Water Conservation Diagrams Illustrate Benefits of Improved Irrigation[1]

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Abstract: A water conservation diagram compares two water destination diagrams on the same chart, and is a wonderful educational tool for documenting, explaining and illustrating the benefits of irrigation improvements. Water destination diagrams are graphical depictions of the ultimate fate of all water applied by an irrigation system. Water destination diagrams show such features as the amount of water going to meet plant water requirements and the amount of water going to non-productive uses (runoff, overspray, deep percolation). The influence of distribution uniformity and of irrigation scheduling decisions on water application are easily shown. Comparing two water destination diagrams in a water conservation diagram clearly shows the benefit of irrigation improvements such as raising uniformity, reducing runoff, or eliminating overspray. This paper describes the construction, interpretation and use of water conservation diagrams for turf and landscape irrigation.

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. For example, the California Department of Water Resources (1998) has observed:

> *"The greatest potential reduction in urban water use would come from reducing outdoor water use for landscaping."*

Improvements in irrigation equipment, design and management all have roles to play in urban water conservation. Education also plays an important role. If water purveyors, irrigation professionals, and water users fail to understand the ways in which irrigation decisions affect water conservation, this lack of understanding poses a barrier to effective implementation of water conservation technologies.

Water destination and water conservation diagrams are useful tools, easily illustrating the fate of applied irrigation water. When used to compare the consequences of alternate irrigation decisions, they can illustrate as well the water conservation to be achieved, and/or the improvement in landscape moisture status to be obtained from making the superior decision.

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Water Destination Diagrams

As we will see, water conservation diagrams are constructed from two water destination diagrams representing competing irrigation decisions. So let's look first at how water destination diagrams are constructed.

As the name suggests, water destination diagrams show the destination or ultimate fate of water applied during an irrigation event. One of the key considerations is the uniformity with which water is applied to the irrigated area. Unfortunately, no irrigation system can apply water with perfect uniformity. Some parts of the irrigated area will receive relatively more water, while other parts receive relatively less.

The most direct way to observe and numerically evaluate this effect is through an irrigation audit. The Irrigation Association (2004) presents detailed procedures for conducting audits, but for our purposes, the key conceptual steps are these: (1) place catch-cans [think rain gages] throughout the area to be irrigated; (2) run the irrigation system as intended; (3) analyze and interpret the results. The first two steps in this process are illustrated in Figures 1a and 1b.

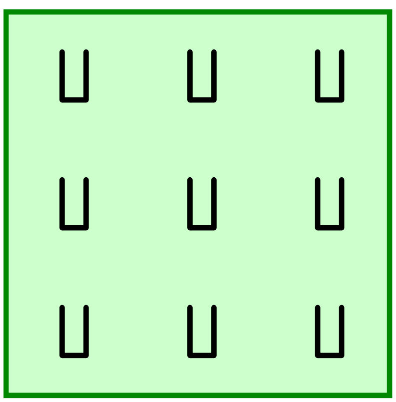


Figure 1a. To perform an audit, catch-cans must be placed throughout the irrigated area.

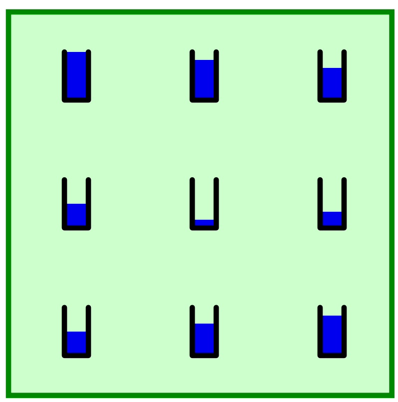


Figure 1b. After the irrigation system has been run, the catch-cans show the amount of water deposited in various locations.

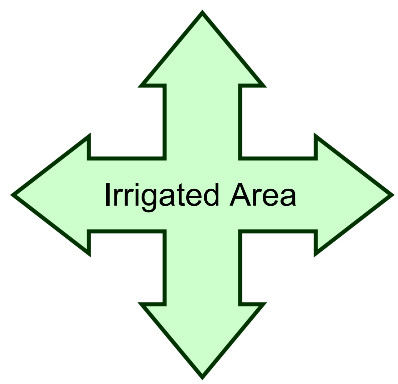


Figure 1c. Since the irrigated area is 2-dimensional (N-S and E-W), water amount represents a third dimension.

Figure 1c emphasizes the difficulty in trying to develop illustrations of audit results. The irrigated area is 2-dimensional (for example, North-South and East-West). So to develop a water diagram, the water amount would have to be graphed in a third dimension, which makes the whole situation difficult to present on a 2-dimensional piece of paper.

Water destination diagrams solve this problem by rearranging the catch-cans, as shown in Figure 2 (next page). The catch-cans are moved into a line, ordered according to the amount of water contained in each, with the larger amounts at the left.

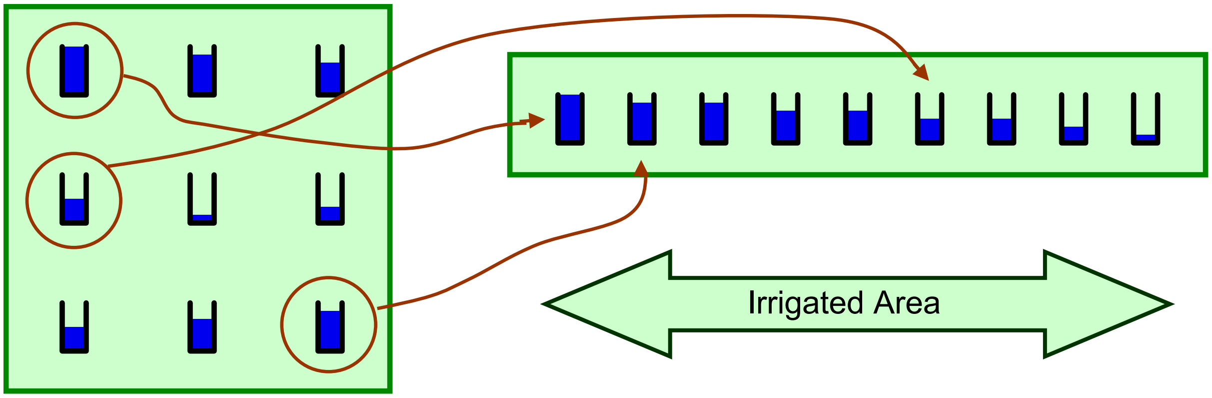


Figure 2. To enable the construction of the water destination diagram, catch-cans from the audit are repositioned into a 1-dimensional array, and sorted according to the amount of water caught in each can, with the larger amounts on the left. [The actual act of repositioning is shown here for only a few of the catch-cans.]

Adjacent catch-cans in the repositioned array don't necessarily come from adjacent locations in the originally audited area. However, each catch-can does represent a certain proportionate share (percentage) of the audited irrigated area. And, since the repositioned array is now a 1-dimensional representation, the amount of water can be illustrated in a normal 2-dimensional graph.

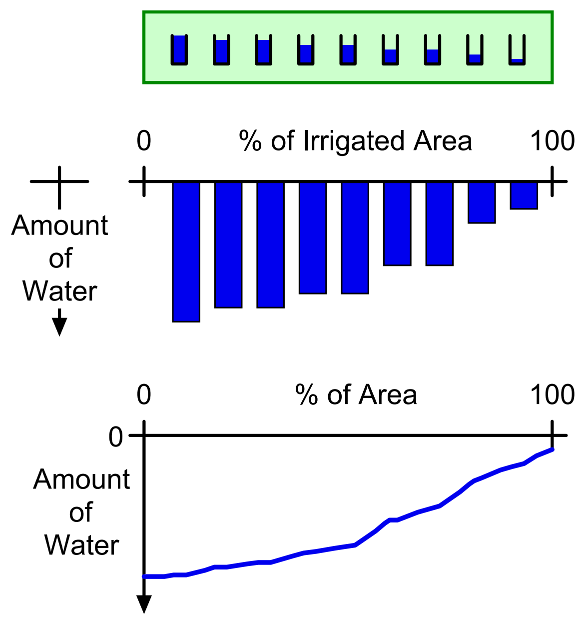


Figure 3. The uniformity part of the water destination diagram is constructed from the 1-dimensional array of repositioned catch-cans (top). The diagram may be shown as a bar graph (middle) or as is most commonly done, as a water application curve (bottom).

It is traditional to plot the amount of water in the downward direction, to represent water infiltrated into the ground (Figure 3). The horizontal axis represents the irrigated area. But since information about specific geographic location has been lost in the repositioning process, the horizontal axis is quantified only as the per cent of the area represented (see further on this point below).

The process of conceptually repositioning the catch-cans from an audit, as shown in Figure 2, is key to the construction and understanding of water destination diagrams. It has been our experience that individuals presented with a water destination diagram for the first time do not always grasp the significance of the horizontal axis. They do not easily make the jump between their mental image of an irrigation audit (as in Figure 1), and the "% of Area" axis in the bottom of Figure 3. However, with an explanation of the repositioning process, and with a demonstration or sketches such as Figures 2 and 3, the situation is usually clear. Most people comfortable with graphical presentations of numerical data in general will understand the water destination diagram, and be able to relate the diagrams to the consequences of irrigation decisions.

The uniformity portion of the water destination diagram from an actual irrigation audit is shown in Figure 4. [Note: The uniformity in this particular case is not very good. The Low Quarter Distribution Uniformity (DU_{LQ}) is only 58%.]

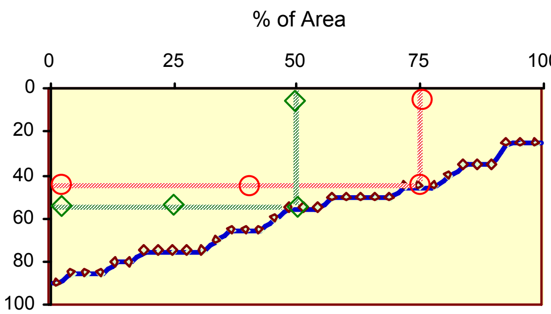


Figure 4. Water destination diagram from an actual irrigation audit.

The dashed lines illustrate how the graph is to be read. The dashed red lines (circle symbols) intersect at a point that indicates that 75% of the irrigated area received a catch-can value of 45 or more. An equivalent reading is that 25% (that is, 100% minus 75%) received a catch-can value of 45 or less. The dashed green lines (diamond symbols) intersect at a point that indicates that the catch-can value of 55 is the median value: about 50% of the area receives this much or more, while the other 50% of the area receives this much or less.

The minimum application amount occurs at the far right of the application curve, directly under the "100% of Area" position. The average application amount tends to occur approximately under the 50% position. The maximum application amount occurs at the far left of the application curve, directly under the 0% position.

Figure 5 shows how the water destination diagram shifts in response to improved uniformity. Water applications with low uniformity are represented by application curves that are relatively steep. They exhibit the widest difference between the minimum and maximum application amounts (red curve, circle symbols). Higher uniformity applications are represented by application curves that are less steep, with smaller differences between minimum and maximum application amounts (blue curve, triangle symbols). Perfect uniformity (an unattainable ideal, and therefore not shown here) would be represented by a perfectly level, horizontal application curve, with minimum, average and maximum application amounts all the same.

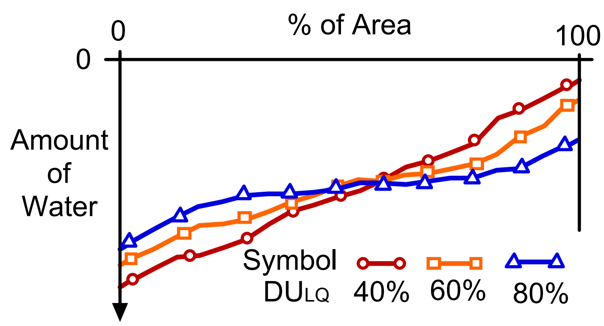


Figure 5. Steeper slopes on the application curve of the water destination diagram imply lower uniformity.

Factors Other than Uniformity

If the water destination diagram is to show the destination or ultimate fate of water applied during an irrigation event, more factors must be considered than just uniformity. Not all of the water applied may reach the irrigated area or infiltrate. The fate of some of the applied water may be overspray or runoff. Overspray is water sprayed outside the boundaries of the area to be irrigated, such as on adjacent sidewalks or roadways. Runoff is water that moves across the surface of the soil and leaves the irrigated area before it has the chance to infiltrate into the soil. How are these *destinations* shown on the destination diagram? The convention is to show these amounts above the zero line on the water amount scale (Figure 6).

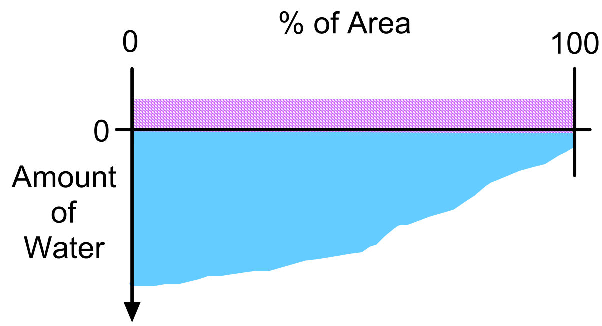


Figure 6. A complete water destination diagram. Infiltrated water is shown in solid blue. Overspray and runoff amounts are placed above the zero line, and are shown here in mottled purple.

Placing water destined for runoff or overspray *above* the water application zero line is consistent with the observation that water destined for these fates is not available to infiltrate into the soil, and therefore cannot contribute to meeting the goal of the irrigation, which is to deliver the required amount of water to the root zone of the landscape plant material.

Because the water lost in these ways never reaches the irrigated area, uniformity does not apply. In other words, it makes no sense to talk of the uniformity of runoff or overspray – they are extracted from the system before uniformity of application applies. Therefore, these losses are shown as a fixed amount across the entire irrigated area (see mottled purple bar in Figure 6).

Diagram Changes with Run Time

Figure 7 shows how water destination diagrams change with run time [actually, the net result of changes in both number of cycles and run time per cycle]. Increasing run time shifts the water application curve and the runoff/overspray line from the dashed to the solid curves.

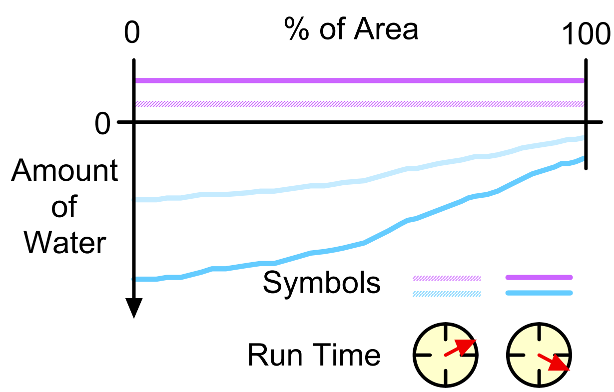


Figure 7. The effect of run time on water destination diagrams

Each application amount is scaled in direct proportion to the increase in run time (from 1x to 2x in Figure 7), so increasing run time shifts the application curve down. The numerical value of uniformity (DU_{LQ}), though, is not changed. Since each water amount is increased by the same proportion, both the average and the average of the low quarter application amounts are also changed by that same proportion. Therefore the value of the ratio by which DULQ is calculated will not change.

Increasing the run time will also increase the amount of overspray in the same proportion. The runoff will increase as well, though perhaps not in the same proportion. Unless cycle numbers and soak time between cycles are adjusted, it is possible that runoff could increase by a factor greater than the increase in run time.

Irrigation Target

In order to determine whether or not an irrigation application has been effective, we must consider not only the application (uniformity, runoff, overspray), but the job that the irrigation is intended to do. A number of factors influence irrigation management and scheduling decisions, but ultimately, an irrigation event is intended to place a specific amount of water into the root zone of the landscape plant material being irrigated. The Irrigation Association (2005) presents an excellent review of all such factors, and procedures to determine irrigation intervals, run times, number of cycle starts, and soak time between cycles. For our purposes, we will assume that these considerations and procedures have been duly followed, and that the required water application amount is known. This amount is also known as the irrigation target.

The target amount can be plotted on the water destination diagram, and comparisons of water application amounts to this target can form the basis of judgments about the adequacy and effectiveness of the irrigation event.

Different management strategies can be used to set the position of the water application curve relative to the target. Figure 8 illustrates three possible strategies (in these water destination diagrams, it has been assumed that overspray and runoff are negligible).

On the water destination diagram in the top part of Figure 8, the crossing point of the water application curve (blue) and the target amount (horizontal green line) is nearly under the 0% position. Very little of the area receives more water than it needs, and the amount of over watering is very small.

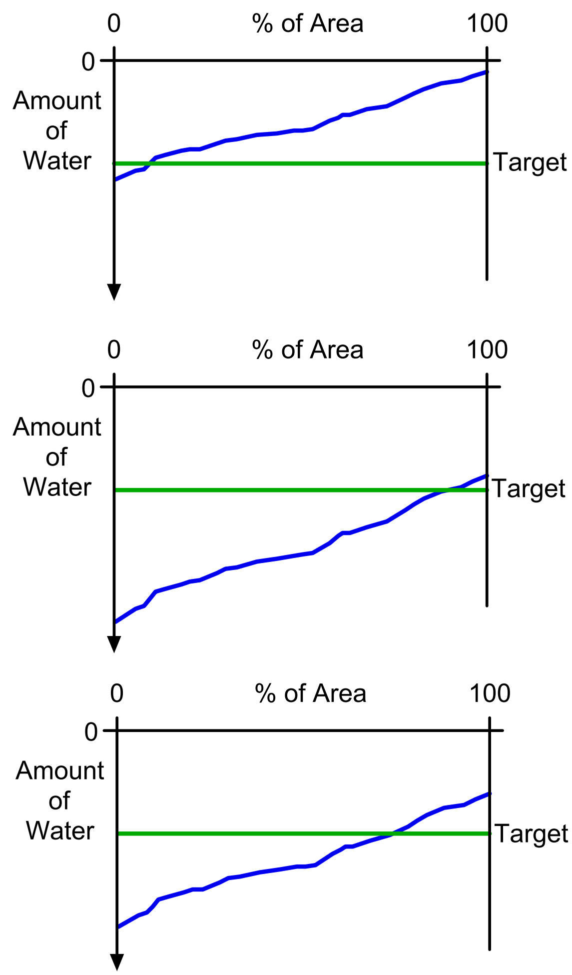


Figure 8. Different management strategies specify the positioning of the water destination diagram's application curve with respect to the target amount.

f th is management strategy is that almost all of the irrigated area receives less water than it needs, and for much of the area the deficit is quite large. This strategy minimizes water applied, but will probably produce landscape with very poor visual quality.

The management strategy shown in the middle of Figure 8 takes the opposite extreme. Virtually all of the irrigated area receives water at the target level or more, so there is very little deficit. However, most of the area receives more water than is necessary, and the amount of water applied in excess of the target amount is quite large.

Various management strategies in between these two extremes represent different trade offs between over- and under-irrigation, between water conservation and excess water application, and between landscape adequately irrigated and landscape suffering significant water deficit. Unless there is a drainage problem on the property, excess water application is usually less apparent than landscape with poor visual quality due to water deficit.

The bottom portion of Figure 8 illustrates the Irrigation Association's recommended management strategy. The IA (2005) suggests that irrigation run times be adjusted so that the low half average application is equal to the target irrigation amount (the amount required for local weather and plant conditions). In this case, the water application curve (blue) crosses the horizontal line indicating the target amount (green) approximately under the 75% position on the horizontal axis of the water destination diagram. 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 for scheduling purposes is the *lower-half* distribution uniformity [as computed from catch-can values]" (IA, 2005, page 1-22).

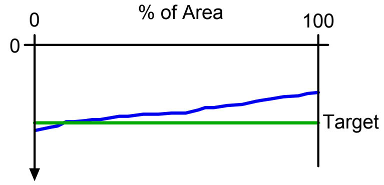
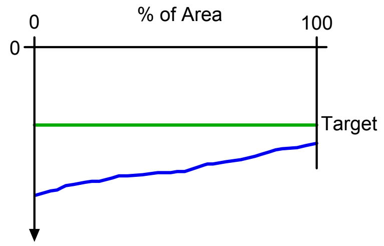
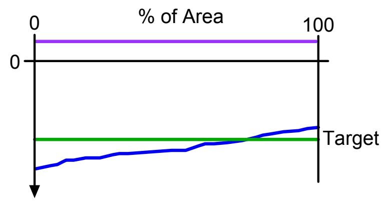
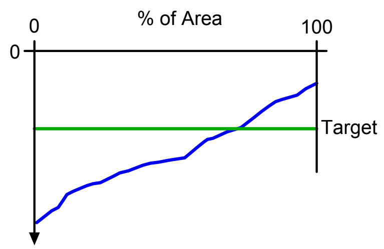
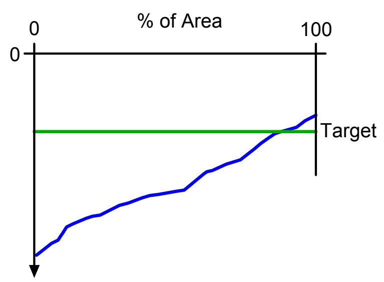
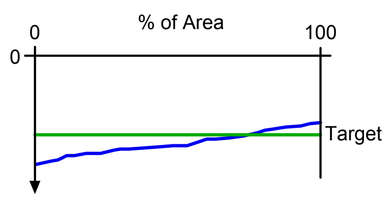
This approach to irrigation scheduling has proved reasonable for systems with adequate uniformity. However, for systems with low uniformities, this method of scheduling may result in some visual signs of stress in the turf or landscape (Allen, 2001). In such cases, it is recommended to correct those problems that cause the low uniformity, instead of just over-watering in an attempt to deliver adequate water to those areas receiving the least amount of water. From the water conservation standpoint, this is certainly the preferred approach.

Interpreting Water Destination Diagrams

Once the basic concepts of water destination diagrams are grasped, they can often be interpreted intuitively. Table 1 (next page) presents interpretations and recommendations based on characteristics easily discernable in water destination diagram sketches. It is relatively easy to make qualitative judgments about the uniformity, run time selection, and amount of overspray or runoff present just from the appearance of the water destination diagrams. Once these judgments have been made, recommended actions to improve or maintain the situation are obvious.

Overspray – Water lost because it is thrown outside the area to be irrigated may be reduced or eliminated by selecting sprinklers with coverage arc and radii appropriate to the area, or by adjusting sprinkler arc and radius settings if possible. Take care that arc or radius adjustments do

Table 1. Water Destination Diagram – Interpretations and Recommendations

Water Destination Diagram*	Interpretation	Recommendations
	• No overspray or runoff loss • Good uniformity • Poor run time selection: a significant portion of the area is in deficit	Increase run time so that the low half average application amount equals the target amount.
	• No overspray or runoff loss • Good uniformity • Poor run time selection: all of the area receives more water than the target amount; considerable water is wasted due to excess application	Reduce run time so that the low half average application amount equals the target amount.
	• Overspray or runoff losses are excessive • Good uniformity • Proper run time selection: application curve crosses target under 75% position (approx.)	Adjust arc and radius of sprinklers to eliminate overspray; reduce precipitation rate or adjust cycle starts and soak time between cycles to minimize runoff.
	• No overspray or runoff loss • Poor uniformity • Proper run time selection: application curve crosses target under 75% position (approx.)	Take steps to improve uniformity.
	• No overspray or runoff loss • Poor uniformity • Poor run time selection: excess water applied to try to eliminate deficit areas caused by poor uniformity	Take steps to improve uniformity; adjust run time so that the low half average application amount equals the target amount.
	• No overspray or runoff loss • Good uniformity • Proper run time selection: application curve crosses target under 75% position (approx.)	Monitor the system to maintain the current high level of performance.

* Water application curves in **blue**; Target application amount in **green**; Overspray/runoff loss in **purple**.

not affect the matched precipitation status of sprinklers on the same circuit – if the flow rate delivered to an adjusted arc or radius sector is not adjusted as well, the precipitation rate will change. Also, watch that adjustment of the radius doesn't adversely alter the water pattern for the sprinkler, resulting in lower distribution uniformity.

Runoff – Runoff may be reduced or eliminated by selecting or retrofitting to sprinklers with reduced precipitation rates, or by adjusting the number of cycles and soak time between cycles.

Run Time Selection – Proper run time selection results in the low half average application amount matching the target or required application amount (this according to IA recommendations). To achieve this result in practice requires:

- an understanding of plant characteristics and weather conditions to establish the target amount,
- an understanding of the sprinkler system's application rate and uniformity characteristics to calculate the necessary run time, and
- the ability to control the sprinkler system to achieve the desired run time.

With poor uniformity systems, proper run time selection as defined above may not result in adequate coverage for the entire area – portions of the landscape may receive insufficient water and have an unacceptable visual appearance. Inexperienced water managers observing this condition tend to increase irrigation run times in an attempt to eliminate deficits. Unfortunately, this may require a large increase in the amount of water applied (compare rows 4 and 5 in Table 1). It's just not efficient to fight a uniformity problem with water. Much better is to make changes to the system to improve the uniformity, and then select run times as recommended (so that the low half application amount matches the target).

Uniformity – As there are many factors that influence uniformity, there are many possible steps toward making improvements. Selecting the right sprinkler, nozzle, operating pressure and spacing *before* installation is the best course. However, even after the initial system has been installed, retrofitting to a more appropriate sprinkler selection can significantly improve uniformity.

Make sure that all sprinklers on the same circuit have the same precipitation rate, even after any arc and radius adjustments have been made to eliminate overspray. Selecting, or retrofitting, sprinklers with lower flow rates may improve uniformity in a couple of ways. First, the lower flow rates will reduce friction losses through meters and supply lines, resulting in an increase in the pressure entering the circuit. Second, the lower flow rates will also reduce friction losses in the piping within the circuit, resulting in a more uniform distribution of pressure among all sprinklers on the circuit.

Water Conservation Diagrams

When alternate irrigation decisions are contemplated, or when a change is proposed to a previous decision, water destination diagrams for the competing options will show the consequences of each choice. However, to emphasize the net effect of the differences between options, it is plot the water destination diagrams for both options on the same chart. This is called a *water conservation diagram* since it is such an effective way to illustrate the conservation benefits to be associated with the superior irrigation decision. Two examples are presented to demonstrate the concept.

Case 1 – An existing system has been audited and found to have excessive overspray and runoff losses, and poor uniformity. Due to low uniformity, portions of the landscape had poor visual quality. The irrigation manager has increased run times to try to apply sufficient water in these "dry spots." A system retrofit was performed to improve the situation. The existing spray heads were replaced with sprinklers that had lower flow rates and superior coverage on the existing spacings. The reduced precipitation rate eliminated runoff, and arc and radius settings were adjusted to eliminate overspray. The improved uniformity eliminated deficit areas, so run times were selected in accordance with the IA recommendations: so that the low half average matched the target application amount. Figure 9 shows the separate water destination diagrams for this system, both before and after the retrofit, and the combined water conservation diagram that highlights the net benefits of the improvement.

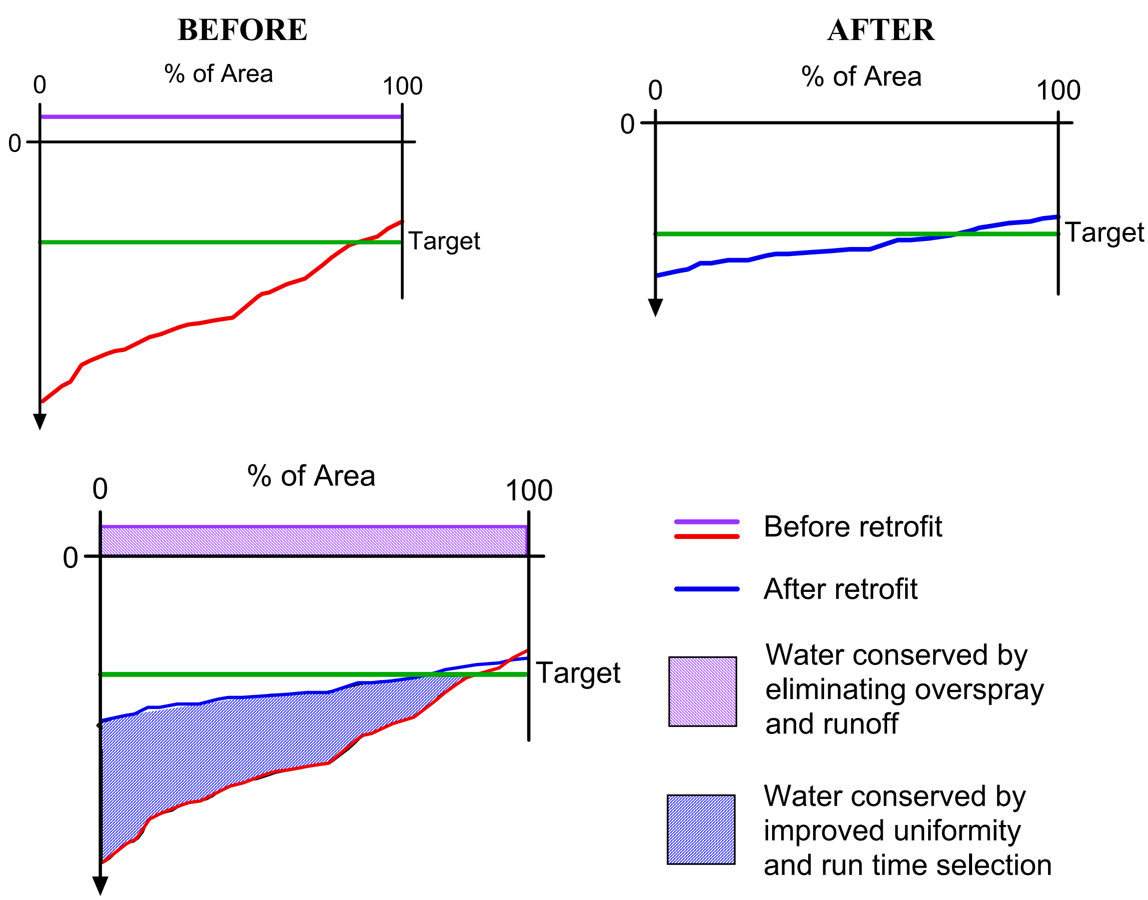


Figure 9. Diagrams for Case 1. Top left, water destination diagram for the existing system, before the retrofit. Top right, water destination diagram for the improved system, after the retrofit. Bottom, water conservation diagram highlighting the water conserved by the improvements.

efit of this retrofit was water conservation. Although poor uniform ity had initially resulted in deficits and landscape of poor visual quality, the irrigation manager had overcome this problem by increasing water application. This also increased the amount of water lost to overspray and runoff. Although deficits were negligible in both the *before* and *after* situations, considerably more water was required to eliminate the deficits before the retrofit. The water conservation diagram (Figure 9, at bottom) emphasizes the amount of water saved by the retrofit, and identifies the cause of each conservation component.

Case 2 – An existing system has been audited and found to have poor uniformity. No overspray or runoff were observed. Run times were selected according to IA recommendations. Due to low uniformity, portions of the landscape had poor visual quality. The irrigation manager recognized the cause as poor uniformity, and ordered a retrofit to improve the situation. The existing spray heads were replaced with sprinklers that had superior coverage on the existing spacings and better resisted pattern distortion under windy conditions. The improved uniformity greatly reduced deficit areas, so run times continued to be selected according to IA recommendations: so that the low half average matched the target application amount. Figure 10 shows the separate water destination diagrams for this system, both before and after the retrofit, and the combined water conservation diagram that highlights the net benefits of the improvement.

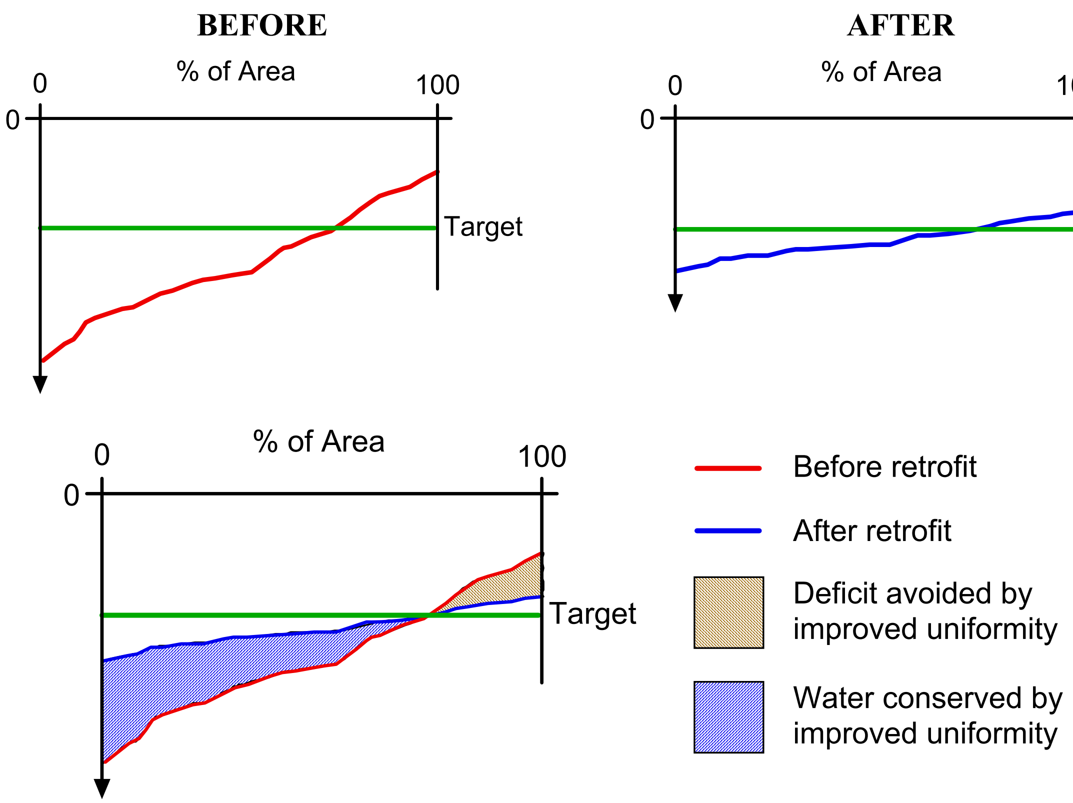


Figure 10. Diagrams for Case 2. Top left, water destination diagram for the existing system, before the retrofit. Top right, water destination diagram for the improved system, after the retrofit. Bottom, water conservation diagram highlighting both the water conservation and the deficit reduction achieved by the retrofit.

The benefits of the second retrofit were both water conservation and better looking landscape. The deficits and poor quality landscape evident in the existing system were corrected by the retrofit. The new system does a better job of caring for the landscape, since it greatly reduces the deficits previously experienced. Furthermore, it does so using less water than the old system! The water conservation diagram (Figure 10, at bottom) emphasizes both benefits of the retrofit – the amount of water saved and the reduction of deficits that had been causing poor quality landscape.

Summary and Conclusions

A *water destination diagram* shows the ultimate fates (destinations) of applied irrigation water. Techniques for explaining the construction of water destination diagrams to those unfamiliar with the concept are presented. When the target irrigation amount is also plotted on a water destination diagram, the adequacy and effectiveness of the irrigation can be judged. Intuitive interpretations of water destination diagrams are possible. Key characteristics of the irrigation system may be recognized in the water destination diagrams, and appropriate actions for correcting problems can be recommended. When water destination diagrams for two alternate irrigation situations are plotted on the same chart, the result is a *water conservation diagram*. A water conservation diagram emphasizes the net benefit of making the best decision or choosing the best system, and can be an effective tool in arguing for the superior alternative.

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