Landscape Irrigation Strategies in Aqaba.

The Desert Irrigation Research and Training Center (DIRT center) evaluates irrigation strategies appropriate for desert urban landscapes. The site includes bubbler irrigation (figure 1), in-line drip emitter irrigation of shrubs and trees, and sprinkler irrigation of turf. The DIRT center is located on at 7525 E Speedway Blvd. in Tucson, Arizona (figure 2) at Desert Christian Middle School. Materials for the center have been provided by Western Sod (turf) **http://www.westernsod.com/** Hunter Industries (sprinklers and bubblers) **http://www.hunterindustries.com/,** and Kalamazoo Materials (landscape rock) **http://www.k-zoo.net/.** The climate in Tucson Arizona includes a monsoon season in July and August, but is generally very dry in other months. Winter nights rarely drop below freezing, and the weather is generally hot, especially in summer. The DIRT center has a sandy soil and is near a wash (dry river bed). Tucson’s climate is very similar to Aqaba’s and results from the DIRT center can be used in Aqaba.

Figure 1. Cassia watered by bubbler.

Bubbler irrigation

Bubbler irrigation systems (figure 3) operate at a much higher flow rate than drip irrigation systems. Thus, bubbler system run times are measured in minutes while drip systems run for several hours.

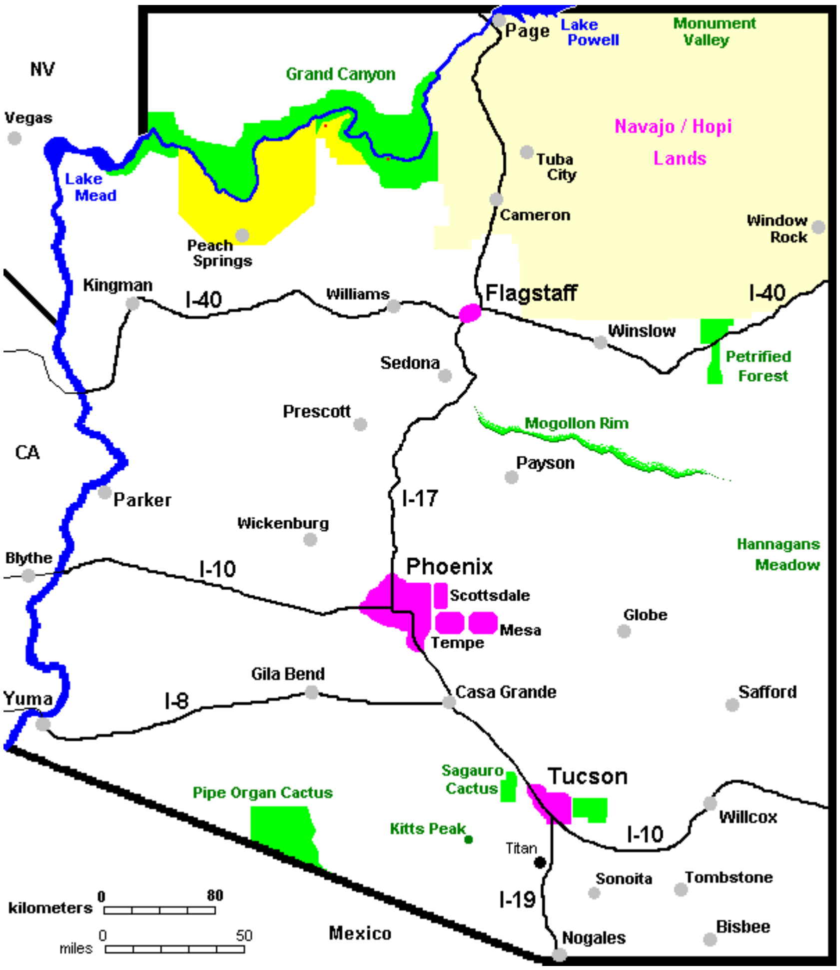

Figure 2. Arizona.

Figure 3. Bubbler irrigation of pine trees.

There are two primary types of bubblers: pressure compensating and adjustable flow (figure 4). Pressure compensating emitters are available in 2-, 4-, 6-, and 8-lpm flow rates. Adjustable flow bubblers are adjusted for flows between 0- and 8-lpm.

The DIRT center recommends the following for installation and maintenance of bubbler basins. (1) No more than one plant should be supplied by an individual bubbler (some bubblers at the DIRT center were installed in a location that enabled water to flow from one plant to another; however, the basins around plants were hard to maintain, and it was hard to maintain the correct distribution of water between plants). (2) If the basin diameter is too large, then two bubblers are required for complete coverage. (3) Labor time to increasing the size of basins during the first few years is approximately 20 minutes per plant per year. (4) Basins with the plant planted below grade are fairly stable; however, basins with ridges above the ground surface are unstable and need maintenance. (5) Trees susceptible to damage by ponded water next to the trunk (rot) should be planted in the center of a doughnut shaped basin with a raised center in order to prevent ponded water next to the trunk. (6) Install most plants 2 to 3 inches below grade, and, thus, large ridges or mounds around basins are unnecessary.

One of the problems with installation of sprinklers and bubblers on solid pipe is that people kick and crack the riser pipe or lateral pipe in the ground. Because of the threat of pedestrians at the site kicking the risers, the first bubblers installed at the DIRT center were mounted on rigid Schedule 80 PVC pipe with triple swing joints connecting the pipe to the PVC lateral. This installation was time consuming and adjustment of bubbler height and location was difficult once the pipe was glued into place. The DIRT center developed an easy and inexpensive method of installing bubblers that is both durable and resistant to breakage: flexible PVC connects the bubbler to the lateral pipe. The flexible PVC is a much easier installation than the triple swing joint approach: two quick glue fittings are connected rather than 4 screwed connections on the triple swing joint, and the flexible PVC tube can be extended to any point in the landscape with ease. Flexible PVC tube is resistant to breakage because it bends when struck, and it has a thick wall that resists deformation or puncturing of tube walls.

Figure 4 shows bubbler fittings. First, glue flexible PVC (1/2 inch diameter black tubing from Ag Products) into a 1x1x1/2 TEE. Second, glue a ½ inch (12 mm) male adapter to the flexible PVC. Third, screw the bubbler onto the male adapter. It is best to tilt the Tee in lateral sideways (figure 5, right figure). The left side configuration in figure 5 causes the tubing to stick out of the ground and is less attractive. The end of the bubbler should face the shrub so that water sprays away from the plant. In order to facilitate bubbler flow rate measurements, one of the following two methods should be used:

1. Install the flexible PVC with 45 cm (1.5 feet) length above the ground surface. Thus, the bubbler can be inserted into a container such as a milk carton in order to measure volume of flow over a given time.
2. Install the flexible PVC with the bubbler close to grade. A flexible PVC extension with a male adapter and a female adapter can be attached to the installed flexible PVC while it is kinked to temporarily stop water flow.

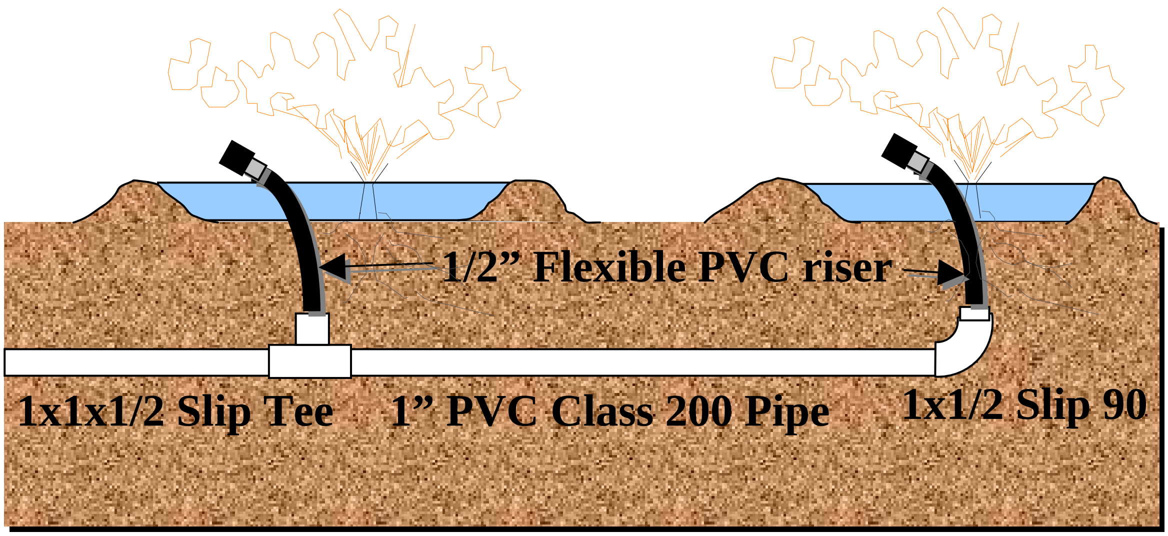

Figure 4. Bubbler fittings.

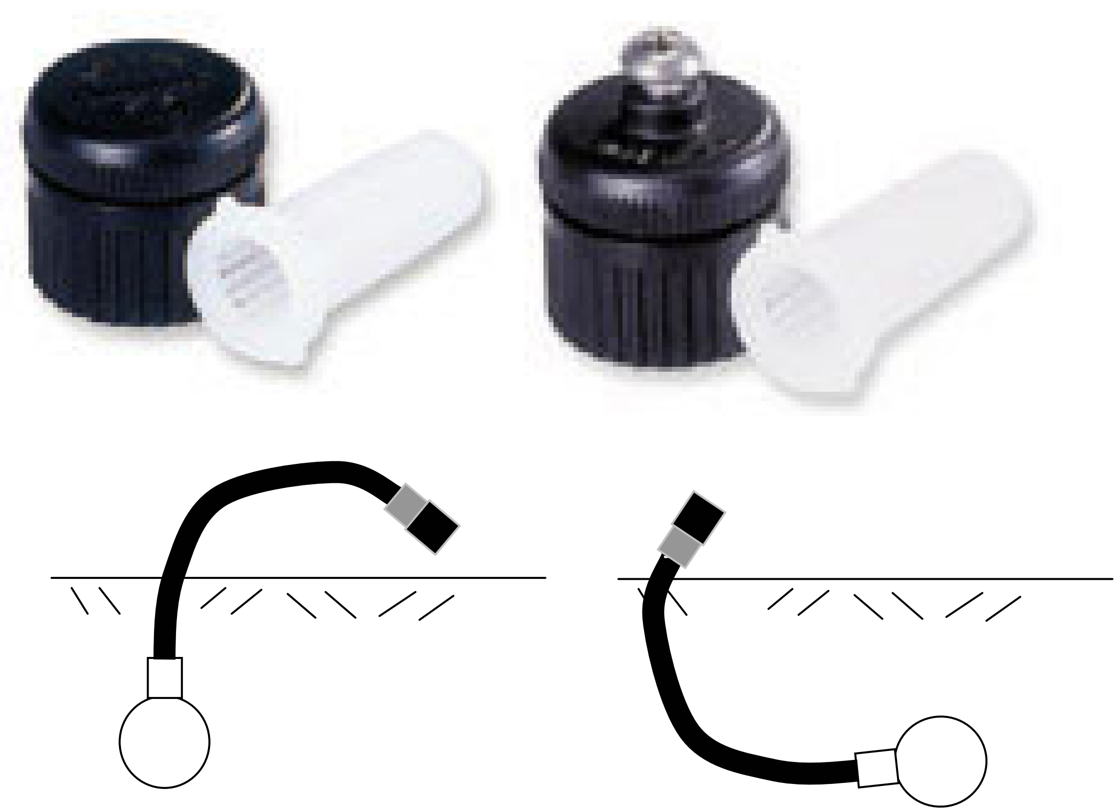

Figure 5. Bubblers and bubbler installation methods.

At the DIRT center, bubblers mounted on flexible PVC have been a reliable system. There was some worry about the stability of the glue joints between flexible PVC and rigid PVC, but no glue joints on approximately 100 bubblers have failed in the last 2 years, even in the extreme desert heat. Flexible PVC is thicker than drip tubing and very durable. A rake damaged one bubbler emitter, and three bubblers plugged with rocks. There were no other breakages or plugging.

The ridges around the basins in figure 4 are not very attractive in landscapes. One alternative that also promotes water harvesting is a contoured basin design (figure 6). It is possible that the contoured basin design would alleviate the problem of expanding basin size as plants grow: Bubblers could be left on for a longer period of time and the basin could be allowed to fill to a greater diameter.

Contoured basin design

The advantages of the contoured basin design are water harvesting (directing rain water to plant roots), basin stability, and aesthetics. Basins appear as natural undulations in the landscape, and ridges need not be more than several inches above basins.

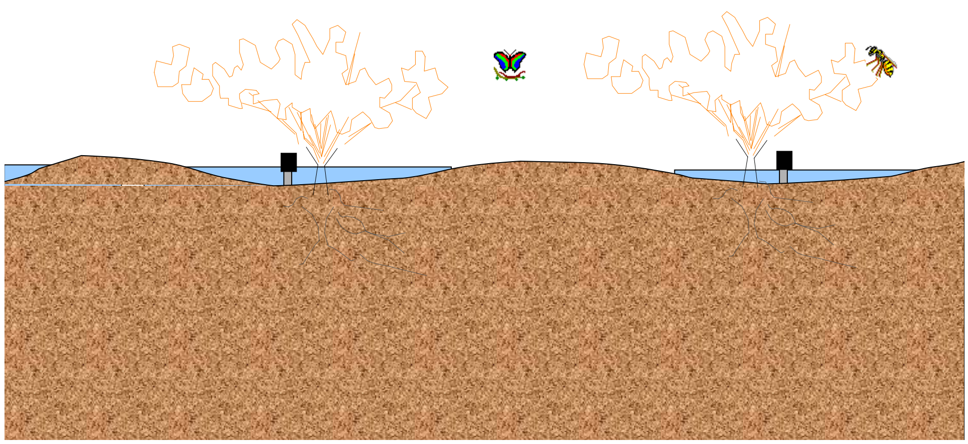

Figure 6. Contoured basin design.

Bubbler irrigation scheduling

Irrigation schedules are calculated based on ET rate and soil water holding capacity. Calculating a bubbler irrigation schedule requires the following steps:

- **Calculate plant water use (LPD)**
  - **Where LPD = Liters per day used by the plant.**
- **Calculate soil water storage (S)**
  - **Where S = volume of usable water (liters) in soil.**
- **Calculate days between irrigation (S/LPD)**
- **Calculate irrigation run time (S/Q)**
  - **Where Q = bubbler flow rate (LPM)**

In this section, calculations are in metric units: volume of evapotranspiration for high water use plants such as citrus trees during peak ET in terms of liters per day (LPD) is

$$LPD = \left(\frac{13\ mm}{day}\right)\left(\frac{m}{1{,}000\ mm}\right)\left(\frac{\pi D^2\ m^2}{4}\right)\left(\frac{1{,}000\ L}{m^3}\right) = 10D^2 \qquad (1)$$

where

D = diameter of trunk canopy in m.

The numerator in equation 1 for various plants and seasons in the desert is shown in table 1.

Table 1. Coefficient for equation 1.

Plant type	Summer	Spring	Fall	Winter
High water use	10	5	5	2.5
Medium water use	5	2.5	2.5	1.2
Low water use	2.5	1.2	1.2	0.6

Calculate the soil water holding capacity based on soil texture, root zone, allowable soil water depletion for specific plants, and the diameter of the basin.

$$S = \left(\frac{\pi D_b{}^2\ m^2}{4}\right)(Z\ m)\left(\frac{AWHC}{100\ \%}\right)(MAD)\left(\frac{1{,}000\ L}{m^3}\right) = 8 * Z * AWHC * MAD * D_b{}^2 \qquad (2)$$

where

S = Volume of water storage in soil available to the plant, L.
Z = root zone depth, m (1.0 m for trees and 0.5 m for shrubs),
AWHC = available water holding capacity, % (see table 2),
MAD = management allowable depletion (1.0 for desert plants, 0.5 for other plants),
D_b = diameter of the basin, m.

The available water holding capacity (the percent of soil volume that holds water that is available for the plant) for different textured soils is shown in table 2.

Table 2. Available water holding capacity for several soil textures.

Soil texture	AWHC %
Sand	8
Sandy loam	12
Loam	17
Clay loam	18
Silty clay	20
Clay	23

Assume that depth of the root zone, Z, is 0.5 m for shrubs and 1.0 m for trees unless better information is available.

The number of days between irrigations (Days) is the Liters of storage divided by the Liters used per day.

$$\text{Days} = S / LPD \qquad (3)$$

The irrigation cycle run time (Minutes) is the soil water storage divided by the application rate (LPM)

$$\text{Minutes} = S / LPM \qquad (4)$$

Example 1. Calculate the watering schedule for an acacia tree (low water use plant) in Aqaba with the following parameters

Canopy diameter = 3 m.
The basin diameter, D_b, is 1.2 m.
The soil is sandy.
Bubbler flow rate, Q, is 8 LPM.

- **Calculate plant water use (LPD)**

  LPD = $2.5D^2$ for a desert plant in the desert during summer.

  $LPD = 2.5 * 3^2 = 22.5$ LPD

- **Calculate soil water storage (S)**

Assume that the Acacia is a desert tree and that the MAD is 1.0.

AWHC for a sandy soil is 8 %
MAD for a desert plant is 1.0

Root zone depth, Z, for a tree is 1.0 m.

$$S = 8 * Z * AWHC * MAD * D_b^{\ 2} = 8 * 1.0 * 8 * 1.0 * 1.2^2 = 92\ L$$

- **Calculate days between irrigation (S/LPD)**

  Days = S / LPD = 92 L / 22 LPD = 4.2 days

- **Calculate irrigation run time (S/Q)**

  Minutes = S / LPM = 92 L / 8 LPM = 11.5 minutes

The small basin relative to the canopy diameter and the low water holding capacity of sandy soil leads to very frequent irrigation (every 3 to 4 days). It would be better to have a larger basin. A larger basin would also encourage root growth.

Redo the acacia example with 3 m diameter basin.

- **Calculate plant water use (LPD)**

  Same as above = 22 LPD

- **Calculate soil water storage (S)**

$$S = 8 * Z * AWHC * MAD * D_b^{\ 2} = 8 * 1.0 * 8 * 1.0 * 3^2 = 576\ L$$

- **Calculate days between irrigation (S/LPD)**

Days = S / LPD = 576 L / 22 LPD = 26 days

- **Calculate irrigation run time (S/Q)**

Minutes = S / LPM = 576 L / 8 LPM = 72 minutes

It is typically better to water a desert plant infrequently in order to allow the root zone to dry out between irrigation events and to encourage root growth. Thus, based on the time between irrigations, the 3 m basin is a better choice. However, it is doubtful that the bubbler flow would be high enough to overcome the high infiltration rate of the sandy soil and fill the entire basin. As a compromise, redo the acacia example with a 2 m basin.

- **Calculate plant water use (LPD)**

Same as above = 22.5 LPD

- **Calculate soil water storage (S)**

$$S = 8 * Z * AWHC * MAD * D_b^{\ 2} = 8 * 1.0 * 8 * 1.0 * 2^2 = 256\ L$$

- **Calculate days between irrigation (S/LPD)**

Days = S / LPD = 256 L / 22 LPD = 11 days

- **Calculate irrigation run time (S/Q)**

Minutes = S / LPM = 256 L / 8 LPM = 32 minutes

Nine or 10 days between irrigations is acceptable and the 2 m basins would probably fill so 2 m diameter basins is probably the best choice.

In-line drip emitters

The second type of watering system at the DIRT Center is inline drip emitter irrigation (figure 7). This drip irrigation system includes emitters embedded within a drip irrigation tubing lateral. The inline emitters irrigate oleander hedges on the property (figure 8). In-line emitters were selected instead of individual emitters that are placed in the drip tubing near each plant for several reasons.

- There are a large number of emitters (1/ft), and thus the watered area is large.
- Emitters degrade quickly and it is easy to replace one tube rather than many individual emitters.
- The tube can be coiled in areas with increased water requirements in order to concentrate emitters in one location
- In-line emitters have proven to be a reliable watering system in agriculture
- Some irrigation companies are now installing in-line emitters in landscapes.

Figure 7. In-line emitter tubing.

Figure 8. Oleander hedge irrigated with in-line emitters.

In-line emitter flow rates were measured at the DIRT center 1.5 years after installation on December 2, 2002. The results of the measurements are shown in table 3.

The test was conducted for 219 seconds on the upper tube (east oleander hedge) and for 144 seconds on the lower tube (west oleander hedge). Flow rate for each emitter was found by dividing the volume collected by the time. For example flow rate of the first emitter on the upper line was calculated as follows.

Flow rate = 145 ml / 219 seconds = 0.66 ml/sec.

The average flow rate was found by adding all of the flow rates and then dividing by the number of emitters. For example on the upper drip tube, the sum of all of the flow rates was 28.29 ml/sec. There were 32 measurements collected. Thus, the average flow rate was:

28.29 ml/sec / 32 measurements = 0.88 ml/sec = 3.18 LPH.

The average flow rate in the upper tube emitters (0.88 ml/sec, 3.18 LPH) was less than the average flow rate in the lower tube emitters (1.10 ml/sec, 3.96 LPH).

Table 3. Drip irrigation flow rate data.

Upper tube Time - 219 seconds Volume (ml)	Flow rate milliliter/second	Lower tube Time - 144 seconds Volume (ml)	Flow rate milliliter/second
145	0.66	70	0.49
155	0.71	115	0.80
165	0.75	115	0.80
165	0.75	125	0.87
165	0.75	125	0.87
165	0.75	125	0.87
170	0.78	125	0.87
175	0.80	125	0.87
175	0.80	130	0.90
175	0.80	135	0.94
175	0.80	135	0.94
180	0.82	135	0.94
180	0.82	135	0.94
185	0.84	140	0.97
185	0.84	140	0.97
190	0.87	150	1.04
195	0.89	155	1.08
195	0.89	155	1.08
200	0.91	160	1.11
200	0.91	180	1.25
205	0.94	190	1.32
205	0.94	200	1.39
210	0.96	225	1.56
218	1.00	245	1.70
218	1.00	250	1.74
225	1.03	250	1.74
225	1.03	250	1.74
225	1.03	**average**	**1.10**
225	1.03		
225	1.03		
225	1.03		
250	1.14		
average	**0.88**		

A histogram of the data is shown in figure 9.

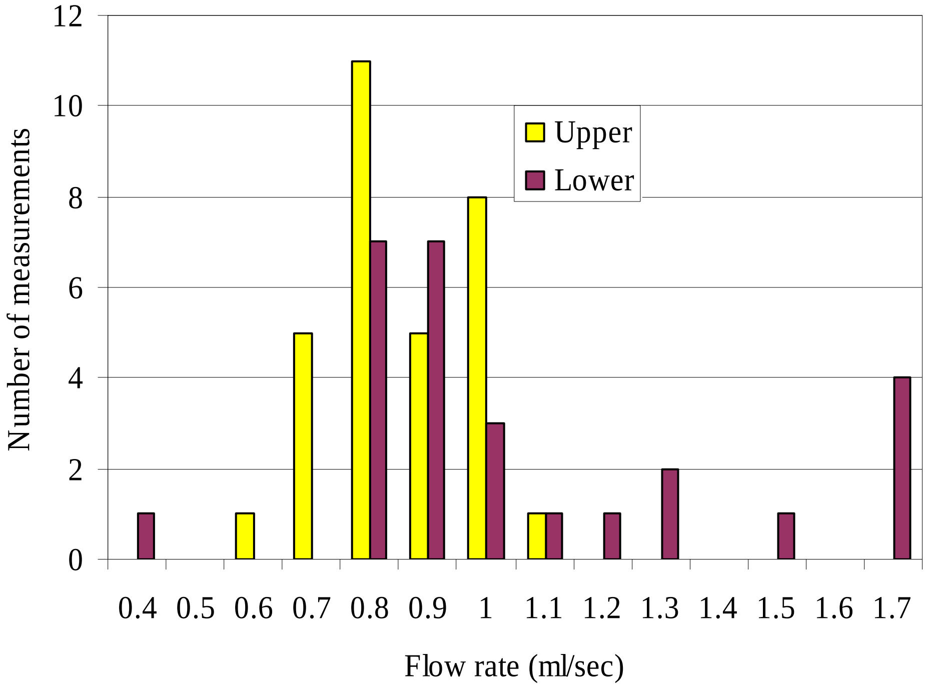

Figure 9. Histogram of flow data for inline emitters.

The coefficient of variation (CV) measures the relative values of the standard deviation and the mean. Drip emitter tubing is often advertised as having a 5 % CV when it comes from the factory. The CV is calculated as follows:

$$CV = (\text{stdev} / \text{mean}) * 100\ \% \qquad (5)$$

CV's for the upper and lower laterals are:

$$CV_{upper} = 0.117 / 0.88 * 100\ \% = 13\ \%$$

$$CV_{lower} = 0.337 / 1.10 * 100\ \% = 31\ \%$$

The statistical uniformity is 1.0 – CV. Thus, the statistical uniformity for the upper tube is 87 % and the statistical uniformity for the lower tube is 69 %.

The distribution uniformity for both tubes is the average of the low quarter of the observations divided by the average of all observations. For the lower tube, the average of all observations is 1.10 ml/sec, and the average of the low quarter of the observations is 0.8 ml/sec (first seven readings out of 28 total readings).

$$DU = 0.8/1.10 * 100\ \% = 72\ \%$$

In-line drip emitter scheduling

Because the wetting patterns from the emitters overlap, the in-line emitter drip system can be considered a line source of water rather than a set of point sources. This makes the irrigation schedule calculation simpler. The watering schedule for the hedge is a function of the hedge geometry and the wetting pattern geometry. Instead of calculating a watering time based on the entire hedge, it is simpler to calculate based on a length of hedge equal to the distance along the tubing between two emitters.

- **Calculate plant water use (LPD/emitter)**
  - **Where LPD = Liters per day used by the hedge for a distance equal to the emitter spacing.**
- **Calculate soil water storage (S / emitter)**
  - **Where S = volume of usable water (liters) in soil in wetted area for each emitter.**
- **Calculate days between irrigation (S/LPD)**
- **Calculate irrigation run time (S/Q)**
  - **Where Q = emitter flow rate (LPH)**

The evapotranspiration rate (LPD) for a length of hedge equal to the distance between 2 emitters is calculated as follows (figure 10).

$$LPD = \left(\frac{ET\ mm}{day}\right)\left(\frac{m}{1{,}000\ mm}\right)(H * L)\left(\frac{1{,}000\ L}{m^3}\right) = ET * H * L \qquad (6)$$

where

LPD	=	evapotranspiration per emitter, liters per day,
L	=	length between emitters, m,
H	=	hedge (plant) width, m,
ET	=	depth of evapotranspiration, mm.

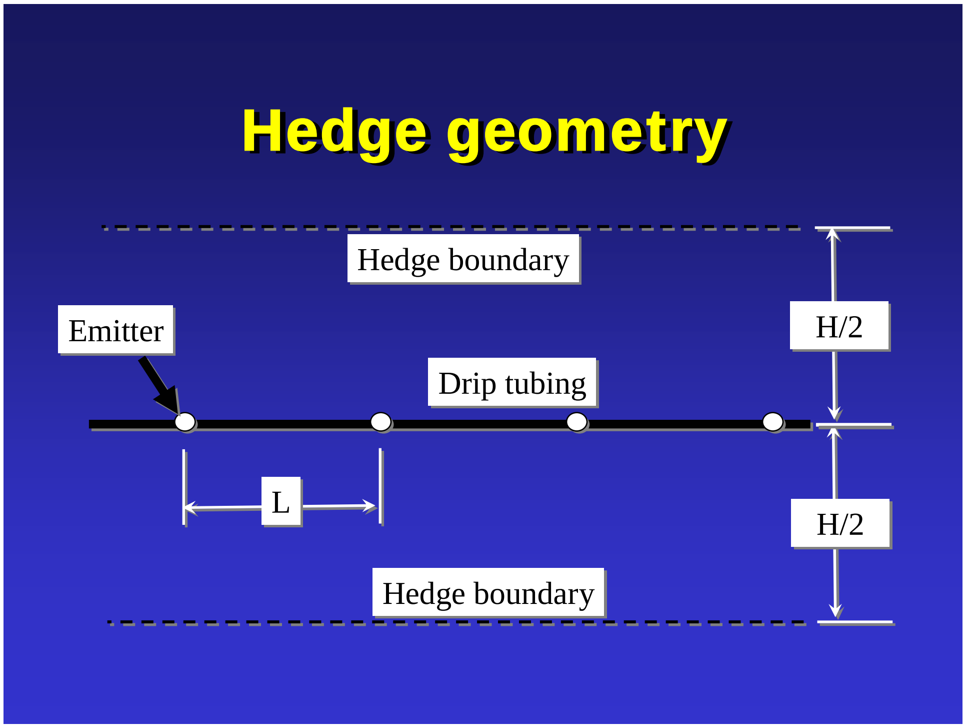

Figure 10. Parameters used to calculate ET for hedge.

The equation to calculate water storage capacity per emitter is similar to equation 6 except that the width of the wetted area is used instead of the width of the hedge (figure 11.

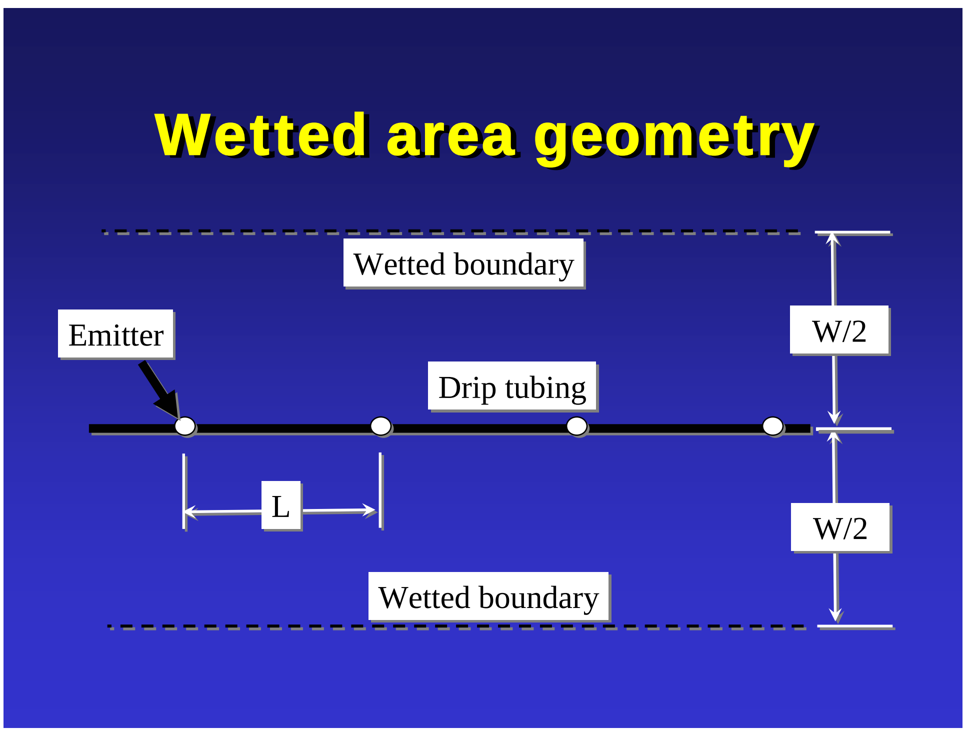

Figure 11. Parameters used to calculate soil water storage.

$$S = L * W * Z * \left(\frac{AWHC\ \%}{100\ \%} \right) * MAD * \left(\frac{1{,}000\ L}{m^3} \right) = 10LWZ * AWHC\ \% * MAD \quad (7)$$

where

W = wetted width

Example 2. Calculate the watering schedule for an oleander hedge during summer in Aqaba. Oleanders are a medium water use plant so assume that ET = 6 mm/day. However, they can survive on very little water so assume that the MAD is 1.0. It is likely that the oleanders at the DIRT center are very deep rooted (based on the length of time between irrigations without plant wilting) so assume that the rooting depth, Z, is 2 m.

The oleander hedge width, H, is 1.5 m.
The distance between emitters, W, is 0.3 m.
Emitter flow rate is 4 LPH.
Wetted width from emitters is 0.8 m

- **Calculate plant water use (LPD/emitter)**

LPD = ET * H * W = 6 mm/day * 1.5 m * 0.3 m = 2.9 LPD / emitter

- **Calculate soil water storage (S / emitter)**

$$S = 10LWZ * AWHC\ \% * MAD = 10 * 0.3 * 0.6 * 2 * 8 * 1 = 28.8\ L$$

- **Calculate days between irrigation (S/LPD)**

Days = S / LPD = 29 / 2.9 = 10 days

- **Calculate irrigation run time (S/Q)**

Hours = S / LPH = 28.8 L / 4 LPH = 7.2 hours.

The schedule above is close to the schedule run at the DIRT center. Plants are watered whenever plants begin to appear wilted: oleanders quickly recover from wilting so no harm is done to the plants with the water when needed approach.