Defining the Run Time Multiplier

By

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Introduction

Sprinkler or spray irrigation is probably the most widely accepted method of irrigation of turf grass areas, but due to the inherent non-uniformity of the application method it becomes necessary to overwater some portions of the turf in order to preserve the appearance and persistence desired in the turf. The question to be addressed revolves around how much to increase the irrigation to ensure adequate quality in the irrigated area.

Non-Uniformity

The non-uniformity of sprinkler irrigation is can be shown graphically by plotting the depth of water applied through an irrigation system. The following example was produced by four irrigation sprinklers, each with a perfect triangular distribution pattern on a grid with the sprinklers spaced 50% of wetted diameter by 70% of wetted diameter. This figure shows the relative depth to which the water would have infiltrated into the soil, so the greater depths are farther down.

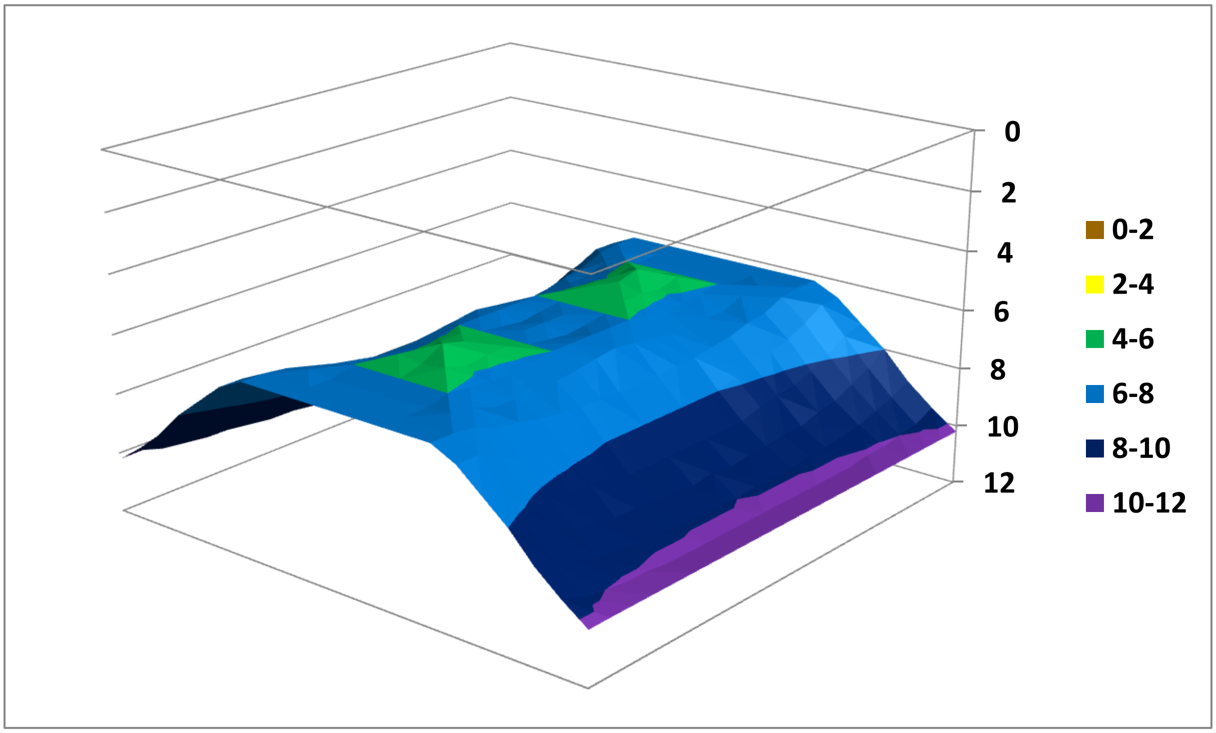

Figure 1. Overlapped Sprinkler Pattern, Example 1.

Along the edge where the sprinklers are spaced 50% of wetted diameter, the relative depth is exactly the same—10. Along the edge where the spacing is 70% of wetted diameter, the depth varies from 10 at the sprinkler to 6.2 in the overlapped area. Near the middle of the pattern, the lowest value (5.4) occurs in two spots. The average depth applied is 7.8. This system has a Christiansen's Coefficient of Uniformity of 0.805, a DU_{lh} of 0.810, and a DU_{lq} of 0.772.

There is a minimum value (depth) below which we are not willing to accept either due the appearance or decreased longevity of the turf. In order that all the area receives that minimum depth, we must run the system longer resulting in more water in some areas than needed. For the sake of discussion, let's assume that the average needed is 8.6. In order to achieve that number, we need to increase the time the system is run to by a factor of 8.6/7.8 = 1.10. Furthermore, if the average is 8.6, there is a level below which the depth is insufficient to achieve either the quality or longevity desired. For further discussion, let's assume that is 70% of the 8.6 or 6.0. The new plot of depth has the same shape and same location of minimum depth but has all the depths increased so that a very, very small spot has less than 6.0 as indicated by the tiny green spots. These two tiny spots (which are actually 5.94) represent 0.45 % of the area.

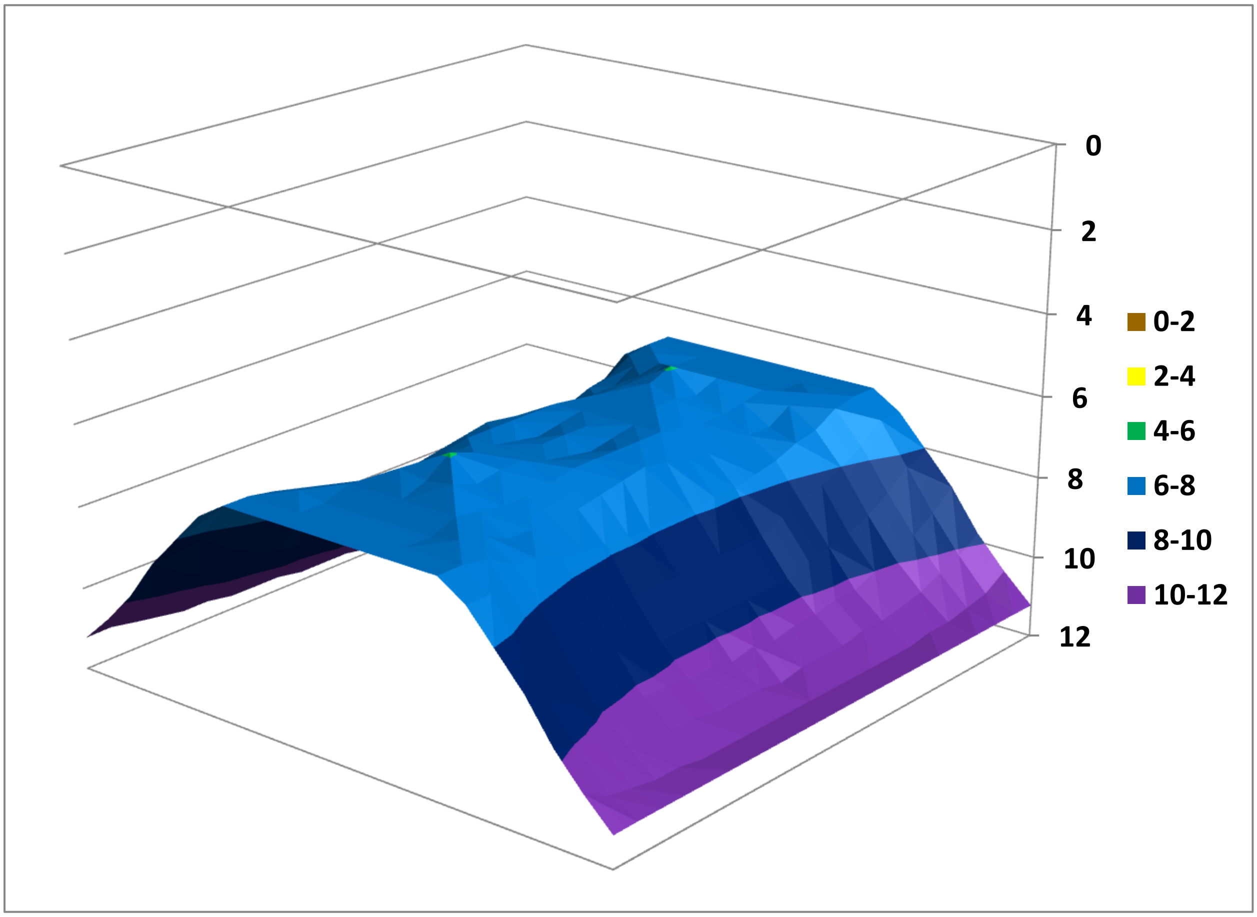

Figure 2. Overlapped Sprinkler Pattern, Example 2. 10% additional run time.

Two decisions have been made regarding this irrigation system. First, it was decided to run it longer in order to raise the average amount (and the minimum amount) and that anything below a given amount (6.0) was unacceptable. One more small correction will is necessary to meet the minimum acceptable amount by running the system 11.1% longer instead of 10% longer. The new average is 8.68, and the minimum is 6.00. The CU and DU's do not change.

Run Time Multiplier(s)

The Run Time Multiplier [RTM] as presented in several places in the Irrigation Association literature is based upon various methods of evaluating sprinkler performance. "*A run time multiplier is used to help compensate for the lack of perfect uniformity in sprinkler systems…RTM's are derived from the various methods of evaluating irrigation uniformity.*" (Irrigation Association, 2002.)

The idea of RTM was to communicate to the practitioner how much extra water should be applied based upon the lack of uniformity of the sprinkler system. In the auditing program, which is based on the original program developed in California, the plant water requirement was divided by the low-quarter distribution uniformity to determine irrigation water requirement. The RTM based on DU_{lq} is the same equation as determined by the irrigation water requirement (IWR) if the plant water need was one.

$$IWR = PWR / DU_{lq}$$

$$RTM_{lq} = 1/ DU_{lq} \tag{1}$$

In this example, if the plant water requirement is 1 and the DU_{lq} is 0.772 the irrigation water requirement is 1.30 inches. The practitioner would calculate that 30 percent more water would be needed, and would then increase the run time by 30%. By creating a RTM based on low-quarter distribution uniformity the practitioner sees immediately that 30 percent more water would be added or 30 percent more run time would be programmed compared to the ideal run time based on a perfect system. If the ideal run time were to be 20 minutes he would use the RTM of 1.30 to calculate a run time for the station of 26 minutes (20 minutes x 1.30 = 26 minutes). The system in the example run 30% longer as suggested by the RTM would have a minimum value of 7.0 and an average of 10.16.

If the run time multiplier is based upon Christiansen's Coefficient of Uniformity (CU_c) or DU_{lh}, then the amount of water applied would be different even though the information for CU came from the same data the was used to calculate DU_{lq}. Again referring to the example, the CU is 0.805 so the RTM can be calculated by equation 1 as

$$RTM_{lh} = 1/ DU_{lh} \approx 1/ CU_c.$$

If this is the case then the RTM would be 1.24 or 24 percent more water would need to be added. This is less water than a RTM based upon DU_{lq} but would it be a sufficient amount of extra water?

The Scheduling Coefficient is treated slightly differently in the IA Landscape Irrigation Auditor text (IA, 2007). "*The scheduling coefficient is a measurement of irrigation uniformity in an area that was* *developed for turfgrass irrigation. It is based on the critical turf area because in turfgrass irrigation it is common to irrigate any critical area until it is sufficiently watered. The SC indicates the amount of additional water needed to adequately irrigate the critical area. In the purest form, scheduling coefficient is based upon the absolute lowest precipitation rate versus the average precipitation rate. The critical area is typically defined as a percent of the total area (1%, 5% or 10%)*". The text goes on to explain that "*the difference between SC and DU is the fact that SC uses a contiguous area in defining the dry spot area to be used in establishing design and operational parameters*." Common practice is to use a"window "or contiguous area that is equal to five percent of the total area. In order to get a representative can test, a large number of catch cans would be necessary, and it just isn't practical to perform such test. However, computer simulations such as the one shown or densograms from SpacePro (CIT, 2009) are good examples.

It has been said that the SC could be used as a run time multiplier. Using the previous example, the SC would be 1.30, leading to a RTM of 1.30 and resulting in 95% of the area being overwatered.

Which RTM should be used? Vastly different amounts of water could be applied, all based upon sprinkler performance but measured by different parameters—DU, CU or SC. It is time to define which run time multiplier makes the most sense. Additional water is needed to compensate for the lack of perfect uniformity, but the efficient use of water resources is part of the IA's stewardship and mission statement.

Destination Diagrams

The authors believe that the best way to understand uniformity and management of sprinkler systems is by using destination diagrams. A destination diagram is a plot of the depth applied by a sprinkler system against the area. By plotting the line representing the depth against the area receiving at least that much water, a diagram such as shown below is produced. Figure 3 is the destination diagram for the system shown and operated as in Figure 1.

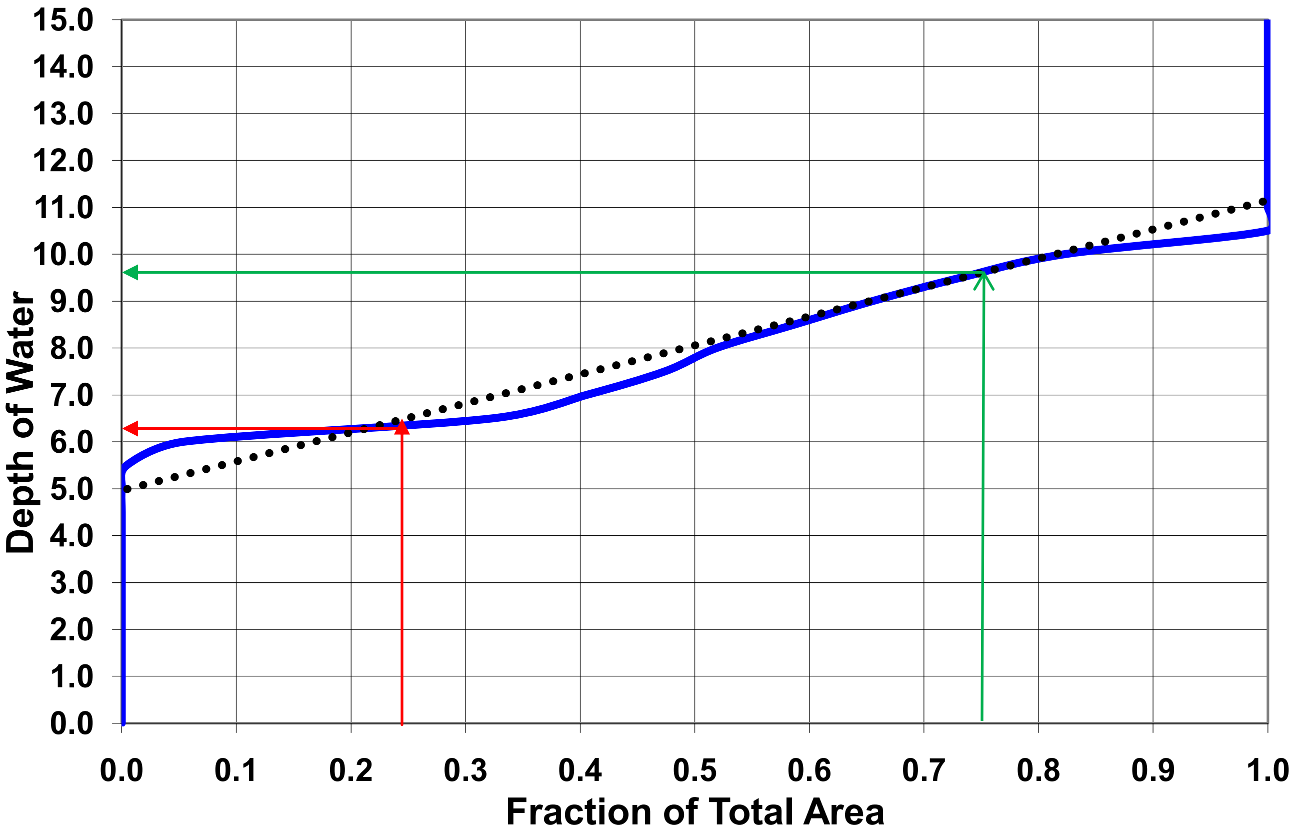

Figure 3. Destination Diagram for Example 1.

The actual line produced from the overlapped data is shown as the blue line, and the dotted black line is a straight line approximation. The destination diagram is interpreted as follows: by choosing a value on the y axis and following it to the line and then to the x axis, we see how much of the area receives a given amount. For example, we see that 50% of the area receives 7.8 or more. Similarly, 75% of the area receives 9.5 or less (green arrows). That can also be interpreted that 25% of the area receives 9.5 or more. We are mostly interested in the lower end, and we see that 25% of the area receives 6.2 or less (75% receives 6.2 or more[red arrows]).

If we used the RTM based upon DU_{lq}, we would have increased the irrigation amount by 30% (RTM = 1/ DU_{lq} = 1/0.772 = 1.30). The resulting values would have been: average=10.1, high = 13.2, and low = 7.0.

Two important questions arise from this discussion. 1. At what fraction of the average application (presumably based upon ET) defines critical? 2. What is the appropriate fraction of area to deem critical as referred to in the SC explanation above?

<u>Critical Application Amount</u>

There is a body of literature representing the research to indicate that most turfgrass irrigated to 70-80% of grass-based ET is enough to meet the goals of appearance and longevity. Aronson, et. al.

(1987) suggest that 80% of ET is adequate. DaCosta and Huang (2006) concluded that 60 to 80% of ET measured in a lysimeter was adequate for bentgrass. Bastug and Buyuktas (2003) concluded that 75% of class A pan evaporation was adequate for the conditions they tested in a Mediterranean climate in Turkey. McCready, et.al. (2009) found that water use could be reduced 11 to 53% without quality degradation on St. Augustine grass. The literature review presented by Bastug and Buyuktas (2003) shows a range of acceptable values from 50% to 130%, but the dominance of the values are between 70% for warm season grasses and 80% for cool season grasses.

Critical Application Area

What percentage of the area receiving less than the critical amount should we be concerned with? As the IA literature states, it depends upon whether the area is contiguous. The authors would argue that large portions of contiguous area are likely due to system malfunction and solvable as opposed to systematic and distributed areas due to spacing and sprinkler distribution profiles. If we agree that 70% is a number we can accept for the critical application amount, we should revisit example 1. As shown in Figure 1, the percentage of the area receiving less than 6.0 is 5.4%. With the pattern as shown in Figure 1, it likely is noticeable. However, a mere 10% increase in run time essentially eliminates the critical area. So, with this system with a CU of 0.805, a DU_{lh} of 0.810, and a DU_{lq} of 0.772, 10% increase is enough.

One could argue that the system in example 1 wasn't properly managed to begin with, and that the average should not be based upon ET but some fraction of ET thereby lowering the critical application amount. For example, if the average was based on 80% of ET, then the critical application amount to meet 70% of ET would be 0.875. (0.8 x 0.875 = 0.70). If that is the case, then the system under discussion would be run to give an average of 8.0 (2% more). Pursuant to that premise, the maximum would be 10.4 and the minimum would be 5.5. The area receiving less than 6.0 is a mere 4.5% of the total distributed in the same two locations as shown in Figure 1. Maybe the assumption that 6.0 is adequate just doesn't apply enough water. What would be the results if we used 80% rather than 70% resulting in 6.4 being adequate? What impact does that have on the result? With an average of 8.0 in example 1, 29.7% of the area receives less than 6.4. We could probably agree that isn't acceptable. In order to reduce the critical area to 10%, we would have to run 6% longer, and to reduce the critical area to 5% we would have to run 9% longer.

Our argument is that a run time multiplier based upon DU_{lq} results in much more water being applied than is necessary. In fact, a run time multiplier based upon DU_{lh} results in excess application. While we can't say exactly what the perfect way is to determine the RTM we believe it would be best to base it on no more than DU_{lh} . Furthermore, it makes sense to limit the RTM to a maximum value. For the practitioner the RTM helps define the upper limit of water to be applied and gives the manager guidelines for irrigation scheduling.

Maximum Value of RTM

Allen and Howell developed a method based upon the assumption of a normal distribution of water depths. It was published in document entitled Landscape Irrigation Scheduling and Water Management (2005) where they suggested a run time multiplier derived by equation 2 as follows.

$$RTM = \frac{1}{(0.4)+(0.6)DU_{lq}} \qquad (2)$$[1]

Shown in Appendix B is the derivation of a similar equation for the scheduling coefficient based upon the assumption that the destination diagram is linear. It is shown below as equation 3.

$$RTM = \frac{1}{\left(\frac{1}{3}\right)+\left(\frac{2}{3}\right)DU_{lq}} \qquad (3)$$

Both of these equations limit the extra run time or water that would be applied. Without the cap included in the RTM, very poor performing systems with a low DU_{lq} would likewise have a very low DU_{lh} and would require excessive amount of water. Equation 2 limits the value to 2.5 whereas equation 3 limits the value to 3.0. Both are based upon $DU_{lq.}$ Nonetheless, these two equations, based upon the distribution patterns and resulting destination diagrams lead to RTM's with maximum values. As opposed to current teaching where poor uniformity gets increasingly more water, with the cap created in the RTM poor performing systems are not rewarded with excessive water. As a practical matter, poor performing systems even with additional water will show stress areas. The solution is to fix the sprinkler system and not just add additional water because it is perceived as easiest and cheapest way. As shown in the chart below, significant amounts of water can be saved compared to old teachings. Run time multiplier is a practical and defensible way to determine the upper amount of water required to adequately manage turfgrass in the landscape. A comparison of the methods presented is shown below in Table 1.

Conclusions

We believe that the current method of determining irrigation water requirement by dividing plant water requirements by DUlq leads to excessive water application. In the spirit of the IA's mission statement to promote efficient irrigation, the RTM presented in the Landscape Irrigation Scheduling and Water Management document and taught in Golf Irrigation Auditor should become the current and relevant teaching and practice to determine the upper limit of irrigation water to be applied to the turfgrass within the landscape. The destination diagrams and graphics validate the logic and reasoning behind the RTM. We further believe that there is room for more improvement, but further improvement depends upon fully understanding both the critical application amount and the critical application area.

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[1] This equation appears in the IA publication (2004) entitled Golf Irrigation Auditor. It was derived from an equation presented in Landscape Irrigation Scheduling and Water Management (2005) document under review. A discussion of how it could be derived is in Appendix A.

Table 1. Scheduling Parameters Derived by Three Methods

Du_{lq}	IWR (PWR/DUlq)	Linear distribution	RTM based on normal distribution
0.30	3.33	1.88	1.72
0.35	2.85	1.77	1.64
0.40	2.50	1.67	1.56
0.45	2.22	1.58	1.49
0.50	2.00	1.50	1.43
0.55	1.82	1.43	1.37
0.60	1.67	1.36	1.32
0.65	1.54	1.30	1.27
0.70	1.43	1.25	1.22
0.75	1.33	1.20	1.18
0.80	1.25	1.15	1.14
0.85	1.18	1.11	1.10
0.90	1.11	1.07	1.06
0.95	1.05	1.03	1.03
1.00	1.00	1.00	1.00

Appendix A

A relationship between the DU_{LH} and DU_{lq} based upon the assumption that the depths are normally distributed can be developed in the following manner. The normal distribution assumption makes the Christiansen's Coefficient of Uniformity (CU_c) equal to the DU_{lh}. CU_c is given by the following equation expressed in terms of the standard deviation and mean of the population.

$$DU_{lh} = CU_c = 1 - \sqrt{\frac{2}{\pi}}\left(\frac{\sigma}{\mu}\right)$$

Where σ is the population standard deviation and
μ is the population mean.

This allows the determination of the standard deviation given the DUlh. Therefore, σ is given by the following equation. The mean, μ, is set to one.

$$\sigma = \sqrt{\frac{\pi}{2}}\,(1 - DU_{lh})$$

It is straightforward to determine the mean of the low quarter of values once the standard deviation and mean have been determined. This sets the relationship between $DU_{lh} = CU_c$ and $DU_{lq.}$ The only problem with the relationship is that DU_{lh} values less than 0.70 lead to negative values in the lower quarter. That, of course, is impossible, so it is necessary to truncate the distribution and limit it to non-zero values. When all values are preserved (including negative), or DU_{lh} is limited to values greater than about 0.70, the relationship is linear and is as follows.

$$DU_{lh} = 0.6537 + 0.3463\, DU_{lq}.$$

For a range of values below $DU_{lh} = 0.70$ and with negative values in the lower quarter set to zero, a range of coefficients for the equation above results, and the correlation is no longer perfectly linear. It is this analysis that leads to slightly differing coefficients. For example, the draft for review of the Landscape Irrigation Scheduling and Water Management shows the values to be 0.614 and 0.386 respectively.

Appendix B

Development of the run time multiplier

The run time multiplier or scheduling coefficient is the amount by which to multiply the run time in order to assure that the area receiving inadequate water is minimized. If we use $1/DU_{lq} = RTM_{lq}$ as the multiplier, we assure that 87.5% of the area receives adequate irrigation. RTM_{lq} makes the average application equal to the average of the low quarter. That is represented by the purple line in the graphic below. Following the purple line intersection with the destination diagram line vertically to the scale, we see that 87.5% of the area receives adequate or more. On the other hand, if we make use $1/DU_{lh} = RTM_{lh}$ as the multiplier, the green line points to the area receiving adequate or more, and that is 75%. Many people are used to using DU_{lq} as the measure of uniformity, so the question comes up as to what the relationship is between RTM_{lh} and DU_{lq} . The sequence below shows how that relationship is developed.

$$DU_{lh} = Average\ \ lh\ values/Average$$

$$Average = v$$

$$Average = 1$$

$$Average\ lh\ values = d$$

Therefore, we have

$$DU_{lh} = d$$

Looking at the lower quarter,

$$Average\ lq\ values = q$$

The average of the low quarter values will be the average height of the trapezoid in the lower quarter. It has height of d minus one half of v minus d, so

$$q = d - \left(\frac{v-d}{2}\right) = \left(\frac{3d-v}{2}\right)$$

$$DU_{lq} = \frac{q}{v}$$

$$DU_{lq} = \left(\frac{\frac{3d-v}{2}}{v}\right)$$

However, we set v equal to 1, so

$$DU_{lq} = \left(\frac{3d-1}{2}\right)$$

We define the RTM as v/d, so

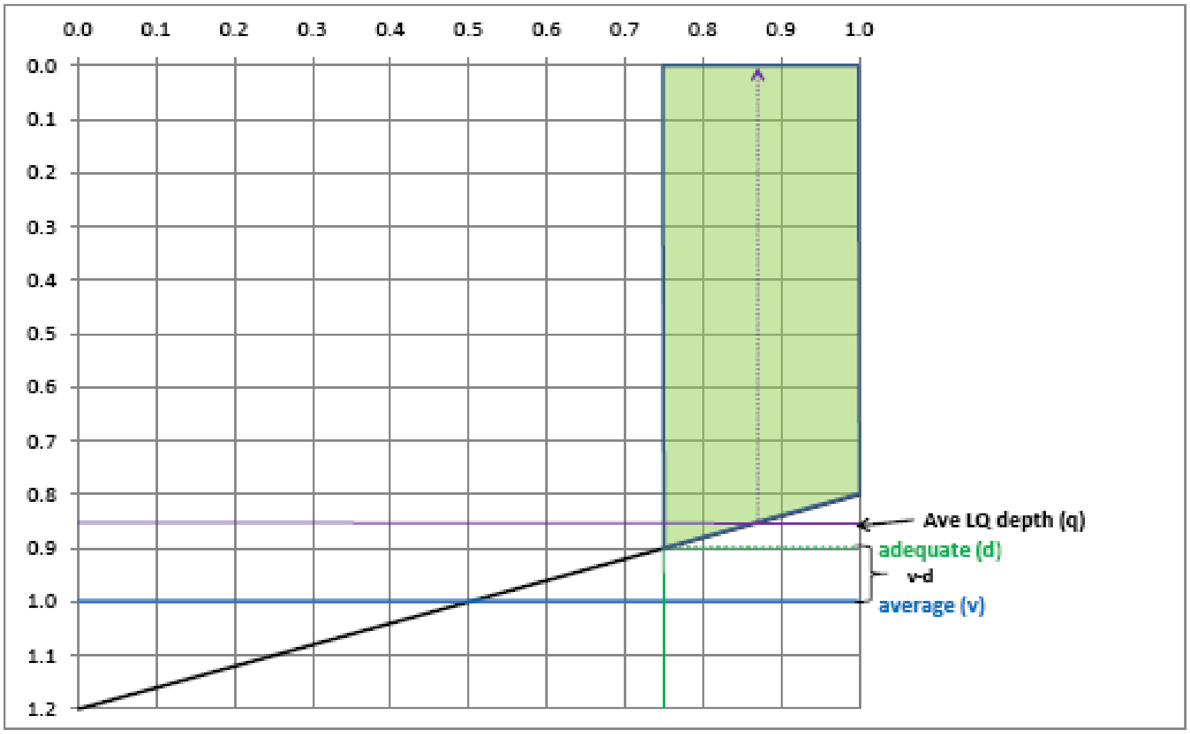
$$d = \frac{1}{RTM}$$

Substituting

$$DU_{lq} = \frac{\frac{3}{RTM} - 1}{2}$$

By a little math manipulation,

$$RTM = \frac{1}{\left(\frac{1}{3}\right) + \left(\frac{2}{3}\right) DU_{lq}}$$



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