Evaluation of
Potential Best Management Practices
-
Rotating Nozzles

Prepared for

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INTRODUCTION

Urban irrigation primarily applies water to either turfgrass or ornamental planting areas. The two most common types of sprinklers are spray and rotor heads. A new sprinkler in the landscape irrigation arena is the multi-stream, multi-trajectory (MSMT) rotating nozzle. The technology is relatively new, with small rotating nozzles introduced in 2001 by the Walla Walla Sprinkler Company, a subsidiary of the Nelson Irrigation Corporation. Since then, a number of irrigation manufacturers are now producing and selling MSMT rotating nozzles: Hunter Industries, K-Rain, Rain Bird, and Toro Company.

This Potential Best Management Practice (PBMP) report focuses on the ability of the MSMT rotating nozzle to save water and the operational feasibility, and provides a recommendation of the device's merit as a PBMP.

HOW AN MSMT ROTATING NOZZLE WORKS

MSMT rotating nozzles distribute water via a number of individual streams, of varying trajectories which turn slowly (Figures 1A and Figure 2), as compared to a fixed spray nozzle (Figure 1B) or a single stream rotor utilized for irrigating larger areas (Figure 1C).

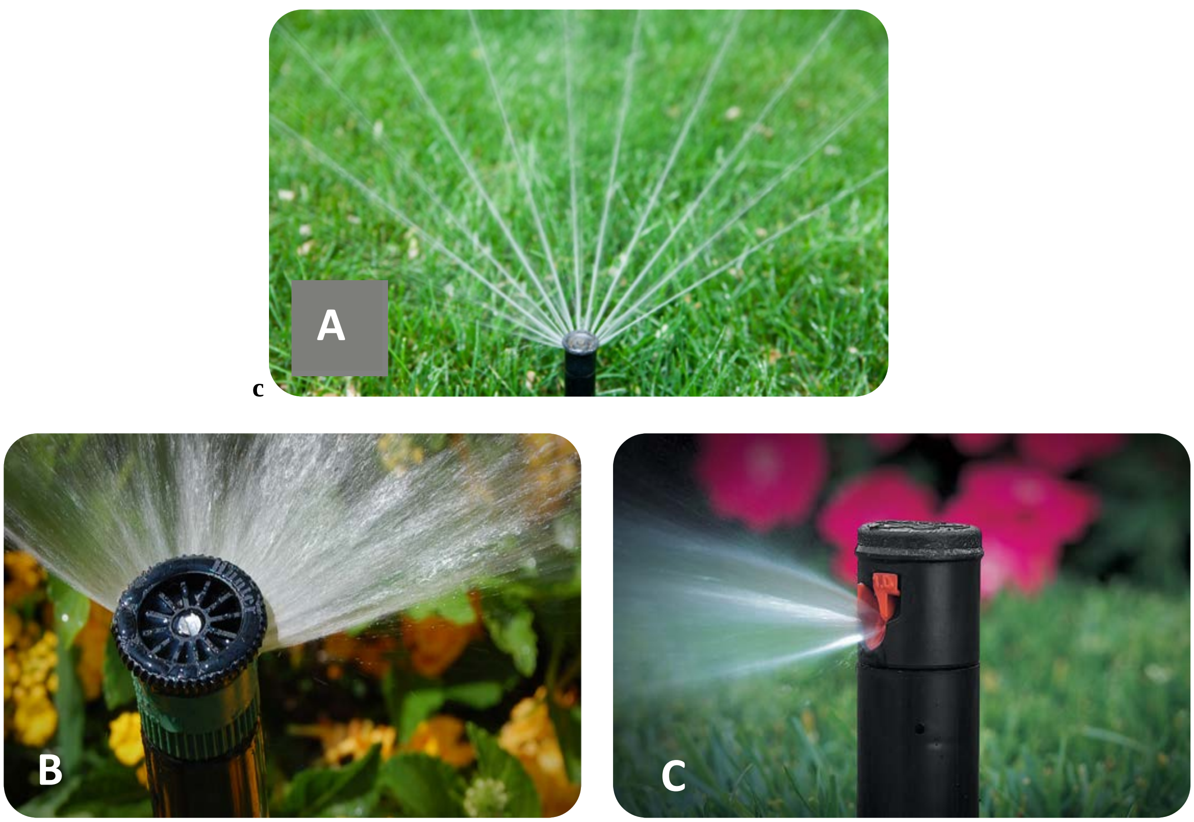

Figure 1. Examples of common landscape irrigation sprinklers.
(A) multi-stream, multi-trajectory rotating nozzle, (B) conventional spray nozzle, and (C) conventional rotary sprinkler.
Source: Hunter Industries

The shape of the nozzle orifice in the majority of the MSMT nozzles creates the multiple streams of water (Figure 2), while the nozzle itself rotates. A variation in functionality is the Toro Company's Precision™ series nozzle where, as a result of the water internally entering the nozzle from either side, it expands and collapses resulting in oscillation in the stream. This oscillation truncates the flow without a reduction in throw. Although the oscillating nozzle (Figure 3) is slightly different from the rest of the MSMT nozzles, it is also often considered in the same high efficiency category because precipitation and flow rates are reduced as compared to conventional spray nozzles.

Figure 2. Example of the MSMT rotating nozzle functionality.
Source: Rain Bird

Figure 3. Example of the oscillating nozzle functionality.
Source: The Toro Company

Sprinkler Equipment Comparison

The spray head is a common sprinkler typically utilized in landscape irrigation for smaller or bedded areas. Conventional fixed spray heads (Figure 1A) have shorter throws than conventional rotary sprinklers (rotors) (Figure 1B). Conventional spray heads also have application rates higher than other sprinkler types meaning greater amounts of water are applied in a shorter period of time. An MSMT rotating nozzle is a high(er) uniformity spray nozzle. It is an alternative nozzle that can fit on a conventional spray body because these nozzles are threaded for easy retrofit.

Table 1 presents an example to highlight the differences between sprinkler types, where a full circle pattern (360^{o}) at 30 psi is compared by equipment type. For consistency, the radius selected was 15 feet. However, the throw of MSMT nozzles is truncated when all other variables are the same, and the radius is actually between 12 and 15 feet.

Through this example, the reduction of flow rate and precipitation rate is also highlighted. The flow and precipitation rates for the conventional rotor are very similar to that of the MSMT rotating nozzle. Conventional rotors are used for larger applications, with radii ranging from approximately 15 to 50 feet for residential and small commercial uses and up to 100 feet for larger commercial/municipal uses.

Table 1. Example of sprinkler flow and precipitation rates variation by equipment type.

Sprinkler Type (360^{o} at 30 psi)	Radius (feet)	Flow Rate (gal/min)	Precipitation Rate[a] (in/hr)
MSMT rotating nozzle	12 to 15	0.8 to 1.5	0.4 to 0.6
Precision™ nozzle	15	2.0 to 2.3	0.6 to 1.0
Conventional (fixed) spray	15	3.7	1.6
Conventional rotor[b]	15	0.6	0.6

[a] Assuming square spacing rather than triangular
[b] Conventional rotary nozzles are recommended at higher pressures.

Adapted from: Manufacturer published product specification by Hunter Industries, Rain Bird, and Toro Company.

BENEFITS OF ROTATING NOZZLES

As compared to conventional spray nozzles, MSMT rotating nozzles have reduced application rates, increased uniformity, and increased water droplet sizes. These differences can potentially result in benefits relating to runoff and overspray reduction.

Runoff Reduction

The precipitation rate of the MSMT rotating nozzle is closer to the soil infiltration rates than that of a conventional spray nozzle. By applying water more slowly, the water is able to absorbed and runoff can be greatly reduced, resulting in:

- Reduction in dry-weather stormwater runoff
- Reduction in the transmission of pollutants

Increased Uniformity

The most touted benefit resulting from the use of MSMT rotating nozzles is an increase in distribution uniformity. For landscape plants with a uniform water requirement and equidistant spacing/density, uniform water application is desirable. Uniformity within a zone indicates that the irrigation system applies the same rate of water volume (precipitation rate) to the entire landscape zone. When a zone has poor uniformity, some portion of the irrigated area will receive more applied water than other areas.

The water within the root zone is the most important water for the plant. Water beyond the root zone is considered deep percolation and is out of the plant's reach (likewise, water which results in runoff is wasted). When water is not available within a section of the root zone, the plant will stress, resulting in a degradation of appearance or quality and, potentially, weed or disease prevalence. Due to irrigation non-uniformity, the common tendency is to increase irrigation to compensate for "dry spots." Since the increased water is applied to the entire zone, this results in inefficient watering.

Although frequently used interchangeably, there is a difference between irrigation efficiency and distribution uniformity. Efficient irrigation is when water is beneficially used compared to the amount of irrigation water applied or supplied to the site and is expressed as a percentage. Distribution uniformity is actually not a measure of efficiency, but rather a way to characterize the evenness of application of water to the planted area and is expressed as a decimal value. In landscape irrigation, this has greatest importance in turfgrass areas. However, high irrigation efficiency is only possible if there is high distribution uniformity.

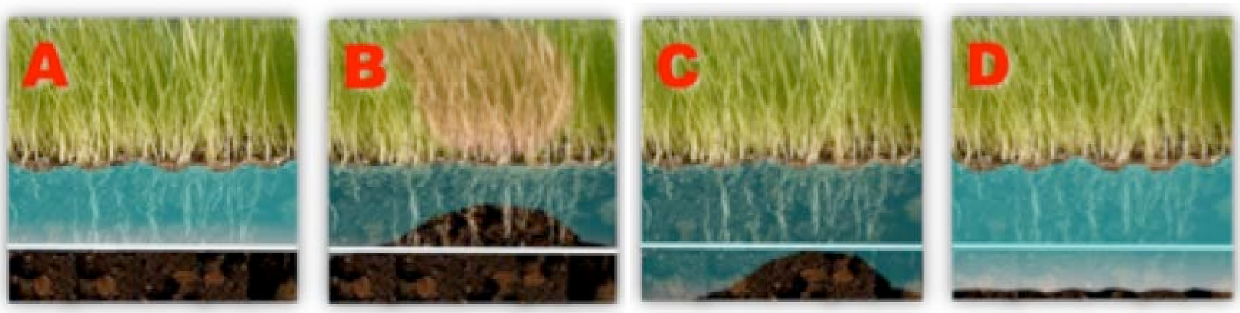

Figure 4. Illustration of the difference between efficiency and uniformity within the root zone. (A) Uniform and efficient. (B) Non-uniform but within the root zone. (C) Non-uniform and inefficient. (D) Uniform but inefficient.
Source: Baum-Haley (2011).

Figure 4 illustrates this concept between efficiency and uniformity. In Figure 4A, the irrigation water applied is both uniformly and efficiently. In Figure 4B, while efficient in terms of conservative water use (not watering beyond the root zone), the irrigation is not uniform. Under-watering areas in the root zone will result in a decline in plant quality (leading to pest and weed invasion, or “dry spots”). Figure 4C, illustrates the common cure for the “dry spots” – water longer. This perpetuates the non-uniform and leads to inefficiency due to over watering some areas. Figure 4D is uniform, but inefficient due to overwatering, resulting in drainage below the root zone (which, with time, can result in plant loss as well as the transport of excess nutrients, fertilizers, and pesticides that harm the environment).

A number of factors can affect the distribution uniformity (Mecham, 2005; Moore et al., 2010: Shaw et al., 2005), such as:

- Sprinkler head arc adjustment, height, tilt or trajectory, hydraulics, etc
- System pressure
- Wind
- Slope
- Obstructions
- Plant material canopy
- Amount and type of mulch
- Soil characteristics, i.e. compaction and thatch

The catch-can test is a commonly used measurement tool to assess the uniformity of sprinkler systems. However, sub-surface uniformity can be measured through the use of a soil moisture sensor or soil core sampling.

Uniformity values refer to the lower quarter distribution uniformity (DU_{lq}) unless explicitly noted. The DU_{lq} can be calculated as follows:

$$DU_{lq} = V_{lq} / V_{avg}$$

where:

V_{lq} = average of the lowest one-fourth of measurements (volume)
V_{avg} = average application of all measurements (volume)

Through a study comparing conventional spray head sprinklers to rotor nozzles, conclusions showed three main points: 1) the rotor nozzles had a significant better catch-can DU_{lq} in both plot and residential tests across a variety of brands[1]; 2) soil moisture was uniform regardless of decreasing uniformity due to irrigation equipment; and 3) the spray heads tend to have better uniformity with a minimum pressure at 30 psi (Baum et al., 2005). Catch-can measurements for DU_{lq} are the recommended practice for quantifying system uniformity (IA, 2013). However, this

[1] Baum et al. (2005) found rotary sprinklers to have significantly ($p = 0.043$) higher average DUlq of 0.49 compared to 0.41 for spray heads across a variety of brands.

method neglects the important process of water redistribution through the landscape canopy, turfgrass thatch, and on and beneath the soil surface.

The complex process of redistribution of water within the soil profile can compensate for non-uniform application of water down to 4 inches so long as catch-can uniformity, DU_{lq}, is greater than 0.50. The soil moisture uniformity, measured within the soil profile, in the top 4 inches is more sensitive to sprinkler application variability, than at the 8 inch depth. Variability of the moisture within the soil profile is less sensitive as depth increases and variation in application depths are dampened.

Influence of Pressure on Uniformity

Following on the pressure test conclusions from the study comparing conventional spray head sprinklers to rotor nozzles (Baum et al., 2005), spray heads were tested at one pressure level above, and two levels below (Dukes et al., 2006). From the detailed analysis at varying ranges of pressure, a range of significantly different ($p = 0.0014$) DU_{lq} values were obtained, as measured by the catch-can method due to adjustment of the system supply pressure. The test results showed that as pressure increased, so did the catch-can DU_{lq}. It should be noted that these results were obtained through plot test, where wind effects were not a variable.

Reduced Influence by Wind

Wind drift greatly influences the performance of sprinkler irrigation (Montgomery, 2013). As water droplet size increases, less irrigation water is lost to wind drift and evaporation. MSMT rotating nozzles tend to fare better in windy conditions as a result of increased water droplet size. The majority of major cities experience year round wind conditions of, on average, at least four miles per hour. While the “best practice” of irrigating in the early morning is recommended because the effects of wind are minimized during this time, many major cities still have wind conditions of greater than three miles per hour between 5:00 a.m. to 6:00 a.m.

CONSIDERATIONS OF SPRINKLER RETROFITS

The two aspects that affect the functionality of the irrigation system are technology and user. Likewise, with sprinkler retrofits, there are two aspects that affect water savings potential – system maintenance and scheduling[2].

Installation Considerations

While the majority of the water savings potential analysis considers only the uniformity-related aspects, comprehensive system maintenance at the time of implementation will strengthen the benefit potential by increasing overall system efficiency, resulting in water savings and minimization of runoff and overspray. In many cases, the benefit potential, by the proxy of an increase in uniformity, is enhanced by the system maintenance that occurs at the same time as the sprinkler retrofit. This is not a bad thing. In fact, if an easy retrofit device can instigate

[2] Both system maintenance and scheduling are components of system management (IA, 2013).

system maintenance, then the retrofit device itself serves dual purposes. However, the savings may depreciate over time.

Scheduling Considerations

To compensate for non-uniformity through scheduling, the Irrigation Association has developed a Run Time Multiplier (RTM). This RTM provides the recommendation of how much additional water is needed to overcome the low spots of application. Since the water may move horizontally through thatch or soil profile, and sub-surface uniformity may be higher than the DU_{lq} represents, the lower half distribution uniformity (DU_{lh}) value is utilized for scheduling purposes.

The DU_{lh} can be calculated as follows:

$$DU_{lh} = V_{lh} / V_{avg}$$

where:

V_{lh} = average of the lowest one-fourth of measurements (volume)
V_{avg} = average application of all measurements (volume)

The DU_{lh} can be calculated from DU_{lq} as follows (IA, 2005):

$$DU_{lh} = 0.386 + (0.614 * DU_{lq})$$

The Run Time Multiplier (RTM) can be calculated from DU_{lh} as follows (IA, 2005):

$$RTM = 1 / DU_{lh}$$

For example, if the DU_{lq} is increased from 0.45 to 0.65, the corresponding DU_{lh} is increased from 0.66 to 0.78. The RTM would, thereby, reduce from 1.51 to 1.27, and the irrigation times would be reduced accordingly, potentially saving about 16% of the water that would have been needed with the lower uniformity system.

Another consideration with regard to scheduling relates to the reduced application rate of MSMT rotating nozzles. With spray retrofits, the device is upgraded, but the plant material will remain the same. In this case, the plant-water requirement does not vary. With a reduced application rate, the schedule should be adjusted appropriately (increased). It has been hypothesized that a major contributor to water savings as a result of MSMT rotating nozzle retrofits is a neglect of re programming the irrigation controller post-implementation. Even taking system efficiency into consideration, this may not actually be a problem as many domestic irrigators apply irrigation in excess of plant-water requirements.

Design and Installation Considerations

Whereas spray and MSMT nozzles automatically match precipitation, rotary sprinklers do not. The features of MSMT rotating nozzles that promote these benefits are: lower precipitation rates, adjustable settings for arc of coverage and radius of throw, and the ability to maintain matched precipitation rates during a retrofit and while making these adjustments. Additionally, the throw of MSMT nozzles is slightly reduced when all other variables are the same. This is one of the chief reasons why overspray is greatly minimized from the retrofit of preexisting conventionally spray heads with MSMT rotating nozzles.

Labor and Cost Savings

While the water savings from direct spray nozzle retrofits is less than converting a spray zone to drip irrigation, the amount of overall material and labor to retrofit a conventional spray system with MSMT rotating nozzles is considerably less costly than installing drip irrigation since the spray bodies can remain intact. Additionally, to accommodate existing spray bodies, MSMT rotating nozzles are available in both internal and external threading options (Figures 2 and 3).

POTENTIAL WATER SAVINGS

Meta-Analysis of Studies

The majority of studies have been focused on the DU_{lq} improvements, where the potential for water savings is derived from the percent of water reduction attributed to improving uniformity of application. Generally the sample sizes have been small, some no more than case studies with very limited sample sets. There is little data prioritizing the variables of importance, including behavior. Table 2 identifies nozzle retrofit audit results (DU_{lq}) for on-site evaluations. These evaluations are considered “real world,” rather than plot studies. Real world uniformed increases approximately 0.13.

For example, if a site has a existing zone DU_{lq} of 0.49, retrofitting the conventional spray heads with MSMT rotating nozzles could potentially result in the DU_{lq} increasing to 0.61. This increase in uniformity could translate to 9.7% water savings. Assuming the average increase in uniformity is 0.13, the savings potential would range from 12% to 9%, decreasing as pre-implementation DU_{lq} increases.

This savings potential concurs with an evaluation performed in Southern California (A&N Technical, 2013). However, it is less than the 22% to 40% suggested by Solomon et al. (2007). Neither the long-term study conducted by the Southern Nevada Water Authority, nor the Eugene Water and Electric Board evaluation found significant water savings compared to the general population.

Table 2. Summary of on-site nozzle studies comparing uniformities of conventional spray nozzles to MSMT rotating nozzles.

Study Location	No. of Zones in Study	Per Station Flow Rate (gal/min)	Uniformity Variation (DU_{lq})	Uniformity Variation (%)	Statistical Difference (95% conf.)
Southern Nevada[a]	378	-49%	+0.15	+36%	Yes
Southern California[b]	230	-	+0.08	+17%	Yes
Eugene, OR[c]	131	-43%	+0.10	+18%	Not reported
AZ, CA, NV[d]	35		+0.26	+59%	Yes
Washington[d]	16		+0.17	+40%	Yes

[a] Sovocool et al., 2013
[b] A&N Technical, 2013
[c] Pertersen, 2013
[d] Solomon et al., 2007

Southern Nevada Water Authority

The Southern Nevada Water Authority (SNWA) observed the long-term results of MSMT heads and associated product retrofits (Sovocool, et al., 2013). The evaluation focused on the persistence of improvements (such as DU_{lq}) and realized water savings. The study was comprised of two phases. The first phase focused on installations, measuring the actual changes in DU_{lq}. The second phase monitored how customers applied irrigation with the new technology, analyzing if the DU_{lq} improvements persist over time and how much water does this variation practically achieve.

For this study the devices installed were:

- Hunter MP Rotators
- Rain Bird Rotary Nozzles
- Toro Precision Series
- Each MSMT device with the addition of a Little Valve
- Existing components with the addition of a Little Valve

The results of phase one found that all of the technologies had an improvement in DU_{lq}; on average the improvement was 0.15 or +36% (Table 3). It was noted that there are diminishing returns when the pre-retrofit DU_{lq} is already on the higher end of the spectrum. Additionally, SNWA found it difficult to attain DU_{lq} values greater than 0.60 from spray head retrofits.

When looking at the technologies individually, the Hunter MP Rotators, Rain Bird Rotary Nozzles, and Toro Precision Series were all significantly similar. An interesting result highlighted that the Little Valve product alone yielded an improvement in DU_{lq} of 0.08. However, when coupled with the MSMT technology, the cumulative savings only ranged from -0.01 to 0.04. Therefore, the notion of "stacking" devices to achieve a significant increase in DU_{lq} was not achievable.

Upon analysis of the persistence of the uniformity improvements, some degradation of the DU_{lq} was observed. At sites which received a follow-up audit, the DU_{lq} varied by -0.06 or -11%. Although there was a decrease in the uniformity over time, the only treatment with a statistically significant decrease was the MSMT device with the addition of a Little Valve. Over time, while the precipitation rates did not significantly vary, the pressure rate did decrease.

The water monitoring results included two to three years of water use of post-retrofit sites (n=138), along with a comparison control group of non-retrofitted sites (n=74). Although there was a net reduction within the pre-/post-retrofit (treatment) group, overall the treatment sites are not significantly different from the general population at either time period (pre-/post-retrofit). In some cases, there was an increase in water use. However, this was not thought to be a result of the irrigation technology functionality.

Through regression analysis, variables were tested for influence on water use: lot size, landscape area, home age, age of front or back yard, income range, assessed home value, home age, or pool. For the entire data set, only lot size and assessed value had an influence on the water use. This result concurred with previous research (Haley, 2007). However, for the study sites only, there was little or no influence from the variables available. Further, no model showed any correlation from the installed MSMT or Little Valve products.

The results of this study were surprising and disappointing for the researchers. They are continuing this analysis to look at behavioral habits of the study participants, automatic meter reading records, and irrigation controller settings.

Table 3. Summary of SNWA long-term results

	Overall Average	Pre-Retrofit	Post-Retrofit	No.	Variation[a]	Percent Variation[b]	Statistical Comparison
Precipitation Rate (in/hr)		2.09	1.01	317	-1.08	-52%	Yes
Per Station Flow Rate (gal/min)		9.88	5.05	504	-4.83	-49%	Yes
Operating Pressure (psi)		34.64	43.78	378	9.14	+26%	Yes
Uniformity	All technologies (DU_{lq})	0.41	0.56	378	0.15	+36%	Yes
Uniformity	MSMT only (DU_{lq})	0.42	0.59	140	0.17	+40%	Yes
Uniformity	MSMT + Little Valve (DU_{lq})	0.39	0.54	84	0.15	+34%	Yes
Uniformity	Little Valve only (DU_{lq})	0.41	0.49	22	0.08	+20%	Yes

[a] Variation = (Post-Retrofit) – (Pre-Retrofit)
[b] Percent Variation = 1 – [(Post-Retrofit) / (Pre-Retrofit)]

Adapted from: Sovocool, et al. (2013).

Eugene Water and Electric Board

The Eugene Water and Electric Board (EWEB) conducted a three-year evaluation on the use of MSMT nozzles for reducing peak hour demand (Petersen, 2013). The study included 131 MSMT matched precipitation rate irrigation zones across 17 residential and 6 commercial sites. The average flow (per station gallons per minute) decreased by 43% from pre- to post-retrofit, with the linear trend depicting a smaller decrease in flow as the number of sprinklers zones retrofitted decreased. Additionally, the DU_{lq} improved 10% on average post-retrofit. Again, in this study the retrofits sites did not yield water savings. However, the goal of peak hour demand was met through per station flow rate reduction.

Municipal Water District of Orange County

The Municipal Water District of Orange County (MWDOC) conducted a water savings analysis of homes within north Orange County that participated in their *Rotating Nozzle Rebate Program*[3], utilizing up to five years of pre-implementation data and one full year of post-implementation data. The analysis consisted of both residential and commercial sites. Table 4 provides some descriptive statistics of the analysis.

[3] Rebate funding was provided in cooperation with Municipal Water District of Orange County, the Department of Water Resources, and the Metropolitan Water District of Southern California.

Table 4. Descriptive statistics of the MWDOC *Rotating Nozzle Rebate Program* Evaluation.

Sector	Program Participation Level	Number of Participants	Pre-Intervention Average Use (gal/day)	No. of Nozzles Rebated (total)	No. of Nozzles Rebated (per account)	Water Savings per Nozzle (gal/day)	Water Savings (% per account)
Residential	Participant	82	393	19,791	31	0.997	8%
	Control	880	415				
Commercial	Participant	148	2,679	107,782	304	0.994	11%
	Control	1,117	2,219				

Adapted from: A&N Technical (2013)

The statistical analysis at 95% confidence attributed approximately one gallon per day, per nozzle, net water savings (ranging from 0.64 to 1.31 gpd) as a result of the nozzle retrofit program (installation of the low precipitation rate nozzles including better management of equipment due to program participation). The analysis controlled for weather conditions and site heterogeneity, and attempted to isolate the program impact from saving that resulted from ongoing messaging in the area. The data also indicated that sites with previously installed *Smart Timers* yielded a higher per nozzle net water savings.

The evaluation team employed a high-resolution method to distinguish water savings, with a standard error less than 0.17 gpd. Standard evaluation techniques (i.e. t-statistics of difference for mean annual use) were unable to distinguish a 10 percent difference in water use.

MARKET TRANSFORMATION

The Smart Water Application Technologies™ (SWAT) arm of the Irrigation Association is a national partnership initiative of water purveyors, irrigation researchers, and industry representatives. SWAT was created to promote landscape water use efficiency through the application of state-of-the-art irrigation technologies. SWAT protocols are developed and utilized for testing the effectiveness of irrigation technology. Manufacturers submit products for testing and must agree for SWAT to publish the results. The High Uniformity Spray Head Sprinkler Nozzles Testing Protocol Version 2.0, was posted June 25, 2013. To date, no manufacturers have submitted products for testing. This is likely for two reasons: first, devices are already rebate-eligible in major markets such as Southern California and, second, standards are also in development.

In May 2010, the International Construction Code initiated projects to develop an American National Standards Institute (ANSI) consensus product standard for landscape irrigation devices. The new International Green Construction Codes and Standards will have specific references to irrigation and will cite these new standards. The American Society of Agricultural and Biological Engineers (ASABE), an ANSI accredited standards developer, is working in partnership in developing the Landscape Irrigation Sprinkler and Emitter Standards, which should be complete by early 2014.

Sprinkler test specifications will include:

- Flow rate
- Distance of throw
- Uniformity: calculated using data from distance of throw
- Hydrostatic burst pressure
- Pressure regulation
- Check valve head (if included)

The United States Environmental Protection Agency (USEPA) WaterSense program is also participating in this process. For irrigation products, WaterSense labeling criteria is typically based on such standards.

MSMT Rotating Nozzle Rebate Programs

The key to effective MSMT rotating nozzle rebate programs will result from outreach and education. Due to the ease of the retrofit and relatively low cost of the device (per unit), the ability to administer rebate programs is relatively simple. Most notable has been the http://www.freesprinklernozzles.com program, founded by Western Municipal Water District and in partnership with the Toro Company. This voucher program provides the end-user with vouchers for the Toro Precision™ Series spray nozzle and education on the device.

Other water districts administer standard rebate programs (i.e. Metropolitan Water District of Southern California, East Bay Municipal Water District) providing a $2 to $6 per nozzle rebate. The variation in rebate level is due to either the availability of additional grant funding, supplemental funding on the part of a retail water agency, or the inclusion of a pressure regulating body.

CONCLUSIONS

An MSMT rotating nozzle is an example of irrigation technology that syncs with the New Landscape Norm. The technology provides runoff and overspray benefits when compared to conventional spray irrigation. Further, these devices are easily retrofitted at existing systems.

The most notable benefit of converting conventional spray heads to MSMT rotating nozzles is improved uniformity (+0.13 on average). Because of uniformity increases, there is the potential for water savings. With an increase in uniformity, run times should be minimized; however, the magnitude of this savings has not been realized. Through current, long-term studies, the water savings has been observed at levels less than 10%. This may be the result of watering habits/behavior.

Why would uniformity increases not yield water savings? The complex process of redistribution of water within the soil profile can compensate for the non-uniform application of water, so long as catch-can uniformity, DU_{lq}, is greater than 0.50. Variability of the moisture within the soil profile (sub-surface) is less sensitive as depth increases, and variation in application depths are dampened.

While the water savings may not be sizable, other benefits associated with this technology should be considered. There is a reduction of flow during irrigation cycles. A reduction of wind drift is due to larger water droplet size. Overspray minimization is due to shorter throw. Finally, runoff minimization can result from lower precipitation rates.

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