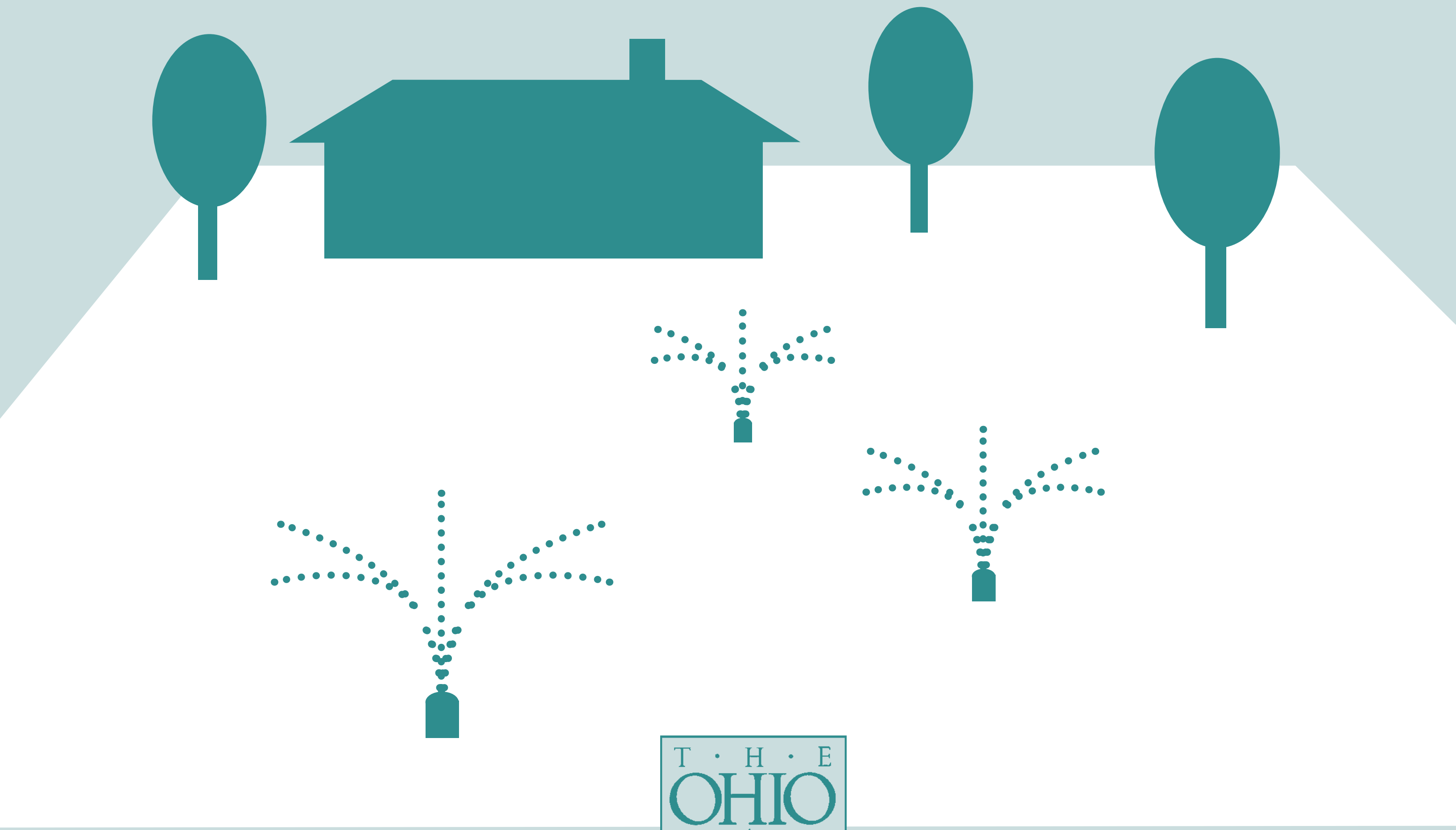
Bulletin 912

On-site Sprinkler Irrigation of Treated Wastewater In Ohio



THE OHIO STATE UNIVERSITY EXTENSION

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On-site Irrigation of Treated Wastewater

Introduction

On-site wastewater treatment systems collect, treat, and release about 225 million gallons of effluent per day from an estimated 1 million homes in Ohio (Source: U.S. Census Bureau, 1990). The most common on-site wastewater treatment systems are septic systems, consisting of a septic tank and a subsurface wastewater infiltration system (i.e., leachfield). These systems use soil as the medium for treatment and, according to the Household Sewage Rule (OAC 3701-29) (1977), require a minimum of 4 feet of soil depth to a limiting condition beneath the distribution point to ensure proper treatment. Figure 1 indicates the percentage of Ohio soils suited for wastewater treatment and disposal. Only 6.4% of the land area is suited for a septic tank/leachfield system. An alternative on-site treatment system is a septic tank/mound system where up to 2 feet of sand is used to aid in wastewater treatment. These systems require 2 feet of soil depth to a limiting condition beneath the sand layer to ensure proper treatment. In Ohio, only 25.4% of the land area is suited for a septic tank/mound system. Approximately 32% of Ohio's land area is suited for on-site wastewater treatment using these two options. Installing these systems in unsuited soils leads to incomplete wastewater treatment and the contamination of surface and ground water with nutrients and pathogens. This poses a significant risk to public health and safety.

Most of Ohio's soil natural resource is too shallow to use for wastewater treatment. For specific soil types refer to Ohio State University Extension Bulletin 896, *Suitability of Ohio Soils for Treating Wastewater.* Where sufficient soil depth for treatment is not present, irrigation of treated wastewater may provide an acceptable alternative provided the following conditions are met.

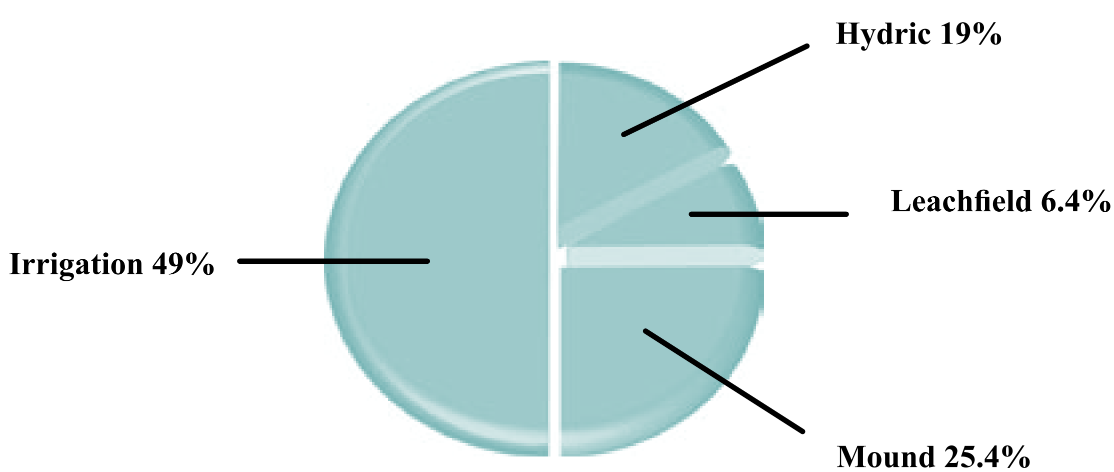


Figure 1. Soil Suitability of Ohio Soils

Condition 1: Irrigation systems require the wastewater be treated and disinfected before the effluent can be distributed to the soil. In order to eliminate odors, treatment should achieve a reduction of Carbonaceous Biochemical Oxygen Demand (CBOD) to 25 mg/L. To minimize health risks, a reduction of fecal coliform bacteria to 20 organisms/100 ml is recommended. This is a one-log reduction from the Bathing Beach Standard of 200 organisms/100 ml. These standards can be achieved by various treatment methods including stabilization ponds or sand bioreactors followed by disinfection. Commercially available bioreactors are also used. Consult OSU Extension Bulletin 876, *Sand Bioreactors for Wastewater Treatment in Ohio*, for more information on constructing sand bioreactors.

Condition 2: The site must have at least 1 foot of soil depth to a limiting condition (Box 1). Natural undisturbed soil is preferred but well-established fill of 20 to 30 years is acceptable if soil structure has been established. In Ohio, nearly 49% of the land area is suited for on-site treatment and dispersal systems. Site and soil investigations are required before a system is installed, to confirm adequate soil depth. Consult OSU Extension Bulletin 905, *Soil and Site Evaluation for On-site Wastewater Treatment,* for details on conducting a septic system site and soil evaluation.

Box 1. Limiting Conditions That Prevent or Short Circuit the Soil Treatment Process of Wastewater

- High water tables, with saturated soil conditions present near the soil surface.
- Restricted soil depth above dense, slowly permeable substratum materials including unfractured bedrock and dense glacial till.
- Restricted soil depth above dense slowly permeable subsurface soil layers including fragipans, compacted soil, and heavy clay materials.
- Other layers with inadequate permeability.
- Poor drainage conditions.
- Flooding.
- Presence of excessive amounts of rock in the soil.
- Fractured bedrock at shallow depths.
- Sandy soil with excessive permeability.
- Sand and gravel layers below finer textured soil materials.

Regulations and Permits

Permits for wastewater treatment systems are required by the Ohio Legislature under the Ohio Revised Code. The local health department issues permits for systems serving single-family homes, duplexes, or triplexes. Wastewater spray irrigation systems will require a variance from the local Board of Health with concurrence from the Ohio Department of Health.

Systems for all other building types require permits from the Ohio Environmental Protection Agency. They are issued through their district office. The Ohio Legislature now requires that an Ohio registered engineer design all systems permitted by state agencies.

Onsite wastewater irrigation system serving a 3-bedroom home at the OSU Molly Caren Agricultural Center near London, Ohio.

System Design

Step 1: Determine Wastewater Volume

Proper treatment of domestic wastewater is essential before irrigation can be considered. Several treatment options are available including stabilization ponds or sand or commercially available bioreactors followed by disinfection. For public access sites a $CBOD_5$ of less than 25 mg/L and fecal coliform bacteria count of less than 20 organisms/100 ml is recommended.

The first step in designing a system that will meet these requirements is to determine wastewater volume. This is done by identifying the number of bedrooms in the house and assuming 120 gallons of wastewater per bedroom per day. Table 1 shows the gallons per day of wastewater generated for one to five bedroom homes.

Bedrooms	Gallons
1	120
2	240
3	360
4	480
5	600

Table 1. Wastewater design volume.

Example: Step 1

Home has three bedrooms.

3 x 120 gals = 360 gallons

Wastewater volume = 360 gallons per day

Step 2: Calculate the Minimum Land Area Requirement

The amount of water that can safely be applied to the least permeable soil in Ohio is 0.2 inch per day. Applying more than 0.2 inch may result in water puddling or running off the site rather than just wetting the plants and infiltrating into the soil.

Each gallon of water requires approximately 8 square feet of area to insure proper infiltration. Table 2 shows the irrigation area requirement for one to five bedroom homes. See Box 2 for conversions of gallons to square feet.

Bedrooms	Gallons	Area (Square feet)
1	120	962.5
2	240	1925
3	360	2887.5
4	480	3850
5	600	4812.5

Table 2. Irrigation Area

Box 2. Conversion from Gallons to Square Feet

$$1 \text{ gal} \times \frac{231 \text{ in}^3}{\text{gal}} = 231 \text{ in}^3$$

$$\frac{231 \text{ in}^3}{0.2 \text{ in}} = 1155 \text{ in}^2$$

$$1155 \text{ in}^2 \times \frac{0.0069444 \text{ ft}^2}{\text{in}^2} = 8.021 \text{ ft}^2$$

Example: Step 2

Home has three bedrooms.

Wastewater volume = 360 gallons per day

360 x 8.021 ft = 2887.5 sq ft

Land area requirement = 2887.5 sq ft

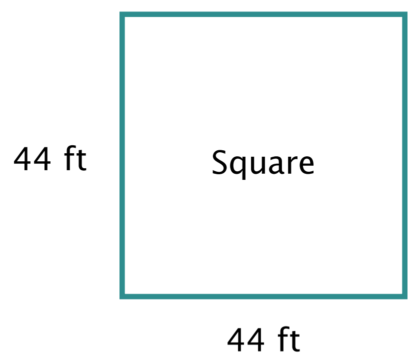
Remember to provide for a 10-foot setback from property lines and buildings. Water irrigation area must be at least 50 feet from a well, pond, or stream. Avoid spraying vegetable gardens or roadways.

Step 3: Determine the Dimensions of the Area to Be Irrigated

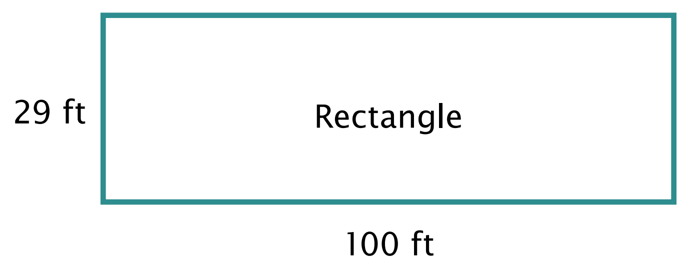
Spray areas typically consist of squares, rectangles, or combinations of both. Avoid spraying near vegetable gardens, buildings, ponds, and streams. All irrigated water must be kept at least 10 feet from property lines and 50 feet from drinking water wells.

Below are examples of typical shapes used in irrigation design based on the area required for 2, 3, and 4 bedroom homes.

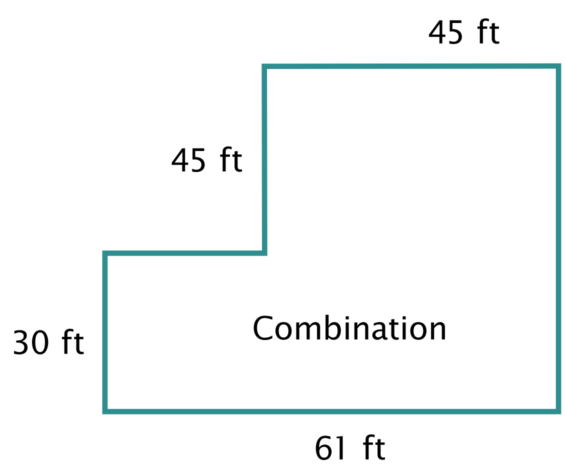
2 Bedroom (1925 sq ft) = 44 X 44 feet



3 Bedroom (2887.5 sq ft) = 29 X 100



4 Bedroom (3850 sq ft) = 30 X 61 sq ft
+ 45 X 45 sq ft

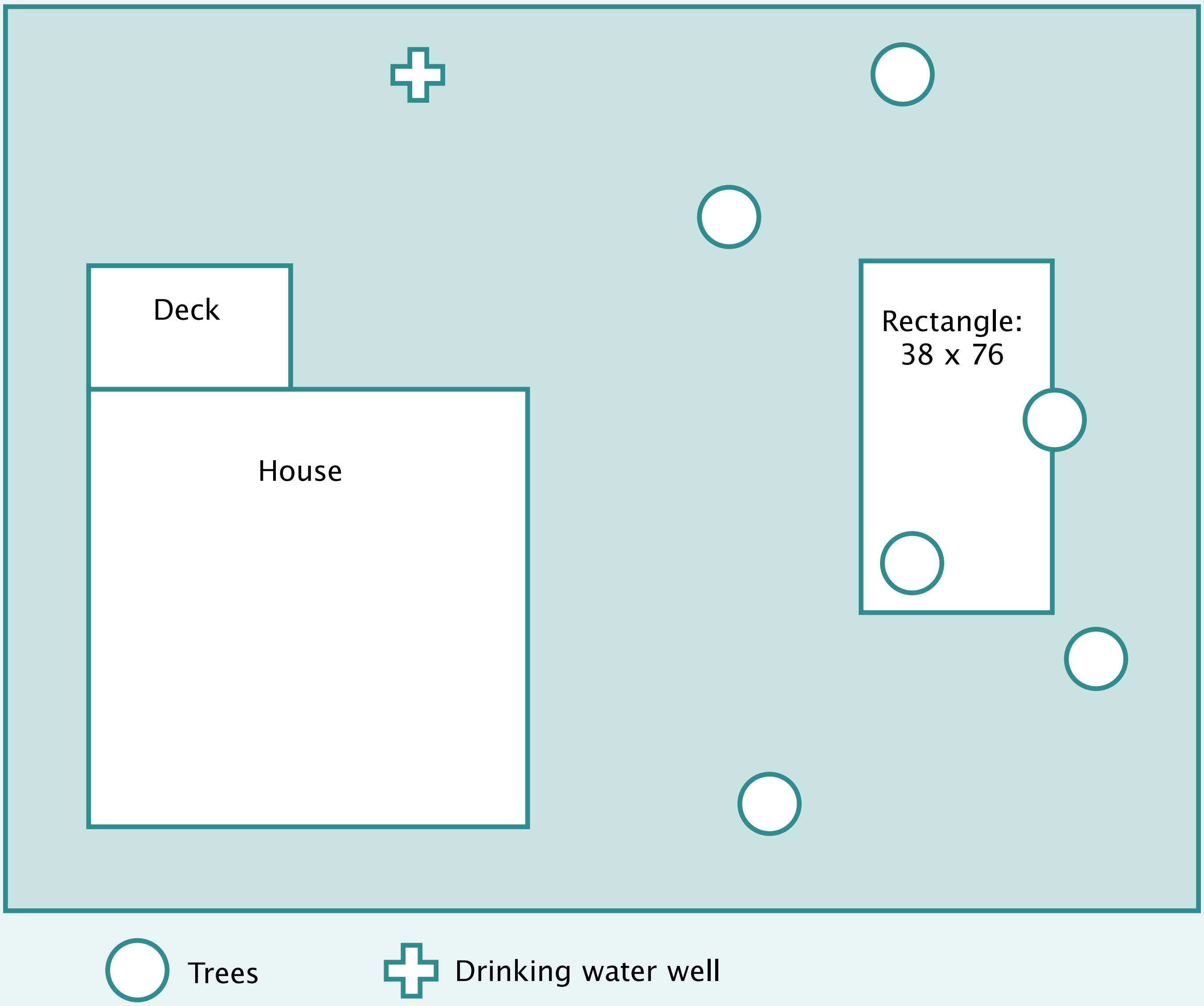


* *Drawings are not to scale*

Example: Step 3

Home has three bedrooms.

Land area requirement = 2887.5 sq ft



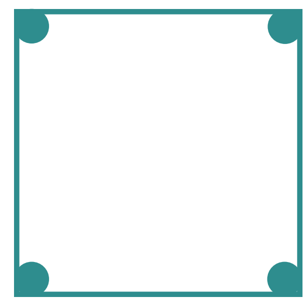
Land area required = 2887.5 sq ft

Land area provided = 2888 sq ft

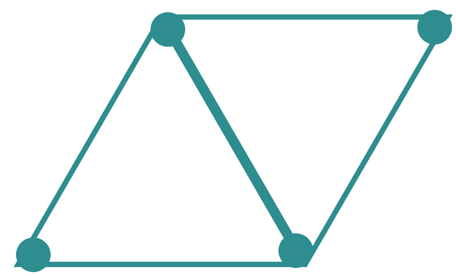
Dimensions: 38 ft x 76 ft

Step 4: Place Sprinkler Heads

The two approaches to sprinkler head placement are square spacing patterns and triangular spacing patterns.

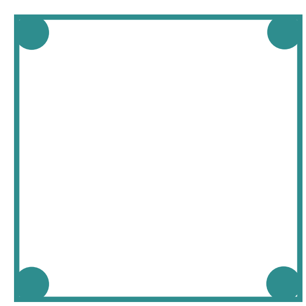


With **square spacing** the heads in one row are directly across from the heads in the adjacent row. In small landscape areas, square spacing provides the least amount of over-spray outside the irrigation area.



With **triangular spacing** the heads are positioned at the corners of an equilateral triangle. Triangular spacing provides a higher uniformity of coverage inside the irrigation area than does square spacing.

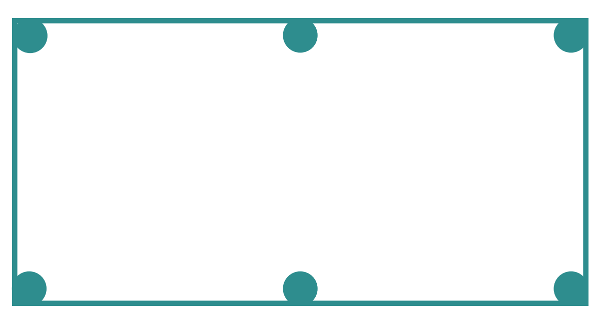
With both square and triangular spacing, heads should be placed to provide **head-to-head** coverage, meaning the spray area of one head reaches the next head.



30 ft X 30 ft

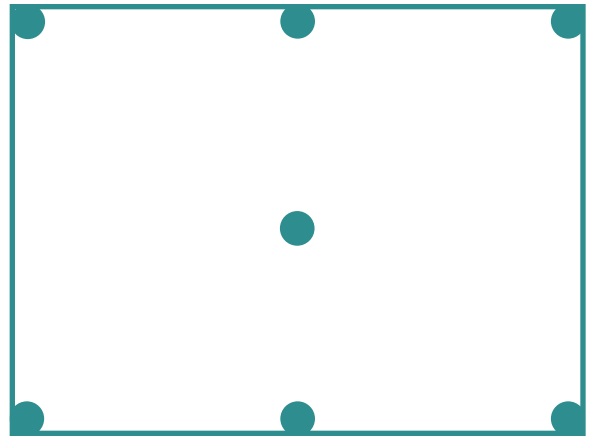
Begin placing sprinklers in the corners of the area to be irrigated. For square areas place four quarter-circle heads in the corners as shown.

If the quarter circle heads do not reach each other, place half circle heads along the perimeter.



30 ft X 60 ft

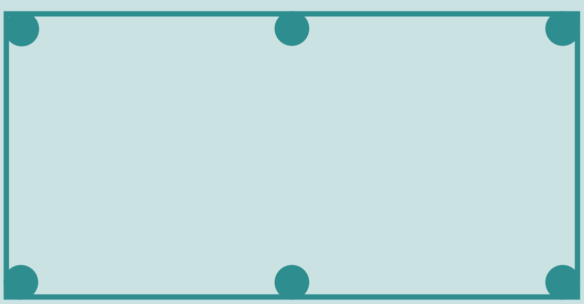
If the perimeter heads do not spray across the area to the heads on the other side, place full circle heads in the middle of the area.



45 ft X 60 ft

Example: Step 4

Sprinkler heads placed in a square pattern.



38 ft X 76 ft

Step 5: Select Sprinkler Heads

Selecting sprinkler heads for a system will require investigating various sprinkler models to find one with the characteristics best suited for the site and watering needs. The important information to the selection includes the operating pressure, flow range, precipitation rate, and the radius and arc of coverage. This information is found in the product catalogs provided by the sprinkler manufacturer. In addition, many sprinklers have special features (such as angles of trajectory and nozzle options), which may be important in the selection process. While no single head will work best in all wastewater applications, this bulletin will provide a step-by-step method for selecting a head that will provide proper application for the site.

Types of Sprinkler Heads

Three general types of sprinklers used for small residential irrigation projects are:

1. Bubblers
2. Sprays
3. Rotary Heads

All three types are suitable for traditional irrigation of potable water, however for irrigation with treated wastewater the first two should be avoided and the system should be designed using rotary heads (Figure 2).

Rotary heads provide a large spray radius (15-50 ft) and a relatively low gpm flow rate, which reduces the probability of puddling and runoff. Rotors also spray with more force, preventing clogging of the heads with particles or icing up in the winter. The heads should be installed on stationary risers (a minimum of 18 inches) to allow for continued application through the Ohio winter season. Higher risers may be needed in the high snowfall area of northeast Ohio.

Recommended for Wastewater Irrigation	Not Recommended for Wastewater Irrigation
Rotary Heads	Bubblers
	Spray Heads

Figure 2. Impact Drive and Gear Drive Rotary Sprinkler Heads

Selecting the Proper Sprinkler

Selecting the proper sprinkler for the project is a matter of analyzing the amount of water to be distributed and the area to be watered. Sprinkler selection will determine the pressure requirement, pump size, and irrigation run times. This may be an iterative process requiring several attempts before the right combination of these factors merge. The following guidelines will provide a general rule for sprinkler selection.

Guideline 1: Sprinkler Radius

Based on the application area geometry, how far does the sprinkler need to throw water? The system design should include head to head coverage, which means that the spray from one head reaches the next head (+/- 10%). As a general rule, using the largest radius sprinkler will result in less initial system cost. However, while rotors have the ability to spray up to 75-100 feet, a pump that can create the required pressure may be cost prohibitive for most projects. A radius of 35-50 feet is a reasonable starting point. For distances greater than 40 feet additional heads will be required. To avoid over-spray (spraying outside the application area) in areas with irregular perimeters, the shortest dimension should be considered when selecting the sprinkler spray radius.

Guideline 2: Flow Rate

The type and number of sprinklers on a zone will determine the required capacity of the pump used for the system. If a zone contains four sprinkler heads with 3 gpm flow rates, the pump will need to have a minimum capacity of 12 gpm. The flow rate of a system is controlled by selecting heads with specific flow rates and by separating heads into different zones. It is important to keep pump costs in mind and not oversize the zones of the system.

Guideline 3: Pressure Requirements

Operating pressure is the pressure that provides optimum sprinkler performance. Manufacturers establish the optimal pressures for their sprinklers and publish them in catalogs and product literature. As a general rule, greater throw radius requires greater pressure, which in turn requires a more powerful pump. Proper functioning of the sprinkler head requires that the dynamic pressure of the system meets or slightly exceeds the pressure specifications given for the sprinkler head. In addition to the pressure requirement of the sprinkler head, account for pressure losses due to elevation changes and friction in the piping system. Pressure loss calculations are discussed further in Step 8.

Guideline 4: Sprinkler Spray Pattern

Most sprinklers distribute water in a circular pattern. The "pattern" describes the portion of the full circle that is covered by the sprinkler. The pattern of some sprinklers is predetermined or "fixed," while the pattern of others is adjustable.

- The fixed arc patterns are set to portions of a circle such as 360° (full), 270° (two-thirds), 180° (one-half), 120° (one-third), and 90° (one-quarter). Other arcs may be available from some manufacturers.
- Adjustable arc sprinklers can be adjusted to any degree desired. This feature provides the flexibility to accommodate odd-shaped areas, as well as curves.

Guideline 5: Angles of Trajectory

The standard trajectory of most sprinklers ranges from 18° to 28°. The trajectory affects the throw radius and the precipitation rate of the sprinkler. For irrigating with treated wastewater consider using low trajectory sprinklers with angles of 13° to 15°. The lower trajectory shortens the throw distance radius of the head and increases the precipitation rate, but it also reduces the wind drift, which may be a concern when irrigating areas close to homes or other structures. Low angle heads also allow for spray under low hanging tree branches or large shrub foliage.

We Recycle

Irrigated with Reclaimed Water

Notes:

- Identify the systems as applying reclaimed water (non-potable). This can be accomplished by placing signs around the system or stickers on the sprinkler heads or both.
- Most sprinklers are designed so that the throw radius can be adjusted from 75% to 100% of the manufacturer's listed full radius. Typically, the radius can be reduced by up to 25% and still provide acceptable uniformity of water distribution. This is helpful in providing head to head coverage and in reducing over-spray.

Sprinkler head manufacturers publish specifications for sprinkler head optimal pressure, throw radius, and discharge flow rate (see Example: Step 5). Use this information to select sprinkler heads for the system.

Example: Step 5

Sprinkler type: rotor

Pressure: 30 psi

Spray radius: 38 ft

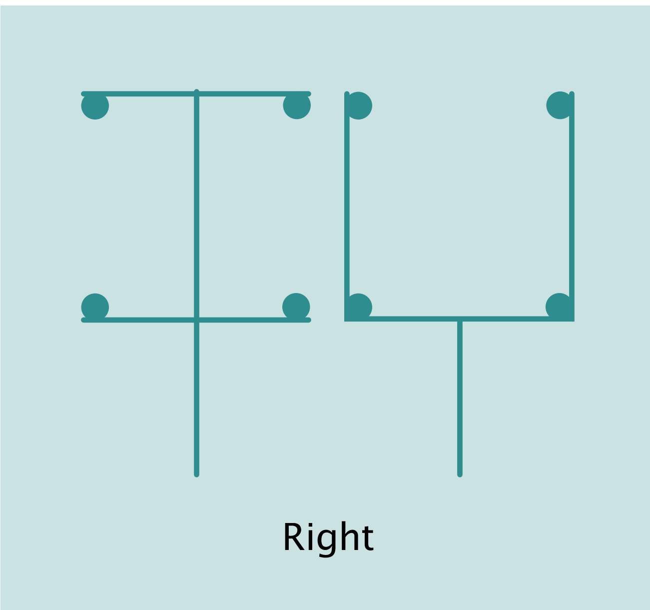
Flow rate: 2.4 gpm

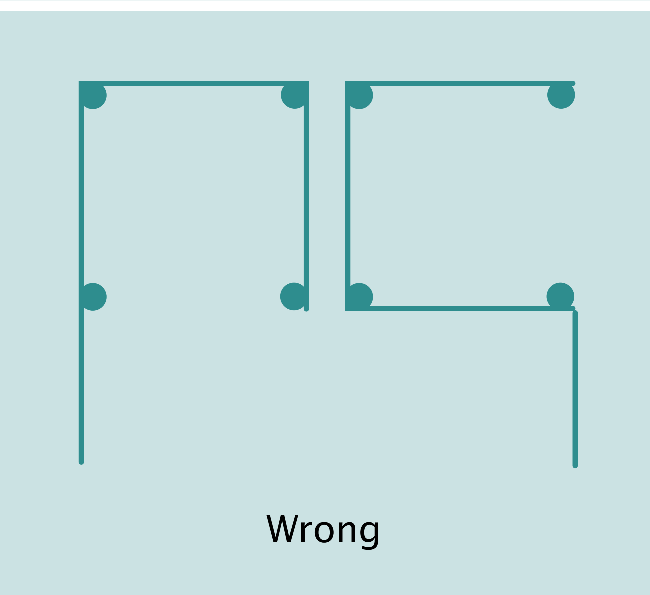
Sprinkler Head Performance

Pressure (psi)	Radius (ft)	Flow Rate (gpm)
30	38	2.4
40	40	3.1
50	41	3.4
60	42	3.7

Step 6: Layout and Sizing of Pipe

Selecting pipe and laying out the system depends on the sprinkler placement (Step 4) and sprinkler selection (Step 5). Smaller systems of 15 gpm (4-5 heads) can be treated as one zone whereas larger systems should be separated into multiple zones. The total zone gpm will determine the size and cost of the pump required to deliver the water.





Layout

Polyvinyl chloride (PVC) and polyethylene (Poly) pipe are commonly used for irrigation systems. Connect all sprinkler heads in each zone using the most direct route possible. Keep turns and changes in direction to a minimum.

Sizing Lateral Lines

For small residential installations it is standard practice to use the same size of Poly or PVC pipe for all lateral lines. It is important to use the proper size. Using too small a pipe will result in unacceptable friction losses, while using too large a pipe will result in reduced pressure and insufficient pipe scouring. **It is recommended that a velocity of greater than 2 feet/second is maintained throughout the pipe network to prevent the build-up of slime and bacterial growth.** Using pipe that is too large or too small will impair sprinkler head function.

Example: Step 6 illustrates how to size pipe based on flow rates. The procedure for proper sizing is outlined here.

1st Identify the gpm requirement of the furthest head from the zone valve based on Step 5. For systems with only one zone use the head furthest from the main line point of connection (POC).

2nd On a Friction Loss Chart (Figure 3) for the type of pipe selected, find the gpm amount from 1st item in the far left column.

3rd In that row, move right across the chart until a velocity of less than 5 feet per second is reached.

4th Move up that column to find the minimum pipe size necessary to carry the flow to this head.

5th Add the gpm requirement of the last and the next to the last head together to size the next pipe.

6th Find the total gpm in the 1st column of the Friction Loss Chart and repeat steps 3 and 4.

7th Continue this process until you reach the zone valve or main line POC.

8th Select the largest of the pipe sizes for the entire zone.

Notes:

Do not size pipe smaller than the chart indicates.

If the required pipe size becomes unrealistic (i.e., too large, too expensive, or not available), add more zones to the design.

Sizing Main Line

Size the main line using the Friction Loss Chart as described above. The main line must be large enough to handle the entire flow rate of the largest zone in the system without exceeding a velocity of 5 feet per second.

Figure 3. Friction Loss Chart

PVC Schedule 40 IPS Plastic Pipe

PSI loss per 100 feet of pipe
Size 1/2" through 2 1/2"
Flow GPM 1 through 75
Shading indicates that the 5 ft/sec maximum velocity has been exceeded.

size (in)	**1/2**		**3/4**		**1**		**1 1/4**		**1 1/2**		**2**		**2 1/2**	
ID (in)	0.622		0.824		1.049		1.380		1.610		2.067		2.469	
Flow	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**
(gpm)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)
1	1.05	0.43	0.60	0.11	0.37	0.03	0.21	0.01	0.15	0.00				
2	2.11	1.55	1.20	0.39	[illegible]	0.12	0.42	0.03	0.31	0.02	0.19	0.00		
3	3.16	3.28	1.80	0.84	[illegible]	0.26	0.64	0.07	0.47	0.03	0.28	0.01	0.20	0.00
4	4.22	5.60	2.40	1.42	[illegible]	0.44	0.85	0.12	0.62	0.05	0.38	0.02	0.26	0.01
5	5.27	8.46	3.00	2.15	1.85	0.66	1.07	0.18	0.78	0.08	0.47	0.02	0.33	0.01
6			3.60	3.02	2.22	0.93	1.28	0.25	0.94	0.12	0.57	0.03	0.40	0.01
7			[illegible]	4.01	2.59	1.24	1.49	0.33	1.10	0.15	0.66	0.05	0.46	0.02
8			[illegible]	5.14	2.96	1.59	1.71	0.42	1.25	0.20	0.76	0.06	0.53	0.02
9			5.40	6.39	3.33	1.97	1.92	0.52	1.41	0.25	0.85	0.07	0.60	0.03
10					3.70	2.40	2.14	0.63	1.57	0.30	0.95	0.09	0.66	0.04
11					4.07	2.86	2.35	0.75	1.73	0.36	1.05	0.11	0.73	0.04
12					4.44	3.36	2.57	0.89	1.88	0.42	1.14	0.12	0.80	0.05
14					5.19	4.47	2.99	1.18	2.20	0.56	1.33	0.17	0.93	0.07
16							3.42	1.51	2.51	0.71	1.52	0.21	1.07	0.09
18							3.85	1.88	2.83	0.89	1.71	0.26	1.20	0.11
20							4.28	2.28	3.14	1.08	1.90	0.32	1.33	0.13
22							4.71	2.72	3.46	1.29	2.10	0.38	1.47	0.16
24							5.14	3.20	3.77	1.51	2.29	0.45	1.60	0.19
26									4.09	1.75	2.48	0.52	1.74	0.22
28									4.40	2.01	2.67	0.60	1.87	0.25
30									4.72	2.28	2.86	0.68	2.00	0.29
35									5.50	3.04	3.34	0.90	2.34	0.38
40											3.81	1.15	2.67	0.49
45											4.29	1.43	3.01	0.60
50											4.77	1.74	3.34	0.73
55											5.25	2.08	3.68	0.88
60													4.01	1.03
65													4.35	1.19
70													4.68	1.37
75													5.01	1.56

Example: Step 6

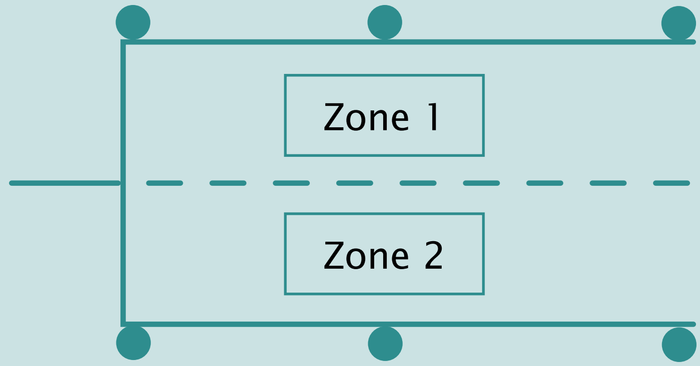
Lateral Lines

1st—gpm of furthest head = 2.4 gpm
2nd—3 gpm on Friction Loss Chart
3rd—3.16 ft/sec
4th—Minimum nominal pipe size is 1/2 inch.
5th—gpm total (2.4 + 2.4) = 4.8 gpm

Repeat 2nd—5 gpm on Friction Loss Chart
Repeat 3rd—3.0 ft/sec
Repeat 4th—minimum nominal pipe size is 3/4 inch.
Repeat 5th—gpm total (4.8 + 2.4) = 7.2 gpm

Repeat 2nd—8 gpm on Friction Loss Chart
Repeat 3rd—4.8 ft/sec
Repeat 4th—minimum nominal pipe size is 3/4 inch.

For this example, 3/4 inch PVC schedule 40 pipe will be used for all lateral lines in zone 1 and zone 2.



Main Line

Since the area is divided into two zones, the total gpm of each zone is 7.2 gpm. Using the Friction Loss Chart as described above, the minimum nominal size of the main line is 3/4 inch.

If the area was considered one zone, the total gpm would be 14.2 gpm. This design would require a minimum nominal pipe size of 1 1/4 inch.

For quick pipe sizing use the following summary chart based on flow rates of 5 feet per second.

Pipe Sizing Chart			
Maximum Flow Rates			
Pipe Size	PVC Schedule 40	PVC Class 200	Polyethylene
3/4 inch	8 GPM	10 GPM	8 GPM
1 inch	13 GPM	16 GPM	13 GPM
1 1/4 inch	23 GPM	26 GPM	23 GPM

Step 7: Establish Zones and Select Valves

Dividing an irrigation system into zones can reduce the flow requirement of the irrigation system and reduce the size and cost of the pump used to operate the system. A zone is a section of the irrigation system where the valves, piping system, and spray heads are operated at the same time.

Matched Precipitation

To insure even distribution of wastewater, a single zone must have the same sprinkler heads with the same precipitation rate throughout. Matched precipitation heads are recommended to ensure that wastewater is evenly applied to avoid ponding and surface runoff. Matched precipitation means that sprinkler heads apply the same depth of water regardless of the spray pattern. This can be accomplished by selecting the proper sprinkler head or by swapping the sprinkler nozzle (see **Step 5**). If a full circle spray head puts out 4 gpm, the 180° spray head should put out 2 gpm and the 90° spray head should put out 1 gpm. All of these spray heads can be located in the same zone and still provide even coverage of the application area.

Creating Zones

Zones are created using valves. For wastewater irrigation, electrically actuated diaphragm valves are used. While a variety of manual valves exist and may be appropriate for traditional irrigation systems, they will not work in wastewater applications where water must be irrigated at the same rate that it is generated. The programmable control unit will determine when the valves open and close by sending a 24-volt signal creating a magnetic field that moves a small metal plunger inside the valve.

Diaphragm valves are available as either normally open (NO) or normally closed (NC) models. In NC models, the valve is closed whenever a signal is not being received from the controller. The NC valve is preferred in wastewater irrigation systems to ensure that wastewater is not sprayed during a malfunction of the controller or wiring network.

Selecting the Right Valve

Selecting the proper size diaphragm valve is essential for the valve to operate correctly. Each model has a minimum flow rate. It is important to consult the manufacturer's specifications and select a valve that works well at the designed flow rate.

Example: Step 7

Number of zones created: 2

Valves selected: 3/4 inch 24 volt plastic globe valve with manual shutoff

Step 8: Calculate Pressure Losses

For an on-site wastewater irrigation system, water pressure is created by the distribution pump. Calculating pressure losses is necessary for determining the appropriate size pump. The total pressure loss in the system results from the combined losses due to elevation changes and friction.

Losses Due to Elevation Change

Water pressure can be expressed as either "psi" (pounds of pressure per square inch) or "feet of head." A column of water 1 foot high exerts 0.433 psi at the bottom and therefore 1 psi is equivalent to 2.31 feet of head. This means that for every foot of elevation change from the pump to the sprinkler heads, the corresponding change in pressure will be 0.433 psi.

> 1 foot of head = 0.433 psi
>
> 1.0 psi = 2.31 feet of head

Losses Due to Friction

As water moves through the irrigation system, pressure losses occur due to water contact with pipes, valves, and fittings. The four factors that determine friction losses in pipe are:

1. **The velocity of the water:** Water velocity is measured in feet per second. As velocity increases, pressure losses increase. Velocity is directly related to flow rate. An increase or decrease in flow rate will result in a corresponding increase or decrease in velocity. For irrigation systems, the velocity should never exceed 5 feet per second. At velocities greater than 5 feet per second, the friction losses become prohibitive.
2. **The size (inside diameter) of the pipe:** Smaller pipe causes a greater proportion of the water to be in contact with the pipe, which creates friction. Pipe size also affects velocity. Given a constant flow rate, decreasing pipe size increases the water's velocity, which increases friction.
3. **The roughness of the inside of the pipe:** Pipe inside wall roughness is rated by a "C" factor, which is provided by the manufacturer. The lower the C value, the rougher the inside and the more pressure loss due to friction.
4. **The length of the pipe:** The friction losses are cumulative as the water travels through the length of pipe. The greater the distance, the greater the friction losses will be.

Friction Losses Due to Valves, Fittings, and Other Components

The friction losses for couplings, elbows, and tees are given in Appendix B. Friction loss from these components must be accounted for when calculating friction losses for each section of pipe. Add the equivalent length of pipe for each fitting or valve that occurs in each section of the lateral and main lines.

Consult the manufacturer's literature for friction losses through valves, regulators, filters, and other components not listed. Several formulas have been developed to calculate friction losses in irrigation systems and, for convenience, friction loss charts based on these formulas are listed.

Friction Losses in Lateral Lines

Using the pipe layout plan with the pipe size and the gpm requirements for each sprinkler head clearly labeled, begin calculating the pressure losses as follows:

1st Determine the gpm flow rate of the furthest sprinkler head from the mainline connection.

2nd Locate the gpm value in the "FLOW" column on the Friction Loss Table.

3rd Across the top of the table locate the pipe size (inside diameter) of the pipe that supplies this sprinkler head with water.

4th Move down this column and across the row for the gpm value to the corresponding "psi loss," given per 100 feet of pipe. Divide this number by one hundred for the per foot pressure loss.

5th Locate any fittings in this section and determine the corresponding equivalent length of pipe from Appendix B. Add this number to the actual length of the pipe in this section to determine the effective pipe length.

6th Multiply the per foot pressure loss value by the effective length of the pipe supplying this sprinkler head only (from this head to the next head in the zone).

7th Record this information on the Friction Loss Worksheet (Appendix C).

Note the gpm flow rate of the next to the last head on this same zone. Add this gpm to the previous head gpm to determine the total amount of water flowing though this section of pipe. Repeat steps 2-6. Continue adding consecutive sprinkler heads and calculating friction losses using steps 2-6 until every section of pipe is accounted for. If the system contains multiple zones, calculate friction losses for each zone but use only the zone with the greatest friction loss to determine total friction losses in the system.

Friction Losses in the Main Line

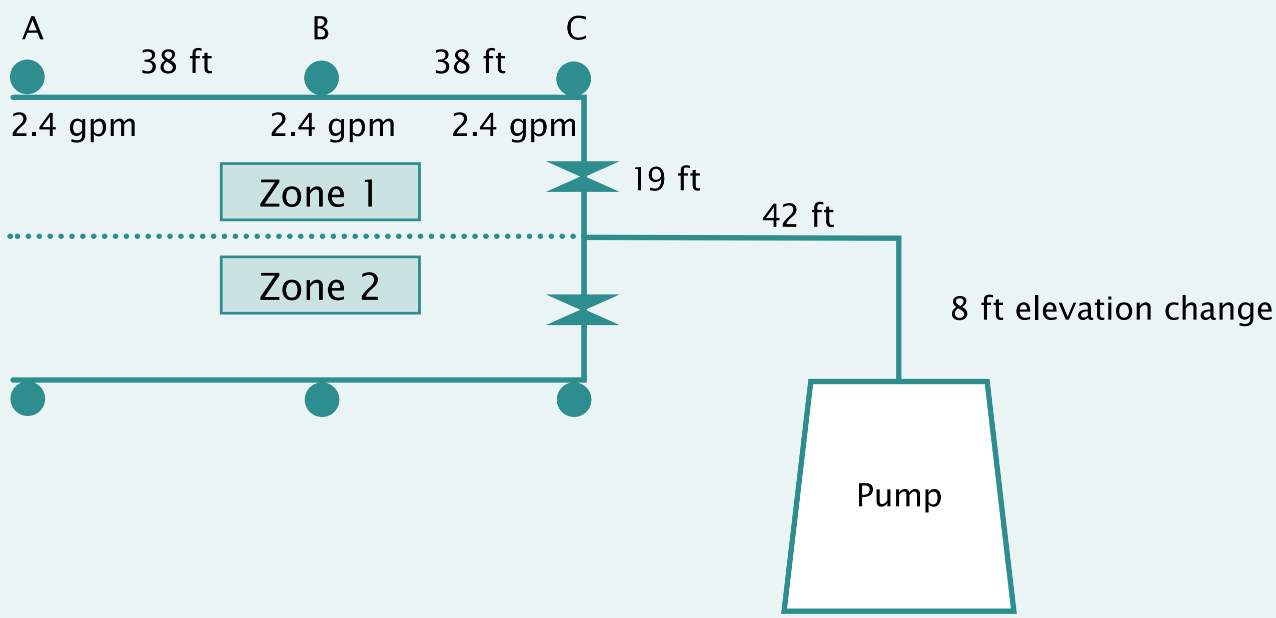
Use the total gpm flow rate for the zone to calculate the friction loss through the main line using the same procedure as described above. If the mainline size or pipe material is different from the laterals, be sure to use the appropriate Friction Loss Table.

Total Friction Losses

Add the friction losses for all lateral lines, main lines, and other components in the system all the way back to the pump. Add this to the pressure loss due to elevation change from the pump to the highest sprinkler head in the system. This total added to the operating pressure of the sprinkler heads will determine the pump requirements to ensure the proper operation of all the sprinkler heads in the system.

Example: Step 8

Using PVC schedule 40, 3/4 in. plastic pipe.



To calculate the friction loss from A to B:

1st The gpm of the furthest head (A) is 2.4.

2nd In the "Flow" column on the friction loss chart 2.4 falls between 2 gpm and 3 gpm.

3rd At the top of the chart find the 3/4 inch pipe size.

4th Move down this column and across the row for 3 gpm to the corresponding psi loss, (0.84). Interpolate the figures on the chart for more precise values. The interpolated friction loss value is 0.57. Divide by 100 to get 0.0057 psi/ft.

5th No fittings or valves are in this section, therefore the effective length is the length of the pipe itself. Multiply the per foot pressure loss value by the length of pipe supplying this sprinkler head. 0.0057 X 38 = 0.22

6th Record this information on the Friction Loss Worksheet.

To calculate the friction loss from B to C:

1st Add the gpm flow rate of the last two heads in this zone. 2.4 + 2.4 = 4.8 Repeat steps 2-6.

2nd Between 4 and 5 gpm

3rd 3/4 inch

4th 2.0/100 = 0.02 psi/ft

5th 0.02 X 38 = 0.76

6th Record these figures on the Friction Loss Worksheet.

Example: Step 8 Continued

To calculate the friction loss from C to the automatic control valve:

1st Determine the total gpm for Zone 1.
2.4 + 2.4 + 2.4 = 7.2
Repeat steps 2-6.

2nd Between 7 and 8 gpm

3rd 3/4 inch

4th 4.24/100 = 0.0424

5th A 90º elbow occurs in this section. This represents an additional 4.5 feet of pipe length. Add this to the 19 feet of actual pipe to determine the effective pipe length and multiply this number by the per foot pressure loss. 0.0424 X 23.5 = 1.0 psi

6th Record these figures on the Friction Loss Worksheet.

To calculate losses in the main line:

1st Use the gpm of the largest zone in the entire system. In this example, Zone 1 and Zone 2 are identical; therefore, it is not necessary to calculate both zones. Repeat steps 2-6.

2nd Between 7 and 8 gpm

3rd 3/4 inch

4th 0.0424/100 = 0.0424 psi/ft

5th This section of pipe includes a 90º elbow and a standard T fitting. The elbow adds 4.5 feet and the T fitting adds 3 feet. Therefore, the effective pipe length is 57.5 feet. 0.0424 X 57.5 = 2.44 psi

According to the manufacturer's specifications, pressure loss due to the control valve for this zone is 3 psi.

6th Record these figures on the Friction Loss Worksheet.

Calculate pressure losses due to changes in elevation:

8 ft X 0.433 psi/ft = 3.46 psi

Total Pressure Losses in the System:

Add up all of the losses that have been calculated and recorded on the Friction Loss Worksheet.

0.22 + 0.76 + 1.0 + 2.44 + 3.0 + 3.46 = 10.88 psi

Interpolating Friction Loss Tables

In this example, the flow rates were between two values listed on the table of Friction Losses. Therefore, the values used in the calculations were interpolated. To interpolate values follow these steps:

The flow rate of the first section of pipe is 2.4 gpm. Calculate friction losses at 2.4 gpm as follows:

1st Determine the friction loss that occurs in a 3/4 inch pipe between 2 gpm and 3 gpm.

0.84 - 0.39 = 0.45

2nd 2.4 is 4-10ths of the way to 3.0, so multiply 0.45 by 4/10.

0.45 X 0.40 = 0.18

3rd Add this to the friction loss value for a 3/4 inch pipe with a 2 gpm flowrate.

0.39 + 0.18 = 0.57 psi

Step 9: Select a Pump and Dosing Tank

The pumping system is submerged in a watertight dosing tank as shown in Figure 4. The dosing tank should be sized to accommodate the daily volume of wastewater plus two additional days of storage. See Box 3 for guidance on dosing tank selection. Note the smaller tank volumes required for a system that includes a stabilization pond. The retention and storage of water in the pond compensates for the smaller dosing tank capacity.

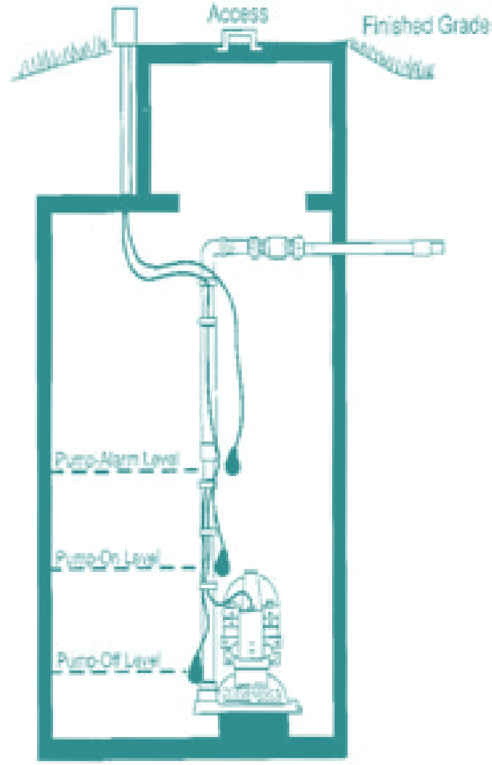


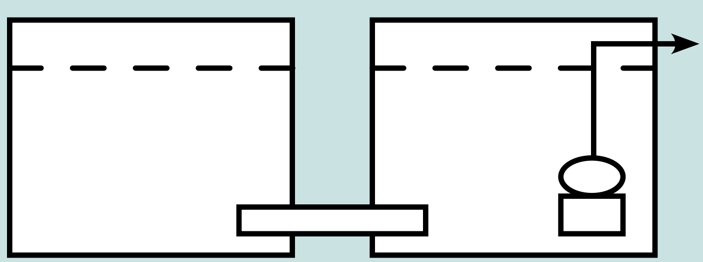
Figure 4. Dosing Tank

Box 3. Dosing Tank Selection

Minimum Dosing Tank Size
(in gallons)

	Treatment System	
Bedrooms	Bioreactor	Stabilization Pond
1	500	500
2	1000	500
3	1500	500
4	2000	1000
5	2000	1000

Note: Two tanks in series connected at the bottom will work in areas where it is difficult to set a large tank.



Centrifugal pumps are typically used for residential irrigation systems. Only use pumps that have been specifically designed for use with septic tank effluent or pond water for irrigation of treated wastewater. Examine pump curves to determine an appropriate pump. Total dynamic head (TDH) and flow rate (GPM) are used to make the selection. The total dynamic head is the sum of the total friction losses and the operating pressure of the sprinkler heads, while the flow rate is the output in gallons per minute for all of the sprinkler heads in the largest zone in the system. Avoid selecting too large a pump, with the GPM versus TDH well below the pump curve. Large pumps are more expensive. The required TDH for the GPM should be on or just below the pump curve, within the middle two-thirds of the curve, for most efficient operation.

Example: Step 9

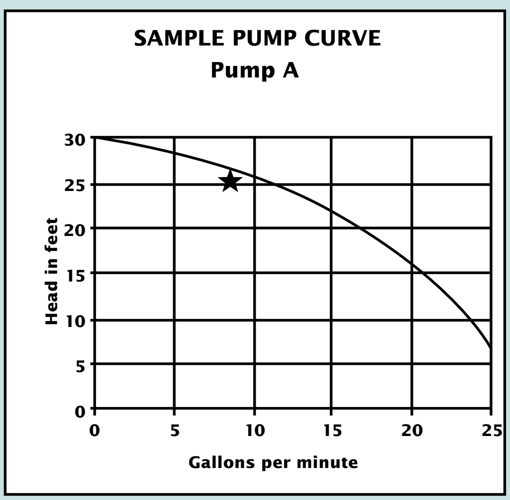
Determine **Total Dynamic Head** from step 8.

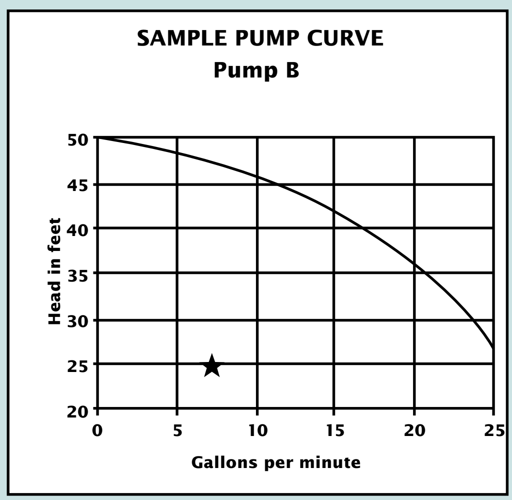
Total friction loss X 2.34 ft ➔ 10.88 psi X 2.34 ft/psi = 25.46 ft of head.

Calculate the **Total Flow Rate** for the largest zone from step 6.

2.4 + 2.4 + 2.4 = 7.2 gpm

Using the pump curve determine the size pump needed for the irrigation system.





Select pump A since the desired gpm and TDH are just below the curve and within the middle two-thirds of the curve.

Step 10: Select a Controller

Three types of controllers exist for use in residential irrigation. A mechanical controller has gears and mechanical timers. They are easy to program and use but have limited programming capability. Solid State controllers are typically less expensive and have more capability but require more user interaction. Hybrid controllers combine the best features of both of these types. Any type of controller should be installed using a surge protector.

Program the controller to determine the day, time, and duration of each irrigation cycle as well as to open and close zone valves in the prescribed sequence. The controller will also permit manual control of the irrigation system.

For more information on electrical wiring and setting float switches refer to pages 27-33 of Ohio State University Extension Bulletin 829, *Mound Systems: Pressure Distribution of Wastewater.*

Step 11: Determine Irrigation Schedule

Because it can be unpleasant to be sprayed with water, irrigation should be done when people and pets are not present. Early in the morning (4:00-5:00 a.m.) is a good time to run the system, since irrigating late at night may lead to the growth of fungi and promote turf disease. Since wastewater is generated every day, the system should run every day. The run duration depends on the flow rate of the sprinkler heads in the system. Two important conditions are necessary when programming the controller.

- The duration should allow the distribution of the design daily flow of wastewater.
- The duration is limited to the time it takes to apply 0.2 inches per day.

If Steps 1, 2, and 3 were completed properly, these two conditions will occur simultaneously.

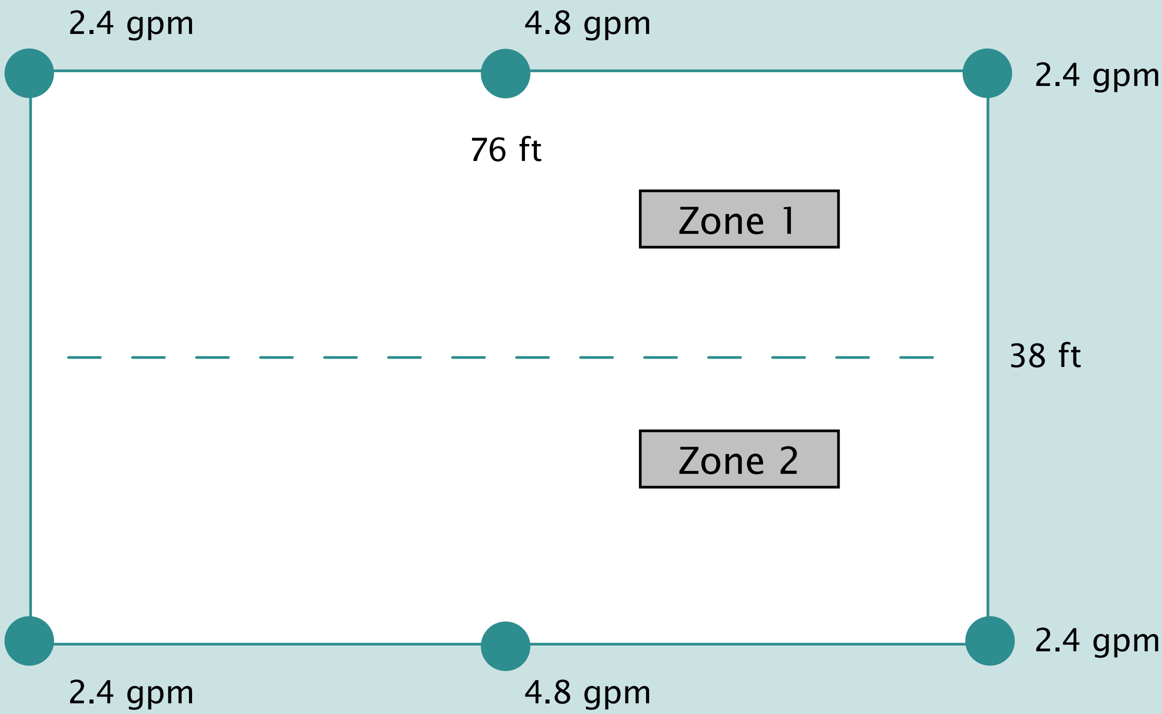
If the irrigation system is designed for "matched precipitation rates," all zones will run the same length of time. If the zones are not matched, the run times should be programmed accordingly to assure that the wastewater is applied evenly.

Calculating the "precipitation rate" will provide the proper run time for the system. The precipitation rate (PR) for an individual sprinkler, a zone, or an entire sprinkler system is the depth of water applied in a given area, expressed in inches per hour. The PR of a zone is determine by multiplying the total gallons per minute of the zone by 96.25 and dividing by the total area the zone covers:

$$\text{PR} = \frac{\text{GPM applied X 96.25}}{\text{area covered}}$$

Use the precipitation rate to determine the run time of the zone. If the PR is 1 inch per hour, the run time would be 0.2 of an hour or 12 minutes. Check the system with rain gauges and make adjustments as needed.

Example: Step 11



Zone 1

Flow rate = 9.6 gpm (2.4 + 4.8 + 2.4)
Area = 1444 sq ft (76 x 38/2)

$$PR = \frac{9.6 \text{ gpm} \times 96.25}{1444 \text{ sq ft}} = 0.64 \text{ in/hr}$$

96.25 is a conversion factor that converts cubic inches of water into inches per square foot per hour.

$$\text{Run time} = \frac{0.2 \text{ in}}{0.64 \text{ in/hr}} \times \frac{60 \text{ mins}}{1 \text{ hr}} = 18.75 \text{ mins}$$

Step 12: Operation and Maintenance

All landscape irrigation systems require regular maintenance to protect the investment in the equipment. Wastewater irrigation systems are no different. In addition, proper operation and maintenance are essential to protecting public health and the environment. Periodic inspection and maintenance of the system will ensure that the system is working as designed and will save the homeowner money by preventing premature repairs to or replacements of the system components.

Every 6 months:

1. Check the pumps and alarms.
2. Turn on the irrigation system to check spray head function and spray pattern. Repair, adjust, or replace spray heads as needed. Also check for ponding or runoff.
3. Place several rain gauges in the irrigation area to check the depth of application. The system should apply no more than 0.2 inches per day to prevent ponding or runoff.
4. Sample the quality of the irrigated water by placing a sterile container in the irrigation area and allowing the irrigated water to fill the container. Test for $CBOD_5$ and fecal coliform bacteria. Refer to the SETLL website **www.ag.ohio-state.edu/~setll** for a list of qualified wastewater testing labs.
5. Check for landscaping changes that interfere with system operation. Be especially watchful for paved areas and regrading where soil fill has been brought in or soil has been stripped away.

Irrigation Area Landscaping

The goal of establishing plants in the irrigation area is to improve the appearance of the lot. Providing irrigation water year-round, in Ohio, benefits landscape plants in a number of ways:

- Supplemental water during dry periods, especially in late summer, helps the establishment of adolescent plants as well as maintaining water supply to established plants.
- Year-round irrigation also provides a cooling effect on the plants as the water evaporates.

When cooling occurs in the summer, plants are better protected from heat stress. The occurrence of an unseasonably warm, winter day will not cause the plants to prematurely bloom because of the evaporative cooling effects provided by the irrigation. In this way, the irrigated plants are protected from the damage that occurs when delicate buds and shoots are frozen when temperatures return to normal sub-freezing temperatures. Protection from desiccation from cold and dry winds is also provided when an ice coating forms on plants (Figure 5, back cover).

Research to determine appropriate plants for on-site irrigation systems is ongoing at The Ohio State University. Initial results reveal that most native trees and shrubs grow better when irrigated year-round compared to plants receiving no irrigation. Figure 6 and Figure 7 (see back cover) are photographs showing late summer leaf color and plant vigor. Comparisons of the two show an extreme disparity of plant health, with the year-round irrigated plot showing a much healthier appearance.

A preliminary list of appropriate plants appears in Appendix D. Additional plants will be posted on **http://www.ag.ohio-state.edu/~setll/** as research continues.

Some plants are not recommended for wastewater irrigation sites. Listed in Appendix E are plants that are adversely impacted by ice build-up. Other plants, which are not included on this list, but should not be planted in wastewater irrigation areas, are those that produce fruit for human consumption.

Appendix A-1

PVC Schedule 40 IPS Plastic Pipe

PSI loss per 100 feet of pipe
Size 1/2" through 2 1/2"
Flow GPM 1 through 75
Shading indicates that the 5 ft/sec maximum velocity has been exceeded.

size (in)	1/2		3/4		1		1 1/4		1 1/2		2		2 1/2	
ID (in)	0.622		0.824		1.049		1.380		1.610		2.067		2.469	
Flow	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**
(gpm)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)
1	1.05	0.43	0.60	0.11	0.37	0.03	0.21	0.01	0.15	0.00				
2	2.11	1.55	1.20	0.39	0.74	0.12	0.42	0.03	0.31	0.02	0.19	0.00		
3	3.16	3.28	1.80	0.84	1.11	0.26	0.64	0.07	0.47	0.03	0.28	0.01	0.20	0.00
4	4.22	5.60	2.40	1.42	1.48	0.44	0.85	0.12	0.62	0.05	0.38	0.02	0.26	0.01
5	5.27	8.46	3.00	2.15	1.85	0.66	1.07	0.18	0.78	0.08	0.47	0.02	0.33	0.01
6			3.60	3.02	2.22	0.93	1.28	0.25	0.94	0.12	0.57	0.03	0.40	0.01
7			4.20	4.01	2.59	1.24	1.49	0.33	1.10	0.15	0.66	0.05	0.46	0.02
8			4.80	5.14	2.96	1.59	1.71	0.42	1.25	0.20	0.76	0.06	0.53	0.02
9			5.40	6.39	3.33	1.97	1.92	0.52	1.41	0.25	0.85	0.07	0.60	0.03
10					3.70	2.40	2.14	0.63	1.57	0.30	0.95	0.09	0.66	0.04
11					4.07	2.86	2.35	0.75	1.73	0.36	1.05	0.11	0.73	0.04
12					4.44	3.36	2.57	0.89	1.88	0.42	1.14	0.12	0.80	0.05
14					5.19	4.47	2.99	1.18	2.20	0.56	1.33	0.17	0.93	0.07
16							3.42	1.51	2.51	0.71	1.52	0.21	1.07	0.09
18							3.85	1.88	2.83	0.89	1.71	0.26	1.20	0.11
20							4.28	2.28	3.14	1.08	1.90	0.32	1.33	0.13
22							4.71	2.72	3.46	1.29	2.10	0.38	1.47	0.16
24							5.14	3.20	3.77	1.51	2.29	0.45	1.60	0.19
26									4.09	1.75	2.48	0.52	1.74	0.22
28									4.40	2.01	2.67	0.60	1.87	0.25
30									4.72	2.28	2.86	0.68	2.00	0.29
35									5.50	3.04	3.34	0.90	2.34	0.38
40											3.81	1.15	2.67	0.49
45											4.29	1.43	3.01	0.60
50											4.77	1.74	3.34	0.73
55											5.25	2.08	3.68	0.88
60													4.01	1.03
65													4.35	1.19
70													4.68	1.37
75													5.01	1.56

Polyethylene SDR-Pressure Rated Tube

PSI loss per 100 feet of pipe
Size 1/2" through 2 1/2"
Flow GPM 1 through 75
Shading indicates that the 5 ft/sec maximum velocity has been exceeded.

size (in)	1/2		3/4		1		1 1/4		1 1/2		2		2 1/2	
ID (in)	0.622		0.824		1.049		1.380		1.610		2.067		2.469	
Flow	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**	**Velocity**	**Loss**
(gpm)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)
1	1.05	0.49	0.60	0.12	0.37	0.04	0.21	0.01	0.15	0.00	0.09	0.00		
2	2.10	1.76	1.20	0.45	0.74	0.14	0.42	0.04	0.31	0.02	0.19	0.01		
3	3.16	3.73	1.80	0.95	1.11	0.29	0.64	0.08	0.47	0.04	0.28	0.01	0.20	0.00
4	4.21	6.35	2.40	1.62	1.48	0.50	0.85	0.13	0.62	0.06	0.38	0.02	0.26	0.01
5	5.27	9.60	3.00	2.44	1.85	0.76	1.07	0.20	0.78	0.09	0.47	0.03	0.33	0.01
6			3.60	3.43	2.22	1.06	1.28	0.28	0.94	0.13	0.57	0.04	0.40	0.02
7			4.20	4.56	2.59	1.41	1.49	0.37	1.10	0.18	0.66	0.05	0.46	0.02
8			4.80	5.84	2.96	1.80	1.71	0.47	1.25	0.22	0.76	0.07	0.53	0.03
9			5.40	7.26	3.33	2.24	1.92	0.59	1.41	0.28	0.85	0.08	0.60	0.03
10					3.70	2.73	2.14	0.72	1.57	0.34	0.95	0.10	0.66	0.04
11					4.07	3.25	2.35	0.86	1.73	0.40	1.05	0.12	0.73	0.05
12					4.44	3.82	2.57	1.01	1.88	0.48	1.14	0.14	0.80	0.06
14					5.19	5.08	2.99	1.34	2.20	0.63	1.33	0.19	0.93	0.08
16					5.93	6.51	3.42	1.71	2.51	0.81	1.52	0.24	1.07	0.10
18							3.85	2.13	2.83	1.01	1.71	0.30	1.20	0.13
20							4.28	2.59	3.14	1.22	1.90	0.36	1.33	0.15
22							4.71	3.09	3.46	1.46	2.10	0.43	1.47	0.18
24							5.14	3.63	3.77	1.72	2.29	0.51	1.60	0.21
26									4.09	1.99	2.48	0.59	1.74	0.25
28									4.40	2.28	2.67	0.68	1.87	0.29
30									4.72	2.59	2.86	0.77	2.00	0.32
35									5.50	3.45	3.34	1.02	2.34	0.43
40											3.81	1.31	2.76	0.55
45											4.29	1.63	3.01	0.69
50											4.77	1.98	3.34	0.83
55											5.25	2.36	3.68	1.00
60													4.01	1.17
65													4.35	1.36
70													4.68	1.56
75													5.01	1.77

Appendix A-3

PVC Class 200 IPS Plastic Pipe

PSI loss per 100 feet of pipe
Size 3/4" through 2 1/2"
Flow GPM 1 through 85

size (in)	3/4		1		1 1/4		1 1/2		2		2 1/2	
ID	0.930		1.189		1.502		1.720		2.149		2.601	
Flow	Velocity	Loss	Velocity	Loss	Velocity	Loss	Velocity	Loss	Velocity	Loss	Velocity	Loss
(gpm)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)	(ft/sec)	(psi)
1	0.47	0.06	0.28	0.02	0.18	0.01	0.13	0.00				
2	0.94	0.22	0.57	0.07	0.36	0.02	0.27	0.01	0.17	0.00		
3	1.42	0.46	0.86	0.14	0.54	0.04	0.41	0.02	0.26	0.01	0.18	0.00
4	1.89	0.79	1.15	0.24	0.72	0.08	0.55	0.04	0.35	0.01	0.24	0.01
5	2.36	1.20	1.44	0.36	0.90	0.12	0.68	0.06	0.44	0.02	0.30	0.01
6	2.83	1.68	1.73	0.51	1.08	0.16	0.82	0.08	0.53	0.03	0.36	0.01
7	3.30	2.23	2.02	0.67	1.26	0.22	0.96	0.11	0.61	0.04	0.42	0.01
8	3.77	2.85	2.30	0.86	1.44	0.28	1.10	0.14	0.70	0.05	0.48	0.02
9	4.25	3.55	2.59	1.07	1.62	0.34	1.24	0.18	0.79	0.06	0.54	0.02
10	4.72	4.31	2.88	1.30	1.80	0.42	1.37	0.22	0.88	0.07	0.60	0.03
11	5.19	5.15	3.17	1.56	1.98	0.50	1.51	0.26	0.97	0.09	0.66	0.03
12			3.46	1.83	2.17	0.59	1.65	0.30	1.06	0.10	0.72	0.04
14			4.04	2.43	2.53	0.78	1.93	0.40	1.23	0.14	0.84	0.05
16			4.61	3.11	2.89	1.00	2.20	0.52	1.41	0.17	0.96	0.07
18			5.19	3.87	3.25	1.24	2.48	0.64	1.59	0.22	1.08	0.09
20					3.61	1.51	2.75	0.78	1.76	0.26	1.20	0.10
22					3.97	1.80	3.03	0.93	1.94	0.32	1.32	0.12
24					4.34	2.12	3.30	1.09	2.12	0.37	1.44	0.15
26					4.70	2.46	3.58	1.27	2.29	0.43	1.56	0.17
28					5.06	2.82	3.86	1.46	2.47	0.49	1.68	0.19
30							4.13	1.66	2.65	0.56	1.80	0.22
35							4.82	2.20	3.09	0.75	2.11	0.29
40							5.51	2.82	3.53	0.95	2.41	0.38
45									3.97	1.19	2.71	0.47
50									4.41	1.44	3.01	0.57
55									4.85	1.72	3.31	0.68
60									5.30	2.02	3.61	0.80
65											3.92	0.93
70											4.22	1.06
75											4.52	1.21
80											4.82	1.36
85											5.12	1.52

Appendix B

Pressure Loss in Valves and Fittings

Equivalent Length in Feet of Pipe

Nominal Pipe Size	Globe Valve	Angle Valve	Gate Valve	Standard Tee	Standard Elbow	45-degree Angle
1/2	17	9	0.4	1	2	1
3/4	22	12	0.5	2	3	1
1	27	15	0.6	2	3	2
1 1/4	38	18	0.8	3	4	2
1 1/2	45	22	1	3	5	2
2	58	28	1.2	4	6	3
2 1/2	70	35	1.4	5	7	3

Friction Loss Worksheet

Zone Number ______
Type of Pipe ____________________

	GPM Flow	Pipe Size	Loss per 100 ft	Loss per foot	Length of Pipe	Equivalent length of fittings	Effective length	Loss per Length
Lateral Line								
Lateral Line								
Lateral Line								
Lateral Line								
Lateral Line								
Lateral Line								
Lateral Line								
Lateral Line								
Lateral Line								
Lateral Line								
Main Line								
Main Line								
Main Line								
							Subtotal	

	Zone GPM	Size	PSI Loss
Subtotal Pressure Losses in Pipe (from above)			
Zone Valve			
Miscellaneous components			
Miscellaneous components			
Miscellaneous components			
Loss or Gain due to elevation change			

Total Pressure Loss		
Pressure Required at the Sprinkler Head	+	
Minimum Pressure Required for Optimal System Operation (Required Pump Pressure)	=	

Appendix D

Listing of Appropriate Plants for Wastewater Irrigation Sites in Ohio

Botanical Name	Common Name
Acer nigrum	Black Maple
Acer rubrum	Red Maple
Aronia arborea brilliantissima	Red Chokeberry
Aronia melanocarpa	Black Chokeberry
Aronia x prunifolia	Purple-fruited Chokeberry
Chaenomeles speciosa	Common Quince
Clethra alnifolia	Summer Sweet
Cornus mas	Cornealian Cherry Dogwood
Cornus sanguinea	Bloodtwig Dogwood
Deutzia gracilis	Slender Deutzia
Diervilla sessilifolia	Summer Stars Honeysuckle
Dutzia x lemoinei	Lemoine Dutzia
Euonymus alatus	Winged Euonymus
Euonymus americanus	American Euonymus
Forsythia x intermedia	Border Forsythia
Fraxinus americana	White Ash
Fraxinus pennsylvanica	Patmore Ash
Hamamelis vernalis	Vernal Witch Hazel
Hamamelis virginiana	Witch Hazel
Ilex verticulata	Winter Red Holly
Itea virginiana	Virginia Sweetspire
Juniperus scopulorum	Virginia Red Cedar
Magnolia virginiana	Sweetbay Magnolia
Myrica pennsylvanica	Northern Bayberry
Rhus aromatica	Fragrant Sumac
Salix caprea	Pussywillow
Salix melanostachys	Black Pussywillow
Salix purpurea	Arctic Willow
Spiraea x bumalda	Bumald Spirea
Syringa patula	Manchurian Lilac
Tilia americana	American Linden
Tsuga caroliniana	Carolina Hemlock
Viburnum acerifolium	European Vibernum
Viburnum dentatum	Chicago Luster Viburnum
Viburnum lentago	Nannyberry
Viburnum opulus	Cranberrybush Viburnum
Wigela florida	Old Fashioned Weigela

Appendix E

Listing of Plants Not Appropriate for Wastewater Irrigation Sites in Ohio

Botanical Name	Common Name
Chamaecyparis obtusa	False Cypress
Chamaecyparis pisifera ‘Boulevard’	Sawara Cypress
Chamaecyparis pisifera ‘Filifera Aurea’	Sawara Cypress
Thuja occidentalis	Emerald Arborvitae
Tsuga canadensis	Canadian Hemlock

Figure 5. Ice Coverage Following Winter Cycles at Sub 0°C

Figure 6. Species in Year-Round Irrigated Plot Displaying Mid-Summer Leaf Color and Vigor

Figure 7. Species in Control Plot (No Irrigation) Displaying Extremely Poor Vigor and Mortality