Uniformity and Water Conservation Potential of Multi-Stream, Multi-Trajectory Rotating Sprinklers for Landscape Irrigation

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Introduction

Urban water use is an increasingly significant portion of total water use, particularly in the arid West. A major component of urban water use is for irrigation of the urban landscape. Improvements in the efficiency of landscape irrigation could offer considerable potential for water conservation in the urban sector.

In California, for example, urban water use is projected to increase from 8.7 MAF [3] in 1995 to 12.0 MAF in 2020, growing from 11% to 15% of California's total water use (California Department of Water Resources, 1998, page ES4-16). Urban landscape irrigation accounts for over one-third (35%) of California's urban water use (California Department of Water Resources, 2004). The Department has observed:

> *"The greatest potential reduction in urban water use would come from reducing outdoor water use for landscaping."*
> *– California Department of Water Resources, 1998, page 6-9.*

A new landscape irrigation product, a Multi-Stream, Multi-Trajectory Rotating (MSMTR) sprinkler, appears to offer improved distribution uniformity, when compared to the fixed spray heads traditionally used in sprinkler systems for landscape irrigation (Blumhardt, 2004; Teske, 2005). In well managed systems, improved uniformity would mean higher irrigation efficiency, and water conservation potential. This paper explores the uniformity performance and water conservation potential of MSMTR sprinklers when used in landscape irrigation.

Landscape Irrigation Sprinklers

Frequently used in landscape irrigation sprinkler systems, fixed spray heads produce a static spray, distributing water over the entire arc of their coverage (1/4, 1/2, full, variable arc, etc.). These may be installed on fixed risers, or in "pop-up" spray heads, which rise when the water is turned on (Figure 1, next page).

Multi-Stream, Multi-Trajectory Rotating (MSMTR) sprinklers distribute water in a number of individual streams, of varying trajectories, which turn slowly (Figure 2, next page). These sprinklers are the size of spray nozzles and thread onto pop-up heads just as spray nozzles do. They can also be threaded onto shrub adapters for installation onto risers.

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[3] MAF = Million Acre Feet

Photo credit: Water Education Foundation

Figure 1. Fixed spray heads traditionally used in landscape irrigation produce a static spray over their arc of coverage.

Photo credit: Walla Walla Sprinkler Company

Figure 2. Multi-Stream, Multi-Trajectory Rotating sprinklers distribute water in individual streams, which turn slowly.

Distribution Uniformity

Distribution uniformity (DU) measures the evenness with which water is applied to the landscape by an irrigation system (Irrigation Association, 2005). It is measured by conducting an "audit," or catch-can test, of the system (Irrigation Association, 2004). DU calculation is based on the average volume of water caught in catch-cans in the least watered areas when compared to the average volume of water caught in catch-cans in the entire area. The Irrigation Association (2005) uses two versions of DU, DU_{LQ} and DU_{LH}.

Low Quarter Distribution Uniformity (DU_{LQ})

- The low quarter DU (DU_{LQ}) is computed when the least watered area is taken to be the quarter (25%) of the catch-can values with the lowest readings

  $$DU_{LQ} = 100 \times \left(\frac{V_{LQ}}{V_{avg}}\right)$$

  where V_{LQ} is the average of the lowest one-fourth of the catch-can values and V_{avg} is the average of all the catch-can values.

DU_{LQ} is used to classify the quality of coverage (as related to irrigation water usage) in a fixed spray zone, (Irrigation Association, 2005, Table 1-8, page 1-22):

Rating	Excellent	Very Good	Good	Fair	Poor
Fixed Spray Zone DU_{LQ}	75	65	55	50	40

Mecham (2004) reviewed the results from a large number (about 6,800) audits of landscape irrigation systems from around the country. DU_{LQ} values for residential fixed spray head systems (6,649 audits) were typically in the low 50s. The average value was 52%. (Mecham also reported a wide variation in DU_{LQ} values, from 11% to 89%.) On average, then, fixed spray systems rate only Fair to Good.

Low Half Distribution Uniformity (DU_{LH})

- The low half DU (DU_{LH}) is computed when the least watered area is taken to be the half (50%) of the catch-can values with the lowest readings

$$DU_{LH} = 100 \times \left(\frac{V_{LH}}{V_{avg}}\right)$$

where V_{LH} is the average of the lowest one-half of the catch-can values and V_{avg} is the average of all the catch-can values.

The Irrigation Association (2005, page 1-22) recommends that DU_{LH} be used for irrigation scheduling. They use DU_{LH} as an efficiency term, and compute a run time multiplier (RTM) as

$$RTM = \frac{100}{DU_{LH}}$$

If T is the theoretical (i.e., assuming a 100% uniform application of water) run time needed for the irrigation system to apply the required amount of water, then T x RTM is the actual irrigation run time that will be needed to overcome the effects of non-uniformity. Since higher DU_{LH} values mean lower run time multipliers, DU_{LH} is a very important indicator of water conservation potential. For example, if DU_{LH} could be raised from 60% to 80%, RTM would reduce from 1.67 to 1.25. Reducing the irrigation times accordingly would save about 25% of the water that would have been needed with the lower uniformity system.
[1 – (1.25/1.67) = 0.25]

The practical meaning of the IA's recommendation (2005, page 1-22) and the RTM computation is that run times should be adjusted so that the low half average amount is equal to the required irrigation amount. If the low half average is considerably lower than the overall average (poor uniformity), considerable over watering may be needed to bring the low half average up to the required amount. Higher uniformity (higher DU_{LH}) means that the overall average is closer to the low half average, so less water is needed to bring the low half average up to the required amount. [This will be illustrated graphically in Figure 9 below.]

Generalized Distribution Uniformity (DU_{LXX})

The concept of Distribution Uniformity can be generalized, with various DU values calculated depending on the size of the critical, least watered portion of the irrigated area.

- The low XX% DU (DU_{LXX}) is computed when the least watered area is taken to be the XX% of the catch-can values with the lowest readings

$$DU_{LXX} = 100 \times \left(\frac{V_{LXX}}{V_{avg}}\right)$$

where V_{LXX} is the average of the lowest XX% of the catch-can values and V_{avg} is the average of all the catch-can values.

In this more generalized terminology, $DU_{LQ} = DU_{L25}$ and $DU_{LH} = DU_{L50}$.

Low 30% Distribution Uniformity (DU_{L30})

It will be useful for some of the analysis to be presented later to consider the case where XX% = 30%, and define DU_{L30} as follows.

- The low 30% DU (DU_{L30}) is computed when the least watered area is taken to be the 30% of the catch-can values with the lowest readings

$$DU_{L30} = 100 \times \left(\frac{V_{L30}}{V_{avg}}\right)$$

where V_{L30} is the average of the lowest 30% of the catch-can values and V_{avg} is the average of all the catch-can values.

Before/After Irrigation Audits

To investigate the water conservation potential of MSMTR sprinklers due to improved uniformity, the first author conducted audits of several existing landscape irrigation systems employing fixed spray heads. These audits followed the protocol recommended by the Irrigation Association (2004). The systems were first inspected and any obvious deficiencies (such as missing nozzles, broken pipes, leaking fittings) were corrected. An audit was performed to determine the uniformity achieved by the fixed spray heads. Then the irrigation systems were converted to the MSMTR [4] sprinklers, and a second catch-can test was conducted.

It is important to note that the head spacing and other operating conditions were the same during each pair of audits, except for the sprinklers used. These before/after audits provide the basis for evaluating the potential for the MSMTR sprinklers to improve uniformity, and conserve water. In all, 13 before/after sets of audit comparisons were done.

Uniformity Improvement as Measured by DU_{LQ}

Figure 3 (next page) illustrates the improvement of low quarter distribution uniformity attributable to the conversion from spray heads to MSMTR sprinklers. Uniformities (DU_{LQ}) for the fixed spray audits ranged from the high 30s to just under 50%, with an average of 44%. According to the IA quality rating scheme (IA, 2005, Table 1-8, page 1-22) for fixed spray zones, 10 of the 13 audited zones rated *Poor*. Three of the audited zones did not even achieve the minimum DU_{LQ} for the *Poor* quality range.

Uniformities (DU_{LQ}) for the MSMTR sprinklers were higher for all 13 zones (e.g., front yard, back yard) audited. The improvement ranged from 5 to over 40 percentage points, with an average change in DU_{LQ} of + 27 percentage points. With one exception, the performance of the MSMTR sprinkler zones earned quality ratings of *Good*, *Very Good* or *Excellent*. On average,

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[4] The Multi-Spray, Multi-Trajectory Rotating nozzles used in these tests were the MP 2000 Rotator sprinklers manufactured by the Walla Walla Sprinkler Company.

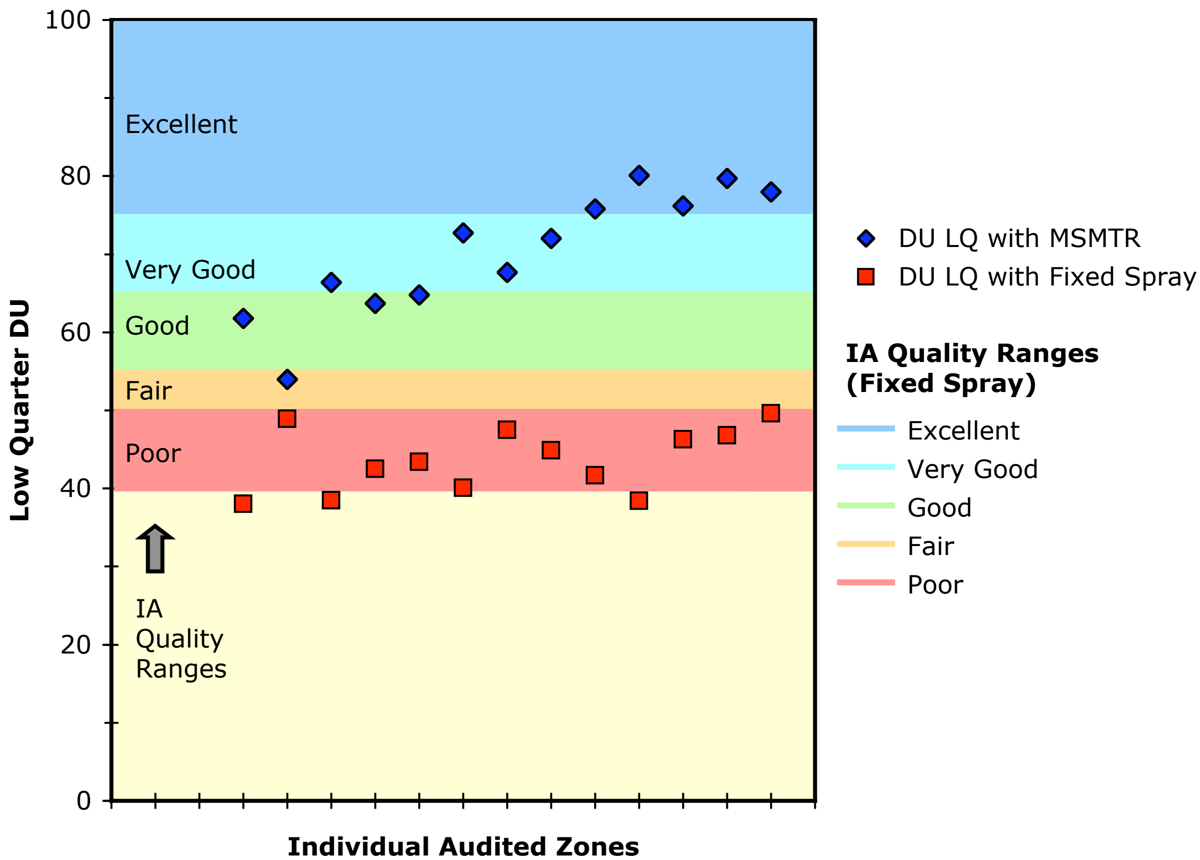

Figure 3. DU_{LQ} and quality changes due to conversion from fixed spray to MSMTR sprinklers. On average, DU_{LQ} improved from 44% to 70%, and quality rating from *Poor* to *Very Good*.

conversion to the MSMTR sprinklers improved DU_{LQ} from 44% to 70%, corresponding to an improvement in quality rating from *Poor* to *Very Good*.

Uniformity Improvement as Measured by DU_{LH} and RTM

All of the zones audited showed an improvement in DU_{LH} when fixed spray heads were converted to MSMTR sprinklers (see Table 1, next page). The amount of improvement ranged from + 4 to + 28 percentage points, and averaged + 18 percentage points.

Run Time Multipliers (RTM) also improved (see Figure 4, next page). On average RTM improved from 1.59 to 1.23. This corresponds to a potential water savings of about 22% of the pre-conversion amount. If both the fixed spray and MSMTR sprinkler systems were scheduled as recommended (Irrigation Association, 2005), cycle numbers and run times would be set so that the average of the low half application amount equaled the required irrigation amount. With scheduling as recommended, zones using the MSMTR sprinklers would use 22% less water than the corresponding zones with fixed spray heads.

Table 1. Improvement in DU_{LH} Due to Conversion from Fixed Spray to MSMTR Sprinklers

Zone Identifier	Fixed Spray Heads DU_{LH} (%)	MSMTR Sprinklers DU_{LH} (%)	Change (%)
01B	66	70	+ 4
01F	64	77	+ 13
02B	63	85	+ 22
02F	58	86	+ 28
03F	62	80	+ 18
04V1	62	76	+ 14
04V2	65	85	+ 20
05V1	71	87	+ 16
05V2	62	83	+ 21
05V3	65	81	+ 16
09F	63	75	+ 12
10FD	55	75	+ 20
IE04	63	87	+ 24
Average	63	81	+ 18

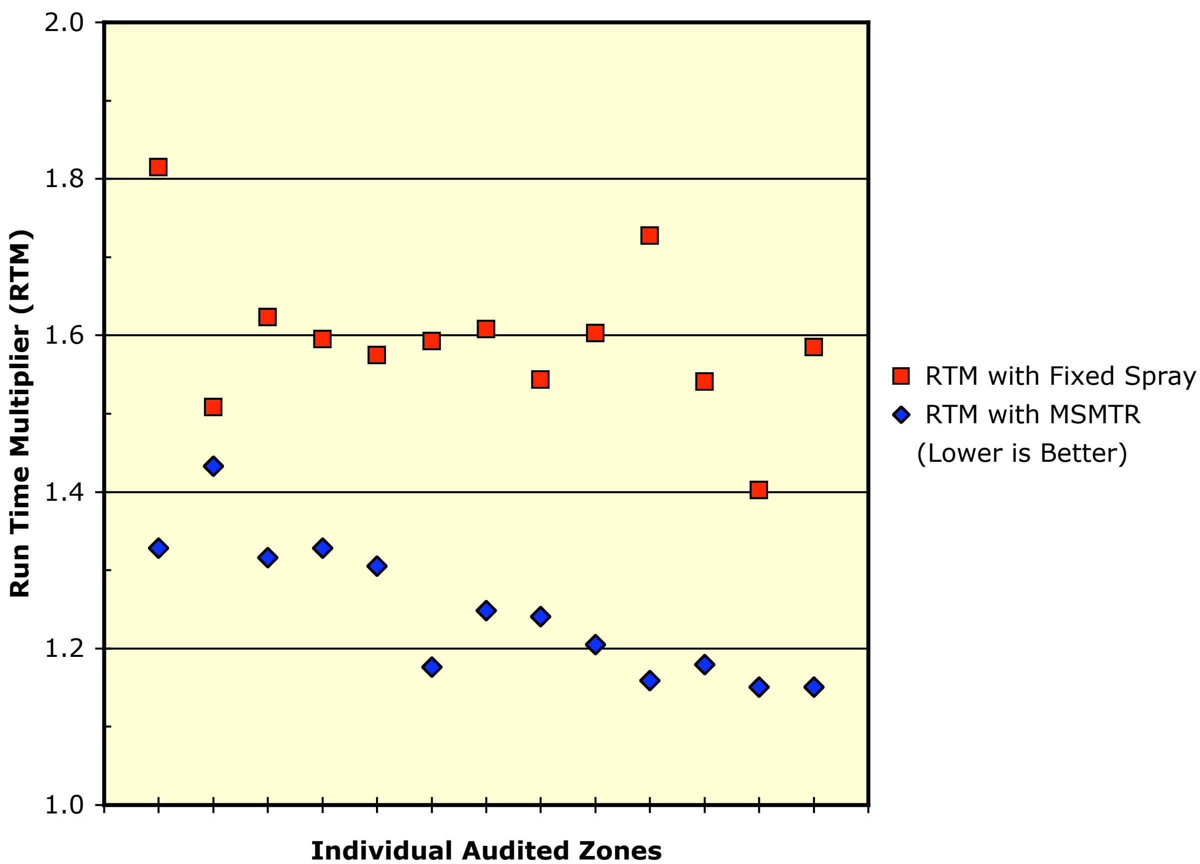

Figure 4. Changes in RTM due to conversion from fixed spray to MSMTR sprinklers. On average, RTM improved from 1.59 to 1.23. This corresponds to a reduction in water application of 22% of the pre-conversion amount.

Water Destination Diagrams

Water destination diagrams provide an alternate way to display visually the uniformities measured during the before/after audits. In addition, they are a convenient way to illustrate the water conservation potential associated with uniformity improvements. To develop the diagrams shown below, the field audit catch-can values were adjusted so that all audits could be considered and compared on an equal basis. Field audit catch-can values were converted using a 2-step process, and then water destination diagrams were developed from the converted data.

Water destination diagrams show catch-can values, sorted from large to small values, plotted vertically down (to represent water that has infiltrated into the soil). The horizontal scale represents the area being irrigated. Figures 6 and 7 to follow are water destination diagrams.

To compare data from several different audits in an unbiased way, the number of data points from each audit should be the same. Otherwise, the significance of a system audit which used a large number of catch-cans could completely over-ride the significance of another system audit using fewer catch-cans, regardless of the relative merits of the two systems. Therefore a linear interpolation scheme on the original sorted audit data was used to produce an equivalent set of 100-catch-can data points. Figure 5 illustrates this process for the 03F system audit with MSMTR sprinklers installed. There were 31 catch-can values actually collected during the original audit, and the interpolation process produced an equivalent set of 100 catch-can values.

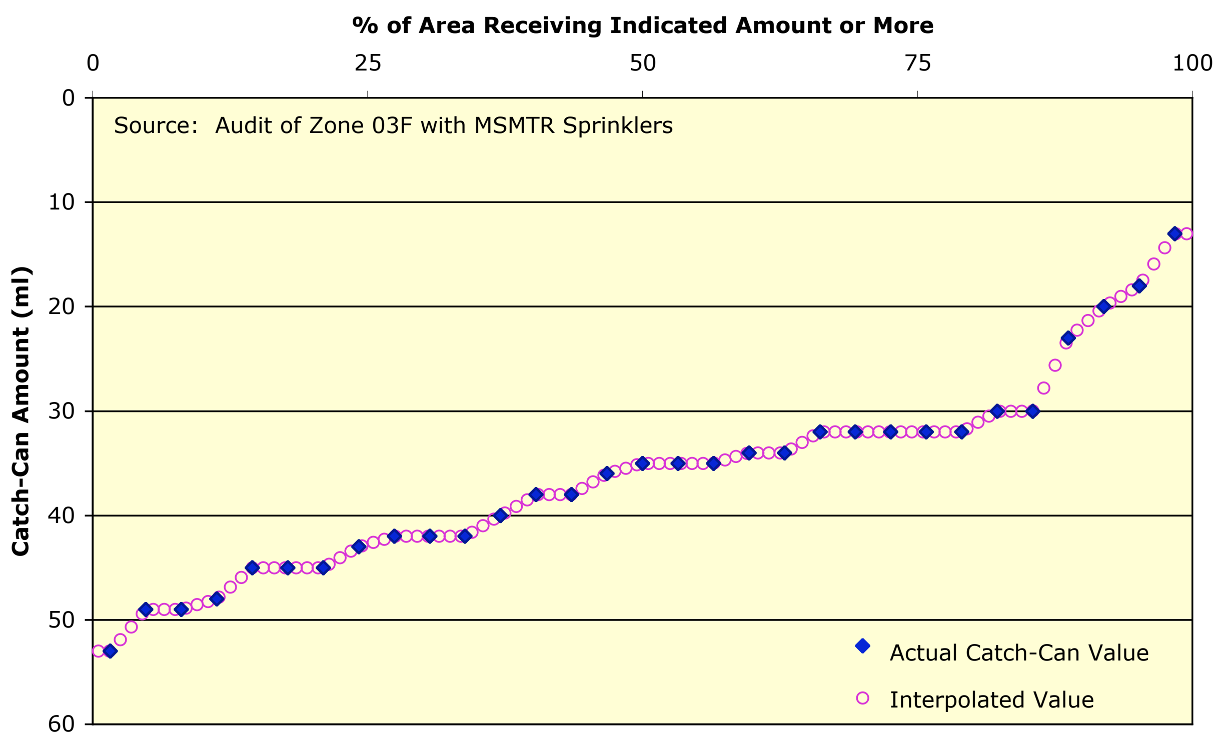

Figure 5. Comparison of actual and interpolated catch-can values for the audit of zone 03F with MSMTR sprinklers.

The second stage of the adjustment process was to convert all catch-can amounts to normalized values so they could be considered on the same scale. The catch-can amounts from each audit were normalized according to

$$\text{Normalized Amount} = \left(\frac{\text{Individual Catch Can Amount}}{\text{Average Catch Can Amount}} \right)$$

In other words, the amount scale for each audit was adjusted so that the overall average of all catch-can amounts was 1.0.

Figures 6 and 7 illustrate water destination diagrams for the zones audited with fixed spray heads and with MSMTR sprinklers. For each type of device, there is considerable similarity among the audit results for that device. However, the two devices have significantly different typical results.

Figure 6 summarizes the water destination diagrams for all 13 audits of zones using fixed spray heads. Even though there is some scatter in the data points for individual audits (individual data points marked as x), all audit results follow the same general trend, and the *Typical* curve (solid red line) is a reasonable representation of the uniformity performance of all fixed spray zones audited. For each area percentage (position on the horizontal scale) individual values for the red *Typical* curve are calculated as the average of normalized catch-can values for each of the 13 fixed spray audits at that same area percentage.

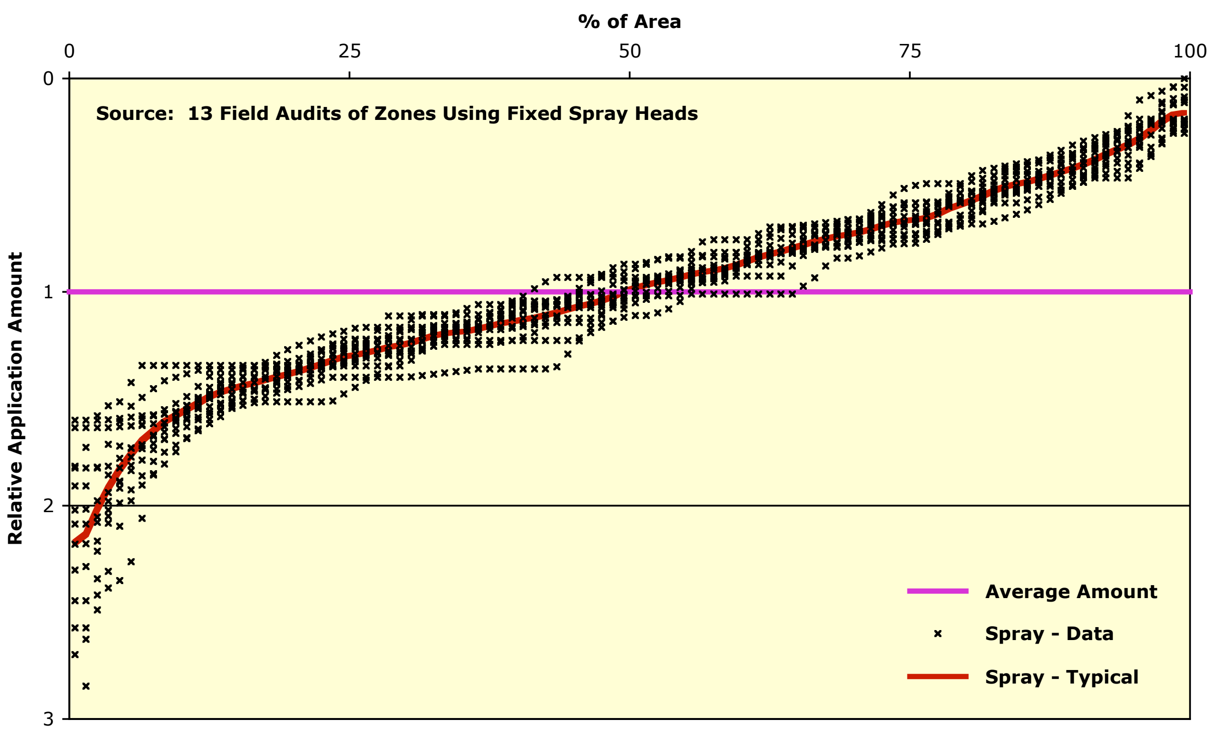

Figure 6. Water destination diagrams from 13 field audits of zones using fixed spray heads.

Figure 7 summarizes the water destination diagrams for all 13 audits of systems with the MSMTR sprinklers installed. Even though there is some scatter in the data points for individual audits (individual data points marked as +), all audit results follow the same general trend, and the *Typical* curve (solid blue line) is a reasonable representation of the uniformity performance of all MSMTR sprinkler zones audited. For each area percentage (position on the horizontal scale) individual values for the blue *Typical* curve are calculated as the average of normalized catch-can values for each of the 13 MSMTR audits at that same area percentage.

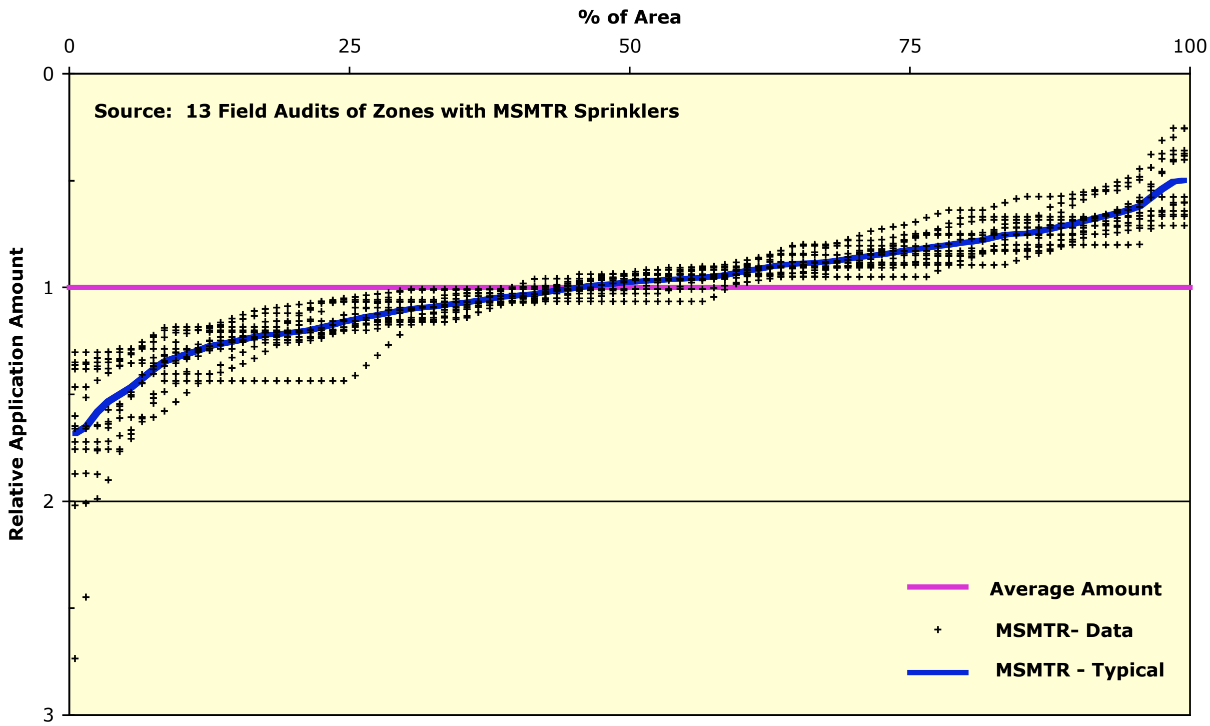

Figure 7. Water destination diagrams from 13 field audits of zones using MSMTR sprinklers.

Comparing Figures 6 and 7, one sees that the slope of the red *Spray-Typical* curve is steeper than the blue *MSMTR-Typical* curve. This indicates that for the systems and zones audited, the MSMTR sprinklers delivered better uniformity than the fixed-spray heads. This uniformity comparison is valid because the audits were before/after evaluations of a conversion from fixed sprays to MSMTR sprinklers. In each comparative case, other system variables (head spacing and operating conditions) remained the same. Thus observed differences are logically attributed to product performance differences, and not to differences in other system variables.

A direct comparison, on the same water destination diagram, of uniformity for both types of sprinklers is shown in Figure 8 (next page).

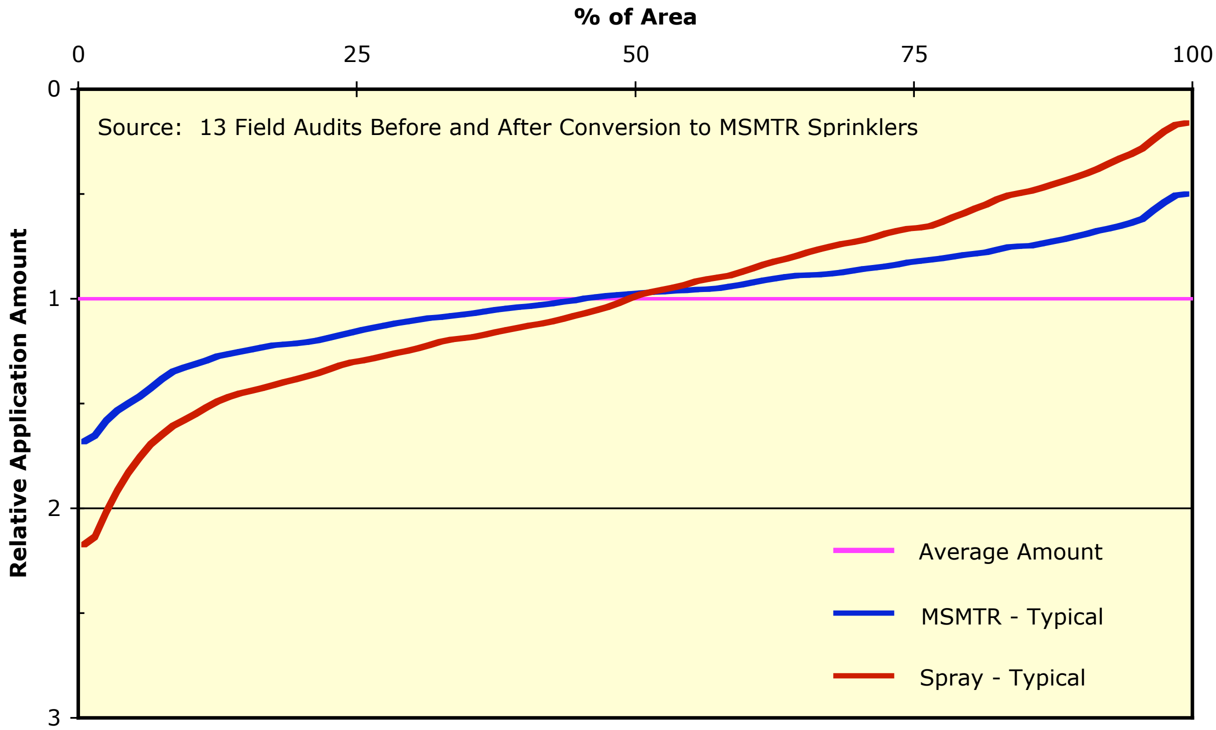

Figure 8. Direct comparison of typical uniformity for fixed spray and MSMTR sprinklers.

Water Conservation Potential

The audit results, especially Figure 8, demonstrate that conversion from fixed sprays to MSMTR sprinklers will generally improve the uniformity of water application. This should allow the turfgrass to be irrigated with reduced water applications. Before estimating what this potential for water conservation is, however, some consideration must be given to the management regimes upon which irrigation scheduling decisions are based. This is because the amount of water applied by an irrigation system depends not only on characteristics of that system, but on irrigation management decisions as well. Two approaches to irrigation management will be considered here, spanning the likely range of irrigation scheduling decision-making.

Irrigation Scheduling Based on DU$_{LH}$

As noted above, the Irrigation Association recommends that irrigation scheduling be based on DU$_{LH}$. In practice, this means that irrigation run times be adjusted so that the low half average application is equal to the irrigation amount required for local weather and plant conditions.

The rationale for this recommendation (Mecham, 2001) is that since water may move horizontally through the thatch or the soil, the uniformity of soil moisture may be higher than indicated by catch-can tests. "An improved representation of soil moisture uniformity <u>for scheduling purposes</u> is the *lower-half* distribution uniformity [as computed from catch-can values]" (IA, 2005).

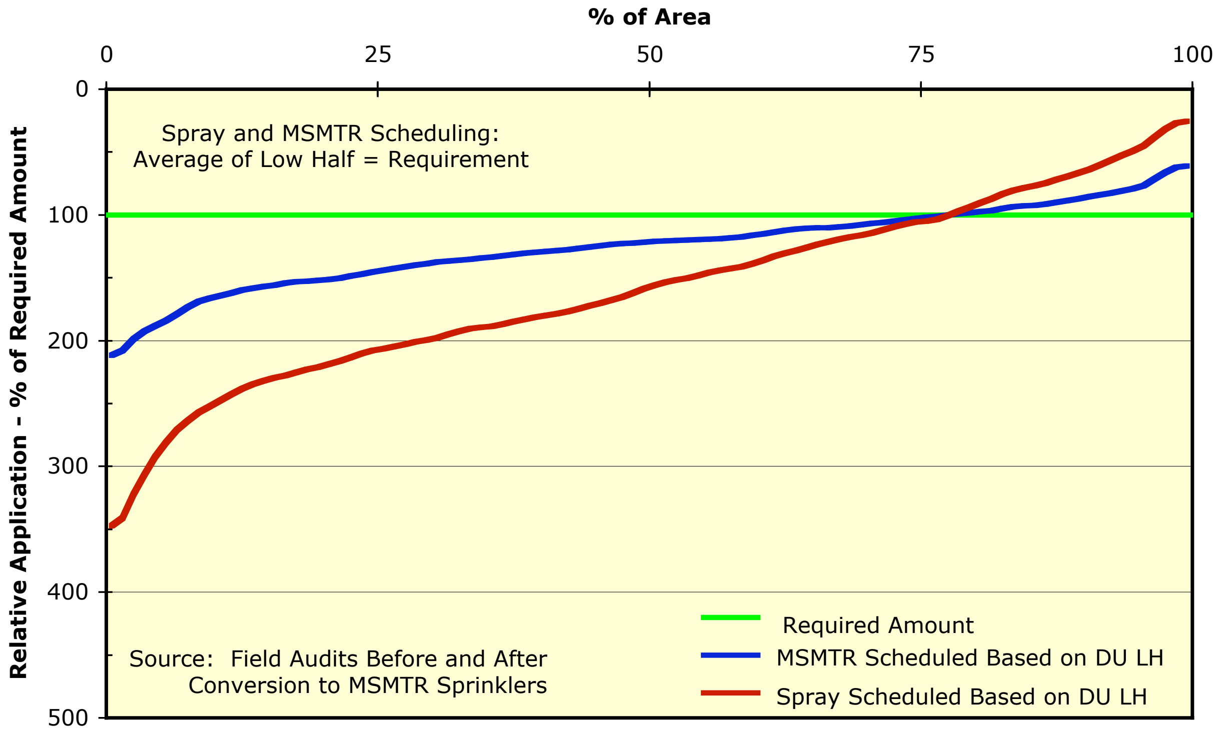

Figure 9. Water application patterns for fixed spray and MSMTR sprinklers when scheduled so that the average of the low half meets 100% of the locally appropriate irrigation requirement.

This approach to irrigation scheduling has proved reasonable for systems with adequate uniformity. However, for systems with low uniformities, it is probable that this method of scheduling will result in some visual signs of stress in the turfgrass (Allen, 2001). This is illustrated in Figure 9. For the higher uniformity MSMTR sprinkler applications, the maximum deficit is 39%[5] below the required amount. This may provide visually acceptable turfgrass. For the lower uniformity fixed spray applications, the maximum deficit is much lower, 74%[5] below the required amount. This degree of deficit may result in visible signs of stress.

Thus irrigation scheduling based on DU_{LH} (so that the low half average application equals the required amount) can be problematic for low uniformity systems. One approach to solving this problem is to change the system so as to correct those problems causing the low uniformity. From the water conservation standpoint, this is certainly the preferred approach.

Applying Extra Water to Eliminate Dry Areas

Even though fixing a uniformity problem is preferable, not all turfgrass managers would follow this recommendation (at least not immediately). Instead they may simply increase run times to apply more water in an attempt to alleviate the dry or visually poor-quality portions of the

[5] These values are the differences between the Required Amount and the minimum application amounts for the MSTR and Fixed Spray curves respectively (at the far left edge of the graph).

irrigated area. The irrigation manager has made the "decision to fight uniformity defects with more water" (Allen, 2001).

To further analyze this style of irrigation management, it is necessary to define quantitatively what *watering to eliminate dry areas* means. Since application amounts and run times are to be increased beyond the point where the low half average equals the required amount, the average of some smaller portion of the area will be equal to the required amount. It is almost a certainty that managers watering to eliminate dry areas do not think in terms of irrigation scheduling based on DU_{LXX}. But since their actions have equivalent consequences, this approach may be used to quantify their actions.

Mecham (2005) indicates that when irrigation run times are calculated based on catch-can DU_{LQ}, the run times are usually more than what is already set on the controller. Further, in these cases the owners were reasonably happy with the turfgrass appearance. So calculating run times and water application amounts based on DU_{LQ} probably over-estimates the application amounts of managers watering to eliminate dry areas.

These types of turfgrass managers may be irrigating so that the average application in the low 30% matches the irrigation water requirement. For the purposes of water conservation estimates, we will assume that *watering to eliminate dry areas* is equivalent to adjusting run times so that the average application in the low 30% is equal to the required amount, i.e., scheduling based on DU_{L30}. Figure 10 illustrates this management approach, and also shows why it is not an effective use of water.

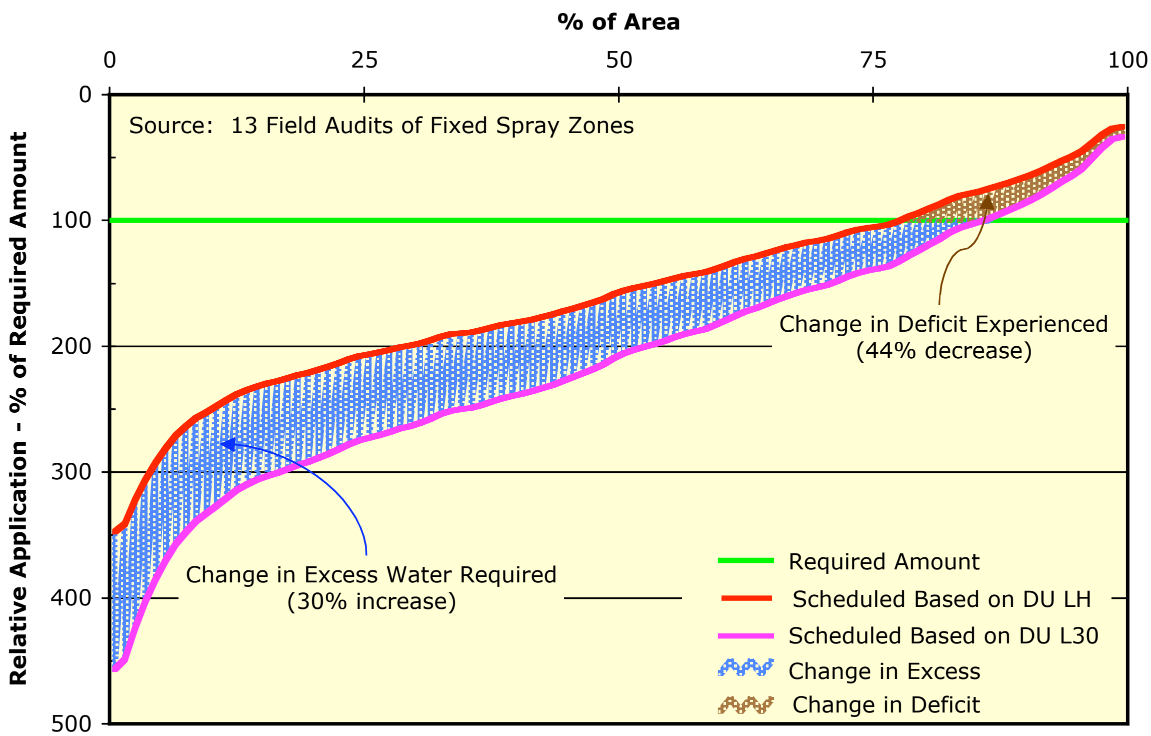

Figure 10. The consequences of low uniformity coupled with the decision to schedule based on DU_{L30}. The manager has decided to match the average application in the low 30% of the area to the required amount (watering to eliminate dry areas).

For low uniformity systems, scheduling based on DU_{L30} (instead of DU_{LH}) can indeed reduce the deficit, in this instance by 44% (the brown-hatched area in Figure 10). However, most of this decrease comes in those areas just slightly under-watered. The maximum deficit is only slightly improved, from 74% below the required amount when scheduled based on DU_{LH} to 66% below the required amount when scheduled based on DU_{L30}. Considerable additional water is required to achieve this modest improvement. The excess water required to overcome non-uniformity increases by 30% when scheduled based on DU_{L30} (the blue-hatched area in Figure 10). It is clear why irrigation experts do not recommend this solution to poor uniformity. Applying extra water only masks uniformity problems – it doesn't solve them.

Water Conservation Estimates

When two water destination diagrams are compared on the same chart, the result might be called a "Water Conservation Diagram." If the change represented by moving from one curve to the next results in improved uniformity, then the water savings attributable to that change are readily identified on the chart. Based on the *Typical* curves in Figures 6 and 7, a direct comparison of the two product types may be made.

The first conservation estimate is based on the assumption that the irrigation manager followed IA recommendations for scheduling both before and after the system conversion was made, i.e., irrigation schedules were calculated based on DU_{LH}. The water conservation diagram for this comparison is shown in Figure 11.

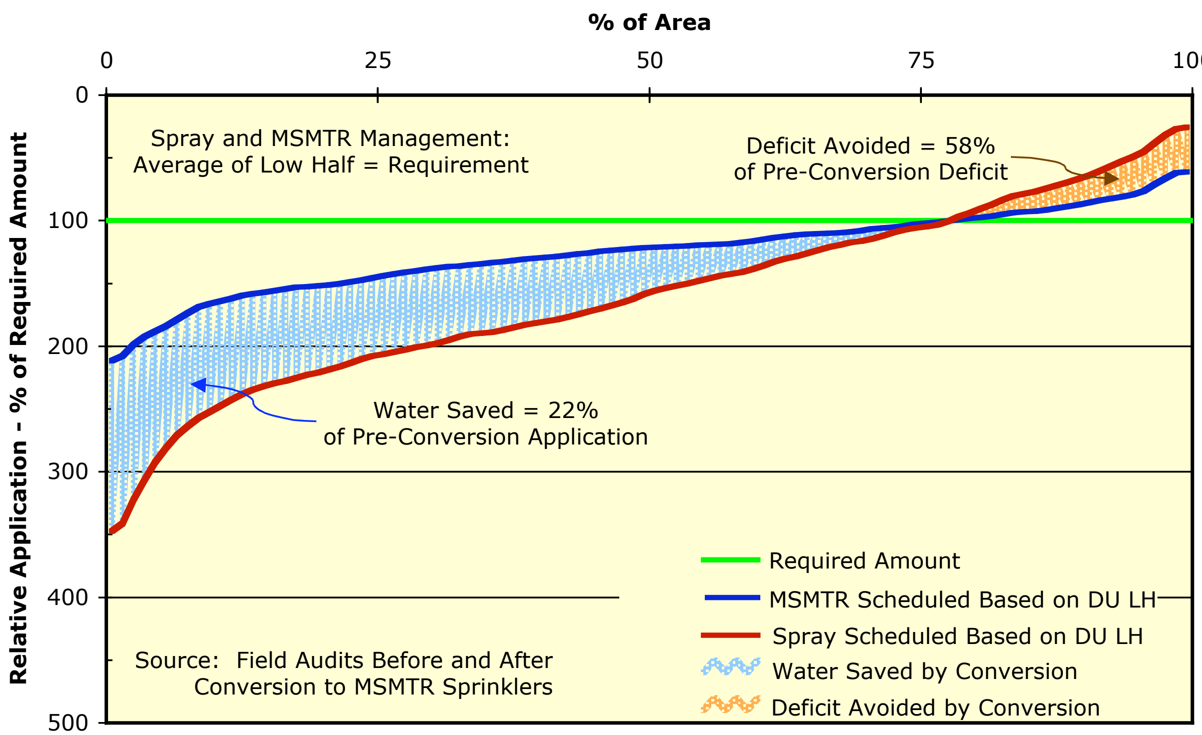

Figure 11. Consequences of converting to MSMTR sprinklers from fixed spray heads, assuming both systems are scheduled based on DU_{LH}. On the diagram, conversion shifts from the red *Spray-Typical* curve to the blue *MSMTR-Typical* curve.

Making the change to the higher uniformity MSMTR system allows *both* a reduction in the water applied *and* a reduction in the deficit previously experienced. The higher uniformity system saves 22% of the pre-conversion water application. It also eliminates 58% of the deficit experienced with the pre-conversion (fixed spray) system, eliminating as well the dry spots and visually poor-quality areas of turfgrass that may have been apparent with the lower uniformity system.

A second water conservation estimate can be made on the assumption that the manager of the lower uniformity system had been scheduling based on DU_{L30} (i.e., watering to eliminate dry areas). Naturally, the improved uniformity systems would be expected to save more water compared to this management regime. The water savings come from two types of improvements: (1) allowing scheduling to be based on DU_{LH} while still avoiding dry areas, and (2) less water need be applied to match the low half average to the required amount. The first might be considered an indirect benefit of improved uniformity, while the second is clearly a direct benefit of increased uniformity. Such a comparison is shown in Figure 12.

When compared to the more water intensive management of the poor uniformity system (scheduling based on DU_{L30}), the MSMTR system saves 41% of the pre-conversion water application. It also further reduced the deficit, avoiding 36% of the pre-conversion deficit (not as high as in the previous comparison, because scheduling that system based on DU_{L30} eliminates a portion of the deficit, albeit at the expense of applying considerably more water).

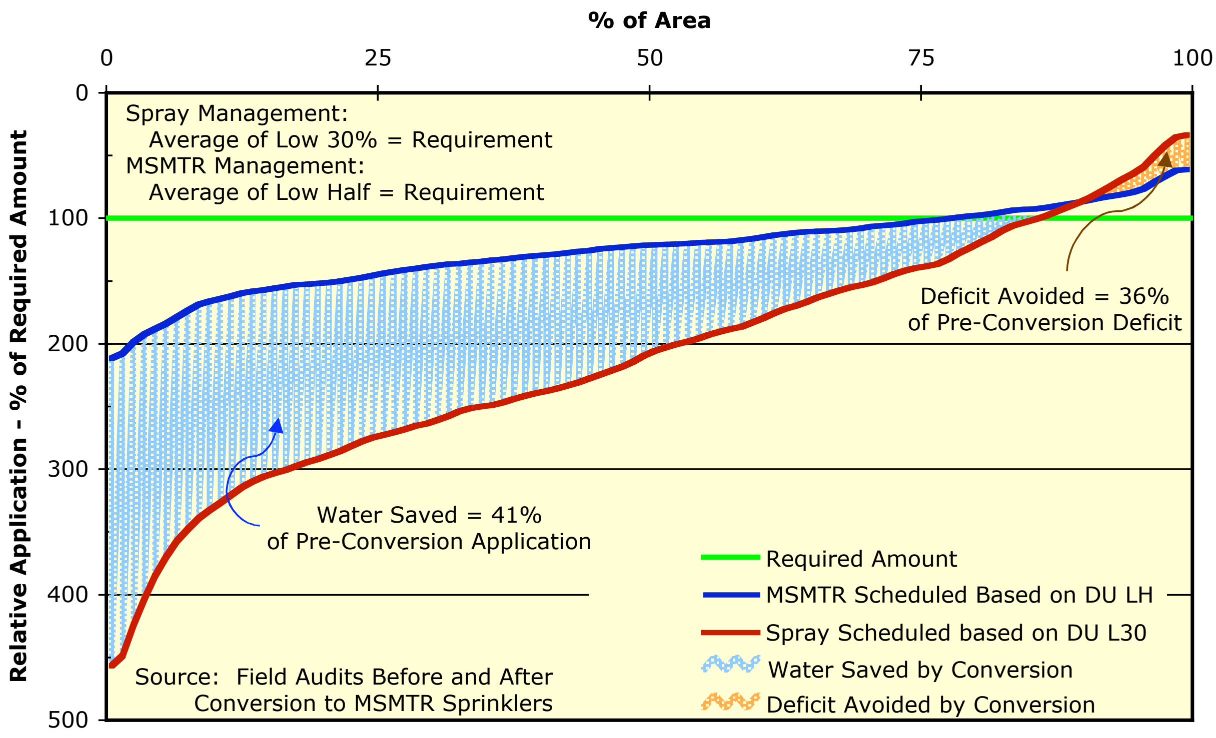

Figure 12. Consequences of converting to MSMTR sprinklers scheduled based on DU_{LH} from fixed spray heads scheduled based on DU_{L30}.

Other Considerations

The analysis presented here considers only the uniformity-related aspects of water conservation. Other system improvements that might further increase water conservation include the elimination of runoff and the elimination of overspray (water sprayed outside the boundary of the area to be irrigated). Sprinkler features that would help to achieve these benefits are lower precipitation rates, adjustable settings for arc of coverage and radius of throw, and the ability to maintain matched precipitation rates while making these adjustments. Not all turf/landscape irrigation sprinklers possess these properties, though the MSMTR sprinklers evaluated during these audits do. No attempt has been made to estimate the water conservation significance of these additional considerations.

Conclusions

(1) The MSMTR sprinkler systems do achieve higher uniformity than fixed spray head systems (Figure 3; Table 1; Figures 6, 7 and 8). For the audits reported here, conversion from fixed spray to MSMTR sprinklers increased average DU_{LQ} from 44% to 70%, and average quality rating from *Poor* to *Very Good*. Average DU_{LH} increased from 63% to 81%. This improved uniformity can lead to reduced water applications and superior turfgrass appearance and quality.

(2) Irrigation systems should be scheduled based on DU_{LH} since basing schedules on DU_{LQ} or even DU_{L30} wastes too much water (Figure 10). For lower uniformity systems, though, scheduling based on DU_{LH} may result in dry spots and visually poor-quality areas of turfgrass (Figure 9).

(3) An irrigation manager’s response to dry spots and visually poor-quality areas of turfgrass should be to convert to a higher uniformity system. Higher uniformity will enhance water conservation and reduce deficits as well. For the audits reported here, conversion from fixed spray to MSMTR sprinklers (both scheduling based on DU_{LH}) saved 22% of the water previously applied, and simultaneously reduced the deficit by 58% (Figure 11).

(4) An irrigation manager may respond to dry spots and visually poor-quality areas of turfgrass by increasing run times to alleviate the trouble spots. However, basing run times on DU_{L30} requires that considerably more water be applied, and the deficit reductions achieved are modest (Figure 10). In this case, conversion to a higher uniformity system will save water by allowing irrigation schedules to be based on DU_{LH} while still avoiding dry areas, and by allowing the low half average to match the required amount with less total water applied. For the audits reported here, conversion from fixed spray to MSMTR sprinklers, along with a management change from DU_{L30}-based to DU_{LH}-based schedules, saved 41% of the water previously applied, and further reduced by 36% the deficit in the under watered areas (Figure 12).

(5) The recommended approach when encountering a system with poor uniformity is to convert the system so as to eliminate the uniformity problems, not to increase run times in an attempt to reduce or eliminate dry spots or visually poor-quality turfgrass (Figures 11 and 12). If you have a uniformity problem, fix it – don’t drown it.

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