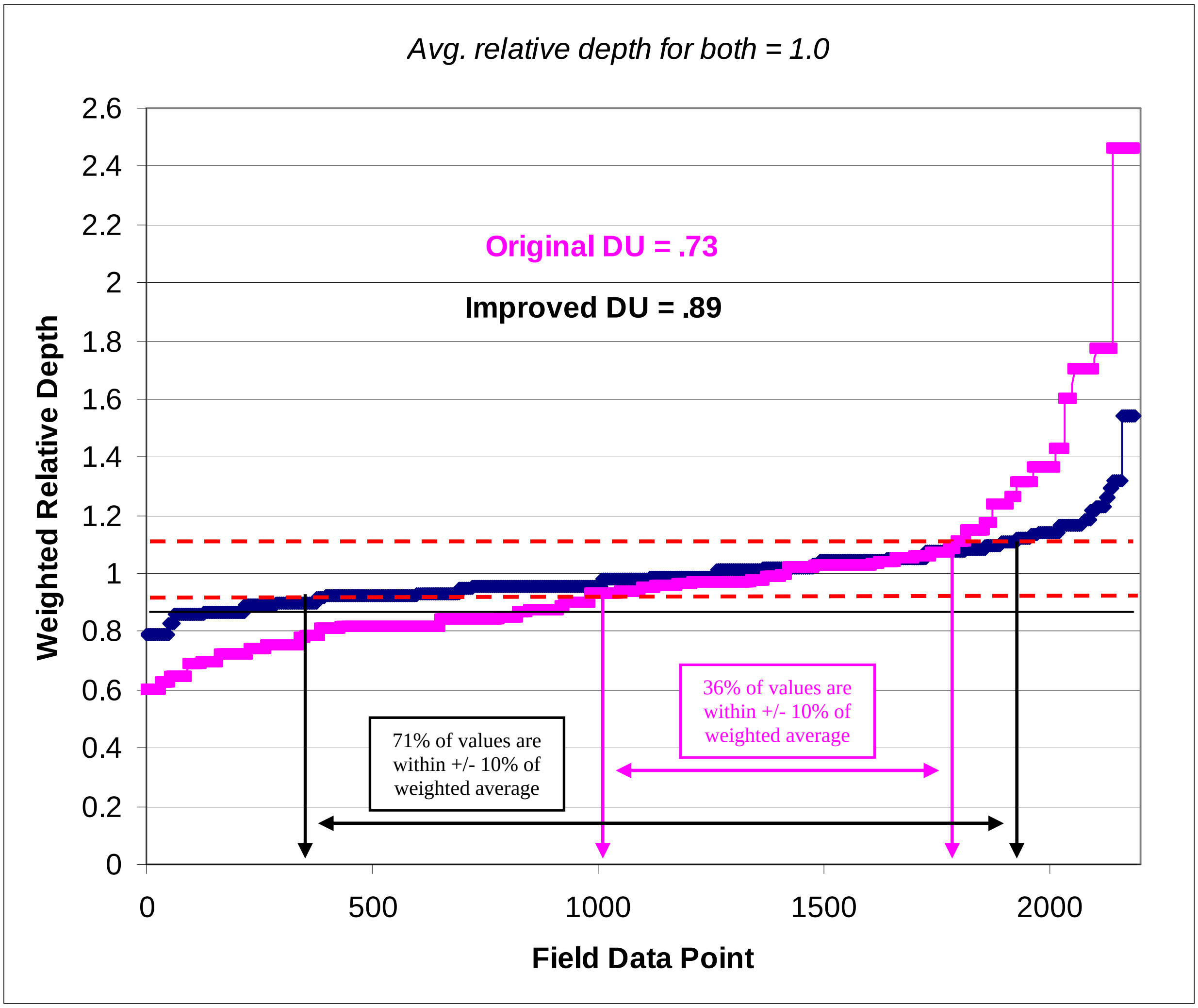

Figure 12. Improved performance in DU

Figure 12 demonstrates that with the original package, approximately 36% of the field is representative of the entire field. However, increasing the DU from 0.73 to 0.89 improves the representative segment of the field to about 71%. This simplifies management and operation by improving the likelihood that a plant tissue sample or soil moisture sensor station is within a representative portion of the field.

Standardizing the Entire Distribution Site

With a practical value for an obtainable DU many additional improvements were made at the Palmdale EMS to make the operation of the entire center pivot distribution systems simpler and more systematic. These operational improvements included modifying the pivot sprinkler package to:

1. match precipitation (application) rates for all pivots
2. provide a precipitation rate that would work in both the summer and winter months without runoff
3. minimize pressure requirements to reduce operating costs
4. add pressure regulation to stabilize pressure to sprinklers
5. make maintenance of the pivots and sprinklers simpler without negatively impacting DU

All of the operational improvements above work in correlation with one another. To provide improved operation of the system as a whole, each of these topics needed to be addressed. Implementing them individually would only have yielded mediocre benefits.

Matching Precipitation Rates for All Center Pivots

An analysis of the center pivots' design flow rates compared to the peak evapotranspiration (ET) requirement for alfalfa in the Antelope Valley indicated that most of the large pivots did not have enough flow rate capacity. On the other hand, the small pivots had application rates nearly three times what is required, making irrigation scheduling more difficult. The peak evapotranspiration of alfalfa irrigated using center pivots will vary depending on the speed at which the center pivot moves.

For example, running a pivot on a 14-hour rotation will lead to higher evaporation because the plant surface is wetted more frequently than when using a 48-hour rotation. The estimated peak evapotranspiration rate of alfalfa in July in Palmdale, assuming a 24-hour rotation, is about 0.4 inches/day or 7.5 GPM/Acre (940 GPM/125 Acres). After incorporating a minimum distribution uniformity of 0.80, the required system flow rate is 0.5 inches/day or 9.4 GPM/Acre (1200 GPM/125 Acres) with no under-irrigation.

To simplify irrigation management all pivot packages were designed with the same 9.5 GPM/Acre requirement. That way, the same depth is applied per hour, regardless of what machine is operating. **Figure 13** shows that the original application flows varied from 7.3 to 27.3 GPM/Acre and the current application flow range varies from 9.4 to 9.6 GPM/Acre. In most cases the District had to re-nozzle each individual pivot. However, making these modifications greatly simplified the operation and irrigation scheduling for each center pivot.

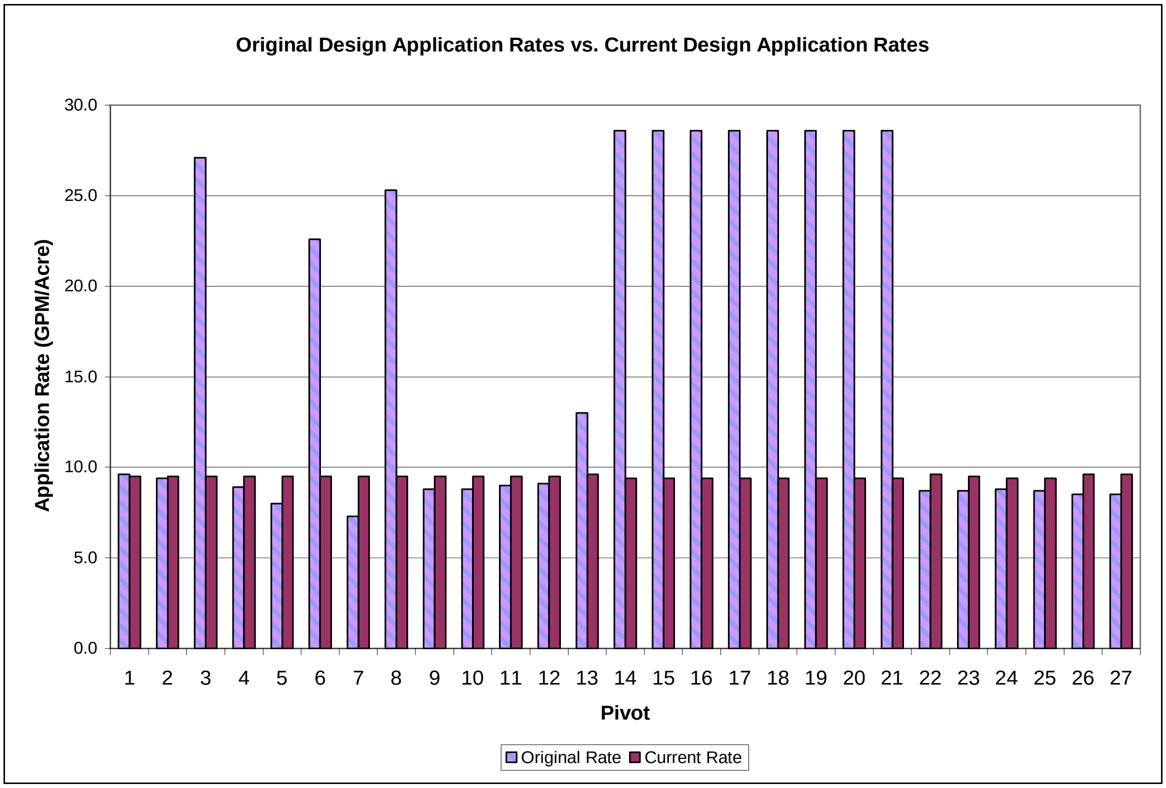

Figure 13. Original design precipitation rates vs. current design precipitation rates

One Package Year-Round

The pivot packages need to support both summer and winter crops without runoff. This would typically be a major task. However, because the DU is very good and the soils are classified as loamy sand and range to a sandy loam, the application rates do not exceed the infiltration rates. These factors reduce the likelihood of runoff even during the winter months. Furthermore, the installation of a single application rate simplifies operation of the pivots.

In areas where the soil is somewhat heavier (sandy loam) the drops were strung over the truss rods to increase the wetted area (reducing the instantaneous application rates) without replacing the nozzles (**Figure 14**).

Figure 14. Drops strung over truss rods to increase the wetted area

Pivot Operating Pressure
The nozzle pressure near the pivot center should be within 1-2 psi of the designed operating pressure. In most cases, the operating pressures and flow rates were originally below their design recommendations. During the DU evaluations several valves had to be adjusted to get the center pivot being evaluated up to its design flow rate and pressure recommendations. To do this, valves to other center pivots had to be throttled back, causing their flow rate and pressure to be nearly half of what they are designed to operate at. The practice of manipulating one center pivot's pressure to adjust another could not continue.

To reduce under-pressurizations the pivot sprinkler packages were reduced from about 50 psi to about 35 psi. This has several benefits, including larger nozzles that will pass debris more easily and less stream break-up due to increased droplet size – improving the sprinklers' wind fighting abilities to maintain a reasonable DU even during high wind events.

Figure 15 illustrates how the pressure requirements were adjusted. Pivots 22-25 needed increased pressure to compensate for the increase in flow rate and the addition of end guns.

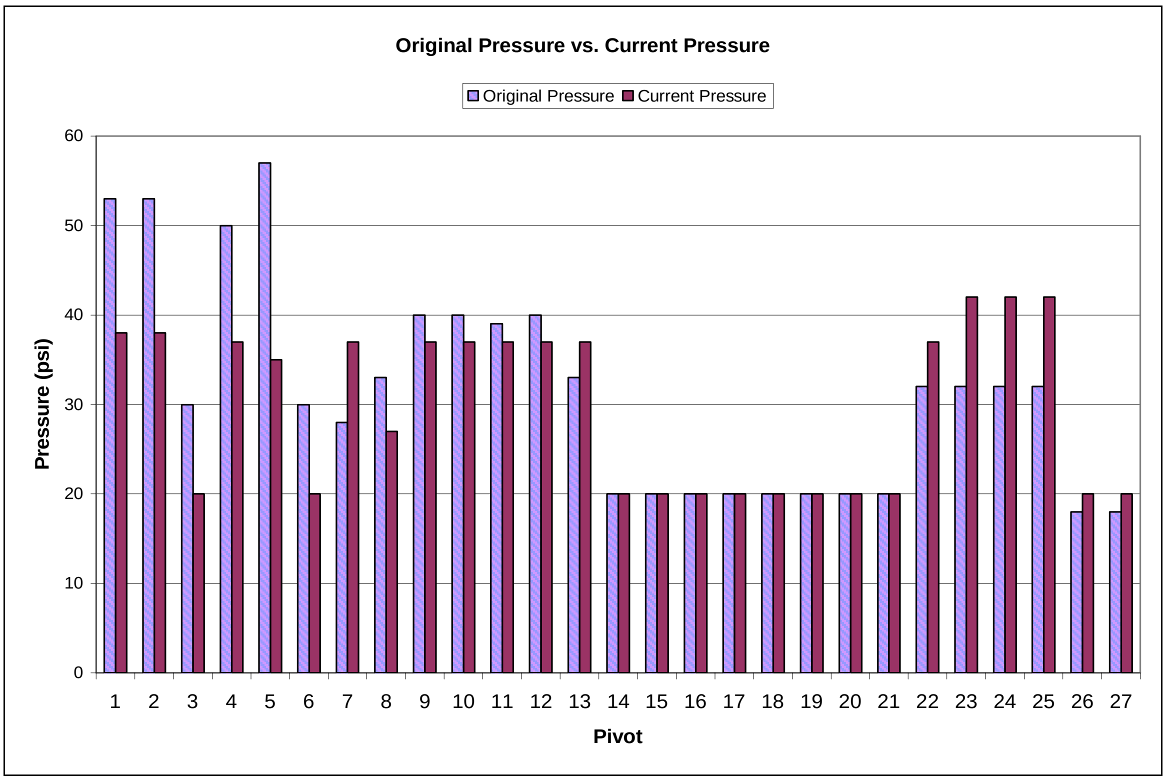

Figure 15. Original pressure vs. current pressure requirements

Pressure Regulation
It is difficult to accurately schedule irrigations when the flow rate varies from irrigation to irrigation or is different than expected when scheduling the irrigation. To combat this problem pressure regulation was installed on all center pivots. Pressure regulation ensures that the pressure does not exceed a preset limit. It does not, however, guarantee that the pressure is available. Therefore, booster pumps are run to provide slightly more pressure than is required at the most critical spots and pressure regulators are used to meet the designed pressure requirements of the center pivot.

All mini pivots (shorter than 700 ft in length) have individual sprinkler regulators and all large pivots (greater than 770 ft in length) have one in-line pivot regulator. The decision to use two types of pressure regulation was linked to economics. **Figure 16** shows both types of regulators. Both options provided adequate results and helped stabilize the flows onto each field.

Figure 16. In-line pressure regulator (left) and individual pressure regulators (right)

Center Pivot Maintenance

A major component of managing the site is to not only have a good DU but to maintain it. The inherent debris conditions of secondary treated chlorinated wastewater require a regular maintenance schedule for not only the filter stations but also the center pivots themselves. Between each harvest (or at least once a month) the pivots sprinklers are thoroughly cleaned. To make sprinkler maintenance easy, the sprinklers were positioned to an average height of 4 ft from the ground – staggered 3.5 to 4.5. This enables the sprinklers to be cleaned easily by operations personnel.

To overcome the slight reduction in DU caused by the lower sprinkler heights the rotator plates were changed to brown (see **Figure 16**). The brown rotor plates replaced the green plates for a number of reasons:

- Higher application uniformity – even at the lower height
- 10 water streams vs. 4 for the green plate
- Varying stream trajectories
- Gentler impact on the soil surface

In addition, a flush valve with a battery-operated automatic timer was installed at the end of most machines to flush large debris from the pivot twice daily. Because the process is automatic the system is flushed during operation and not just at startup, which was the previous standard protocol (**Figure 17**).

Figure 17. Automatic center pivot end flush

Conclusions

Providing real-time irrigation scheduling and achieving representative soil moisture monitoring throughout the year is important because irrigation demands fluctuate monthly and wastewater supply is fairly constant year-round. Therefore, it is easy to over-apply in winter months when crops demands are low and have a deficit in summer months when crops demands are high. Achieving a high DU reduces the possibility of deep percolation in the winter and improves the yield during the summer because water is more evenly applied to the entire field.

The results of the "before" and "after" DU evaluations of a "representative" center pivot show that a single machine, with the proper hardware and adjustments, can achieve a high DU. However, standardization for all pivots was needed to operate the whole system easily and uniformly. To achieve that, all precipitation rates needed to match, a single application rate was required year-round, pressure requirements needed to be adjusted and pressure regulation utilized, and a frequent maintenance program was put in place to sustain the high distribution uniformities.

All of the operational improvements described in this paper needed to work in correlation with one another. In order improve the system operations as a whole, the entire system must be examined and all factors must be addressed. Implementing any one of these factors individually would have provided little, if any, benefit.

References

Burt, C.M., R.E. Walker, and S. W. Styles. 1999. Irrigation Evaluation Manual. Irrigation Training and Research Center. Cal Poly. San Luis Obispo, CA. 93407.

Burt, C.M., A. J. Clemmens, T.S. Strelkoff, K.H. Solomon, R.D. Bliesner, L.A. Hardy, T.A. Howell, and D.E. Eisenhauer. 1997. Irrigation Performance Measures - Efficiency and Uniformity. Journal of Irrigation and Drainage Engineering. ASCE 123(6):423-442.

Nelson Irrigation Corporation. 2005. Sprinkler Technology. Water Application Solutions for Center Pivot Irrigation. p4-10. www.nelsonirrigation.com