Landscape bubbler irrigation system design

The typical landscape irrigation system has a set of valves that activate different irrigation zones in the landscape. It is best to divide trees and shrubs into different zones (figure 1). Tree water requirements are so much greater than shrub requirements that it is nearly impossible to water them in the same zone. When trees and shrubs are in the same zone, shrubs are often given so much water that root rot occurs. In addition, it is best to divide high water use, medium water use, and low water use plants into different zones. Some plants lose foliage in winter while others continue to use water and require winter irrigation in the desert. If the plants are on the same zone, then it is impossible to meet the variable water requirements of the different plant types.

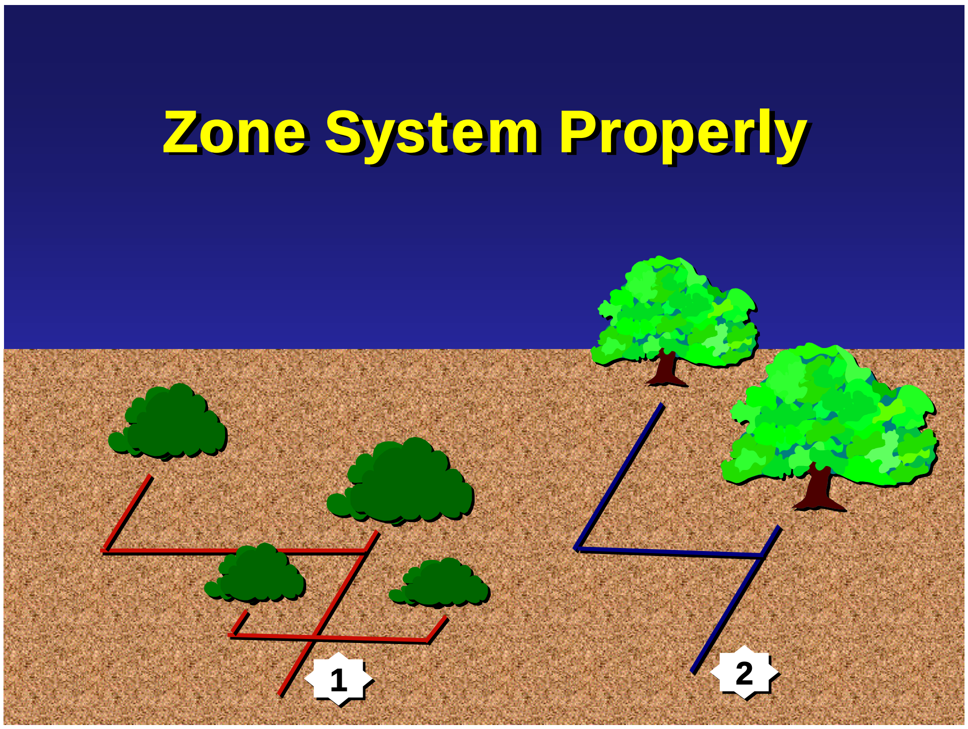

Figure 1. Irrigate trees and shrubs in different zones.

Within each zone, it is likely that each drip emitter or bubbler will water a different size plant because of variable plant growth rates. Thus, it is necessary to increase drip emitter or bubbler flow rate for larger plants and vice versa for smaller plants. Some drip emitters have adjustable flow rates but most do not, and it is necessary to increase the number of drip emitters under larger plants (figure 2).

Bubbler flow rate is adjusted by turning the screw on the adjustable bubbler (figure 18-5). Each type of bubbler has a unique screw mechanism so the relationship between number of screw turns (table 1), flow rate and pressure is unique for each bubbler. The relationship between flow rate and normalized number of screw turns (figure 3) was measured by Yuan (2002): in order to show the difference between flow characteristics of the different bubblers, the number of 360 degree screw or cap turns was normalized to a 0-1 range.

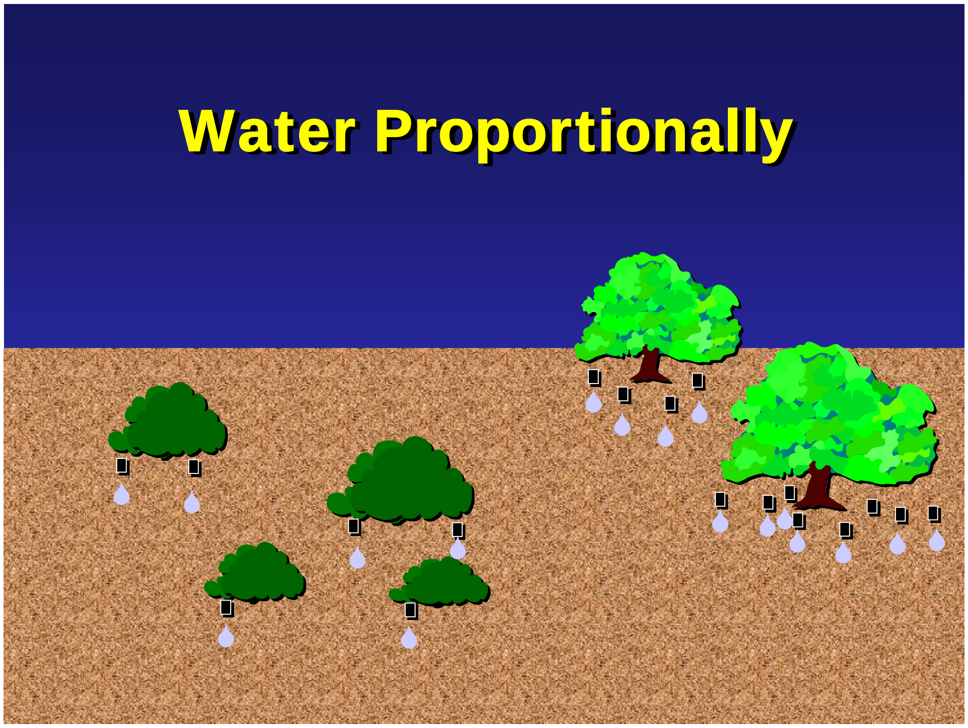

Figure 2. Increase the number of drip emitters under larger plants within the zone.

Table 1. Maximum number of 360 degree screw or cap turns.

Brand	Rainbird	Toro	Hunter	Irritrol	Lego
Minimum # turns	3	2	0	0	0
Maximum # turns	5.5	7	1.25	0.44	0.25

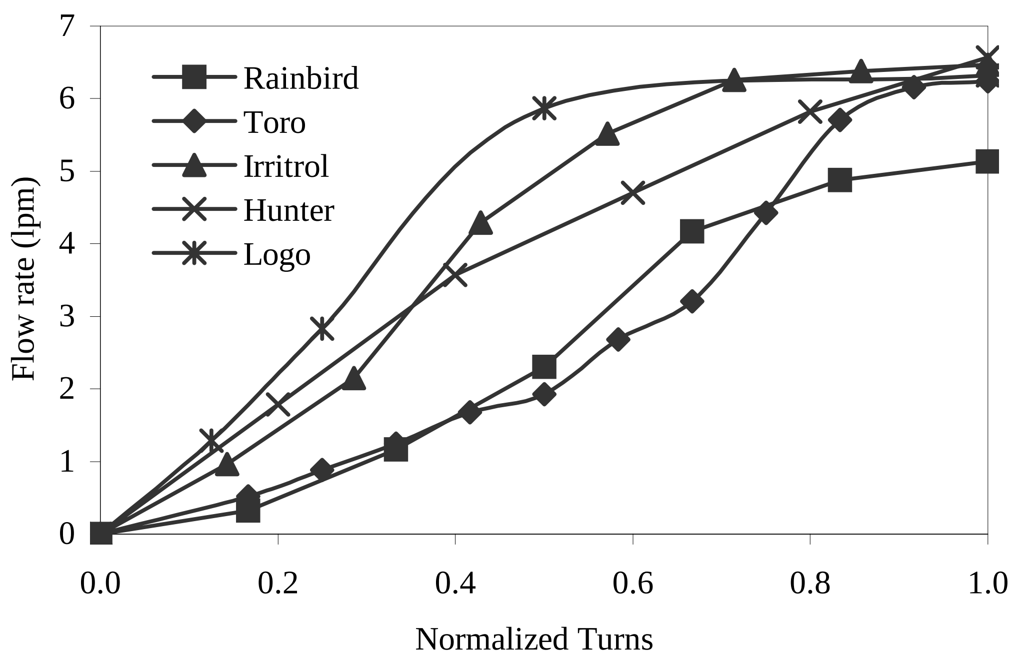

Figure 3. Flow rate vs. number of screw turns (normalized) for 5 bubblers at 140 kPa.

During the design or management of an irrigation system, the desired flow rate is attained by adjusting the bubbler with the correct number of screw turns. The correct number of screw turns can be calculated by knowing the relationship between number of bubbler screw turns, flow rate, and pressure. In order to develop this relationship, an experiment was conducted in order to develop equations for bubbler flow rate as a function of number of screw turns and pressure. The equations were based on the KH^x equation where x is a dimensionless exponent.

$$q = kH^x \tag{1}$$

where

q	=	bubbler flow rate, lpm,
k	=	coefficient, dimensionless,
H	=	pressure, kPa,
x	=	exponent, dimensionless.

In the experiment, flows were measured at a specified number of screw turns at two different pressures. An x-value could be found based on the two flows and two pressures as follows.

$$x = \frac{\log(Q_{140}) - \log(Q_{210})}{\log(140) - \log(210)} \tag{2}$$

where

Q_{140}	=	flow rate at 140 kPa, LPM,
Q_{210}	=	flow rate at 210 kPa, LPM,

$$k = \frac{Q_{140}}{140^x} \tag{3}$$

Yuan (2002) attempted to use the raw data to develop equations for k and x vs. number of turns; however, the k and x curves were too unstable to develop k and x equations. Thus, raw flow data was smoothed by regression. Regression equations for flow rate vs. number of screw turns were calculated for each of the bubblers (table 2). The regression curves for the Rainbird and Hunter bubblers as well as the measured flow data are shown in figures 4 and 5.

Table 2. Polynomial equations for flow rate vs. number of screw turns at 140- and 210-kPa.

Brand	Equation for flow rate vs. number of screw turns	R^2
Rainbird (140 kPa)	LPM = -0.3392 * turns^2 + 4.9568 * turns - 11.796	0.971
Rainbird (210 kPa)	LPM = -0.2508 * turns^2 + 4.5747 * turns - 11.155	0.980
Toro (140 kPa)	LPM = 0.2745 * turns^2 - 0.9858 * turns + 1.5684	0.996
Toro (210 kPa)	LPM = 0.2256 * turns^2 - 0.4127 * turns + 0.6349	0.990
Hunter (140 kPa)	LPM = -2.3846 * turns^2 + 8.3037 * turns - 0.0983	0.998
Hunter (210 kPa)	LPM = -4.9412 * turns^2 + 13.001 * turns - 0.8787	0.999
Irritrol (140 kPa)	LPM = -33.017 * turns^2 + 34.723 * turns - 1.2559	0.986
Irritrol (210 kPa)	LPM = -76.49 * turns^2 + 50.336 * turns - 1.1917	0.971
Lego (140 kPa)	LPM = -69.979 * turns^2 + 50.903 * turns - 1.8282	0.953
Lego (210 kPa)	LPM = -109.14 * turns^2 + 67.972 * turns - 2.6332	0.977

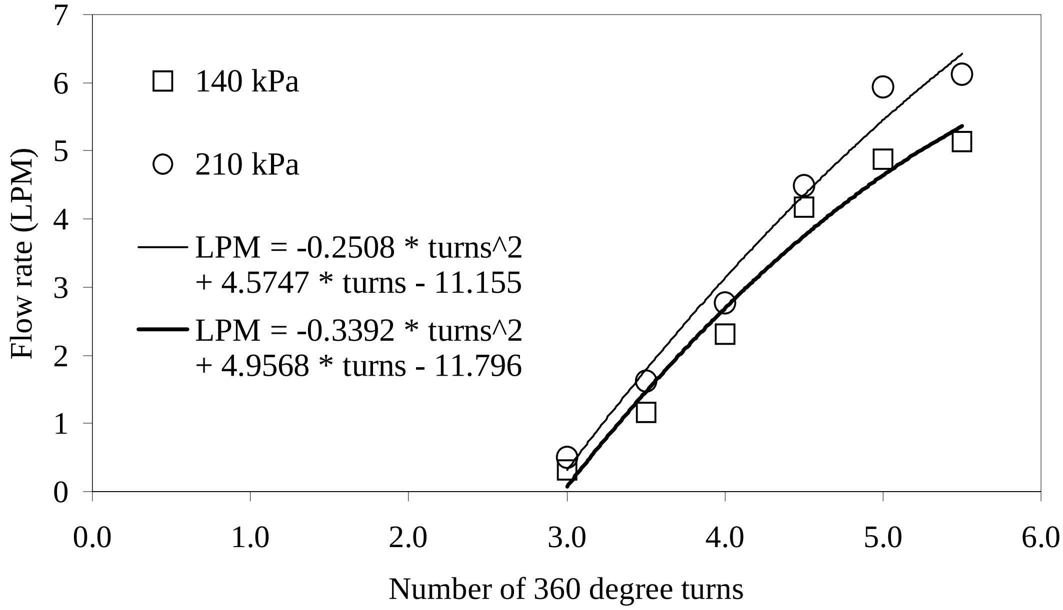

Figure 4. Rainbird bubbler flow rate vs. number of screw turns.

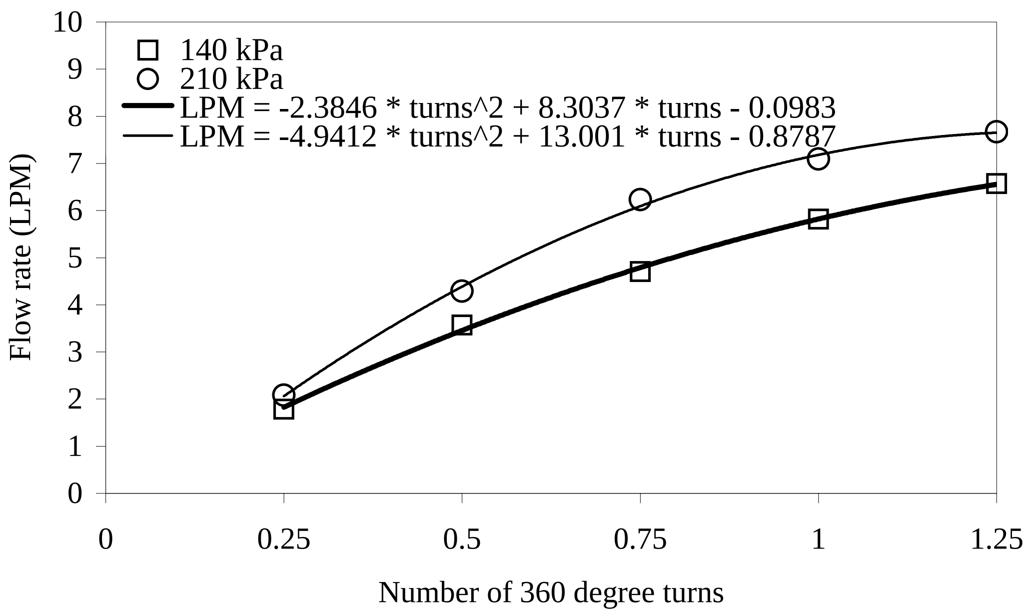

Figure 5. Hunter bubbler flow rate vs. number of screw turns.

The best fit was not always achieved with second order equations; however, additional complexity resulting from higher order polynomials resulted in overly complex k and x curves. Thus, second order polynomials were always chosen in this phase of the analysis. The extreme ends of the curves were often dropped before regression if they resulted in a poor fit, if flows at the high end were very close to the flow rate at the previous screw position, or if flows at the low end were very close to zero. It is important to remember that the goal of this project was not to derive the most accurate equation to match the flow curve, but to develop relatively simple flow equations that can be used in a spreadsheet by irrigation system designers and landscapers.

The next step was to calculate k and x at each screw turn position based on the fitted equations for bubbler flow rate vs. the number of screw turns. Once k and x were calculated for each screw turn position, regression was used to derive equations for k or x vs. the number of screw turns (figures 6 and 7). When curves were too complex to model with one equation, the curve was broken into 2 sections and an equation was derived for each section. The average % difference between calculated flows with k and x and raw flow data at 140 kPa is in table 3.

Table 3. Average difference between measured flow rates and calculated flow rates (LPM).

Brand	k and x based on raw flow data.	Equations for k and x based on smoothed flow data
Rainbird	0.30	0.52
Toro	0.13	0.29
Hunter	0.051	0.098
Irritrol	0.21	1.12
Lego	0.41	0.41

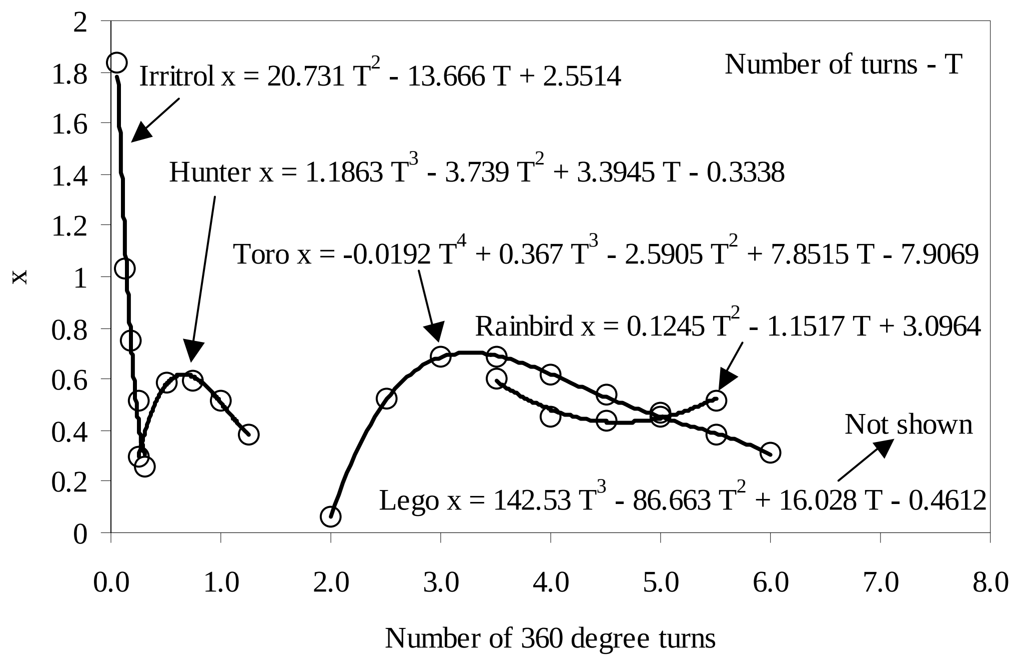

Figure 6. Bubbler flow equation exponent x vs. number of turns for five bubblers.

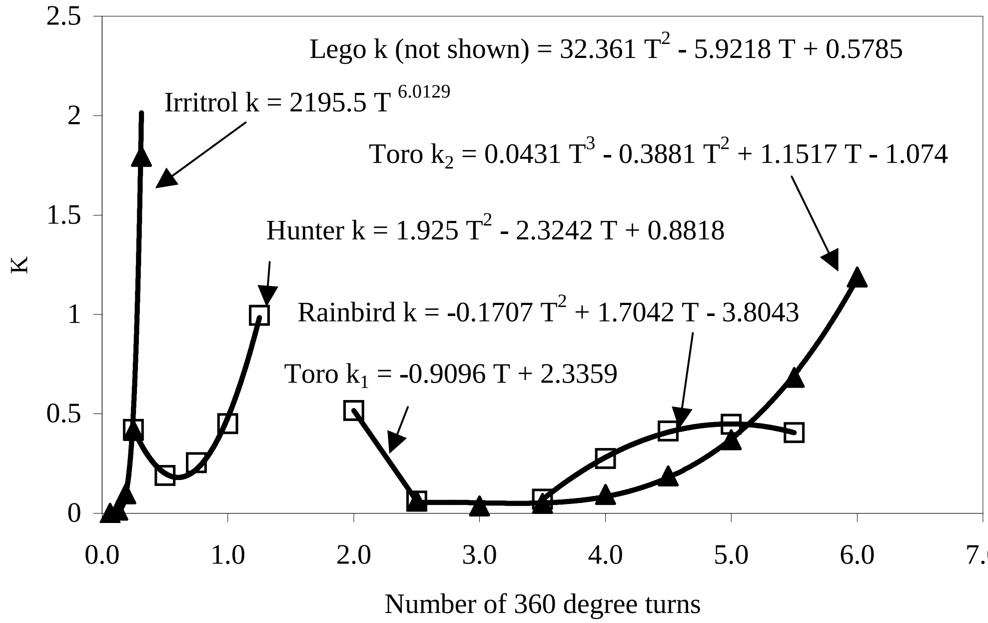

Figure 7. Bubbler flow equation coefficient k vs. number of turns.

Two examples (Hunter and Irritrol) of calculated and measured flows are shown in figures 8 and 9.

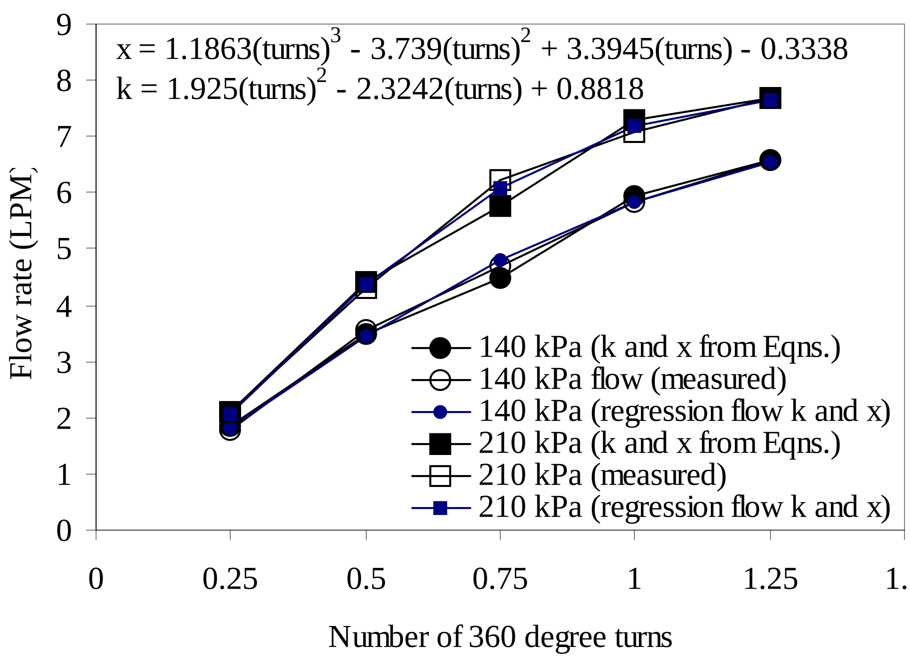

Figure 8. Hunter bubbler flow rate vs. number of screw turns at 140- and 210-kPa for measured values and calculated values.

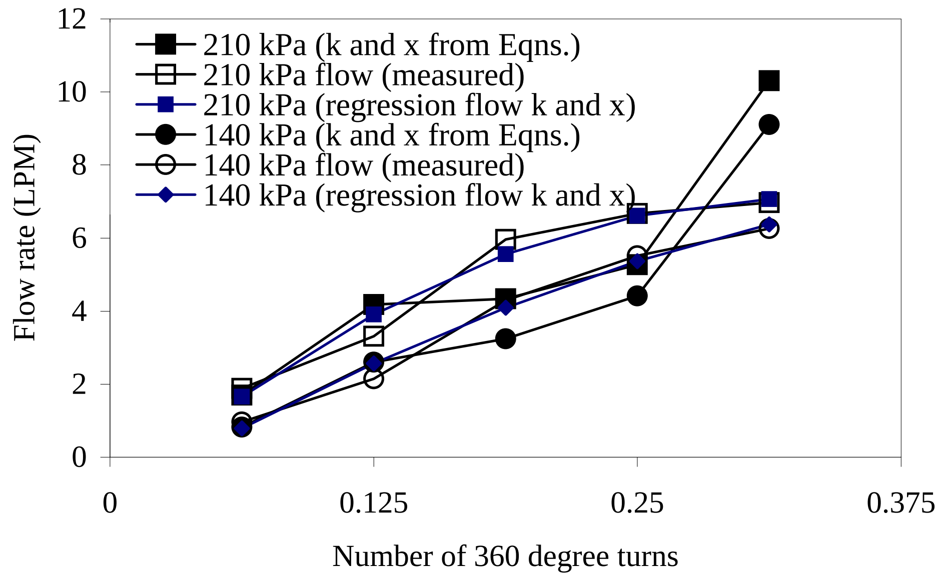

Figure 9. Irritrol bubbler flow rate vs. number of screw turns at 140- and 210-kPa for measured values and calculated values.

For the fully open position, bubblers were evaluated for uniformity at the fully open position at 210 kPa. A summary of statistics is shown in table 4.

Table 4. Summary statistics for bubbler evaluation at 210 kPa pressure.

	Rainbird	Toro	Hunter	Irritrol	Lego
Mean (LPM)	6.90	6.70	7.43	6.73	7.45
Standard Deviation	0.803	0.668	0.684	0.549	1.55
Minimum (LPM)	5.6	5.6	6.2	5.8	5.0
Maximum (LPM)	8.7	8.1	8.6	8.1	10.2
CV	12%	10%	9%	8%	21%
Uniformity	88%	90%	91%	92%	79%

The coefficients of variation for the five bubblers ranged from 8 % to 21 %, and the corresponding uniformity ranged from 79.2% to 91.8%. The coefficients of variation were worse than the coefficients of variation for high quality drip emitters - in the range of 3 %.

Because of nonuniformity of bubbler manufacturing, it is best to check flow rates with a simple volumetric flow test: insert the bubbler into a container and divide the container volume by the filling time to find flow rate.

Design of bubbler irrigation zone.

Design of a bubbler irrigation zone requires 10 steps:

1. Calculate each plant's daily irrigation requirement (LPD).
2. Calculate each plant's soil water holding capacity (S).
3. Find the plant with the highest daily irrigation requirement in the irrigation zone
4. Calculate the water requirements of all other plants in the zone as a percentage of the water requirement of the largest tree in the zone.
5. Calculate the maximum flow possible from the bubbler brand that is used, and assign this flow rate to the plant with the highest water requirement. Calculate the flow to all other plants as the product of the (percent of the maximum water requirment) * (maximum bubbler flow rate).
6. Design the pipe system to connect the bubblers to the irrigation valve.
7. Calculate the number of screw turns or cap turns for each bubbler based on bubbler flow rate and irrigation pipeline pressure.
8. If basin volume is less than SWHC, then S = basin volume
9. Calculate the days between irrigations as S/LPD for the largest plant.
10. Calculate the watering time as S / LPM for the largest plant (maximum flow rate).

Example 1. Design a bubbler irrigation system for the 4 orange trees in figure 10. Use Hunter bubblers. The pressure on the discharge side of the valve is 288 kPa. Design for Tucson in the summer. Assume that orange tree rooting depth is 1.5 m. Let MAD = 0.5. Soil is sandy loam. Depth of 2 m basins is 7 cm. Assume that there is no slope on the property.

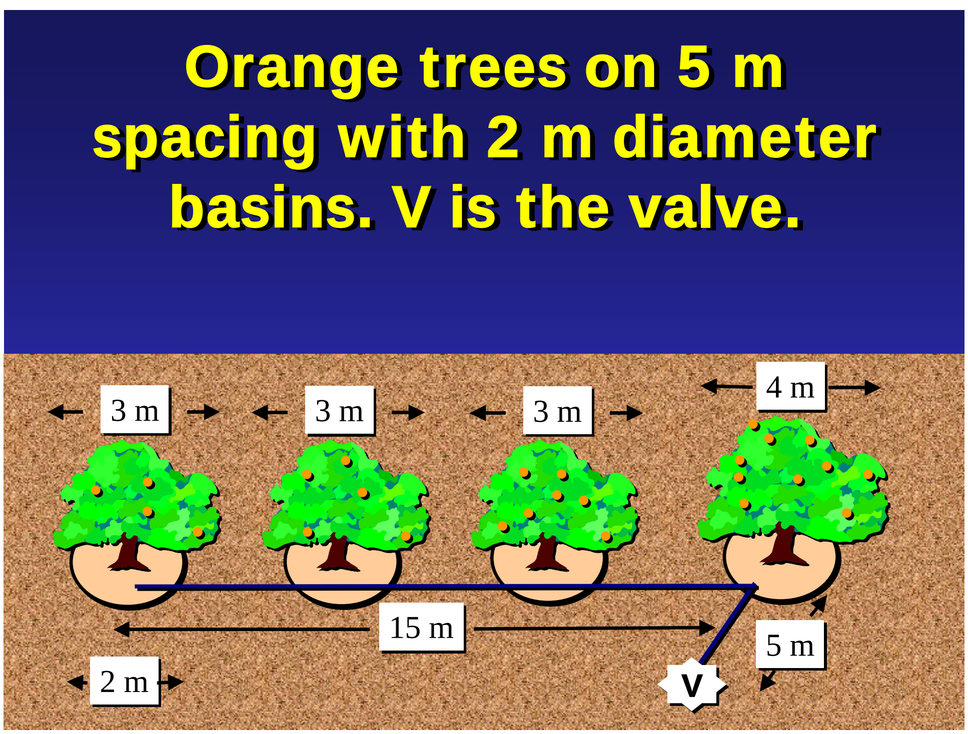

Figure 10. Layout for example 1.

Calculate each plant's daily irrigation requirement (LPD).

Bubbler 1: LPD = 4 * 4 * 10 = 160 LPD
Bubblers 2-4: LPD = 3 * 3 * 10 = 90 LPD

Calculate each plant's soil water holding capacity (S).

All bubblers have 2 m basins.

$S = 8 * D_b^2 * Z * MAD * AWHC\ \% = 8 * 2^2 * 1.5 * 0.5 * 12 = 288$ L

Find the plant with the highest daily irrigation requirement in the irrigation zone

Bubbler # 1 requires 160 LPD

Calculate the water requirements of all other plants in the zone as a percentage of the water requirement of the largest tree in the zone.

Bubblers 2-4 require 90/160 * 100 % = 56 %

Calculate the maximum flow possible from the bubbler brand that is used, and assign this flow rate to the plant with the highest water requirement. Calculate the flow to all other plants as the product of the (percent of the maximum water requirment) * (maximum bubbler flow rate).

Calculate maximum flow at system operating pressure of 280 kPa for Hunter bubblers.

Maximum number of turns for Hunter bubblers is 1.25 turns

From figure 6

$x = 1.1863(T)^3 - 3.739(T)^2 + 3.3945(T) - 0.3338$

$x_{max} = 1.1863(1.25)^3 - 3.739(1.25)^2 + 3.3945(1.25) - 0.3338 = 0.384$

From figure 7

$k = 1.925(T)^2 - 2.3242(T) + 0.8818$

$k_{max} = 1.925(1.25)^2 - 2.3242(1.25) + 0.8818 = 0.984$

Calculate maximum flow

$Q = kH^x = 0.984 * 280^{0.384} = 8.67$ LPM

Calculate flow rate for bubbler 2-4.

Q = 0.56 * 8.67 LPM = 4.85 LPM

Design the pipe system to connect the bubblers to the irrigation valve.

The pipe system includes 4 lengths of 5 m pipe.

The first pipe carries the entire flow = 8.67 + 4.85 * 3 = 23.2 LPM = 0.39 LPS

The second pipe carries the flow for bubblers 2-4 = 4.85 * 3 = 14.55 LPM = 0.24 LPS

The third pipe carries the flow for bubblers 3 and 4 = 9.7 LPM = 0.16 LPS

The last pipe carries 4.85 LPM = 0.081 LPS

Use one inch (25 mm) diameter pipe for the entire system. Calculate pressure loss in each pipe with the Hazen-Williams equation.

$$H_{L1} = 1.22 * 10^{10} * 5\ m \left(\frac{\left(\frac{0.39}{140}\right)^{1.852}}{25^{4.87}} \right) = 0.17\ m$$

$$H_{L2} = 1.22 * 10^{10} * 5\ m \left(\frac{\left(\frac{0.24}{140}\right)^{1.852}}{25^{4.87}} \right) = 0.07\ m$$

$$H_{L3} = 1.22 * 10^{10} * 5\ m \left(\frac{\left(\frac{0.16}{140}\right)^{1.852}}{25^{4.87}} \right) = 0.03\ m$$

$$H_{L4} = 1.22 * 10^{10} * 5\ m \left(\frac{\left(\frac{0.081}{140}\right)^{1.852}}{25^{4.87}} \right) = 0.01\ m$$

Calculate pressures in the pipeline. First calculate pressure loss in each section in kPa.

Pipe 1 → 0.17 m * 9.86 kPa / m = 1.7 kPa pressure loss
Pipe 2 → 0.07 m * 9.86 kPa / m = 0.7 kPa pressure loss
Pipe 3 → 0.03 m * 9.86 kPa / m = 0.3 kPa pressure loss
Pipe 4 → 0.01 m * 9.86 kPa / m = 0.1 kPa pressure loss

Find pressures at each bubbler

Discharge side of valve	= 288 kPa
Bubbler 1	= 288 – 1.7 = 286.3 kPa
Bubbler 2	= 286.3 – 0.7 = 285.6 kPa
Bubbler 3	= 285.6 – 0.3 = 285.3 kPa
Bubbler 4	= 285.3 – 0.1 = 285.2 kPa

Calculate the number of screw turns or cap turns for each bubbler based on bubbler flow rate and irrigation pipeline pressure.

As a reasonable approximation, calculate all bubbler flow rates at 286 kPa.

Bubbler 1 flow rate = $Q = kH^x = 0.984 * 286^{0.384} = 8.64$ LPM

Bubblers 2-4 flow rate = 8.64 * 0.56 = 4.84 LPM

Find the number of turns in bubblers 2-4 by solving the following equation ($Q = kH^x$) for T by iteration

$q = (1.925\,T^2 - 2.3242\,T + 0.8818)H\text{^}(1.1863\,T^3 - 3.739\,T^2 + 3.3945\,T - 0.3338)$

If T = 0.44 turns, then q = 4.84 LPM.

Adjust bubblers 2-4 to 0.44 turns.

If basin volume is less than SWHC, then S = basin volume

Basin volume = $S = \pi * D_b^2 / 4 * \text{depth} * 1{,}000\ L/m^3 = 3.14 * 2^2 * 0.07\ m * 1{,}000 = 879$ L

SWHC = 288 L so SWHC is limiting

S = 288 L

Calculate the days between irrigations as S/LPD for the largest plant.

Days = S/LPD = 288 / 160 = 1.8 days

This is not a very long time between irrigations. One could possibly put on 10 % extra water and hope that the plant root zone would be great enough to use the water. Then, irrigation could take place every two days. The other option is to increase the size of the basin so that the soil can store more water.

Calculate the watering time as S / LPM for the largest plant (maximum flow rate).

Minutes = S / LPM = 288 / 8.64 LPM = 33 minutes

Possibly increase the time to 36 minutes in order to go 2 days between irrigations.

Because the smaller trees were irrigated at a fraction of the rate for the large tree, all trees are provided the correct amount of water and can be on the same watering schedule.

In summary, there are many sources of potential error in calculating water application rates to landscape plants and plant water requirements, and there can be a high manufacturers variability in bubbler flow rates. It is best to measure and adjust bubbler flow rates as the irrigation system is running. It is also wise to adjust the system based on observations of plant response to watering over time.

References

Yuan, Zhixu. 2002. Flow variation in irrigation system components. Ph. D. dissertation. Agricultural and Biosystems Engineering. University of Arizona.