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Go with the Flow

Simple Calculations for Small Drip Irrigation Systems

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While drip irrigation is relatively easy, information about it is often more complicated and confusing than it needs to be. Well-meaning professors and engineers use terms like "head" and "flow rate" without explaining exactly what they mean and how they are used. And it's often difficult to get help planning a small farm system in states without large irrigated acreages and irrigation traditions. The purpose of this bulletin is to help farmers understand the simple calculations involved in designing a small drip irrigation system.

We will discuss flow rates, pressures, pipe sizes, amount of drip tape, and pump size required for an acre of peppers, although it would be about the same for most vegetables, flowers, or other high-value horticultural crops. This example will help you better understand how to figure out the optimum layout of a small drip irrigation system.

Most of the calculations shown here are unnecessary if you know how to use tables and charts provided by irrigation supply companies and manufacturers; this discussion should help you better understand how to use those resources. *Don't be afraid of the math*—it's all simple arithmetic.

Peppers are usually grown on black plastic mulch with two rows per bed in beds 6 ft apart. A single drip line is used in the center of each bed between the two rows of peppers (drip lines are therefore also 6 ft apart). Let's say our field is 200 ft long with 36 beds or 216 ft wide (36 x 6 ft = 216 ft). We will irrigate from a pond which is below the level of our field (**Figure 1**).

The field is flat but is 15 ft above the pump; the pump is on a bank that is 8 ft above the pond. The pump is also 300 ft from the pepper field so our delivery or main line will need to be at least 300 ft long. We will also need a secondary pipe (called a submain) to run across the edge (or sometimes in the center) of the pepper field. The drip lines (also called drip "tape") will be connected to this submain line. Since our field is 216 ft wide we will need at least 216 ft of pipe for the submain.

Total System Flow

Each of our 36 rows is 200 ft long so we will need about 36 x 200 ft = 7,200 ft of drip tape. From the irrigation supply catalog or from the label on the roll of drip tape (**Figure 2**) we see that the flow rate of our tape is 0.5 gallons per minute (gpm) for each 100 ft of tape when the system is pressurized at 8 psi. So to determine our total flow in this one-acre plot through 7,200 ft of drip tape, first divide 7,200 ft by 100 = 72 and multiply the result by 0.5 gpm (72 x 0.5 gpm = 36

psi = pounds per square inch; normal pressure for drip tape is in the 8-15 psi range. Some tapes will function at pressures as low as 1-2 psi with gravity systems although flow will be much reduced so that longer irrigation times are required.

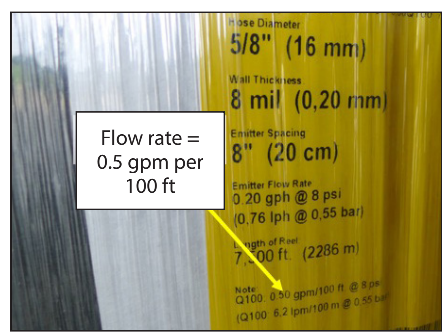


Figure 2. Flow rate in gallons per minute (gpm) per 100 ft of drip tape is indicated on the label attached to each roll of drip tape.

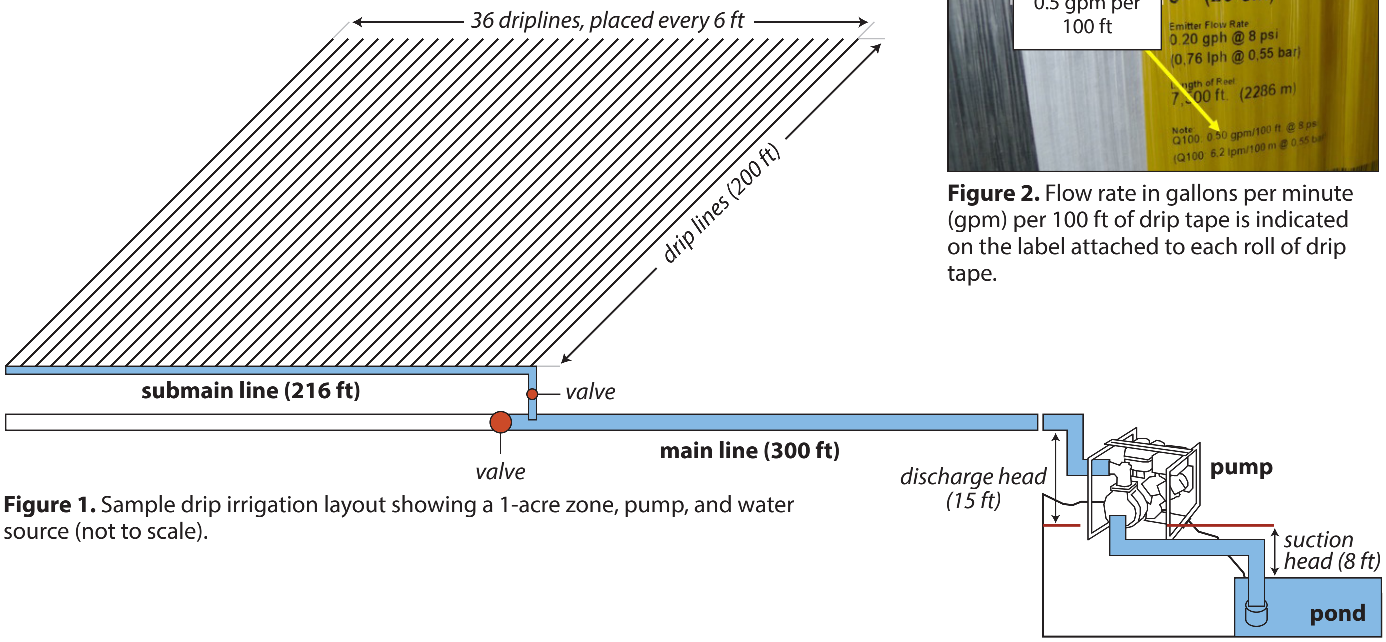


Figure 1. Sample drip irrigation layout showing a 1-acre zone, pump, and water source (not to scale).

gpm). To calculate gallons per hour (gph) simply multiply gpm by 60 minutes (36 gpm x 60 = 2,160 gph). Our pump will need to supply this much water at 10-15 psi pressure to the field's submain.

Pump Pressure and Flow

In pump and irrigation lingo, the term "head" is often used to indicate the maximum height which a pump can push water (**Figure 3a**). It's also used interchangeably with pressure or pressure losses in a system (i.e., "head losses"). Pressure can be expressed either as pounds per square inch (psi) or as the vertical height of a water column in feet:

2.31 ft height of elevated water = 1 psi pressure

Companies usually provide specifications that tell you how powerful a pump is. This is not only in terms of the motor's horsepower but the capacity of the pump to move water. Its pumping power is usually described in terms of maximum pressure (head) and flow rate. The *maximum head* or pressure of the pump is the maximum height to which it will pump water. If a pump's maximum head is 115 ft, it means that all of the pump's energy is used to pump water up to that height, and at that height it can push water no further, so its flow is zero (**Figure 3a**). On the other hand, a pump's *maximum flow rate* is the amount of water it discharges at its outlet (level surface, no head, **Figure 3b**). A pump with this information on its label is shown in **Figure 4**.

But in order to select the right pump, we need to know about its performance in between these two extremes. We need to know its flow rate at different pressures (or heads). Most pump makers provide this in the form of a table or graph. **Figure 5**, for example, is the performance curve for the pump shown in **Figure 4**.

The curve (blue line) shows that the pump's flow (horizontal axis) decreases as it is required to push water upwards to different heights (vertical axis). Flow decreases in the same way if the pump must move water through the restrictions of an irrigation system like pipes, pipe fittings, valves, filters, and injectors. This relationship is different for different pumps; **Figure 5** is just one example.

If you know, for example, that your irrigation setup requires a flow rate of 50 gallons per minute at 40 psi, this pump would be suitable as it will produce a flow of 50 gpm at 45 psi (follow the red

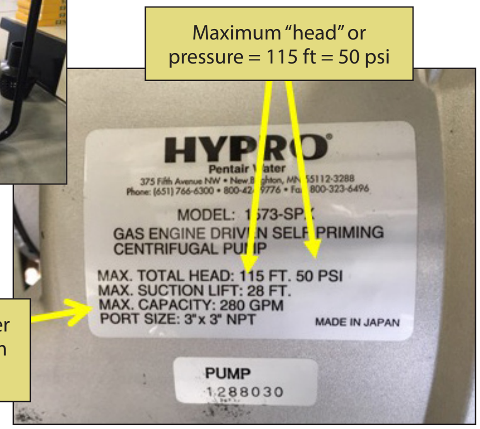


Figure 4. Label on a 6 HP gasoline engine pump showing its maximum head or pressure and its maximum flow rate with no head or pressure.

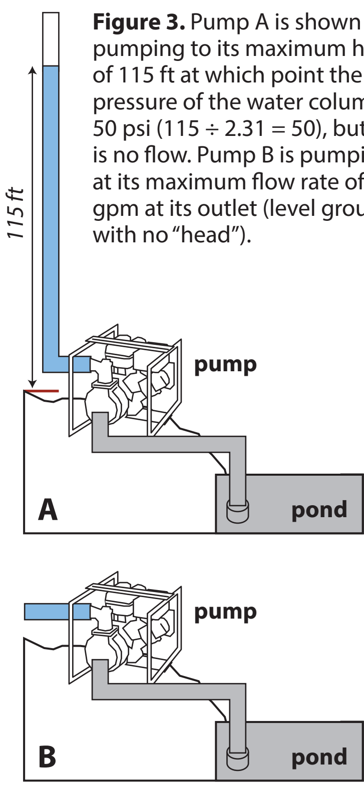
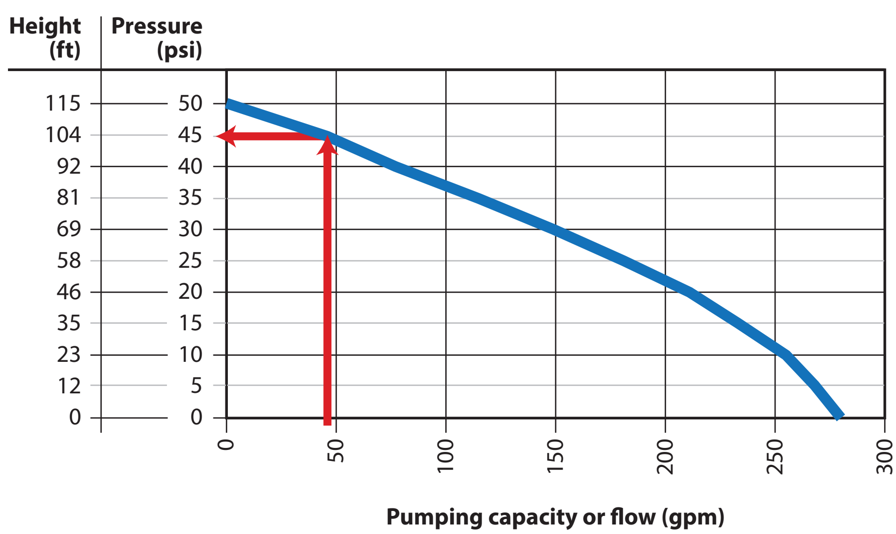


Figure 3. Pump A is shown pumping to its maximum height of 115 ft at which point the pressure of the water column is 50 psi (115 ÷ 2.31 = 50), but there is no flow. Pump B is pumping at its maximum flow rate of 280 gpm at its outlet (level ground with no "head").

Figure 5. Sample of a pump's performance curve. The blue line shows how much water this particular pump can move to a given height or "head". Head is expressed as height of a water column in feet or as pressure in psi. Note that the pump's flow rate decreases as it is required to pump to greater heights or as the head or pressure increases.



arrows in **Figure 5**). Excess pressure can be reduced at the submain with a pressure reducer.

System Pressure

But how do we know how much total water pressure is required for our acre of peppers? Pressure can be estimated for our example in **Figure 1**. First of all we require pressure to push up the 15 ft to the field from the pump and to pull water up from 8 ft below the pump. We add this "discharge head" and "suction head" together so that:

	ft				psi
discharge head:	15 ft	÷	2.31	=	6.49
suction head:	8 ft	÷	2.31	=	3.46
total:				=	9.95

> Most common suction pumps will not lift water more than 23 ft from the water's surface. This suction head is further limited by things such as check valves and filters between the water source and pump.

Next we add our system operating pressure required in the field (at the submain), which for drip should be around 10-15 psi:

9.95 psi (calculated above) + 15 psi = 25 psi

To this we must add pressure that will be needed to overcome friction through pipes, filters, injectors, etc. This type of information is often provided by the manufacturer or can be found in irrigation supply catalogs.

In our example we will use 300 ft of 2-inch layflat for the main line to the field. Knowing that our system flow rate is 36 gpm, we can use **Table 1** to find the friction loss for each 100 feet of this pipe.[1] Our flow rate is between 30 and 40 gpm, so we can estimate that our loss is a little less than the 1.1 psi indicated for 40 gpm flow in the table. Since the pressure loss is about 1 psi per 100 ft (blue box in the table), the loss for 300 ft of 2-inch layflat will be:

1 psi x (300 ÷ 100) or 1 x 3 = 3 psi

Table 1. Pressure losses (in psi) from friction in different diameters of layflat pipe (per 100 feet) at different flow rates.

Flow Rate (gpm)	Pipe Diameter					
	1.5″	2″	2.5″	3″	4″	6″
20	1.2					
30	2.4					
40	5.1	1.1				
50	6					
60		2.4	1.4			
80		4.1	1.9	1		
90	17					
100		6	2.8	1.2		
120				1.8		
140				2.2		
160				2.6	0.6	
180				3.3	0.7	
200		22	7		0.8	
220					1	
250				5		
280					1.4	0.2
300					1.6	0.2
350			22			
380						0.4
420						0.5
460						0.6
500					4	0.7
580				22		0.9
620						1

Courtesy Rain-Flo Irrigation, East Earl, PA

Although we could also use 2-inch layflat for the 216-ft-long submain in **Figure 1**, we instead chose to use 1½-inch layflat. Since our flow rate of 36 gpm lies between 30 and 40 gpm in **Table 1** (red box), our friction loss in the pipe is between 2.4 and 5.1 psi per 100 ft. Since the flow is closer to 40 gpm we'll use 4 psi as our loss per 100 feet of pipe; our total friction loss in 216 ft of 1½ in. layflat will be:

4 psi x (216 ÷ 100)
or
4 x 2.16 = 8.64 psi (about 9 psi)

Since water is being removed through each of the drip lines in the submain, a good rule of thumb is to divide our submain loss by 3 to obtain a more accurate estimate (9 psi ÷ 3 = 3 psi). We will now add this 3 psi to the 3 psi loss from the 2-inch main line above to the total. We will also need to include losses of 10 psi from the filter (as stated by the manufacturer) and 5 psi from a fertilizer injector.[2]

Now our total "head" or pressure requirement is:

	psi	
	25	*operating + discharge + suction head*
+	3	*loss from 300 ft of 2-inch layflat main*
+	3	*loss from 216 ft of 1½-inch layflat submain*
+	10	*filter*
+	5	*injector*
=	**46**	*total head or pressure required from the pump*

This 46 psi can be converted back to height of a water column by multiplying by 2.31, so

46 psi x 2.31 = 106 ft

[1] This table is only for layflat pipe; other types of delivery pipe like black oval hose or PVC will have different friction loss charts.

[2] Check with the manufacturer to find out the pressure losses for your filter and fertilizer injector.

At this point we can use the 46 psi (106 ft) pressure plus our system flow rate of 36 gpm to help select a pump based on dealer recommendations, catalog specifications and pump performance curves like the one in **Figure 5**. This same information can also be used to determine the size of pump we need using the following formula:

HP (horsepower)
= (flow x total head) ÷ (3,969 x 0.6)*

* This formula uses an assumed generic pump efficiency factor of 60%.

So for our example:

(36 gpm x 106 ft) ÷ (3,960 x 0.6)
= 3,816 ÷ 2,376
= **1.6 HP**

To allow for future crop expansion we might want to double this size or at least increase its power by 25% to a 2 HP pump (1.6 HP x 1.25 = 2 HP) or even a 4-5 HP pump. A safer approach is to discuss your needs with a knowledgeable dealer who has experience with pumps and irrigation who can also help you estimate the system flow rate and total head as in the example above. Keep in mind that horsepower is not as important as a pump's overall performance as indicated in graphs like the one in **Figure 5**. Beware of online or other pump purchases based on horsepower or flow rate without knowing the pump's performance characteristics.

This does not mean that this 2 HP pump is limited to an acre, but that you will only be able to irrigate an acre at a time; more one-acre zones could be added.

A "zone" is a section of the field or farm that you will irrigate all at one time, like the acre of peppers discussed in this bulletin. It is usually separated from other zones with valves as shown in **Figure 1**. Larger zone sizes will require larger diameter mains and submains and more pumping power.

Pipe Size Matters

In the above example we calculated friction losses in 1½-inch layflat pipe. Pipe size has a drastic effect on friction losses; the larger the pipe diameter, the lower the friction losses inside the pipe at any given flow rate. Even a small increase in pipe diameter can reduce friction and increase flow, especially in low pressure gravity-fed systems.

You may (or may not) remember from high school math that the area of a circle is equal to πr^2 or 3.1416 x the radius of a circle squared. When this is applied to pipes it becomes clear that doubling the pipe diameter more than doubles the area inside for water to flow. Doubling a pipe size from 1½-inch to 3-inch diameter, for example, results in four times the area for water to flow inside the pipe (**Figure 6**).

If you already know your system flow rate in gallons per minute you can also use **Table 2** to determine the optimum pipe size for your main or submains. If your system flow rate is 36 gpm, for example, the optimum pipe size would be 1½ inches (inside diameter).

But I already have a pump…

How do I know my optimum zone size?

Another approach to determining the optimum size of your drip layout for the most uniform water and fertilizer application is to measure the flow rate of the system you already have. First set up your pump and the other components of your system (main valve, filter, injector, main line, etc.). Work with an assistant to measure the flow rate at the end of a submain without the driplines attached.

Have the assistant open the valve(s) and use a watch or stopwatch to measure the time it takes to fill a 5-gallon bucket, 55-gallon drum, etc. If it takes 10 seconds to fill a 5-gal bucket, for example, your flow rate at that point in the system is 5 gal ÷ 0.17 min = 29.4 gallons per minute.[3]

This flow rate can now be used to determine your *maximum zone size*. Each zone is separated by valves (red dots in **Figure 1**) so that it can be irrigated separately. If we are using the drip tape described in the pepper example with a

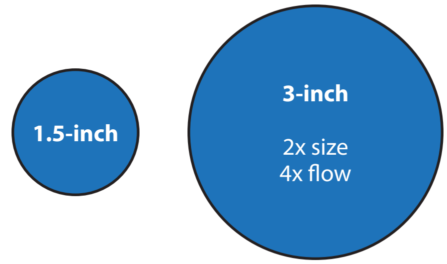


Figure 6. Doubling the pipe diameter results in four times the area inside the pipe and four times the flow.

flow rate of 0.5 gpm per 100 ft, we can estimate the maximum footage of drip tape that can be used for each zone. Simply divide the flow rate at the submain (29.4 gpm, calculated above) by the flow rate of the drip tape (0.5 gpm per 100 ft):

(29.4 gpm ÷ 0.5 gpm) x 100 ft
= 58.8 x 100 ft
= 5,880 ft of drip tape

This means you should not use more than 5,880 total feet of this particular drip tape in a zone and assumes your pump provides 10-15 psi pressure to the submain. If your rows are each 200 ft long, for example, you could have up to 29 rows of drip in a zone (5,880 ft ÷ 200 ft = 29.4). To be on the safe side you could also reduce this zone size by 25%, so 29 rows x 0.75 = 21 two-hundred-foot rows.

You can add more zones of the same size as long as they can be irrigated separately using valves. Keep in mind that additional zones may require a longer main and additional submains which in turn will require additional pressure and flow. These can be added to your total head calculations like those on Page 3.

Table 2. Optimum (most economical with minimal friction losses) pipe sizes for flow rates from 5 to 120 gallons per minute.

Flow (gpm)	Pipe diameter* (inches)
5	½
10	¾
15	1
25	1¼
35	1½
55	2
85	2½
120	3

*Inside diameter of schedule 40 PVC pipe with flow not exceeding a velocity of 5 ft/second.

[3] 10 seconds ÷ 60 sec = 0.17 minutes

Using Larger Zones

If you want to irrigate larger areas at one time of up to say, 3 acres, then you need to know the total flow rate for 3 acres. An acre is 43,560 square feet or roughly 208.7 ft x 208.7 ft. If your row-to-row spacing is 6 ft you will have 208.7 ÷ 6 = 34.7 or 34 rows. Since the 34 rows are 208.7 ft long you will have a total length of drip tape in the field equal to 34 x 208.7 ft = 7,096 ft.

In this example we will use the same drip tape with a flow rate of 0.5 gpm per 100 ft. So to calculate the total flow through 7,096 ft of drip tape, first divide 7,096 by 100 = 70.96. Multiply this result by the flow rate: 70.96 x 0.5 = 35.5 gpm for the whole acre. For three acres that is 35.5 gpm x 3 = 106.5 gpm. For a three-acre zone your pump will need to supply 106 gpm with pressures of 10-15 psi to the submain.

An easier way to determine the total length of drip tape required is to divide the number of square feet in an acre (43,560 sq. ft) by the spacing in feet between drip lines. So in our example 43,560 ÷ 6 ft = 7,260 ft of drip tape. Fortunately, you don't need to do these calculations as they have been done for you in charts such as **Table 3** (available from irrigation-supply dealers). The red arrows indicate the closest drip tape flow rate to our example (0.45 gpm per 100 ft) and a row-to-row spacing of 6 ft (72 in.). The total flow for an acre is where the two arrows meet at 33 gpm per acre which is slightly less than the 35.5 gpm calculated above.

While this publication doesn't contain all you need to know to set up a small drip system, it should be enough to get you started and help you understand more about flow rates, pressures, pumps, pipes, and plot sizes. See also:

- The UK Center for Crop Diversification's Water Resources web page, http://www.uky.edu/ccd/water
- UK publication HO-120: *Off the Grid: Ultra-low Pressure Drip Irrigation and Rainwater Catchment for Small Plots and High Tunnels*, http://www2.ca.uky.edu/agcomm/pubs/HO/HO120/HO120.pdf

Table 3. Flow rates in gallons per minute (gpm) per acre for drip tape. To use this table you will need to know your drip tape's flow rate per 100 ft and its emitter spacing, which are provided by the manufacturer (see **Figure 2**).

Select your row spacing in the left column to determine the amount of drip tape required per acre and its total flow rate per acre.

Row spacing (inch)	Drip tape/acre (ft)	Drip tape emitter spacing (inch)						
		8"	8"	12"	12"	16"	16"	24"
		Drip tape flow rate (gpm per 100 ft)						
		0.67	**0.34**	**0.45**	**0.22**	**0.34**	**0.17**	**0.28**
30	17,424	117	59	78	38	59	30	49
32	16,335	109	56	74	36	56	28	46
34	15,374	103	52	69	34	52	26	43
36 (3 ft)	14,520	97	49	65	32	49	25	41
38	13,756	92	47	62	30	47	23	39
40	13,068	88	44	59	29	44	22	37
42	12,446	83	42	56	27	42	21	35
44	11,880	80	40	53	26	40	20	33
46	11,363	76	39	51	25	39	19	32
48 (4 ft)	10,890	73	37	49	24	37	19	30
50	10,454	70	36	47	23	36	18	29
52	10,052	67	34	45	22	34	17	28
54	9,680	65	33	44	21	33	16	27
56	9,334	63	32	42	21	32	16	26
58	9,012	60	31	41	20	31	15	25
60 (5 ft)	8,712	58	30	39	19	30	15	24
62	8,431	56	29	38	19	29	14	24
64	8,168	55	28	37	18	28	14	23
66	7,920	53	27	36	17	27	13	22
68	7,687	52	26	35	17	26	13	22
70	7,467	50	25	34	16	25	13	21
72 (6 ft)	7,260	49	25	33	16	25	12	20
74	7,064	47	24	32	16	24	12	20
76	6,878	46	23	31	15	23	12	19
78	6,702	45	23	30	15	23	11	19
80	6,534	44	22	29	14	22	11	18
82	6,375	43	22	29	14	22	11	18
84 (7 ft)	6,223	42	21	28	14	21	11	17
86	6,078	41	21	27	13	21	10	17
88	5,940	40	20	27	13	20	10	17
90	5,808	39	20	26	13	20	10	16
92	5,682	38	19	26	13	19	10	16
94	5,561	37	19	25	12	19	9	16
96 (8 ft)	5,445	36	19	25	12	19	9	15
98	5,334	36	18	24	12	18	9	15
100	5,227	35	18	24	11	18	9	15

Courtesy Rain-Flo Irrigation, East Earl, PA

Acknowledgement

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Reference

Rowell, Brent. 5 Jan 2019. *Go with the Flow.* Kentucky Vegetable Growers Assn. Annual Meeting, Lexington, KY. Portions adapted from R.T. Jones and B. Rowell. 2001. *Drip Irrigation: Useful Information for Simple Installations.* Dept. Horticulture, University of Kentucky.

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