DRIP HYDRAULICS PROGRAM

by

Garret Blocher

BioResource and Agricultural Engineering

BioResource and Agricultural Engineering Department

California Polytechnic State University

San Luis Obispo

2014

TITLE : Drip Hydraulics Program

AUTHOR : Garret Blocher

DATE SUBMITTED : April 1, 2015

Daniel J. Howes ____________________
Senior Project Advisor

____
Signature

____
Date

C. Arthur MacCarley ____________________
Department Head

____
Signature

____
Date

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my senior project advisor, Dr. Howes, for all of his help and understanding throughout this process. He has been my mentor during the most arduous years of my life pushing me to achieve great things in the field of water.

Secondly, I would like to thank Dr. Burt to whom I owe thanks for paving the way down this long path on which I have embarked.

ABSTRACT

This senior project report lays out the production of drip hydraulics software composed in Microsoft Excel and backed by coding in Visual Basic for Applications. The program performs 2 main functions useful in the design of irrigation systems. The first is based on performing single hose computations under three different circumstances. It can solve for the average emitter flow rate given the hose inlet pressure, the inlet pressure given the average emitter flow rate, and can model hose pressures and flow rates while flushing. The second function is to place a manifold in the hydraulically optimum location on a slope. One advantage of this software over its former DOS version is the designer has access to all of the data used in the calculations including the entire Bernoulli tables that model flows and pressures at every emitter in the field. As this could also be a point of weakness, great effort was put into making the software simple to follow and displaying pertinent information in intuitive locations.

Throughout the creation of this program, results were compared against the original to ensure it yielded similar answers. However, since the two use drastically different ways to narrow in on a solution, it is impossible to match results exactly. Regardless, various trial inputs and results were recorded using both platforms. These can be seen in Appendix C. All things considered, this project still came within 1% of the results of the original on 84% of the computations and within 10% on 97% of the computations.

DISCLAIMER STATEMENT

The university makes it clear that the information forwarded herewith is a project resulting from a class assignment and has been graded and accepted only as a fulfillment of a course requirement. Acceptance by the university does not imply technical accuracy or reliability. Any use of the information in this report is made by the user(s) at his/her own risk, which may include catastrophic failure of the device or infringement of patent or copyright laws.

Therefore, the recipient and/or user of the information contained in this report agrees to indemnify, defend and save harmless the State its officers, agents and employees from any and all claims and losses accruing or resulting to any person, firm, or corporation who may be injured or damaged as a result of the use of this report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

INTRODUCTION

An efficient irrigation system has many important factors to consider that all apply to maintaining a high distribution uniformity (DU). This idea involves ensuring that all the plants in the field receive similar volumes of water over a given period thus decreasing the amount of discrepancy between the water received by two different areas in the field. With a large gap between the highest and lowest amounts of water distributed, the irrigator has to make a decision on how much water to apply such that the plants in the areas getting little water are still satisfied with over-application and deep percolation in other areas in the field. So, how does this affect you?

Everyone depends on food. With California experiencing a drought, it is vital to conserve water at every corner especially in an industry that consumes a large portion of our water resources — agriculture. People worldwide rely on engineers to make sound design decisions that make possible use of water on crops that result in the highest yield in the field. However, designing the best irrigation system possible relies on several iterations and monotonous computations that engineers just do not have time to do in this fast-paced time in agriculture. Coupled with human input comes human error and without the use of software to aid in these computations, mistakes can be made.

This is where software can assist. Software essentially takes inputs from the user and runs all the necessary calculations behind the scenes to generate outputs. If designed correctly, this can significantly reduce the workload of the users giving them the power to finish multiple projects in the time that was formerly taken to complete just one.

The objective of this project is to create software that will help make irrigation system design decisions with respect to where to place the manifold as well as output desired values based on user input. The project will rely heavily on Microsoft Visual Basic coded into a user-friendly Excel spreadsheet. It will utilize several theoretical calculations regarding friction characteristics as well as rules developed by Dr. Charles Burt, chairman of the Irrigation Training and Research Center at Cal Poly, San Luis Obispo. This software update from DOS to a more recent language is essential due to the limitations associated with the former. The current platform allows the user to change only one variable at a time as well as limits the user to very slow navigation. Most students that come into the department struggle to download and run the necessary applications to use the archaic language while some don’t even know what DOS is. With the proposed software, these issues will no longer be an issue. The Microsoft-based software will give the user the ability to easily navigate through several different design computations while allowing them to use a more up-to-date platform.

LITERATURE REVIEW

Distribution Uniformity

Distribution uniformity (DU) is a value used as a performance index for a singular field (Burt and Styles 2011). Distribution uniformity (DU) has many components that contribute to the overall non-uniformity of a system which include: pressure differences, uneven spacing, unequal drainage, or "other" which takes into account unavoidable irrigation system issues such as clogging or wear (Burt 2004). But before DU is expanded upon, the idea of "low quarter" must first be explained. The low quarter depth, d_{lq}, is equal to the volume accumulated in ¼ total area of elements with the smallest depth divided by ¼ of the total area of elements. This simply means the average depths accumulated in the area of the field that receives the least amount of water (Burt et al. 1997). This value plays a vital role in the computation of DU_{lq} as shown in equation 2 with which a grower or designer can use to gain an understanding of how well the irrigation system is distributing the water. But, before this term can be expressed, one must understand the d_{lq}. This is defined as the average depths of water that is accumulated over the quarter of the field receiving the smallest depths and is expressed in equation 1.

$$d_{lq} = \frac{vol.accum.in\frac{1}{4}\ total\ area\ of\ elements\ with\ smallest\ depths}{\frac{1}{4}\ of\ the\ total\ area\ of\ elements} \qquad (1)$$

$$DU_{lq} = \frac{d_{lq}}{d_{avg}} \qquad (2)$$

where: d_{avg} = Average depth applied

Even though this value is an indicator of the uniformity of distributed water, it does not signify whether the water applied is being beneficially used. This is a term referred to as irrigation efficiency (Burt et al. 1997). A field can have a high distribution uniformity while over-applying water such that it is lost to deep percolation which results in a poor irrigation efficiency.

The best way to ensure that an irrigation system is designed with the highest DU possible is to consider all aspects of the transportation of the water from the water source to the crop with the most important factor being friction loss between the these points. Table 1 shows various issues resulting in a lowered DU as well as what causes them. For sprinkler systems, these uniformity components include flow rate differences between sprinklers, catch can non-uniformity, unequal application while system is starting up and shutting down, and effects crops on the field edge experience. Drip and microspray systems experience similar uniformity issues including differences in discharge been

emitters, variations in emitters due to manufacturing, plugging, and non-proportional volume application to a given plant area (Burt et al. 1997). One of the largest contributors to these issues are variations in pressure along laterals and manifolds which result in discrepancies in emitter out flow and lateral inflows, respectively. This occurs because as water travels down either of these system components, a portion of it exits along the length. This causes differing flow rates in the sections of pipe between points of exit and, as consequence, differing head loses in these sections. How this is accounted for when designing an irrigation system is through the use of a “Bernoulli Table” on a spreadsheet whose purpose is to model the various pressure differences along either a lateral or manifold while taking all the aforementioned variables into account. An example of this can be seen in Appendix B. The proposed software will utilize this technique to acquire the distribution uniformity along individual laterals (DU_{hose}) and DU for manifolds.

Table 1. Examples of components that affect uniformity (Burt et al. 1997)

Uniformity component	Factors causing nonuniformlty
(a) Components and factors of DU for hand-move sprinkler irrigation systems	
Flow rate differences between sprinklers	Pressure differences
	Different nozzle sizes
	Nozzle wear
	Nozzle plugging
Sprinkler pattern nonuniformity	Spacing
	Sprinkler design
	Nozzle size and pressure
	Wind
	Vertical orientation
	Plant interference around sprinkler
Unequal application during start-up and shutdown	Pipe diameter and length
	Duration of set
Edge effects	Inadequate overlap on field edges
(b) Components and factors of DU for drip/microirrigation systems	
Differences in discharge between emitters	Pressure differences
	Plugging of emitters
	Manufacturing variation
	Soil differences, if the emitters are buried
	Different emitter types in the same field
	Temperature differences along a lateral
Volumes applied not proportional to plant area (assuming same plant age)	Variations in plant spacing are not matched by emitter spacing or scheduling

Friction Loss

As water travels through a pipe, it loses energy due to friction. This results in a lowering pressure along the length of the pipe or hose. This is a key element to the design of an irrigation system in regards to hose lengths, manifold placement, and overall layout of a system. Several equations have been generated to estimate losses due to friction, however, the Darcy-Weisbach equation has shown to be the most accurate and reliable (von Bernuth 1990). This equation is shown below:

$$H_f = f\left(\frac{LV^2}{2Dg}\right) \qquad (3)$$

where:
- V = Water velocity (ft/sec)
- L = Pipe length (ft)
- D = Inside diameter (ft)
- g = Acceleration due to gravity (ft/sec^2)
- f = A friction factor dependent on Reynolds Number (Re)

In order to find the correct friction factor (f) for the Darcy-Weisbach equation knowing the relative roughness and Reynolds Number, one must refer to the Moody Diagram which can be seen in figure 1. If the flow of water is considered laminar, that is, having a uniform velocity profile and an $R_e < 2{,}000$, then one would use equation 4. Or, more commonly for this application, if one is determining the friction factor for a small diameter pipe, this factor varies according to equation 5 which is also known as the Blasius equation (Provenzano and Pumo 2004; Demir 2007).

$$f = 64{R_e}^{-1} \qquad (R_e < 2{,}000) \qquad (4)$$

$$f = 0.302\,{R_e}^{-0.25} \qquad (2{,}000 \leq R_e \leq 100{,}000) \qquad (5)$$

Even though the Blasius equation is quite often used in hand calculations, the most common for computer applications is the Fanning equation, shown as equation 6, because of its wider range of allowable Reynolds numbers (Burt and Styles 2011).

$$f = 0.0056 + 0.5\,{R_e}^{-0.32} \qquad (2{,}000 \leq R_e \leq 1{,}000{,}000) \qquad (6)$$

The Reynolds Number (R_e) is a dimensionless value defined as:

$$R_e = \frac{VD}{v} \qquad (7)$$

where:
- V = Water velocity (ft/sec)
- D = Inside diameter (ft)
- v = Kinematic viscosity of water (ft^2/sec)

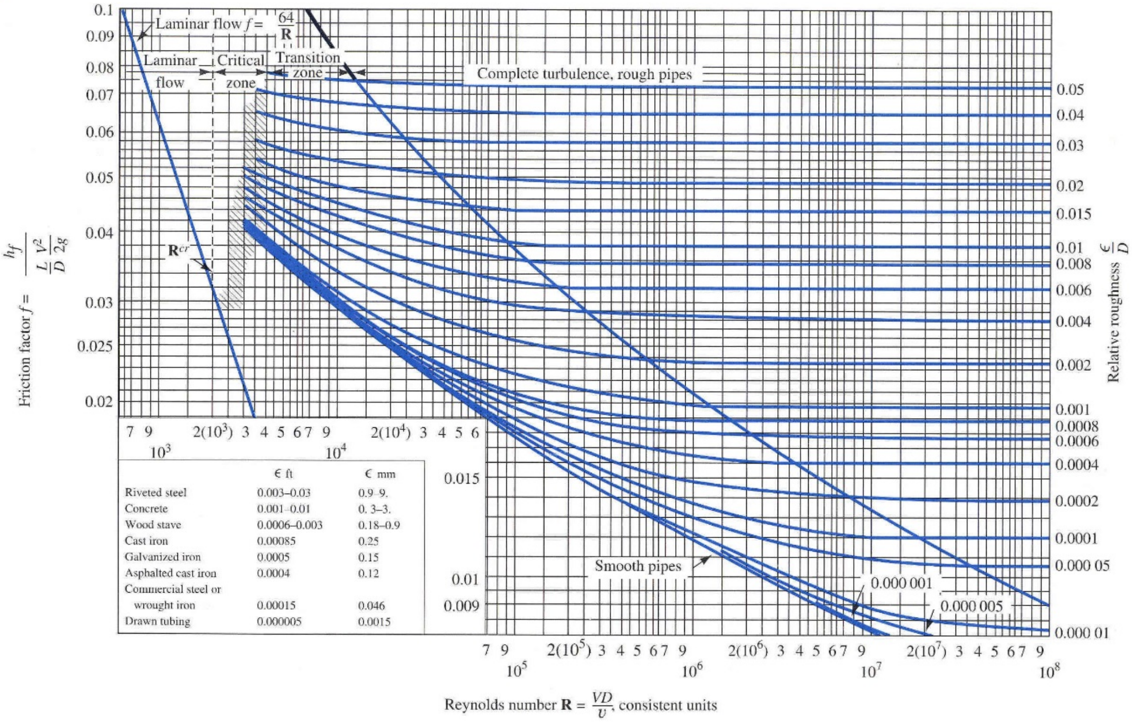

Figure 1. Moody Diagram. This relates the Darcy-Weisbach friction factor (f), Reynolds number (Re) and relative roughness for flow in a circular pipe (Burt and Styles 2011).

Design of a Lateral

A lateral is the smallest diameter pipe in the field onto which emitters (sprinklers, microsprayer, inline/online emitters, etc.) are attached (Phocaides 2007). To design an irrigation system properly, one must assess the total head loss throughout the lateral including friction loss along the pipe, local losses from emitters, and minor losses due to fittings and connectors (Provenzano 2005). In a drip hose/tape system, the lateral is usually composed of a polyethylene and is extruded in various thicknesses depending on the application. In a sprinkler irrigation system, there are also two commonly used options. One consists of 30 foot lateral sections of aluminum or PVC pipe that can be moved by hand. In the second, a solid set system, laterals are buried PVC pipe with sprinkler risers spaced at a predetermined interval. Since both drip and sprinkler systems are still commonly used, the program to be created will be able to handle input for both scenarios.

Emitter Types. Sprinklers are a very common irrigation device in almost all crop types. They are designed with either a fixed or rotating head and utilize a small orifice through which water is discharged.

Drip tape, the thinner of the two polyethylene pipe options, utilizes emitters that are integrated in the tape and use a turbulent path to increase velocity past the emitter such that any suspended solids in the water are carried through the path and beyond the emitter hole. While reducing clogs, this induces a local loss at the emitter that, by itself, is

negligible. However, this loss has gained interest in the development of drip hydraulic modeling software over the last few years. It has been shown to have a considerable contribution to the overall head loss when there are a large number of these instances along the length of a lateral which, in most cases, there are (Gyasi-Agyei 2013). These drip tape emitters come in two forms. The first is a welded-on emitter that can be inserted into the hose as the polyethylene is extruded. The tape then acts as the outer shell of the emitter and has holes along its length for flow discharge. Other tape emitters are part of the tape which has paths spanning the entire run to keep the flow turbulent and solids suspended. They are constructed with overlapping layers of polyethylene (Burt and Styles 2011).

Drip hose, a more stout alternative to drip tape, tends to support microsprayers and on-line drip emitters. Both of these emitters use a barb to stay attached to the drip hose, however, this barb obstructs the flow path resulting in a local head loss as well. A characteristic of on-line emitters is susceptibility to plugging. Unless the emitter has an exceptional tortuous path, multiple flexible orifices, or a rather large orifice, this type of emitter is sensitive to plugging (Burt and Styles 2011).

Discharge. Emitter discharge flow rate is proportional to the point pressure at the orifice with respect to the emitter exponent and an empirically derived emitter constant. This is characterized by equation 8 below (Burt and Styles 2011).

$$Q = k\,P^{x} \tag{8}$$

where: Q = Emitter discharge (GPH)
k = Nozzle discharge coefficient
P = Pressure at nozzle (psi)
x = Emitter exponent

Sprinkler Discharge. Sprinkler discharge uses an emitter coefficient of 05 and can simply be calculated based on the relation between pressure and flow rate shown in equation 9 below (Hathoot et al. 1994).

$$Q = k\,P^{0.5} \tag{9}$$

where: Q = Emitter discharge (GPH)
k = Nozzle discharge coefficient
P = Pressure at nozzle (psi)

The nozzle discharge coefficient can be easily calculated given the manufacturers' sprinkler data. However, a value not typically taken into account is the loss due to friction in the sprinkler riser (Hathoot et al. 1994). Even though this may be a negligible value, it can still alter the emitter discharge and therefore should be taken into account. The following set of equations, 10 through 15, show a condensed progression of formulas used by Hathoot et al. to calculate the exact (theoretical) discharge of a sprinkler with a riser. The variables used relate to figure 2 which shows a lateral, riser, sprinkler assembly.

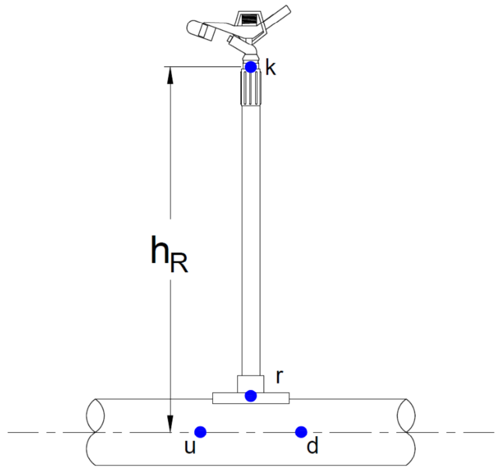

Figure 2. Lateral, riser, sprinkler assembly with marked points of interest (Hathoot et al. 1994)

Equation 10 shows how P_u is related to P_k by taking into account the various losses between the two points.

$$P_u = P_k + P_{ur} + P_{rk} + h_R \tag{10}$$

where: P_u = Pressure at point u (psi)
P_k = Pressure at point k (psi)
P_{ur} = Pressure loss from point u to point r (psi)
P_{rk} = Pressure loss from point r to point k (psi)
h_R = Height of riser

One can note that equation 11 is simply a minor loss formula which multiplies a coefficient specific to the junction by the corresponding velocity head. This head loss P_{ur} can only be calculated if the coefficient K_{ur} is determined.

$$P_{ur} = K_{ur}\left(\frac{Q_u^2}{2gA^2}\right) \tag{11}$$

where: K_{ur} = A coefficient found using Gardel's equation
Q_u = Lateral discharge at point u (GPH)
g = acceleration due to gravity (ft/s^2)
A = Cross-sectional area of lateral (ft^2)

Several studies conducted by Gardel and Rechsteiner (1970) resulted in the development of equation 12. This study involved the research and testing of various pipe connections

including a 90 degree tee connection which most closely represents the link between the lateral and a sprinkler riser.

$$K_{ur} = 0.95\left(1 - \frac{q}{Q_u}\right)^2 + \left(\frac{q}{Q_u}\right)^2\left[-0.3 + \frac{\left(0.4 - 0.1\,\frac{a}{A}\right)}{\left(\frac{a}{A}\right)^2}\right] \tag{12}$$

where:
- q = flow rate through riser (GPH)
- Q_u = Lateral discharge at point u (GPH)
- a = Cross-sectional area of riser (ft^2)
- A = Cross-sectional area of lateral (ft^2)

The result of combining equations 11 and 12 is shown in equation 13.

$$P_{ur} = \frac{Q_u^2}{2gA^2}\left\{0.95\left(1 - \frac{q}{Q_u}\right)^2 + \left(\frac{q}{Q_u}\right)^2\left[-0.3 + \frac{\left(0.4 - 0.1\,\frac{a}{A}\right)}{\left(\frac{a}{A}\right)^2}\right]\right\} \tag{13}$$

If the riser is long, equation 14, developed by Kincaid and Heerman (1970), can be substituted with the Darcy-Weisbach equation. However, most cases do not use particularly long risers so this equation will suffice.

$$P_{rk} = \frac{Q_u^2}{2gA^2}\; x\; e^{\left(9.2\frac{q}{Q_u}\right)} \tag{14}$$

where:
- P_{rk} = Head loss through the riser (psi)
- Q_u = Lateral discharge at point u (GPH)
- g = Acceleration due to gravity (ft/s^2)
- A = Cross-sectional area of lateral (ft^2)

By substituting equations 13 and 14 into 10 while considering sprinkler *i*, one can replace P_k with its respective sprinkler pressure, P_i resulting in equation 15 below.

$$q_i = K_d\left(P_i - \frac{Q_i^2}{2gA^2}\left\{0.95\left(1 - \frac{q_i}{Q_i}\right)^2 + \left(\frac{q_i}{Q_i}\right)^2\left[-0.3 + \frac{\left(0.4 - 0.1\,\frac{a}{A}\right)}{\left(\frac{a}{A}\right)^2}\right] - \frac{Q_u^2}{2gA^2}\; x\; e^{\left(9.2\frac{q}{Q_u}\right)}\right\} - h_R\right) \tag{15}$$

Using equation 15, the sprinkler discharge can be calculated.

Drip Emitter Discharge. Drip emitters bring about an entirely different set of concerns than sprinklers. These include variations due to the manufacturing process, water temperature effects, and clogging (Provenzano 2007). The biggest concern with inconsistency in manufacturing, while usually maintaining a coefficient of variation (cv) below 0.10, is a hose distribution uniformity (DU_{hose}). Some refer to this as emission

uniformity (EU) but the concept is the same. The contribution cv lends to DU_{hose} is represented in equation 16 as defined by Karmeli and Keller (1975).

$$\mathrm{DU}_{hose} = \left(1 - 1.27\,\frac{cv}{\sqrt{N}}\right)\left(\frac{Q_{min}}{Q_{avg}}\right) \tag{16}$$

where: DU_{hose} = Hose distribution uniformity
cv = Coefficient of variation
N = Number of emitters per plant
Q_{min} = Minimum flow rate along the lateral (GPM)
Q_{avg} = Average flow rate along the lateral (GPM)

Another factor one must consider with regard to drip emitters, both online and inline, is local head loss due to either a barb or coextruded emitter that disrupts the streamline and flow characteristics of the traveling water. The protrusion of the barb into the flow path causes a contraction in the drip hose effectively reducing the cross-sectional area of the lateral resulting in an increased head loss. Similarly, an inline emitter reduces the area in the tape compared to a section just upstream of the emitter causing loss in head (Provenzano and Pumo 2004).

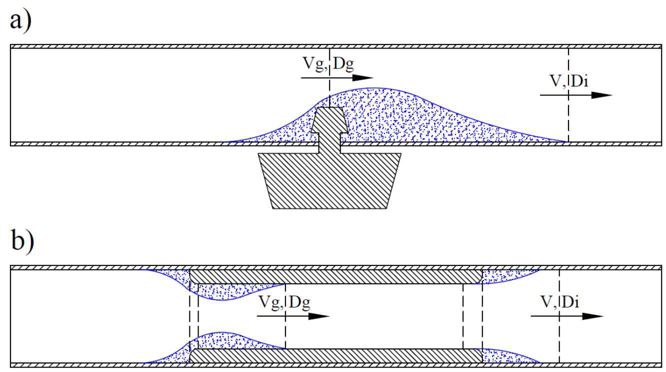

Figure 3. Flow path due to online drip emitter (a) and inline drip emitter (b) (Provenzano and Pumo 2004)

By introducing an emitter in a pipe, the lateral incurs head loss due to both contraction and enlargement represented as λ_c and λ_s, respectively (Provenzano and Pumo 2004). This is modeled in figure 3 above. Below are the equations Provenzano and Pumo (2004) used in their study of flow characteristics past various drip emitters. Equation 17 was developed by Bagarello et al. (1997) and shows that the coefficient of kinetic head is independent of Reynolds number as it only relies on the ratio of the area of the pipe and the reduced area due to a protruding emitter.

$$a = 1.68\left(\frac{A_i}{A_g} - 1\right)^{1.29} \quad (17)$$

where: a = Coefficient of kinetic head
A_i = Area of pipe section (in^2)
A_g = Flow cross-section area (in^2)

Equation 18 is the end result of a series of theoretical computations performed by Provenzano and Pumo (2004).

$$\lambda = a\left(\frac{V^2}{2g}\right) \quad (18)$$

where: λ = Head Loss due to contraction and enlargement
a = Coefficient of kinetic head
V = Mean flow velocity (ft/s)
g = Acceleration due to gravity (ft/s^2)

Using this, one could develop a Bernoulli table as shown in Appendix B that not only takes into account friction loss along the lateral, but local losses due to protruding emitters as well. However, the concern with this is that, to adequately take this effect into account in the proposed software, the dimensions of several emitters would have to be determined and inputted to reduce the work of the user or future professors for the BRAE 414 class.

Effects of Temperature. It is typical to add about 2.5% of the total lateral length to the total computation due to the fact that in changing temperatures, the polyethylene hoses shrink and swell (Burt and Styles 2011). This concept should definitely be considered when calculating the friction loss in a system as it plays a vital role in determining the inlet pressure of the system. The coefficient of thermal expansion for a polyethylene hose is 0.00012 ft/degrees F, however, this changes slightly from polymer to polymer. In a study conducted by Clark (2005), several brands of drip tape were tested to see the effects that an increase in water temperature and pressure would have on the discharge. The drip tapes were tested with water temperatures ranging from 20 degrees C to 50 degrees C at 55, 69, and 83 kPa. To relate the tests to each other, the group used equation 19 below. This ensured that each tape could be compared to the others as it involved determining a "temperature flow rate index" number also referred to as temperature discharge ratio or TDR (Clark 2005).

$$TDR = \frac{q_{t^\circ}}{q_{20^\circ}} \quad (19)$$

where: q_{t° = Emitter discharge at each measured temperature (GPH)
q_{20° = Emitter discharge at initial base temperature (GPH)

In this study, the highest TDR recorded was 1.97 with a water temperature of 50 degrees C at 83 kPa. This means that the discharge of the emitter was almost twice as high as it

was when tested at initial conditions. Other tapes' TDR values ranged from 0.94 to 1.12 which may lead one to believe that the case with a TDR of 1.97 was an outlier, however, even a 12% increase in emitter discharge is substantial enough to cause concern especially in a large field with tens of thousands of emitters. Water temperature doesn't typically play as significant a role in the design of an irrigation system as variations in friction and elevation do, but is should be a point of concern especially in areas with high temperatures.

Spaghetti Hose Losses. Microsprayers typically demand higher flow rates than standard drip emitters (between 4 and 30 GPH for Bowsmith Fanjets) and thus incur large losses in the couplers and tubing supplying them. It is not unusual to see losses of 2 – 6 psi though the two components (Burt and Styles 2011) and this needs to be accounted for in the overall design. The equations below (20 and 21) show how the losses through the tubing and couplers, respectively, are determined:

$$H_f = K\left(\frac{Q^{1.75}}{D^{4.77}}\right) \qquad (20)$$

where:
- H_f = Friction loss (psi/ft)
- K = 4.37 x10^{-7} for English units (4.82 for metric)
- Q = Flow rate (GPH)
- D = Tubing ID (inches)

$$H_f = K\left(\frac{Q^{2}}{D^{4}}\right) \qquad (21)$$

where:
- H_f = Friction loss (psi/ft)
- K = 4.37 x10^{-7} for English units (4.82 for metric)
- Q = Flow rate (GPH)
- D = Tubing ID (inches)

Manifold Placement

The overall goal of an irrigation system is to have all the emitter pressures equal throughout the field so that the distribution uniformity is high. However, this can be difficult to do if the system is to be designed on a sloping field. In order to get relatively similar pressures along all the emitters, a manifold which serves laterals in two directions has to be placed uphill from the serviced area (Burt and Styles 2011). This decision is based on the idea that as water travels down a lateral, it losses energy due to friction. But, if the lateral runs downhill, this lost energy can be accounted for or even negated due to the potential energy of the water being converted to kinetic energy and thus making up the difference. So, if a manifold is placed higher up on the hill, there is a lower pressure requirement needed to serve the most uphill emitter while the downhill lateral remains mostly unaffected by the increased friction loss accompanied with increased length because it is made up for with greater potential energy to begin with. This effect is modeled in figure 4.

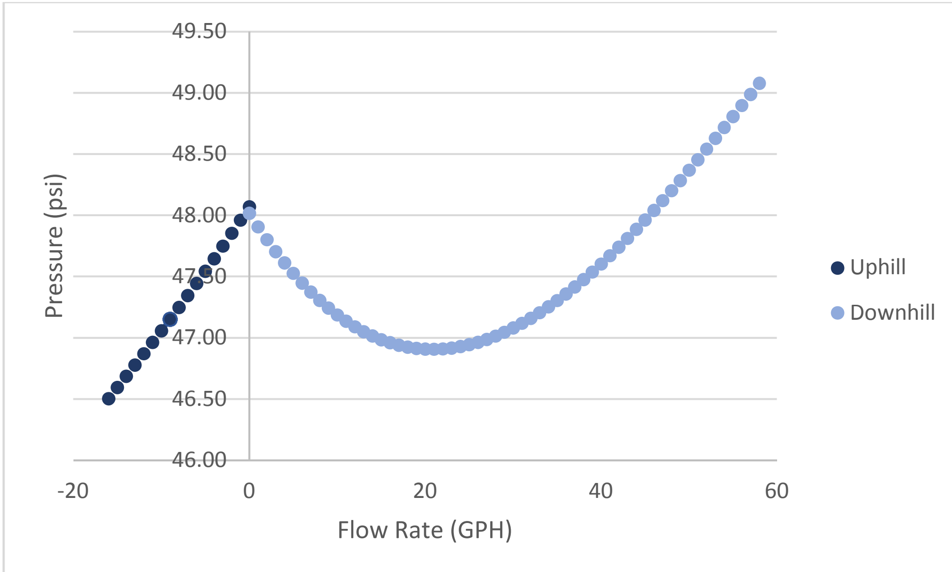

Figure 4. Comparison of pressure variation along uphill and downhill manifold sections (Burt and Styles 2011)

The two conditions for ideal manifold placement are that both the average emitter pressures as well as inlet pressures are equal on both the uphill and downhill sides. So, if the downhill side has da higher pressure than the uphill side, move the manifold down the hill. The same concept applies if the uphill side is greater. This is an iterative process in which differing lengths of uphill and downhill hoses are tested in order to meet these conditions. Keller and Bliesner (1990), however, developed a concept that can significantly reduce the number of iterations. This process first involves determining the number of outlets on the lateral. A correction factor, F, is then found using table 2 which is multiplied by the mainline friction loss yielding the total lateral friction as shown in equation 19. Then, by comparing that number to the slope of the field, the designer can interpolate a Z factor from table 3 with which they can multiply by the overall lateral length, as shown in equation 20, to get an idea of the distance uphill from the bottom the field the manifold should be (Burt 2013).

$$Total\ Lateral\ H_f = F\left(Total\ mainline\ H_f\right) \tag{22}$$

where: H_f = Friction Loss (ft, *m*)
F = Correction Factor

$$Location = Z\ (Total\ Lateral\ Length) \tag{23}$$

where: Z = Keller’s manifold placement factor

Table 2. “F” factor for multiple outlets

Number of outlets on the lateral	Correction Factor, F
1	1
5	0.457
10	0.402
20	0.38
40	0.364
100	0.356
more than 100	0.351

Table 3. “Z” factor for a given elevation/friction ratio

Elevation/Friction	Z
0	0.5
0.1	0.56
0.2	0.6
0.3	0.65
0.4	0.69
0.5	0.72
0.6	0.75
0.7	0.78
0.8	0.81
0.9	0.83
1	0.85
1.1	0.87
1.2	0.89
1.3	0.91
1.4	0.92
1.5	0.93
1.6	0.94
1.7	0.95
1.8	0.96
1.9	0.97
2	0.98
2.1	0.98
2.2	0.99
2.3	0.99
2.4	1

This process can be used to get an idea of where to begin the iterations and rarely yields the best answer on the first try. The proposed program could use this process to help reduce its footprint and speed up computations.

Flushing

Flushing is an essential practice in irrigation system maintenance to ensure the longevity of the investment. By not performing this task, the emitters could become plugged, sediment could accumulate in pipes and hoses, and distribution uniformity could be drastically reduced. Flushing is most easily performed through the implementation of flush manifolds. With a manifold on the downstream ends of the hose runs, the tapes are more likely to be flushed frequently, equalization of pressure can take place in the case of crimped tape, and, in the case of a tape break, the opportunity of soil entry into tape is diminished (Burt and Styles 2011). Some design considerations when it comes to these manifolds include:

1. Pressure regulating valves need to have the ability to allow for higher flow rates and downstream pressures during flushing
2. Drip tape must be thick enough to withstand higher pressures
3. Flush manifolds should not be tapered to allow for high flow rates through the tapes and the manifolds themselves
4. Header manifolds should be designed to handle flows at flushing as opposed to normal operation criteria
5. Pump must be oversized to accommodate flushing requirements.

Tape Inlet Pressure. The drip tape inlet pressure typically increases during flushing periods due to increased friction in the tape (due to higher flows though the tape and the emitters) as well as friction requirements for the flush manifold itself, elevation changes along the manifold, and any minor losses than incur through the tape/manifold fittings, valves, and flushouts.

Tape Inlet Flow Rate. With increased inlet pressures comes an increase in inlet flow rate. Because, when the valves at the downstream ends of the drip tapes are opened, there is an additional loss due to the friction characteristics of the flush manifolds, the tapes have a downstream pressure during flushing. This downstream pressure has an effect on the new inlet flow rate resulting in a flow that is proportional to the difference in the upstream and downstream ends of the drip tape (Burt and Styles 2011).

Computer Programming Options

There are a plethora of computer languages available that have a wide array of advantages and disadvantages with regard to optional functions, user friendliness, and overall performance. For a robust program that will be easy for the users to operate and navigate, it is decided to use Excel as the host for Visual Basic for applications. It is also possible to use VB.NET code with Excel but because the proposed software is operating through a host and not as a standalone program, it will be easier to code through Excel's integrated development environment (IDE).

PROCEDURES AND METHODS

Program Planning

Original Program Analysis. Because this project entails updating an existing program from an out-of-date platform to more recent software, time has to be spent assessing and critiquing the current version in search for a more efficient and user-friendly path to the needed output. By analyzing the original program, one could find and fix flaws or bugs for the update.

User Interface Layout. A program that is to be used by students and professionals for years to come needs to be intuitive and easy to use. It is imperative to establish a program structure with logical flow so the user will not get lost in pages of user forms and sheet after sheet of useless data that will require sorting through. It is for this reason that the new program will utilize Visual Basic coding that will generate only the desired outputs.

Flow Chart Generation. In order to create a program that gets to the final result in the most efficient manner, the program designer must sketch several flow charts to visualize the flow of data though the embedded code. This is the most important step as it dictates whether the construction phase will take days or weeks.

Program Construction

Coding Standards. Like most engineering work, there are several common practices and standards to adhere to. One of the most important standards include commenting throughout the code so anyone that accesses it can understand the steps taken to perform a task. In Visual Basic, comments can be offset using apostrophes ('). By placing this symbol at the beginning of a line, the creator is signifying that they want this marked line to be neglected when the program runs through all the lines of code. Another practice is to condense the code to the fewest lines possible while still performing the task at hand. This ensures the software will have a small electronic footprint and is not taxing on the system when performing routines.

Functions and Subroutines. Functions and subroutines differ in the fact that functions return a result where the latter carries out a set of instructions. These are tested and debugged throughout the programming process to ensure proper operation. It is even more important to keep these two organized and working if several are interrelated and dependent on one another.

Controls. Often times, excel workbooks that have several different options that the user can select from. These options can be displayed, accessed and selected through easy-to-use "controls" such as a list box, combo box, drop downs, and check boxes. The former two are typically used in applications with a large array of data that would be cumbersome in a simple drop down. Checkboxes are often the best option in cases requiring only a few options or when multiple options need to be selected.

Program Description

The workbook created takes user input regarding key aspects of hose hydraulics and generates a solution based on the user's task at hand. There are 3 sub functions behind the "Single Hose" computation selection each based on slightly different calculation methods. These include solving for the average flow rate of the emitters given an inlet pressure, solving for the inlet pressure given a desired average flow rate, and modeling the hose during flushing. The user also has the option to select the "Manifold Placement" computation and this will allow them to place a manifold in a field such that the manifold is the correct distance uphill from the center to minimize energy losses in the system and increasing distribution uniformity.

Input

When the user opens the spreadsheet, they are only given the choice to decide what type of calculation they would like to perform—Single Hose or Manifold Placement. This decision then changes key aspects of the spreadsheet to make navigation somewhat less overwhelming. Once an option is selected, the spreadsheet will allow the user to input more values about the irrigation system in question. Figure 5 below depicts the Input worksheet with a few of the cells filled out and options selected.

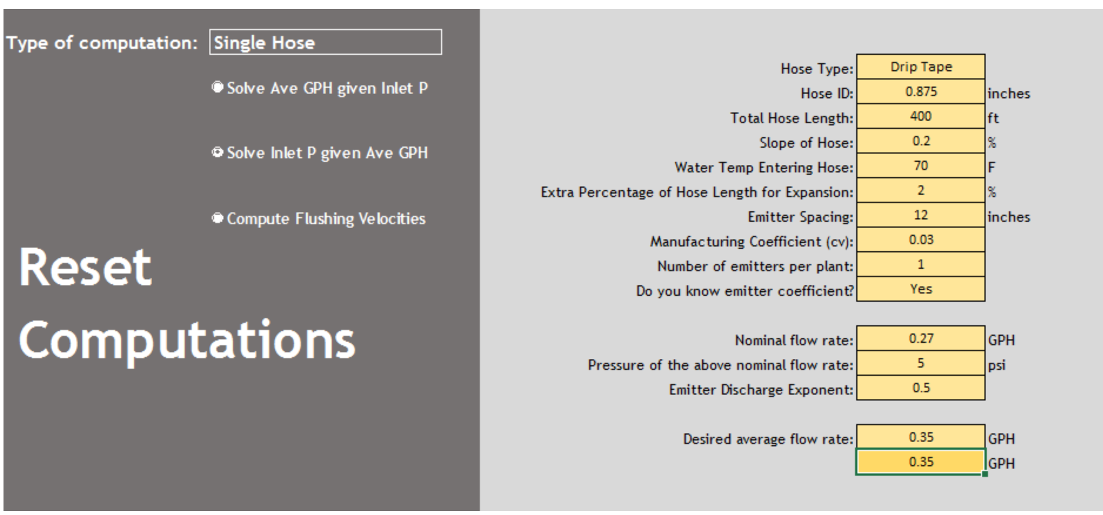

Figure 5. Input sheet shown with example data

User Interface. One of the constraints with the former program was with the step by step terminal based user interface. While the software is very powerful, users were distracted by its outdated feel. With this in mind, this project was designed with consideration to the user throughout the process. Knowing that this workbook would be used by a wide variety of individuals, the user interface was created to be simple and intuitive. More than anything, however, the program needs to be robust. The user needs to have the option to run a calculation then, on a whim, change any value used by the program without being interrupted by an error message. In order to do this, several things need to be performed at once. Depending on which cell was changed, worksheet code may hide or unhide rows with regard to the procedure the user is trying to carry out. By

limiting the cells the user is able to enter data into, several issues can be avoided from the start. The program may also call functions to change other aspects of the workbook such as the chart display, textbox labels, or text color. Some subroutines can also be called with the use of buttons. For example, the button on the Computations worksheet runs certain parts of its code depending on several cell values throughout the workbook. The text on this button is also changed between "Match Flows", "Match Pressures", and "Place Manifold" depending on user input. Another key aspect of the interface is the use of drop down lists on the input sheet further limiting the user to follow designated paths through the workbook.

Output

Main Functions. As can be seen in Figure 5 above, when "Single Hose" is chosen from the drop down list, three check boxes appear which are used to determine which calculations will be performed by the program. The first option is to solve for the average flow rate of the emitters along an individual hose with emitters with a constant spacing given the inlet pressure of the hose. How this function operates is by changing the point pressure of the most downstream emitter until the user's desired input pressure is reached. The second option is to calculate the inlet pressure of an individual hose given an average inlet pressure. This is performed by changing the pressure of the most downstream emitter until the average flow rate is equal to the input desired flow rate. The third and final single hose computation the program can perform is modeling the hose pressures and emitter flow rates while being flushed. In this, the velocity is converted to a flow rate and this is added to the flow rate at the most downstream emitter. The calculations to follow use the same technique as the other two functions to generate a table of flows versus pressures but now with an increased flow rate due to flushing requirements.

If the user decides they would like to determine the hydraulically optimum location for their manifold, they need only to select the "Manifold Placement" option from the dropdown list on the input sheet and the spreadsheet updates all the formulas, text boxes, and chart to allow the computation to take place. The main function driving this is actually dependent on two tables based on the calculations performed in the function to calculate the inlet pressure given the desired average flow rate. One table is dedicated to only the downhill portion of the hose while the other is for the uphill. The program changes the most downstream point pressure on both of the tables (represented as either end of the total length of the hose) until the average flow rate of the hoses equal the user's desired average flow rate. It then compares the inlet pressures of the two sides of the hose and if the uphill pressure is higher than the downhill, then the downhill length can be increased to decrease the friction lost in the excessive length the uphill section has.

Data Portrayal. Once the user has filled in all of the required cells on the Input sheet, they can then press the Computations button to navigate to the results from the data they had entered. Once here, the user must click on the button on the far left of the screen which will read either "Match Flows", "Match Pressures", or "Place Manifold" as

discussed above. The screenshot in Figure 6 shows the overall layout of the sheet with subsequent Figures 7, 8, and 9 being more detailed looks at areas that display useful output data for the user. Table 4 shows the color designations of each section with regard to Figure 6.

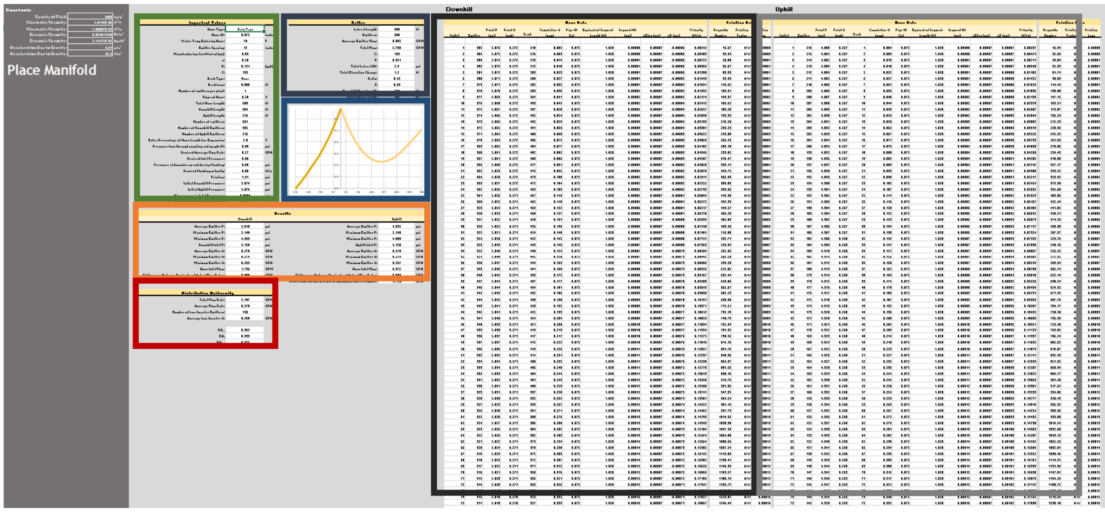

Figure 6. Overall layout of Computations sheet

Table 4. Color designations for Figure 6 above

Color	Section
	Key Values
	Keller Values
	Pressure Distribution Chart
	Results
	Distribution Uniformity
	Downhill Bernoulli Table
	Uphill Bernoulli Table

The Key Values section is exactly that. It displays values from the Input sheet as well as values easily derived from input data all of which will be used in one or more computations carried out by the spreadsheet. The Keller Values table is derived from formulas based on the Keller "Z" method for placing a manifold. This method is not ideal for use in software applications as it is not as accurate as the techniques used by this program. However, it is still good to use as a check to ensure the program is operating as it should. The Pressure Distribution Chart is a dynamic chart that displays the pressures of all the emitters along the hose and changes its axes titles depending on user input. If a "Single Hose" calculation were to be performed, the chart would only display the pressure distribution for hose going one way from the manifold. Alternatively, if a "Manifold Placement" calculation were performed, the chart would model the pressures of the hoses on either side of the manifold. An example of this is shown in Figure 7 using

arbitrary data for a drip tape system. In this figure, the pressure along the y-axis is modeled at all the emitters in on the hose. The emitter number is given on the x-axis.

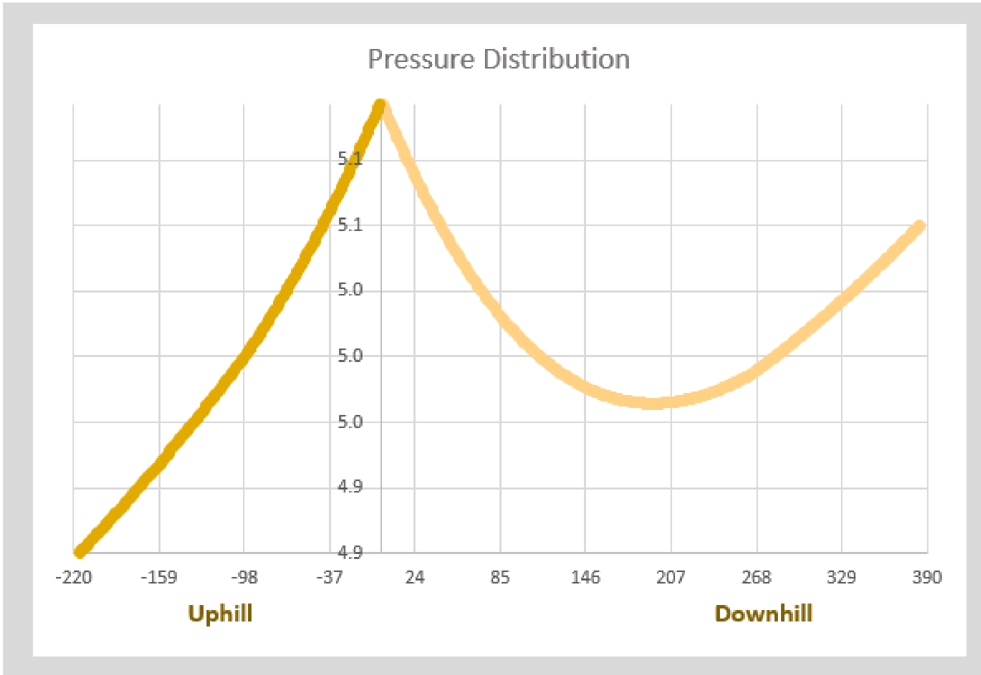

Figure 7. Pressure Distribution Chart on Computations sheet

The Results section, shown in Figure 8, displays important values that reference the Bernoulli tables' dynamic ranges. These values are dependent on where the 0th emitter is which is representative of the inlet to the hose. For example, the table extends down to the maximum number of emitters possible with regard to total length and emitter spacing. However, the table only generates emitter values on the emitters that are in the field. For example, if the total length of the hose is 600 feet with a 12 inch emitter spacing, the downhill length could be calculated to be 384 feet. There would be 385 emitters on the downhill side and 216 emitters on the uphill. To take this farther, to solve for the average emitter pressure on the downhill side, the dynamic range would have to adjust its height to extend from the pressure of the most downstream emitter all the way to the inlet represented as the 385th outlet. This range of pressure values are then averaged to yield your answer.

Results					
	Downhill			Uphill	
Average Emitter P:	5.018	psi	Average Emitter P:	4.995	psi
Maximum Emitter P:	5.148	psi	Maximum Emitter P:	5.148	psi
Minimum Emitter P:	4.969	psi	Minimum Emitter P:	4.880	psi
Downhill Inlet P:	5.150	psi	Uphill Inlet P:	5.150	psi
Average Emitter Q:	0.270	GPH	Average Emitter Q:	0.270	GPH
Maximum Emitter Q:	0.274	GPH	Maximum Emitter Q:	0.274	GPH
Minimum Emitter Q:	0.269	GPH	Minimum Emitter Q:	0.267	GPH
Hose Inlet Flow:	1.736	GPM	Hose Inlet Flow:	0.972	GPH
Difference Between Desired and Actual Flow Rates:	0.000	GPH	Difference Between Desired and Actual Flow Rates:	0.000	GPH
Difference Between Desired and Actual Inlet Pressure:	-5.150	GPH	Difference Between Desired and Actual Inlet Pressure:	-5.150	GPH

Figure 8. Results section on Computations sheet

Distribution Uniformity		
Total Flow Rate:	2.707	GPM
Average Flow Rate:	0.270	GPH
Number of Low Quarter Emitters:	150	
Average Low Quarter Q:	0.268	GPH
DU_{cv}	0.962	
DU_{Q}	0.993	
DU_{hose}	0.955	

Figure 9. Distribution Uniformity section on Computations sheet

Figure 9 above, the Distribution Uniformity section, also uses dynamic ranges but in a very different manner. Since the low quarter distribution uniformity takes into account only a select few of the values in its calculation, all flow rate values had to be ranked from greatest to smallest between two separate tables. A function then averages the lowest 25% of these values and divides it by the average of all flowrates yielding DU_{lq}. Overall, the program uses a total of 10 dynamically named ranges to perform its in-depth computations most of which are in the Downhill and Uphill Bernoulli Tables. These tables are extremely similar except when it comes to the change in elevation column. The elevation in the uphill is subtracted from the pressures instead of added to account for energy loss due to increase in elevation.

RESULTS

Program Testing

Since there was already reliable software available to perform the same tasks as this project, results were tested against it to see how much variance there was between the platforms. In this, one input at a time was changed to extreme values on both the high and low ends. This led to the discovery of various bugs in the program which were fixed and retested. Table 5 below shows the input values used in the tests while Appendix C displays the results

Table 5. Trial input values used in programming testing and debugging

Input Description	Initial Value	Low Value	High Value
Hose ID	0.875	0.5	1
Total Hose Length	500	10	1200
Slope of Hose	0.2	-1	5
Water Temp Entering Hose	70	35	150
Extra Percentage of Hose Length for Expansion	2	0	10
Emitter Spacing	12	6	300
Manufacturing Coefficient (cv)	0.03	0	0.1
Number of emitters per plant	1	1	10
Nominal flow rate	0.27	0.05	0.5
Pressure of the above nominal flow rate	5	1	10
Emitter Discharge Exponent	0.5	0	1
Desired inlet pressure	5	0	10
Desired average flow rate	0.27	0.1	2
Pressure at downstream end during flushing	7	0.1	10

Comparing Results

All of the single hose computations performed very well when compared to the original drip hydraulics software. Table 6 below shows, out of the 408 comparable computations, what the percent error was between platforms. It can be seen that the newer program performed very well considering different techniques were used in the computation of results.

Issues. One of the issues witnessed with comparing the results this way was the lack of precision. Because all of the results were given in values rounded up to the tenths place, it became difficult to realistically stack one against the other. This is even more pronounced when comparing values less than 1. In one case, a maximum pressure difference along a hose that the original program calculated was 0.008 psi when a value of 0.0085 psi was determined for the same output in the new program. A difference of 0.0005 psi can be

Table 6. Percent of computed results that fall within various percent differences

Percent Difference	Number of Values	Percent of total values
< 1%	344	84%
< 10%	395	97%
< 25%	404	99%
< 50%	404	99%

calculated from this which when divided by the 0.008 psi leads to a 6.8% error. It is scenarios like this that made up the majority of the 16% missing from the “less than 1% difference” row in Table 5. As for the 3% of values from “less than 10% difference” up, an explanation can be seen in Appendix C next to these high values. In short, this occurred due to script in the original to code skip processes like tolerance checking and value correction. Another constraint to consider is the older software has a limit of around two thousand outlets but with the new program, the user is only limited by the time they want to spend waiting for calculations to take place. Because this project generates the Bernoulli tables only to the number of emitters necessary, its usefulness is endless.

DISCUSSION

Code Organization

In programming, syntax is the backbone of orders to be carried out by the processor and it varies from language to language. This includes various looping strategies, If statements, and variable declaration that can all be used in different ways to yield the same result. However, some practices are not only more efficient and faster than others, but easier to understand. Great lengths were went to in order to have the most efficient code while maintaining a high level of clarity. In a program with as many variables as this one has, it cannot be stressed enough the importance of having code that not only the author can read, but others as well. As a coding standard, anyone with access to the source code needs to be able to dissect various parts of the code and understand how it functions. A technique used in this project to aid in understanding code is the use of comments throughout. Key parts of functions and subroutines were described in plain English so someone else can get an understanding of what the code is actually doing.

Logic Structure

A difficult task to overcome was determining the best way to direct the user through the user interface. With the user having the ability to do 4 different calculations, subroutines had to be made such that the functions they carry out are dependent on what path the user wants to take. For example, the check boxes on the input sheet are just cells, not objects. In the initial state, the text and border colors in these six cells are the same as the fill of the cells they lie on (dark gray). Upon selecting “Single Hose”, these are made visible by changing the text and border colors to another color (light gray). These then appear to be normal checkboxes that the user can select to determine what task they would like to perform. But, it doesn’t stop there. As the user clicks on the boxed cell, a “Selection_Change” macro (code that fires when cells within a specified range are selected) checks that status of the value within the clicked cell and if it contains not text, then the code changes the value to “X”. While doing so, it also deletes any other X’s that may be in one of the other two check boxes. This is an important step in the avoidance of errors that may arise from having several checkboxes containing X’s as other macros that perform tasks dependent this selection need to know which functions to run.

As for the main functions driving the Bernoulli tables and various other subroutines, the majority of computations were performed using If statements. For example, if the downhill length is equal to the total length, “No Uphill Section” is displayed throughout the workbook. This is, of course, always displayed when the user is performing Single Hose calculations, but also when the manifold placement function decides that the optimum location for the manifold is on the top of the slope. The manifold placement function also incorporates the use of a For loop. The logic behind it goes something as follows. For X = 0 to the number of iterations the code defines, set the downhill length equal to half of the total length plus X multiplies by 10% of the total length. This is performed until the uphill inlet pressure is greater than or equal to the downhill inlet pressure.

Error Handling

Several steps were taken to prevent the user from inputting data that will break the functions used. On the input page alone, there are forty-two possible message boxes that appear and warn the user if a value they entered is either too high or too low. These error messages reference a hidden sheet named "Limits" in which upper and lower bounds are set for all user input boxes. The values on this sheet are also related to the path the user is on in their computations. For example, if the user states they are doing calculations for drip tape, then the maximum nominal flow rate they can enter is two gallons per hour. However, if the user decides to select drip hose, then this upper bound increases to twenty gallons per hour.

Another error message that may occur is one that fires when the slope is too steep for the "Solve average GPH given Inlet P" function. This only occurs when the slope is negative indicating that water is being pumped uphill. In this situation, the most downstream point pressure is set to zero and the Inlet pressure is checked. If the inlet pressure is greater than the desired inlet pressure, then the desired inlet pressure cannot be achieved and the message box appears.

Obsolescence

Technology is an ever-evolving and growing industry. As it was the goal of this project to bring former software up to date, it will be the goal of another to outdo this one. An issue faced during the creation of this program was with the use of ActiveX controls. With a Windows update, all ActiveX controls in workbooks were rendered useless. To avoid this issue altogether, the decision to use shapes instead of controls was made. There is less one can do with shapes as opposed to controls, however, it seems to be the safest route to go with regard to obsolescence.

RECOMMENDATIONS

For the sake of time, over anything else, several ideas for this project were not pursued. These include the ability to select the emitter of choice as opposed to entering manufacturer data manually, generating a summary table for key values, making all formulas dependent upon user-defined constants, working in metric units, as well as making the entire project an excel plugin so use with any workbook. Each one of these would require numerous hours of coding and workbook manipulation to complete without lending much in terms of overall user experience. However, time saved though use of these additions could lead to improved design capability and greater efficiency in the office. How these tasks would have been carried out is described below.

There are hundreds of emitter types, configurations, and orientations to be found in industry literature. Short of releasing new lines or discontinuing old products, the data associated with this key design criteria is relatively constant. One goal for a future release of the project would be allowing the user to select the emitter they would like to use for their design from an easy to use list box. The user would be asked if they know specifically which emitter they would like to use and if the answer is “Yes”, then a list box will be made visible containing an array of available emitters. Upon selection, the project is populated with known values of nominal pressure, flow rates at this nominal pressure, and the emitter exponent stored on an emitter database sheet. But, if the user is unsure of the emitter type or the emitter is not in the database, data would be entered manually like it currently is.

Another update from the original should generate a summary table so the user can have the option to display vital information quickly and can even be given the option to export this data to another workbook. As it is, the Computations sheet displays all of the information used in the complex calculations performed by various macros. It is difficult to find information useful to the user’s design as too many cells have to be sifted through. If a summary table can be generated containing this data, the overall effectiveness of this program will improve.

One area of improvement would be to relate the formulas to cells containing various constants such as viscosity and acceleration due to gravity. This was attempted in early version of the project but was later abandoned in an attempt to compare results with Dr. Burt’s original drip hydraulics software. Now that the workbook is reasonably close to producing the results of the BASIC-backed software, it would not be too difficult to retool the formulas to refer to user-defined constants. This also expands the overall usability of the project to industries designing relatively incompressible fluid conveyance systems with different fluid densities such as the oil industry. This leads to the next suggested upgrade that also increases the number of possible users and that is to give the user the option to work in metric units.

With the option to work in metric units, the user is not confined to work with data displayed with imperial units. This would, again, only increase the reach and worldwide usability of the software. However, this would probably be the most daunting task among

those suggested. Not only would formulas have to be changed, but text next to input and output cells would have to as well.

The last recommendation would be to make the entire workbook an excel plugin. As a plugin, the designer could work in their own irrigation design spreadsheet and press a button on the ribbon to generate this program within it. It would load the required sheets, formatting, formulas, and source code so the designer doesn't have to navigate to another workbook in a separate window. This would be the ideal solution to reduce the footprint of the project as it could be stored in the Excel directory itself and only called when needed.

Other, smaller upgrades that are not so daunting include locking the Computations sheet until all data is filled on Input sheet, running the code behind the variable button on the Computations sheet upon opening the sheet, and warning the user that the Computations sheet is not up to date if input data has been changed since last running the main subroutine. Also, it would be useful if the chart's x axis title changed from "Downhill" to "Uphill" if a negative slope is entered under a single hose computation.

REFERENCES

Book

1. Burt, Charles M. "Hand Move Sprinklers." *Irrigation Design Manual*. San Luis Obispo, Ca: ITRC, 2013. N. pag. Print.

2. Burt, Charles, and Stuart W. Styles. *Drip and Micro Irrigation Design and Management: For Trees, Vines, and Field Crops: Practice plus Theory*. San Luis Obispo, CA: Irrigation Training and Research Center, 2011. Print.

3. Keller, J. and R.D. Bliesner. 1990. Sprinkle and Tricle Irrigation. Van Nostrand Reinhold. N.Y., N.Y.

4. Phocaides, Andreas. *Handbook on Pressurized Irrigation Techniques*. Rome: FAO, 2007. Print.

Technical report

1. Burt, Charles M. *Surface Drip Tape Irrigation Systems as an Alternative to SDI for Field and Row Crops*. Tech. no. 06-002. San Luis Obispo, Ca: ITRC, 2006. Print.

Journal article

1. Bagarello V; Ferro V; Provenzano G; Pumo D (1997). Evaluating pressure losses in drip irrigation lines. Journal of Irrigation and Drainage Engineering (ASCE), 123(1), 1–7

2. Burt, C. M., A. J. Clemmens, T. S. Strelkoff, K. H. Solomon, R. D. Bliesner, L. A. Hardy, T. A. Howell, and D. E. Eisenhauer. "Irrigation Performance Measures: Efficiency and Uniformity." *Journal of Irrigation and Drainage Engineering* 123.6 (1997): 423-42. *ASCE*. Web.

3. Clark, G. A., F. R. Lamm, and D. H. Rogers. "Sensitivity Of Thin-Walled Drip Tape Emitter Discharge To Water Temperature." *Applied Engineering in Agriculture* 21.5 (2005): 855-63. Web.

4. Demir, V., H. Yurdem, and A. Degirmencioglu. "Development of Prediction Models for Friction Losses in Drip Irrigation Laterals Equipped with Integrated In-line and On-line Emitters Using Dimensional Analysis." *Biosystems Engineering* 96.4 (2007): 617-31. Web.

5. Gyasi-Agyei, Yeboah. "A Bayesian Approach for Identifying Drip Emitter Insertion Head Loss Coefficients." *Biosystems Engineering* 116.1 (2013): 75-87. Web.

6. Gardel, A., and Rechsteiner, G. F. (1970). "Les pertes de charge dans les

branchements en te des conduites de section circulaire." *Bulletin Technique de la Suisse Romande,* 96(25).

7. Hathoot, Helmi M., Hussein M. Abo-Ghobar, Ahmed I. Al-Amoud, and Fawzi S. Mohammad. "Analysis and Design of Sprinkler Irrigation Laterals." *Journal of Irrigation and Drainage Engineering* 120.3 (1994): 534-49. Web.

8. Keller, J., and Karmelli, D. (1974). "Trickle irrigation design parameters." *Trans. ASAE,* 17(4), 678-684.

9. Kincaid, D. C., and Heermann, D. F. (1970). "Pressure distribution on a center pivot sprinkler irrigation system." *Trans. ASAE,* 13(5), 556-588.

10. Provenzano, Giuseppe, and Domenico Pumo. "Experimental Analysis of Local Pressure Losses for Microirrigation Laterals." *Journal of Irrigation and Drainage Engineering* 130.4 (2004): 318-24. Web.

11. Provenzano, Giuseppe, Domenico Pumo, and Pietro Di Dio. "Simplified Procedure to Evaluate Head Losses in Drip Irrigation Laterals." *Journal of Irrigation and Drainage Engineering* 131.6 (2005): 525-32. Web.

12. Provenzano, Giuseppe, Pietro Di Dio, and Guillermo Palau Salvador. "New Computational Fluid Dynamic Procedure to Estimate Friction and Local Losses in Coextruded Drip Laterals." *Journal of Irrigation and Drainage Engineering* 133.6 (2007): 520-27. Web.

13. von Bernuth, R. D. (1990). "Simple and accurate friction loss equation for plastic pipe." *J. Irrig. and Drain. Engrg.,* ASCE, 116(2), 294-298.

14. ASCE. (1978). "Describing irrigation efficiency and unifonnity." *J.lrrig. and Drain. Engrg.*• ASCE, 104(1), 35-41.

APPENDIX A
HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

Major Design Experience

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes fundamental elements as outlined below. This project addresses these issues as follows.

Establishment of Objectives and Criteria. The objectives and criteria for this project are established to meet the needs of irrigation designers and the expectations of the Irrigation Training and Research Center. See Design Parameters and constraints below for a more thorough discussion of objectives and criteria.

Synthesis and Analysis. This project incorporates fluid dynamic computations, empirical values derived from ITRC research, and coding techniques to attain key values used for irrigation design.

Construction, Testing and Evaluation. The software was developed using various flow charts to yield the result the user is looking for. It was then tested for bugs and issues to ensure proper operation every time. The results of the finished product were compared to the original software for accuracy and precision.

Incorporation of Applicable Engineering Standards. The coding behind this project follows coding conventions such that it is easy to follow for someone else who may have to edit it for future updates.

Capstone Design Experience

The BRAE senior project is an engineering design project based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge/ skills from these key courses.

- BRAE 236 Principles of Irrigation
- BRAE 312 Hydraulics
- BRAE 414 Irrigation Engineering
- BRAE 533 Irrigation Project Design
- BRAE 438 Drip/Micro Irrigation
- CSC 231 Programming for Engineering Students
- CSC 234 C and Unix

Design Parameters and Constraints

This project addresses a significant number of the categories of constraints listed below.

Physical. The software should be small and require very little computer resources as well as maintain an easy to navigate user interface.

Economic. This program will save time and money as it will speed up the design process.

Environmental. Better irrigation designs created using this software can lead to more efficient use of water and fertilizers decreasing the potential for ground water contamination.

Sustainability. This program can help a designer achieve a high distribution uniformity, a key aspect of irrigation efficiency. With a higher irrigation efficiency, more water and energy can be conserved.

Manufacturability. This is a single software package that will have bugs worked out.

Health and Safety. A better design give the grower the opportunity to focus more on the health of their crop.

Ethical. The software will help the designer along the process deterring them from cutting corners on irrigation design.

Social. Having an irrigation system with high distribution uniformity is good for society as it can potentially lead to more efficient use of water and fertilizer.

Political. Political criteria for this project fall in line with the social aspect as reducing wasted water and fertilizer can help a grower stay within strict political bounds on resource use.

Aesthetic. The program is to be extremely user-friendly and easy to follow as well as have a dark, metro theme to stick to current software norms.

APPENDIX B

BERNOULLI TABLE

Hose Data										
oint P (psi)	Point Q (gph)	Rank	Cumulative Q (gpm)	Pipe ID (in)	Equivalent Segment Length (ft)	Segment Hf (psi)	ΔElev (psi)	ΔP (psi)	Velocity (ft/s)	Reynol Numb
5.577	8.103	11	0.135	0.875	8.571	0.00053	0.00722	-0.00669	0.07196	49
5.570	8.096	10	0.270	0.875	8.571	0.00106	0.00722	-0.00616	0.14387	99
5.564	8.091	8	0.405	0.875	8.571	0.00159	0.00722	-0.00563	0.21573	148
5.558	8.085	6	0.540	0.875	8.571	0.00211	0.00722	-0.00510	0.28754	198
5.553	8.081	4	0.674	0.875	8.571	0.00477	0.00722	-0.00245	0.35931	247
5.551	8.078	2	0.809	0.875	8.571	0.00652	0.00722	-0.00070	0.43106	297
5.550	8.078	1	0.944	0.875	8.571	0.00850	0.00722	0.00128	0.50281	346
5.551	8.079	3	1.078	0.875	8.571	0.01069	0.00722	0.00348	0.57456	396
5.555	8.082	5	1.213	0.875	8.571	0.01310	0.00722	0.00588	0.64634	445
5.561	8.088	7	1.348	0.875	8.571	0.01571	0.00722	0.00850	0.71818	495
5.569	8.096	9	1.483	0.875	8.571	0.01853	0.00722	0.01131	0.79008	545
5.580	8.106	12	1.618	0.875	8.571	0.02154	0.00722	0.01433	0.86207	594
5.595	8.119	13	1.753	0.875	8.571	0.02475	0.00722	0.01754	0.93418	644
5.612	8.135	14	1.889	0.875	8.571	0.02816	0.00722	0.02094	1.00644	694
5.633	8.155	15	2.025	0.875	8.571	0.03176	0.00722	0.02455	1.07887	744
5.658	8.177	16	2.161	0.875	8.571	0.03556	0.00722	0.02834	1.15149	794
5.686	8.203	17	2.298	0.875	8.571	0.03954	0.00722	0.03233	1.22435	844
5.719	8.233	18	2.435	0.875	8.571	0.04373	0.00722	0.03651	1.29747	895
5.755	8.266	19	2.573	0.875	8.571	0.04811	0.00722	0.04090	1.37089	945
5.796	8.303	20	2.711	0.875	8.571	0.05269	0.00722	0.04548	1.44463	996
5.841	8.344	21	2.850	0.875	8.571	0.05748	0.00722	0.05026	1.51874	1047
5.892	8.389	22	2.990	0.875	8.571	0.06246	0.00722	0.05525	1.59325	1099
5.947	8.438	23	3.130	0.875	8.571	0.06766	0.00722	0.06044	1.66819	1150
6.007	8.492	24	3.272	0.875	8.571	0.07306	0.00722	0.06585	1.74361	1202
6.073	8.550	25	3.414	0.875	8.571	0.07869	0.00722	0.07147	1.81955	1255
6.145	8.612	26	3.558	0.875	8.571	0.08453	0.00722	0.07732	1.89604	1308
6.222	8.679	27	3.703	0.875	8.571	0.09060	0.00722	0.08339	1.97313	1361
6.305	8.751	28	3.848	0.875	8.571	0.09691	0.00722	0.08970	2.05085	1414
6.395	8.828	29	3.996	0.875	8.571	0.10345	0.00722	0.09624	2.12925	1468
6.491	8.909	30	4.144	0.875	8.571	0.11025	0.00722	0.10303	2.20838	1523
6.594	8.995	31	4.294	0.875	8.571	0.11729	0.00722	0.11008	2.28827	1578
6.704	9.087	32	4.445	0.875	8.571	0.12460	0.00722	0.11738	2.36898	1634
6.822	9.183	33	4.599	0.875	8.571	0.13218	0.00722	0.12496	2.45054	1690
6.947	9.284	34	4.753	0.875	8.571	0.14003	0.00722	0.13282	2.53300	1747
7.080	9.391	35	4.910	0.875	8.571	0.14818	0.00722	0.14097	2.61641	1805
7.221	9.503	36	5.068	0.875	8.571	0.15663	0.00722	0.14941	2.70081	1863

Downhill Bernoulli Table

APPENDIX C

RESULTS COMPARISON DATA

	Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Change ID	Hose Type:	Drip Tape		Max. pressure difference, psi	0.452	0.457	-0.0051	1.12
	Hose ID:	0.875	inches	Total friction, psi	0.778	0.779	-0.0010	0.13
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.029	-0.0290	0.58
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.656	4.693	-0.0373	0.79
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.646	4.684	-0.0377	0.81
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.173	2.182	-0.0091	0.42
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.048	1.049	-0.0004	0.04
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.257	0.258	-0.0006	0.23
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.271	-0.0012	0.44
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.434	0.435	-0.0013	0.29
	Nominal flow rate:	0.27	GPH	DUp:	0.990	0.990	0.0000	0.00
	Pressure of the above nominal flow rate:	5	psi	Dulq:	0.952	0.952	0.0001	0.01
	Emitter Discharge Exponent:	0.5						
	Desired inlet pressure:	5	psi					
	Hose Type:	Drip Tape		Max. pressure difference, psi	3.783	3.783	0.0002	0.01
	Hose ID:	0.5	inches	Total friction, psi	4.205	4.178	0.0274	0.66
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	4.969	0.0310	0.62
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	1.228	1.227	0.0009	0.07
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	2.030	1.917	0.1134	5.91
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	1.396	1.396	0.0000	0.00
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	2.039	2.045	-0.0055	0.27
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.132	0.131	0.0007	0.53
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.269	0.269	-0.0005	0.17
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.278	0.278	0.0000	0.01
	Nominal flow rate:	0.27	GPH	DUp:	0.790	0.790	0.0000	0.00
	Pressure of the above nominal flow rate:	5	psi	Dulq:	0.760	0.760	0.0001	0.01
	Emitter Discharge Exponent:	0.5						
	Desired inlet pressure:	5	psi					
	Hose Type:	Drip Tape		Max. pressure difference, psi	0.155	0.156	-0.0012	0.78
	Hose ID:	1	inches	Total friction, psi	0.436	0.436	0.0004	0.09
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.029	-0.0290	0.58
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.997	5.031	-0.0336	0.67
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.897	4.931	-0.0337	0.68
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.231	2.239	-0.0079	0.35
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.016	1.016	-0.0002	0.02
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.266	0.266	-0.0003	0.10
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.270	-0.0001	0.03
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.445	0.447	-0.0013	0.28
	Nominal flow rate:	0.27	GPH	DUp:	0.995	0.995	0.0000	0.00
	Pressure of the above nominal flow rate:	5	psi	Dulq:	0.957	0.957	0.0001	0.01
	Emitter Discharge Exponent:	0.5						
	Desired inlet pressure:	5	psi					
Change Length	Hose Type:	Drip Tape		Max. pressure difference, psi	0.009	0.008	0.0005	6.78
	Hose ID:	0.875	inches	Total friction, psi	0.000	0.000	0.0001	0.00
	Total Hose Length:	10	feet	Inlet pressure after hose inlet fittings, psi	4.999	5.000	-0.0007	0.01
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	5.009	5.008	0.0006	0.01
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	5.004	5.004	0.0004	0.01
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	0.050	0.050	0.0000	0.04
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.001	1.001	0.0000	0.00
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.270	0.270	0.0000	0.01
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.270	0.0002	0.09
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.450	0.450	0.0002	0.05
	Nominal flow rate:	0.27	GPH	DUp:	1.000	1.000	0.0001	0.01
	Pressure of the above nominal flow rate:	5	psi	Dulq:	0.962	0.962	0.0001	0.01
	Emitter Discharge Exponent:	0.5						
	Desired inlet pressure:	5	psi					
	Hose Type:	Drip Tape		Max. pressure difference, psi	3.267	3.278	-0.0112	0.34
	Hose ID:	0.875	inches	Total friction, psi	4.139	4.140	-0.0008	0.02
	Total Hose Length:	1200	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.000	-0.0003	0.01
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	1.900	1.905	-0.0047	0.25
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	2.427	2.365	0.0617	2.61
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	3.711	3.717	-0.0062	0.17
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.700	1.702	-0.0018	0.11
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.158	0.158	0.0005	0.31
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.269	0.270	-0.0005	0.20
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.309	0.308	0.0006	0.19
	Nominal flow rate:	0.27	GPH	DUQ	0.859	0.859	0.0001	0.01
	Pressure of the above nominal flow rate:	5	psi	DUhose	0.826	0.826	0.0001	0.01
	Emitter Discharge Exponent:	0.5						
	Desired inlet pressure:	5	psi					
Change Slope	Hose Type:	Drip Tape		Max. pressure difference, psi	0.738	0.738	-0.0003	0.04
	Hose ID:	0.875	inches	Total friction, psi	0.742	0.738	0.0038	0.52
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	4.989	0.0110	0.22
	Slope of Hose:	0	%	Downstream end pressure in the hose, psi	4.258	4.260	-0.0018	0.04
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.454	4.454	0.0002	0.01
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.127	2.128	-0.0006	0.03
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.083	1.083	-0.0004	0.04
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.249	0.249	0.0002	0.07
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.269	0.0008	0.29
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.425	0.423	0.0013	0.30
	Nominal flow rate:	0.27	GPH	DUQ	0.979	0.979	0.0000	0.00
	Pressure of the above nominal flow rate:	5	psi	DUhose	0.941	0.941	0.0000	0.00
	Emitter Discharge Exponent:	0.5						
	Desired inlet pressure:	5	psi					
	Hose Type:	Drip Tape		Max. pressure difference, psi	9.250	9.247	0.0027	0.03
	Hose ID:	0.875	inches	Total friction, psi	1.580	1.575	0.0055	0.35
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	4.999	5.029	-0.0298	0.59
	Slope of Hose:	5	%	Downstream end pressure in the hose, psi	14.263	14.281	-0.0181	0.13
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	9.301	9.120	0.1810	1.98
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	3.042	3.045	-0.0032	0.11
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.684	1.684	0.0001	0.00
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.271	0.270	0.0007	0.27
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.456	0.456	0.0000	0.00
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.607	0.607	0.0008	0.14
	Nominal flow rate:	0.27	GPH	DUQ	0.807	0.807	0.0005	0.07
	Pressure of the above nominal flow rate:	5	psi	DUhose	0.777	0.776	0.0005	0.07
	Emitter Discharge Exponent:	0.5						
	Desired inlet pressure:	5	psi					
	Hose Type:	Drip Tape		Max. pressure difference, psi	2.715	2.710	0.0052	0.19
	Hose ID:	0.875	inches	Total friction, psi	0.554	0.546	0.0080	1.47
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	4.960	0.0400	0.81
	Slope of Hose:	-1	%	Downstream end pressure in the hose, psi	2.277	2.249	0.0282	1.25
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	3.499	3.427	0.0721	2.10
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	1.874	1.867	0.0079	0.42
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.480	1.485	-0.0054	0.36
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.182	0.181	0.0012	0.67
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.268	0.0016	0.59
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.374	0.372	0.0024	0.65
	Nominal flow rate:	0.27	GPH	DUQ	0.858	0.857	0.0011	0.12
	Pressure of the above nominal flow rate:	5	psi	DUhose	0.826	0.825	0.0011	0.13
	Emitter Discharge Exponent:	0.5						
	Desired inlet pressure:	5	psi					

Change Temp

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.443	0.446	-0.0033	0.74
Hose ID:	0.875	inches	Total friction, psi	0.769	0.768	0.0009	0.12
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.019	-0.0190	0.38
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.665	4.693	-0.0282	0.60
Water Temp Entering Hose:	35	F	Pressure of emitter at average flow rate, psi	4.653	4.682	-0.0286	0.61
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.175	2.182	-0.0069	0.32
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.047	1.048	-0.0004	0.04
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.258	0.258	-0.0003	0.13
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.270	-0.0002	0.07
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.434	0.435	-0.0009	0.22
Nominal flow rate:	0.27	GPH	DUQ	0.990	0.990	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.952	0.952	0.0000	0.00
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.457	0.463	-0.0056	1.21
Hose ID:	0.875	inches	Total friction, psi	0.783	0.785	-0.0018	0.24
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.039	-0.0390	0.77
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.651	4.693	-0.0424	0.90
Water Temp Entering Hose:	150	F	Pressure of emitter at average flow rate, psi	4.642	4.685	-0.0429	0.92
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.172	2.183	-0.0104	0.48
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.049	1.049	-0.0005	0.05
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.257	0.258	-0.0007	0.29
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.271	-0.0012	0.44
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.434	0.435	-0.0015	0.34
Nominal flow rate:	0.27	GPH	DUQ	0.989	0.989	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.952	0.952	0.0001	0.01
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Change Expansion

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.439	0.442	-0.0025	0.57
Hose ID:	0.875	inches	Total friction, psi	0.764	0.763	0.0014	0.19
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.019	-0.0190	0.38
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.669	4.693	-0.0237	0.50
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.656	4.680	-0.0238	0.51
Extra Percentage of Hose Length for Expansion:	0	%	Hose inlet flow (GPM)	2.175	2.181	-0.0058	0.27
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.047	1.047	-0.0003	0.03
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.258	0.258	-0.0002	0.09
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.270	-0.0002	0.07
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.434	0.435	-0.0008	0.19
Nominal flow rate:	0.27	GPH	DUQ	0.990	0.990	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.952	0.952	0.0001	0.01
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.501	0.507	-0.0057	1.12
Hose ID:	0.875	inches	Total friction, psi	0.832	0.833	-0.0014	0.17
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.039	-0.0390	0.77
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.602	4.642	-0.0398	0.86
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.607	4.648	-0.0412	0.89
Extra Percentage of Hose Length for Expansion:	10	%	Hose inlet flow (GPM)	2.164	2.174	-0.0099	0.45
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.054	1.054	-0.0005	0.05
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.256	0.257	-0.0009	0.35
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.271	-0.0012	0.44
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.432	0.433	-0.0014	0.33
Nominal flow rate:	0.27	GPH	DUQ	0.988	0.988	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.951	0.951	0.0001	0.01
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Change Spacing

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.451	0.456	-0.0047	1.02
Hose ID:	0.875	inches	Total friction, psi	0.775	0.778	-0.0029	0.37
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.039	-0.0390	0.77
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.658	4.694	-0.0358	0.76
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.648	4.685	-0.0368	0.79
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.171	2.180	-0.0088	0.40
Emitter Spacing:	6	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.048	1.049	-0.0002	0.02
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.129	0.129	-0.0003	0.20
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.135	0.135	0.0000	0.03
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.434	0.433	0.0005	0.12
Nominal flow rate:	0.27	GPH	DUQ	0.990	0.990	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.952	0.952	0.0000	0.00
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.477	0.490	-0.0132	2.70
Hose ID:	0.875	inches	Total friction, psi	0.920	0.820	0.0999	12.18
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.009	-0.0090	0.18
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.535	4.626	-0.0913	1.97
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.547	4.641	-0.0942	2.03
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.253	2.276	-0.0235	1.03
Emitter Spacing:	300	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.044	1.053	-0.0092	0.87
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	6.354	6.420	-0.0655	1.02
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	6.631	6.759	-0.1278	1.89
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.428	0.434	-0.0053	1.21
Nominal flow rate:	0.27	GPH	DUQ	0.988	0.988	0.0001	0.01
Pressure of the above nominal flow rate:	5	psi	DUhose	0.950	0.950	0.0001	0.01
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Change CV

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.452	0.457	-0.0051	1.12
Hose ID:	0.875	inches	Total friction, psi	0.778	0.779	-0.0010	0.13
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.029	-0.0290	0.58
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.656	4.693	-0.0373	0.79
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.646	4.684	-0.0377	0.81
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.173	2.182	-0.0091	0.42
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.048	1.049	-0.0004	0.04
Manufacturing Coefficient (cv):	0		Minimum emitter flow rate, GPH	0.257	0.258	-0.0006	0.23
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.271	-0.0012	0.44
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.434	0.435	-0.0013	0.29
Nominal flow rate:	0.27	GPH	DUQ	0.990	0.990	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.990	0.990	0.0001	0.01
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.452	0.457	-0.0051	1.12
Hose ID:	0.875	inches	Total friction, psi	0.778	0.779	-0.0010	0.13
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.029	-0.0290	0.58
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.656	4.693	-0.0373	0.79
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.646	4.684	-0.0377	0.81
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.173	2.182	-0.0091	0.42
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.048	1.049	-0.0004	0.04
Manufacturing Coefficient (cv):	0.1		Minimum emitter flow rate, GPH	0.257	0.258	-0.0006	0.23
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.271	-0.0012	0.44
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.434	0.435	-0.0013	0.29
Nominal flow rate:	0.27	GPH	DUQ	0.990	0.990	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.864	0.864	0.0000	0.00
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Change Emitters per Plant

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.452	0.457	-0.0051	1.12
Hose ID:	0.875	inches	Total friction, psi	0.778	0.779	-0.0010	0.13
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.029	-0.0290	0.58
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.656	4.693	-0.0373	0.79
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.646	4.684	-0.0377	0.81
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.173	2.182	-0.0091	0.42
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.048	1.049	-0.0004	0.04
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.257	0.258	-0.0006	0.23
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.271	-0.0012	0.44
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.434	0.435	-0.0013	0.29
Nominal flow rate:	0.27	GPH	DUQ	0.990	0.990	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.952	0.952	0.0001	0.01
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.452	0.457	-0.0051	1.12
Hose ID:	0.875	inches	Total friction, psi	0.778	0.779	-0.0010	0.13
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.029	-0.0290	0.58
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.656	4.693	-0.0373	0.79
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.646	4.684	-0.0377	0.81
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.173	2.182	-0.0091	0.42
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.048	1.049	-0.0004	0.04
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.257	0.258	-0.0006	0.23
Number of emitters per plant:	10		Maximum emitter flow rate, GPH	0.270	0.271	-0.0012	0.44
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.434	0.435	-0.0013	0.29
Nominal flow rate:	0.27	GPH	DUQ	0.990	0.990	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.978	0.978	-0.0001	0.01
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Change Nominal Flow Rate

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.383	0.382	0.0010	0.27
Hose ID:	0.875	inches	Total friction, psi	0.050	0.050	0.0001	0.11
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.009	-0.0090	0.18
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	5.384	5.400	-0.0163	0.30
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	5.184	5.200	-0.0160	0.31
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	0.425	0.426	-0.0006	0.14
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.038	1.037	0.0001	0.01
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.050	0.050	0.0000	0.01
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.052	0.051	0.0009	1.73
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.085	0.083	0.0016	1.86
Nominal flow rate:	0.05	GPH	DUQ	0.986	0.986	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.949	0.949	0.0001	0.01
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	1.482	1.473	0.0095	0.64
Hose ID:	0.875	inches	Total friction, psi	1.858	1.838	0.0197	1.07
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	4.960	0.0400	0.81
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	3.576	3.557	0.0190	0.54
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	3.847	3.815	0.0323	0.85
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	3.657	3.647	0.0101	0.28
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.192	1.193	-0.0010	0.09
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.419	0.417	0.0018	0.43
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.499	0.498	0.0010	0.21
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.730	0.727	0.0032	0.44
Nominal flow rate:	0.5	GPH	DUQ	0.957	0.957	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.921	0.921	0.0000	0.00
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Change Nominal Pressure

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	1.938	1.959	-0.0210	1.07
Hose ID:	0.875	inches	Total friction, psi	2.324	2.332	-0.0082	0.35
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.039	-0.0390	0.77
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	3.110	3.142	-0.0321	1.02
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	3.499	3.516	-0.0175	0.50
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	4.205	4.228	-0.0228	0.54
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.277	1.279	-0.0016	0.13
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.471	0.474	-0.0025	0.53
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.602	0.606	-0.0038	0.62
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.839	0.843	-0.0043	0.51
Nominal flow rate:	0.27	GPH	DUQ	0.938	0.938	0.0001	0.01
Pressure of the above nominal flow rate:	1	psi	DUhose	0.902	0.902	0.0001	0.01
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.166	0.163	0.0027	1.63
Hose ID:	0.875	inches	Total friction, psi	0.449	0.443	0.0057	1.29
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	4.949	0.0508	1.03
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.985	4.945	0.0398	0.81
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.888	4.847	0.0408	0.84
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	1.576	1.570	0.0066	0.42
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.017	1.017	0.0000	0.00
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.188	0.186	0.0017	0.91
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.191	0.190	0.0009	0.45
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.315	0.312	0.0030	0.96
Nominal flow rate:	0.27	GPH	DUQ	0.995	0.995	0.0000	0.00
Pressure of the above nominal flow rate:	10	psi	DUhose	0.957	0.957	0.0001	0.01
Emitter Discharge Exponent:	0.5						
Desired inlet pressure:	5	psi					

Change Discharge Exponent

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.505	0.505	0.0004	0.07
Hose ID:	0.875	inches	Total friction, psi	0.836	0.831	0.0053	0.64
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.000	5.039	-0.0390	0.77
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.597	4.646	-0.0486	1.05
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.604	0.000	4.6039	#DIV/0!
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.254	2.254	0.0001	0.00
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.000	1.000	0.0000	0.00
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.270	0.269	0.0010	0.37
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.269	0.0010	0.37
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.450	0.448	0.0017	0.38
Nominal flow rate:	0.27	GPH	DUQ	1.000	1.000	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.962	0.962	0.0001	0.01
Emitter Discharge Exponent:	0						
Desired inlet pressure:	5	psi					

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		Max. pressure difference, psi	0.412	0.410	0.0021	0.52
Hose ID:	0.875	inches	Total friction, psi	0.734	0.728	0.0064	0.88
Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	5.001	4.980	0.0208	0.42
Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	4.700	4.693	0.0072	0.15
Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	4.679	4.671	0.0078	0.17
Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	2.110	2.106	0.0033	0.16
Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.089	1.090	-0.0004	0.04
Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.248	0.247	0.0006	0.25
Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.270	0.269	0.0007	0.26
Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.421	0.420	0.0010	0.25
Nominal flow rate:	0.27	GPH	DUQ	0.981	0.981	0.0000	0.00
Pressure of the above nominal flow rate:	5	psi	DUhose	0.944	0.944	0.0001	0.01
Emitter Discharge Exponent:	1						
Desired inlet pressure:	5	psi					

	Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)	
Change Inlet Pressure	Hose Type:	Drip Tape		Max. pressure difference, psi	0.376	0.371	0.0052	1.40	Original program would
	Hose ID:	0.875	inches	Total friction, psi	0.057	0.061	-0.0041	6.75	not go down to 0 psi inlet
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	0.000	0.039	-0.0390	100.10	pressure because the
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	0.377	0.414	-0.0372	8.98	inlet flow was so small
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	0.181	0.205	-0.0242	11.83	that it finished the
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	0.403	0.457	-0.0541	11.85	correction loop too soon.
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	16.927	3.095	13.8315	446.87	This resulted
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.004	0.025	-0.0206	82.48	exceptionally high flows
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.074	0.077	-0.0029	3.74	and pressures.
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.081	0.090	-0.0095	10.51	
	Nominal flow rate:	0.27	GPH	DUQ	0.495	0.634	-0.1387	21.88	
	Pressure of the above nominal flow rate:	5	psi	DUhose	0.476	0.610	-0.1334	21.88	
	Emitter Discharge Exponent:	0.5							
	Desired inlet pressure:	0	psi						
	Hose Type:	Drip Tape		Max. pressure difference, psi	1.039	1.044	-0.0046	0.44	
	Hose ID:	0.875	inches	Total friction, psi	1.401	1.398	0.0026	0.19	
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	9.999	10.039	-0.0398	0.40	
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	9.032	9.074	-0.0416	0.46	
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	9.188	9.229	-0.0410	0.44	
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	3.056	3.063	-0.0072	0.24	
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.056	1.056	-0.0003	0.03	
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.361	0.362	-0.0007	0.19	
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.382	0.382	-0.0004	0.11	
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.610	0.610	-0.0001	0.02	
	Nominal flow rate:	0.27	GPH	DUQ	0.988	0.988	0.0000	0.00	
	Pressure of the above nominal flow rate:	5	psi	DUhose	0.950	0.950	0.0001	0.01	
	Emitter Discharge Exponent:	0.5							
	Desired inlet pressure:	10	psi						
Change Desired Average Flow	Hose Type:	Drip Tape		Max. pressure difference, psi	0.282	0.279	0.0028	1.01	
	Hose ID:	0.875	inches	Total friction, psi	0.152	0.153	-0.0011	0.72	
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	0.577	0.589	-0.0115	1.95	
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	0.859	0.872	-0.0126	1.45	
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	0.685	0.696	-0.0111	1.60	
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	0.833	0.841	-0.0086	1.03	
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.220	1.212	0.0074	0.61	
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.092	0.093	-0.0012	1.32	
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.112	0.112	-0.0001	0.06	
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	0.166	0.167	-0.0004	0.21	
	Nominal flow rate:	0.27	GPH	DUQ	0.928	0.930	-0.0023	0.24	
	Pressure of the above nominal flow rate:	5	psi	DUhose	0.892	0.895	-0.0021	0.24	
	Emitter Discharge Exponent:	0.5							
	Desired average flow rate:	0.1	GPH						
	Hose Type:	Drip Tape		Max. pressure difference, psi	26.673	26.636	0.0370	0.14	
	Hose ID:	0.875	inches	Total friction, psi	27.243	27.055	0.1881	0.70	
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	294.237	293.639	0.5985	0.20	
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	267.428	267.023	0.4051	0.15	
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	274.409	273.942	0.4673	0.17	
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	16.700	16.688	0.0126	0.08	
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.048	1.049	-0.0002	0.02	
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	1.975	1.973	0.0016	0.08	
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	2.070	2.069	0.0012	0.06	
	Do you know emitter coefficient?	Yes		Avg. tape flow rate (GPM/100')	3.333	3.330	0.0031	0.09	
	Nominal flow rate:	0.27	GPH	DUQ	0.987	0.987	0.0000	0.00	
	Pressure of the above nominal flow rate:	5	psi	DUhose	0.950	0.950	0.0001	0.01	
	Emitter Discharge Exponent:	0.5							
	Desired average flow rate:	2	GPH						
Change Downstream Flush Pressure	Hose Type:	Drip Tape		Max. pressure difference, psi	4.091	4.099	-0.0078	0.19	Original program sets
	Hose ID:	0.875	inches	Total friction, psi	4.537	4.531	0.0052	0.11	desired Q = 0 so it
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	4.203	4.200	0.0029	0.07	bypasses the check
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	0.100	0.110	-0.0100	9.09	section leaving the d/s
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	1.886	1.686	0.2000	11.86	end pressure the input
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	4.117	4.123	-0.0055	0.13	pressure + 0.01 psi
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	6.464	6.185	0.2788	4.51	
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.038	0.040	-0.0019	4.65	
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.247	0.248	-0.0009	0.36	
	Do you know emitter coefficient?	Yes		Actual emitter average flow rate (GPH)	0.156	0.157	-0.0008	0.50	
	Nominal flow rate:	0.27	GPH	Avg. tape flow rate (GPM/100')	0.260	0.261	-0.0014	0.54	
	Pressure of the above nominal flow rate:	5	psi	Flow rate exiting hose during flushing (GPM)	2.814	2.814	0.0007	0.03	
	Emitter Discharge Exponent:	0.5							
	Pressure at downstream end during flushing:	0.1	psi						
	Desired flushing velocity:	1.5	ft/s						
	Hose Type:	Drip Tape		Max. pressure difference, psi	7.491	7.493	-0.0024	0.03	
	Hose ID:	0.875	inches	Total friction, psi	7.952	7.926	0.0257	0.32	
	Total Hose Length:	500	feet	Inlet pressure after hose inlet fittings, psi	17.518	17.500	0.0179	0.10	
	Slope of Hose:	0.2	%	Downstream end pressure in the hose, psi	10.000	10.010	-0.0100	0.10	
	Water Temp Entering Hose:	70	F	Pressure of emitter at average flow rate, psi	12.865	12.787	0.0781	0.61	
	Extra Percentage of Hose Length for Expansion:	2	%	Hose inlet flow (GPM)	6.418	6.419	-0.0015	0.02	
	Emitter Spacing:	12	inches	Ratio of abs. max. emitter flow to abs. minimum, QMAX/QMIN	1.321	1.322	-0.0008	0.06	
	Manufacturing Coefficient (cv):	0.03		Minimum emitter flow rate, GPH	0.382	0.382	-0.0002	0.04	
	Number of emitters per plant:	1		Maximum emitter flow rate, GPH	0.505	0.505	-0.0003	0.06	
	Do you know emitter coefficient?	Yes		Actual emitter average flow rate (GPH)	0.431	0.431	0.0005	0.11	
	Nominal flow rate:	0.27	GPH	Avg. tape flow rate (GPM/100')	0.719	0.718	0.0008	0.11	
	Pressure of the above nominal flow rate:	5	psi	Flow rate exiting hose during flushing (GPM)	2.814	2.814	0.0007	0.03	
	Emitter Discharge Exponent:	0.5							
	Pressure at downstream end during flushing:	10	psi						
	Desired flushing velocity:	1.5	ft/s						

Manifold Placement

Input			Output	New Program	Former Program	Difference Between Values	Percent Error (%)
Hose Type:	Drip Tape		The total length of hose (feet)	500	500	0.0000	0.00
Hose ID:	0.875	inches	The length of the downhill section of hose (feet)	350	350	0.0000	0.00
Total Hose Length:	500	feet	The length of the uphill section of hose (feet)	150	150	0.0000	0.00
Slope of Hose:	0.2	%	Max. pressure differential, psi	0.117	0.100	0.0170	17.02
Water Temp Entering Hose:	70	F	Inlet pressure after hose inlet fittings, psi	5.084	5.000	0.0837	1.67
Extra Percentage of Hose Length for Expansion:	2	%	Downstream end pressure in the downhill hose, psi	5.071	5.000	0.0714	1.43
Emitter Spacing:	12	inches	Downstream end pressure in the uphill hose, psi	4.924	4.900	0.0244	0.50
Manufacturing Coefficient (cv):	0.03		Pressure of emitter at average flow rate on downhill hose, psi	5.004	5.000	0.0040	0.08
Number of emitters per plant:	1		Pressure of emitter at average flow rate on uphill hose, psi	4.997	5.000	-0.0027	0.05
Do you know emitter coefficient?	Yes		Combined Hose inlet flow (GPM)	2.255	2.260	-0.0051	0.22
Nominal flow rate:	0.27	GPH	Minimum emitter flow rate for the uphill hose, GPH	0.268	0.268	0.0000	0.02
Pressure of the above nominal flow rate:	5	psi	Maximum emitter flow rate for the uphill hose, GPH	0.272	0.272	0.0002	0.06
Emitter Discharge Exponent:	0.5		Minimum emitter flow rate for the downhill hose, GPH	0.269	0.269	0.0001	0.02
Desired average flow rate:	0.27	GPH	Maximum emitter flow rate for the downhill hose, GPH	0.272	0.272	0.0002	0.06
			Avg. tape flow rate (GPM/100') for the uphill hose	0.450	0.450	0.0002	0.04
			Avg. tape flow rate (GPM/100') for the downhill hose	0.450	0.450	-0.0002	0.03
			DUQ	0.996	0.996	0.0001	0.01
			DUhose	0.958	0.950	0.0077	0.82
Hose Type:	Drip Tape		The total length of hose (feet)	2000	2000	0.0000	0.00
Hose ID:	0.875	inches	The length of the downhill section of hose (feet)	1040	1060	-20.0000	1.89
Total Hose Length:	2000	feet	The length of the uphill section of hose (feet)	960	940	20.0000	2.13
Slope of Hose:	0.2	%	Max. pressure differential, psi	4.736	5.330	-0.5939	11.14
Water Temp Entering Hose:	70	F	Inlet pressure after hose inlet fittings, psi	8.695	8.760	-0.0652	0.74
Extra Percentage of Hose Length for Expansion:	2	%	Downstream end pressure in the downhill hose, psi	4.063	4.039	0.0235	0.58
Emitter Spacing:	12	inches	Downstream end pressure in the uphill hose, psi	3.512	3.606	-0.0942	2.61
Manufacturing Coefficient (cv):	0.03		Pressure of emitter at average flow rate on downhill hose, psi	5.028	4.980	0.0484	0.97
Number of emitters per plant:	1		Pressure of emitter at average flow rate on uphill hose, psi	5.025	4.980	0.0449	0.90
Do you know emitter coefficient?	Yes		Combined Hose inlet flow (GPM)	8.951	8.993	-0.0426	0.47
Nominal flow rate:	0.27	GPH	Minimum emitter flow rate for the uphill hose, GPH	0.226	0.229	-0.0030	1.32
Pressure of the above nominal flow rate:	5	psi	Maximum emitter flow rate for the uphill hose, GPH	0.355	0.354	0.0016	0.46
Emitter Discharge Exponent:	0.5		Minimum emitter flow rate for the downhill hose, GPH	0.240	0.239	0.0007	0.30
Desired average flow rate:	0.27	GPH	Maximum emitter flow rate for the downhill hose, GPH	0.355	0.361	-0.0055	1.54
			Avg. tape flow rate (GPM/100') for the uphill hose	0.448	0.449	-0.0016	0.35
			Avg. tape flow rate (GPM/100') for the downhill hose	0.447	0.449	-0.0024	0.54
			DUQ	0.876	0.878	-0.0019	0.22
			DUhose	0.842	0.844	-0.0018	0.22
Hose Type:	Drip Tape		The total length of hose (feet)	1000	1000	0.0000	0.00
Hose ID:	0.875	inches	The length of the downhill section of hose (feet)	1000	1000	0.0000	0.00
Total Hose Length:	1000	feet	The length of the uphill section of hose (feet)	0	0	0.0000	#DIV/0!
Slope of Hose:	2	%	Max. pressure differential, psi	3.686	3.680	0.0061	0.17
Water Temp Entering Hose:	70	F	Inlet pressure after hose inlet fittings, psi	4.945	4.980	-0.0350	0.70
Extra Percentage of Hose Length for Expansion:	2	%	Downstream end pressure in the downhill hose, psi	7.720	7.734	-0.0140	0.18
Emitter Spacing:	12	inches	Downstream end pressure in the uphill hose, psi	0.000	5.000	-5.0000	100.00
Manufacturing Coefficient (cv):	0.03		Pressure of emitter at average flow rate on downhill hose, psi	5.048	5.010	0.0384	0.77
Number of emitters per plant:	1		Pressure of emitter at average flow rate on uphill hose, psi	No Uphill Section	5.000	#VALUE!	#VALUE!
Do you know emitter coefficient?	Yes		Combined Hose inlet flow (GPM)	4.503	4.516	-0.0133	0.29
Nominal flow rate:	0.27	GPH	Minimum emitter flow rate for the uphill hose, GPH	No Uphill Section	0.270	#VALUE!	#VALUE!
Pressure of the above nominal flow rate:	5	psi	Maximum emitter flow rate for the uphill hose, GPH	No Uphill Section	0.270	#VALUE!	#VALUE!
Emitter Discharge Exponent:	0.5		Minimum emitter flow rate for the downhill hose, GPH	0.243	0.243	-0.0006	0.25
Desired average flow rate:	0.27	GPH	Maximum emitter flow rate for the downhill hose, GPH	0.335	0.336	-0.0003	0.09
			Avg. tape flow rate (GPM/100') for the uphill hose	No Uphill Section	0.451	#VALUE!	#VALUE!
			Avg. tape flow rate (GPM/100') for the downhill hose	0.450	0.450	0.0000	0.01
			DUQ	0.904	0.904	-0.0005	0.06
			DUhose	0.869	0.870	-0.0005	0.06