B.C. SPRINKLER IRRIGATION MANUAL

Chapter 8

Editor

Ted W. van der Gulik, P.Eng.
Senior Engineer

Authors

Stephanie Tam, P.Eng.
Water Management Engineer

Andrew Petersen, P.Ag.
Regional Resource Specialist

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LIMITATION OF LIABILITY AND USER'S RESPONSIBILITY

The primary purpose of this manual is to provide irrigation professionals and consultants with a methodology to properly design an agricultural irrigation system. This manual is also used as the reference material for the Irrigation Industry Association's agriculture sprinkler irrigation certification program.

While every effort has been made to ensure the accuracy and completeness of these materials, additional materials may be required to complete more advanced design for some systems. Advice of appropriate professionals and experts may assist in completing designs that are not adequately convered in this manual.

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8 PIPE SELECTION DESIGN AND INSTALLATION

Proper design, installation and operation of piping systems will increase the effective life of the pipe and ensure a reliable water supply to an irrigation system. Mainline design must take into account the total system flow rate, total pressure requirement, terrain, and pipe material to be used. Lateral pipe lines must be designed to ensure that the pipe friction losses are not excessive and allow all sprinklers along the lateral to operate within an appropriate pressure range. Appendix B provides additional information on pipe properties, such as friction loss characteristics for pipe generally used in the irrigation industry.

8.1 Pipe Selection

Pipe material should be selected on the basis of site conditions, pressure required and material cost compared to alternatives. The following pipe types are usually used for irrigation purposes.

Aluminum

Aluminum is lightweight, easy to assemble, and used extensively for above ground portable irrigation systems. Aluminum pipe is not buried unless protected with a coating. Pipe size used range from 2 inch to 10 inch with recommended working pressures not exceeding 130 to 140 psi. Working pressures for aluminum are indicated in Table A.1. The pipe is generally available in 30 and 40 foot lengths.

Steel

Steel is commonly used for irrigation pipe larger than 8 inch where high working pressures are desired. Steel is susceptible to corrosion and requires corrosion protection if buried. Steel mainlines for irrigation are usually laid above ground to reduce corrosion and allow for periodic inspection. The pipe is usually available in 20 or 40 foot lengths.

Poly Vinyl Chloride (PVC)

PVC pipe is available in numerous classes and schedules depending on the working pressures desired. It is lightweight, durable, easy to install and has excellent resistance to most chemicals. PVC deteriorates when exposed to sunlight and becomes quite brittle at freezing temperatures making it impractical for most exposed work. For irrigation purposes, the operating pressure of PVC pipe should not exceed 72% of the pipe pressure rating. Pipe sizes typically range from ½ inch to 12 inch. The pipe is available in 20 foot lengths with either a solvent weld or gasket bell end.

Polyethylene (PE)

Polyethylene pipe has similar characteristics to PVC except that it is more flexible. It is not commonly used for high pressure, large pipe installations primarily due to cost. PE pipe is most often used for small solid set sprinkler or trickle irrigation systems. For irrigation purposes, the operating pressure of polyethylene pipe should not exceed 72% of the pipe pressure rating. The typical size range is ½ inch to 2 inch. The pipe is available in coil lengths of 100, 200, 300, 400, 500 feet or reel lengths of 1,000 feet.

High Density Polyethylene Pipe (HDPE)

HDPE pipe more ridged than regular PE pipe. It still has some flexibility and can curve around gentle corners. It is often used when an open ditch is converted to buried pipe. HDPE is available in a large range of sizes and tends to be more expensive than PVC pipe. Higher pressure ratings are available and it can be used as mainline and laterals. The larger pipe sizes come in 40 foot lengths and are joined by heat fusion.

8.2 Pipe Rating Systems

Many different systems are used to rate the pipe that is used for irrigation. Steel pipe uses a gage or schedule system. Aluminum tubing is rated by wall thickness. PVC pipe uses a schedule or class system. Polyethylene pipe uses a maximum working pressure rating system. HDPE pipe uses a pressure rating system and a Surface Dimension Ratio (SDR) system. An understanding of the pressure rating systems is useful in selecting the type of mainline required for an irrigation system.

Gage or Fraction

Straight seam pipe is often available in a gage rating. The gage number refers to a standard wall thickness as specified by the Burmingham or Stub's Iron Wire Gage. The working pressure for each gage number varies with the pipe size. Table A.2 indicates the wall thickness and pressure rating for various gage number and pipe size.

Schedule

Irrigation pipe is often grouped under headings of schedule 40 or schedule 80. It is the familiar designation of pipe for which the outside diameter, wall thickness, and inside diameter are fixed by specification. The dimensions of plastic or steel pipe produced to these schedules are identical. Working pressures vary for different pipe diameters within any schedule. Table A.3 provides the working pressure of various PVC pipe sizes manufactured to "schedule" specifications.

Class, Series or "SDR" System

Polyethylene and PVC pipe are often manufactured to a "class" or "series" system. This system classifies pipe to a pressure rating. It is a system in which the working pressure for all pipe in a given series is the same, having the same safety margin and operating at the same fibre stress. The pipe is grouped according to its standard dimension ratio (SDR). SDR is the relationship of pipe wall thickness and outside diameter.

Equation 8.1 Standard Dimension Ratio (SDR)

$$SDR = \frac{Outside\ Diameter}{Wall\ Thickness}$$

where

SDR =	standard dimension ratio
Outside Diameter =	outside diameter of pipe [in]
Wall Thickness =	wall thickness of pipe [in]

The wall thickness and inside diameter vary with the pressure rating or class of pipe. The number after the class or series indicates the pipe maximum working pressure. Table B.3 provides information on PVC pipe specifications for class or series pipe.

8.3 Calculating Pipe Size

Water flowing through pipelines is always accompanied by a pressure loss due to friction. The amount of friction loss that occurs will depend on:

- the pipe dimensions (length and inside diameter)
- the type of pipe (PVC, aluminum, steel, etc.)
- quantity of water flowing through the pipe

Flow Velocity

When an irrigation pipe mainline or lateral is designed, the pipe size is selected based on a maximum water velocity of 5 feet per second. If the velocity is too high the pressure rating of the pipe can be exceeded with sudden valve closure causing water hammer. For agricultural irrigation design water hammer problems are avoided by ensuring that flow velocities do not exceed 5 ft/sec.

Equation 8.2 Flow Velocity (V)

$$V = \frac{Q}{2.45D^2}$$

where

V = velocity [ft/s]
Q = flow rate [US gpm]
D = inside pipe diameter [in]

The friction loss tables in Appendix B have a dotted line in the size columns to indicate a velocity of 5 ft/s. When using the tables, stay above this line to ensure safe velocities which minimize friction loss and reduce the problems that can be caused by water hammer. See section 8.4.

Helpful Tips – Lateral Pipeline Design

The allowable friction loss in a lateral line should not exceed more than 10 % of the sprinkler operating pressure whenever possible. Therefore a sprinkler operating at a nominal pressure of 50 psi would limit the pressure loss along the lateral to 5 psi or less. Keeping the friction losses within this range will provide improved system uniformity which in turn improves system performance.

Using the 5 ft /sec rule to initially select lateral pipe sizes often results in a friction loss for the lateral line that is within this tolerance. If the range is exceeded then larger pipe sizes should be selected for portions of the lateral line. See the lateral friction loss calculations in Example 8.5.

Example 8.1 Flow Velocity Check

Question: For a travelling gun system having a flow rate of 250 US gpm would a 4-inch PVC mainline be large enough?

Information:

Farm location	Armstrong	1	
Flow rate (Q)	250	2	US gpm
pipe diameter	4	3	in
Inside pipe diameter (D) (Appendix Table A.3)	4.072	4	in

Calculation:

Check to see if the velocity is below 5 ft/s.

Equation 8.2

$$V = \frac{Q}{2.45\ D^2}$$

$$= \frac{250\ [2]\ \text{US gpm}}{2.45 \times (4.072\ [4]\ \text{in})^2}$$

$$= 6.15\ [5]\ \text{ft/s}$$

Since this velocity is greater than 5 ft/s, the 4-inch pipe is too small. The next larger size mainline should be looked at, i.e., 5 inch. The parameters for this pipe are:

Inside pipe diameter (D) (Appendix Table A.3)	5.033	6	in

Equation 8.2

$$V = \frac{Q}{2.45\ D^2}$$

$$= \frac{250\ [2]\ \text{US gpm}}{2.45 \times (5.033\ [6]\ \text{in})^2}$$

$$= 4.02\ [7]\ \text{ft/s}$$

Answer:

Since this velocity for 5 inch mainline is below 5 ft/s, this is the minimum size mainline that should be used. Most manufacturers do not make 5 inch PVC pipe therefore 6 inch may be required.

Pipe Friction Loss

Pipe friction loss is calculated based on properties of the pipe, diameter of the pipe, and flow in the pipe. The most commonly used formula is the Hazen-Williams illustrated in Equation 8.3.

Equation 8.3 Friction Loss

$$H_f(100) = \frac{452 \, (\frac{Q}{C})^{1.852}}{D^{4.87}}$$

where

H_f (100) =	friction loss (psi per 100 feet)
Q =	flow rate [US gpm]
C =	coefficient of retardation based on pipe material
D =	inside pipe diameter [in]

Source: Design and Operation of Farm Irrigation Systems, 2nd Edition, ASABE

Coefficient of Retardation (C Factor)

This coefficient is different for the types of pipe materials being used. The smoother the inside wall of a pipe is, the higher the C factor.

Table 8.1 C Factor

Type of Pipe	C Factor
Old Steel	100
New Steel	120
Aluminum with couplers	120
Plastic polyethylene	140
Plastic PVC	150

Helpful Tips – Friction Loss for Steel Pipes

For agricultural irrigation systems, old steel pipes are more commonly used than new steel pipes due to lower cost. If new steel pipes are used, Appendix Table B.2 (friction loss for aged steel pipes) should be used to calculate friction losses. New steel pipes are generally used for many decades, and will become aged. Therefore, using friction losses of old steel pipes when designing the system is recommended to ensure the friction losses are compensated for.

Example 8.2 Mainline Friction Loss Calculation

Question: What is the friction loss, H_f (100) for a 6-inch PVC mainline delivering 250 US gpm water?

Information:

Farm location	*Armstrong*	1	
Flow rate (Q)	*250*	2	US gpm

Since the mainline is to be buried, PVC pipe will be used. A travelling gun operating at 110 psi will often require Class 200 PVC. For a 6-inch Class 200 PVC pipe,

Coefficient of Retardation (C Factor – Table 8.1)	*150*	3	
Inside pipe diameter (D) (Appendix Table A.3)	*5.995*	4	in

Calculation:

Method 1: Using Hazen-Williams Equation

Equation 8.3

$$H_f(100) = \frac{452\left(\frac{Q}{C}\right)^{1.852}}{D^{4.87}}$$

$$= \frac{452\left(\frac{250 \; [2]}{150 \; [3]}\right)^{1.852}}{5.995 \; [4]^{4.87}}$$

= *0.189* [5] psi/100 ft

Method 2: Using Friction Loss Tables

From Appendix B.7 for PVC 6” Class 200 PSI PVC Pipe, with a flow rate of

250 [2] US gpm

H_f (100) = *0.19* [6] psi/100 ft

Example 8.3 Mainline Friction Loss of Wheeline System in Armstrong

Question: From Example 5.1, each wheelline in the sprinkler system operates at 46 psi with a flow rate of 231 US gpm. The entire system flow rate is 693 gpm. The mainline length required from the pump house to the first hydrant is 600 feet. The remaining hydrants are 120 feet apart. The farmer wishes to use a buried mainline. What type and sizes mainline are required? What is the pipe friction loss?

Information:

Farm location	*Armstrong*	1	
Flow rate (Q)	*693*	2	US gpm
System operating pressure	*46*	3	psi

Since the farmer wants a buried line, PVC pipe will be used. With friction loss and elevation change added to the system pressure, select:

Pressure rating (pipe Class)	*160*	4	psi

Calculation:

1. Determine flow rates through each mainline section

   When looking at the farm plan, start from the furthest wheeline and measure back to the pump. Wheelines #2 and #3 should start on opposite ends of the field and move towards each other. This allows for lower flow rate and potentially smaller pipe size for the second half of the mainline. Keep in mind that section $x_1 - x_2$ must be sized to handle the combined flow rate of the two wheelines when they meet at mid-point.

2. Select pipe size based on the 5-feet-per-second rule

   In the case of wheeline #1, the flow rate would have been under 5 ft/sec for a 5-inch mainline. The product is difficult to obtain with a 160 psi rating, and in some locations may not be available. Therefore, 6-inch pipe was selected.

   If the flow rate was in between two choices on the table, interpolation could be used to achieve a more accurate number. When estimating flow rate, always select the larger value. Refer to Helpful Tips below for interpolating friction loss.

3. Add friction loss for each pipe size, and calculate section loss (Appendix Table B.6)

Pipe Section	Flow Rate Q [US gpm]	Pipe Length L [ft]	Pipe Diameter D [in]	Pipe Length per 100 ft L per 100 ft	x	Friction Loss per 100 ft H_f (100) [psi]	=	Friction Loss for Section H_f (section) [psi]
$x_0 - x_1$	*693*	*600*	*8*	*6.0*	x	*0.33*	=	*1.98*
$x_1 - x_2$	*693*	*660*	*8*	*6.6*	x	*0.33*	=	*2.18*
$x_2 - x_3$	*462*	*660*	*8*	*6.6*	x	*0.15*	=	*0.99*
$x_3 - x_4$	*231*	*1,320*	*6*	*13.2*	x	*0.16* *	=	*2.11*
						Total	=	***7.26***

* Refer to Helpful Tips below for interpolation of friction loss.

Answer:

The mainline friction loss is 7.26 psi (16.8 ft).

Helpful Tips – Interpolation of Friction Loss

Interpolation is required especially with high friction loss or long pipes where the total friction loss difference can become significant. In the above example, interpolation was required to determine the friction loss for the 6-inch mainline with 231 US gpm flow rate.

From Appendix Table B6 for 6-inch Class 160 PSI PVC pipe,

$$H_f(100) \text{ at } 200 \text{ US gpm} = 0.12 \text{ psi}$$

$$H_f(100) \text{ at } 250 \text{ US gpm} = 0.18 \text{ psi}$$

$$\text{The difference in flows on the table} = 250 \text{ US gpm} - 200 \text{ US gpm}$$

$$= 50 \text{ US gpm}$$

$$\text{The difference in friction loss} = 0.18 \text{ psi} - 0.12 \text{ psi}$$

$$= 0.06 \text{ psi}$$

The friction loss of the extra flow of 31 US gpm needs to be added to friction loss at 200 US gpm. This can be calculated by cross multiplication.

$$\frac{31 \text{ US gpm}}{50 \text{ US gpm}} = \frac{f}{0.06 \text{ psi}}$$

$$f = 0.037 \text{ psi}$$

This amount of friction loss ($f = 0.037$ psi) must be added to the friction loss for the 8-inch pipe with a 200 US gpm flow rate. Therefore, the friction loss of a 6-inch Class 160 PVC pipe at 231 US gpm is:

$$H_f(100) = 0.12 \text{ psi} + 0.037 \text{ psi}$$

$$= 0.157 \text{ psi}$$

Fitting and Miscellaneous Losses

When calculating mainline friction loss the length of the pipe line and the fittings losses must be taken in to account. Fitting friction loss is determined by equivalent length of straight pipe. In Appendix Table B.9 has equivalent lengths for steel fittings and Appendix Table B.10 has equivalent lengths for plastic fittings.

Example 8.4 Fitting Friction Loss of Wheeline System in Armstrong

Question: In Example 8.3, there are two 45-degree elbows and two 90-degree elbows before the first hydrant. There is also a reducer coupling from the larger to the smaller mainline. What would the friction loss of the fittings be?

Calculation:

1. From Appendix Table B.10, the equivalent pipe lengths for the various fittings required for the system are as follows:

Pipe Diameter [in]	Fitting Type	Equivalent Pipe Length [ft]	Equivalent Pipe Length [ft/100 ft]	x	Quantity	x	Friction Loss per 100 ft	=	Total Friction Loss [psi]
8	*45° elbow*	*20*	*0.20*	x	*2*	x	*0.33*	=	*0.132*
8	*90° elbow*	*45*	*0.45*	x	*2*	x	*0.33*	=	*0.297*
8 – 6	*coupling*	*24*	*0.24*	x	*1*	x	*0.33*	=	*0.0792*
							Total Fitting Friction Loss, H_f (fitting)	=	***0.508***

Answer:

The fitting friction loss is 0.508 psi.

Helpful Tips – Friction Loss for Miscellaneous Fittings

If fitting losses are not accurately calculated then a 20% miscellaneous loss should be added to the pipe friction loss calculation. Keep in mind that the total friction loss in the system should not exceed 10 % of the operating pressure.

Example 8.5 Lateral Friction Loss of Undertree Solid Set System in Osoyoos

Question: From Example 5.2, the apple farmer in Osoyoos is using an undertree solid set sprinkler system with Class 200 PVC pipe. The sprinkler operating pressure is 34 psi. The lateral line is split in the middle by the mainline. What pipe sizes should be used for the laterals? What is the lateral friction loss?

Information:

Sprinkler spacing (Box 16, Example 5.2)	*30*	**1**	ft
Sprinkler flow rate (Q) (Box 25, Example 5.2)	*2.0*	**2**	US gpm
Number of sprinklers	*10*	**3**	
Sprinkler operating pressure	*34*	**4**	psi

Calculation:

1. In order to properly determine the lateral friction loss, each section along the lateral line would have to be calculated. For the last sprinkler, the flow rate in the lateral section is 2.0 gpm. From Table B.7, 1-inch pipe is the smallest listed size with the flow rate well below 5 feet per second. For the second to the last sprinkler, the flow rate in the lateral section is for 2 sprinklers and therefore 4.0 US gpm. The 1-inch pipe size would still be adequate for the velocity to stay below 5 feet per second.

2. Add friction loss for each pipe section, and calculate lateral friction loss (Appendix Table B.7). Interpolation between friction loss values listed in the Table may be required.

Pipe Section	Flow Rate Q [US gpm]	Pipe Length L [ft]	Pipe Diameter D [in]	Pipe Length per 100 ft L per 100 ft	x	Friction Loss per 100 ft H_f (100) [psi]	=	Friction Loss for Section H_f (lateral) [psi]
1	*20*	*30*	*1-1/4*	*0.30*	x	*1.51*	=	*0.45*
2	*18*	*30*	*1-1/4*	*0.30*	x	*1.24*	=	*0.37*
3	*16*	*30*	*1-1/4*	*0.30*	x	*1.00*	=	*0.30*
4	*14*	*30*	*1*	*0.30*	x	*2.43*	=	*0.73*
5	*12*	*30*	*1*	*0.30*	x	*1.83*	=	*0.55*
6	*10*	*30*	*1*	*0.30*	x	*1.30*	=	*0.39*
7	*8*	*30*	*1*	*0.30*	x	*0.86*	=	*0.26*
8	*6*	*30*	*1*	*0.30*	x	*0.51*	=	*0.15*
9	*4*	*30*	*1*	*0.30*	x	*0.24*	=	*0.07*
10	*2*	*30*	*1*	*0.30*	x	*0.07*	=	*0.02*
						Total	=	***3.29 psi***

Answer:

The total lateral friction loss is 3.29 psi. If fitting losses of 20% are included the total loss is 4.0 psi. To maintain 34 psi at the end of the lateral line, the start of the lateral line needs to have 38 psi, assuming the lateral is flat with no elevation change. This lateral has been designed to stay close to an allowed pressure variation of 10% of the sprinkler operating pressure to improve uniformity. To accomplish this section 3 was designed with 1 ¼ " pipe instead of 1" pipe even though 1 " pipe was within the flow velocity rules. This reduced friction losses by 0.63 psi.

Example 8.6 Mainline Friction Loss of Undertree Solid Set System in Osoyoos

Question: Continuing from Example 8.5, the undertree solid set sprinkler system on the orchard in Osoyoos requires a mainline with four 90° elbows, two 45° elbows, one tee and a gate valve. The water source is 240 feet from the edge of the field. What pipe sizes are required for the mainline and what is the mainline friction loss? (Use class 200 pipe)

Information:

Sprinkler spacing (Box 16, Example 5.2)	30	1	ft
Sprinkler flow rate (Q) (Box 25, Example 5.2)	2.0	2	US gpm
Number of sprinklers per lateral	19	3	
Number of laterals operating at a time	2	4	
Total number of laterals	25	5	

Calculation:

1. Determine the system flow rate.

System Flow Rate = **Sprinkler Flow Rate** x **# Sprinklers per Lateral** x **# of Laterals Operating at a Time**

= 2.07 [2] US gpm x 19 [3] x 2 [4]

= 80 [5] US gpm

2. To allow both laterals to be operated at the end of the field, the same pipe size will be used for the mainline. From Appendix Table B.7, the friction losses along each section of the mainline are as follows:

Pipe Section	Flow Rate Q [US gpm]	Pipe Length L [ft]	Pipe Diameter D [in]	Pipe Length per 100 ft L per 100 ft	x	Friction Loss per 100 ft H_f (100) [psi]	=	Friction Loss for Section H_f (section) [psi]
$x_0 - x_1$	80	240	3	2.4	x	0.52	=	1.25
$x_1 - x_3$	80	465	3	4.65	x	0.52	=	2.42
						Total	=	3.67 [6]

3. From Appendix Table B.10, the equivalent pipe lengths for the various fittings required for the system are as follows:

Pipe Diameter [in]	Fitting Type	Equivalent Pipe Length [ft]	Equivalent Pipe Length [ft/100 ft]	x	Quantity	x	Friction Loss per 100 ft	=	Total Friction Loss [psi]
3	90° elbow	17	0.17	x	4	x	0.52	=	0.3536
3	45° elbow	8	0.08	x	2	x	0.52		0.0832
3	tee	36	0.36	x	1	x	0.52	=	0.1872
3	gate valve	1.4	0.014	x	1	x	0.52	=	0.00728
							Total Fitting Friction Loss, H_f (fitting)	=	0.63 [7] psi

Answer:

Total Mainline Friction Loss	**=**	**Mainline Friction Loss + Fitting Friction Loss**		
	=	3.67 (6) psi +	0.63 (7)	psi
	=	4.3 (8) psi		

When designing an irrigation system the overall pressure requirement must be calculated. In some cases, using a larger pipe to reduce friction loss could allow for a smaller horsepower pump to be used. This would then lower the annual operating costs and help offset the extra expense in purchasing the larger pipe.

Lateral Friction Loss

In Example 8.5, lateral friction loss was determined by calculating loss for each section of pipe. If the pipe size is the same, a factor may be used to determine the lateral frictioin loss. The general friction loss (Equation 8.3) assumes that all of the water is carried to the end of the pipe. If sprinkler outlets are discharging the same amount of water and the spacing is consistant, a factor can be used to calculate the friction loss in a lateral. Factor F(1) is for laterals that start with a full length on the first sprinkler. Factor(F 1/2) is for laterals that start with half spacing on the first sprinkler.

Equation 8.4 Lateral Friction Loss

$$H_f(lateral) = F \times H_f(total)$$

where

H_f (lateral) = Lateral friction loss [psi]

F = Lateral friction loss correction factor

H_f (total) = Total friction loss [psi]

Table 8.2 Lateral Friction Loss Correction Factor, F

F(1) = first section full length, F(1/2) = first section half length

# Spr	1	2	3	4	5	6	7	8	9	10	14	20	25	30	40
F(1)	1	0.64	0.53	0.49	0.46	0.44	0.43	0.42	0.41	0.40	0.39	0.38	0.37	0.37	0.36
F(1/2)	1	0.52	0.44	0.41	0.40	0.39	0.38	0.38	0.37	0.37	0.36	0.36	0.36	0.36	0.36

Example 8.7 Lateral Friction Loss of Microsprinkler System

Question: For the microsprinkler system in Example 5.3, each lateral has 20 outlets at 0.65 gpm for a total of 13 US gpm. The selected pipe size is 1 inch Class 200 PVC. What is the lateral friction loss, H_f (lateral)?

Information:

Friction loss (Appendix Table B.6)	2.1	1	psi/100 ft
Number of sprinklers	20	2	sprinklers

If all the water was carried to the end of the lateral,

Total friction loss, H_f (total) (Table 8.2)	6.3	3	psi

Since the first lateral is half of the spacing,

F factor (Table 8.2)	0.36	4

Calculation:

Equation 8.4

$$H_f \text{ (lateral)} = F \times H_f \text{ (total)}$$

= 0.36 [4] x 6.3 [3] psi

= 2.3 [5] psi

Answer:

The lateral friction loss for the microsprinkler system is 2.3 psi.

8.4 Calculating Pipe Pressure Requirement

The pipe selected must have a pressure rating that exceeds the total pressure that can be exerted on the system. The total pressure head consists of the following components:

Operating Pressure

The pressure required to operate the sprinkler.

Elevation

The maximum elevation difference between the mainline intake and operating point in the field.

Pipe Friction

The pressure loss occurring by water flowing through pipes. Friction loss for the lateral line and mainline must be considered. Appendix B provides additional information on pipe friction loss.

Pressure Surge

The sudden closure of a valve or quick pump start up or shut down will create pressure surges in the irrigation line. This is often referred to as water hammer.

Agricultural irrigation systems are designed to limit flow velocities in irrigation piping at 5 ft/sec. A flow velocity of 5 ft/sec allows friction loss to remain at an acceptable level and limits surge pressures to tolerable levels (See Section 7.4). Appendix B can be used to determine the suggested maximum flow capacities of various pipe types and sizes. All values below the dark lines in the friction loss tables are in excess of 5 ft/sec and should therefore be avoided.

Water Hammer

Water hammer, recognized by a pressure surge, develops when water under pressure in a pipeline is subjected to a change in its flow rate. The rate at which the water velocity is altered determines the water hammer intensity. Mainline design must give consideration to these potential surge pressures that may develop during system operation.

Water velocity in a pipe of constant cross-sectional area will change due to:

- opening or closing a valve
- starting or stopping a pump
- movements of air pockets along a pipeline
- sudden release of air from a pipeline

The pressure increase in a pipeline flowing full of water due to a change in water velocity can be determined by:

Equation 8.5 Pressure Increase

$$P = C\ a\ \Delta V = 0.0135\ a\ \Delta V$$

where

P = pressure increase (psi)

$C = \dfrac{w}{144\ g} = 0.0135$ where $w = 62.4\ lb/ft^3$, $g = 32.2\ ft/sec^2$

a = velocity of pressure wave (ft/sec)

ΔV = velocity change (ft/sec)

Table 8.3 provides values for pressure wave velocities of different pipe types. To minimize water hammer pressure surges it is recommended that the flow velocity in the pipe be limited to 5 ft/sec. For irrigation purposes, the operating pressure of PVC and polyethylene pipe should not exceed 72% of the pipe pressure rating.

Table 8.3 can be used to determine the maximum pressure rise anticipated by operating irrigation mainlines at a flow velocity of 5 ft/sec. The maximum pressure rise possible occurs when the valve closure time is less than system critical time.

Table 8.4 indicates the maximum operating pressure for different classes of PVC pipe and the maximum flow velocity recommended for systems operating at the maximum operating pressure. Exceeding these flow velocities when the system is operating at the maximum recommended operating pressures will create pressure surges that cause the total system pressure to exceed the pipe pressure rating.

The flow velocity in a pipe can be calculated by using Equation 8.2.

Table 8.3 Maximum Pressure Rise for an Instantaneous Valve Closure at a Flow Velocity of 5 ft/sec

Type of Pipe	Class or Schedule	Nominal Size (in)	Outside Diameter (in)	Wall Thickness (in)	Pressure Wave Velocity (ft/sec)	Maximum Pressure Rise (psi)
Steel	Sch. 40	4	4.500	.231	4390	295
		6	6.625	.280	4320	290
		8	8.625	.322	4270	287
		10	10.750	.365	4230	285
Steel	14 Gauge	4	4	.083	3910	263
		6	6	.083	3630	244
		8	8	.083	3400	229
Steel	12 Gauge	4	4	.109	4110	277
		6	6	.109	3870	260
		8	8	.109	3670	247
Steel	10 Gauge	4	4	.134	4230	285
		6	6	.134	4020	270
		8	8	.134	3840	258
		4	4	.050	2730	184
Aluminum		4	4	.072	3070	207
		6	6	.058	2490	168
		6	6	.083	2830	190
		8	8	.064	2320	156
		8	8	.072	2430	164
PVC	Sch. 40	4	4.500	.231	1350	91
		5	5.563	.258	1280	86
		6	6.625	.280	1220	82
		8	8.625	.322	1150	77
		10	10.750	.365	1090	73
PVC	Sch. 80	4	4.500	.337	1640	110
		5	5.563	.375	1550	104
		6	6.625	.432	1530	103
		8	8.625	.500	1440	97
		10	10.750	.593	1400	94
PVC	Class 125	All Sizes			1040	70
	Class 160	All Sizes			1165	78
	Class 200	All Sizes			1300	87
	Class 315	All Sizes			1630	110

Critical Time

The time for a pressure wave to travel from the valve to the pressure source and back is given as the critical time. Critical time can be determined from the following equation:

Equation 8.6 Critical Time

$$T_c = \frac{2\,L}{a}$$

where

T_c = system critical closure time (sec)
L = length of pipeline (ft)
a = velocity of pressure wave (ft/sec)

Table 8.4 Maximum Recommended Operating Pressure and Flow Velocity for PVC Pipe

Class or Schedule	Nominal Pipe Size (in)	Pressure Rating (psi)	Maximum Recommended Operating Pressure (psi)	Allowable Pressure Surge Rise (psi)	Maximum Flow Velocity (ft/sec) *
Sch. 40	3	260	186	74	3.71
	4	220	157	63	3.46
	5	190	136	54	3.13
	6	175	125	50	3.04
	8	160	114	46	2.97
	10	140	100	40	2.72
Sch. 80	3	370	264	106	4.47
	4	320	229	91	4.12
	5	290	207	83	3.97
	6	280	200	80	3.88
	8	250	178	72	3.71
	10	230	164	66	3.50
Class 125	All Sizes	125	89	36	2.57
Class 160	All Sizes	160	114	46	2.92
Class 200	All Sizes	200	143	57	3.25
Class 315	All Sizes	315	225	90	4.10

* Maximum flow velocities suggested are for systems operating at the maximum recommended operating pressures only. If systems are operating well below the maximum recommended operating pressure, a maximum flow rate of 5 ft/sec is suggested.

The water hammer pressure increase is maximum and constant for valve closure times less than the critical time. Water hammer pressure surges can be reduced by slowing the closure time to less than the system's critical time. Table 8.5 can be used to determine the minimum valve closure times for PVC systems at maximum operating pressures and a flow velocity of 5 ft/sec.

Table 8.5 Minimum Valve Closure Time for PVC Pipelines at Maximum Operating Pressures

Class or Schedule	Nominal Pipe Size (in)	Pressure Rating (psi)	Minimum Valve Closure Times [sec]				
			Length [ft]				
			500	1,000	2,000	5,000	10,000
Sch. 40	3	186	1.8	3.6	7	18	36
	4	157	2.1	4.2	8	21	42
	5	136	2.3	4.6	9	23	46
	6	125	2.5	5.0	10	25	50
	8	114	2.8	5.6	11	28	56
	10	100	3.0	6.0	12	30	61
Sch. 80	3	264	1.2	2.4	5	12	24
	4	229	1.5	3.0	6	15	30
	5	207	1.6	3.2	6	16	32
	6	200	1.7	3.4	7	17	34
	8	178	1.9	3.8	7	19	37
	10	164	2.0	4.0	8	20	40
Class 125	All Sizes	89	3.4	6.8	14	34	68
Class 160	All Sizes	114	2.8	5.6	11	28	55
Class 200	All Sizes	143	2.2	4.4	9	22	45
Class 315	All Sizes	225	1.5	3.0	6	15	30

Example 8.8 Operating Pressure and Surge Pressure of a Travelling Gun

Question: A travelling gun has a connection pressure requirement of 110 psi with an elevation lift of 40 ft from the intake to the top of the field. The mainline is 1,500 ft long and a 6-inch Class 200 PVC pipe is used with a flow rate of 210 US gpm. What is the total system operating pressure and maximum surge pressure allowed?

Information:

Travelling gun pressure	110	1	psi
Elevation	40	2	ft
Mainline length	1,500	3	ft
Mainline pipe diameter	6	4	in
Mainline pipe pressure class	200	5	psi
Conversion factor from feet to psi	0.433	6	psi/ft
System flow rate	210	7	US gpm

Calculation:

1. **Operating System Operating Pressure.**

a). Determine the maximum system operating pressure.

Max. System Op. Pressure = Pipe Pressure Class x 72%

= 200 [5] psi x 72%

= 144 [8] psi

b). Determine the elevation pressure loss.

Elevation Loss = Elevation Loss in Feet x Conversion Factor

= 40 [2] ft x 0.433 [6] psi/ft

= 17.3 [9] psi

c). Determine the mainline friction loss.

At a system flow rate of 210 US gpm with 6-inch Class 200 PVC pipe,

Friction loss (Appendix Table B.7) 0.13 [10] psi/100 ft

Mainline Friction Loss = Mainline Length x Friction Loss per 100 ft

$$= 1{,}500\ [3]\ \text{ft} \times \frac{0.13\ [10]\ \text{psi}}{100\ \text{ft}}$$

= 2.0 [11] psi

d). Determine the miscellaneous loss.

Miscellaneous Loss = Mainline Friction Loss x 20%

= 2.0 [11] psi x 20%

= 0.4 [12] psi

e). Determine the total system operating pressure.

Travelling gun pressure	110	1	psi
Elevation loss	17.3	9	psi
Mainline friction loss	2.0	11	psi
+) Miscellaneous loss	0.4	12	psi
Total system operating pressure	130	13	psi

Since the total system operating pressure is less than the maximum suggested for Class 200 PVC, this pipe class and size are appropriate.

2. Maximum Allowable Surge Pressure.

a). Determine allowable maximum pressure surge (P_a).

$$P_a = \textbf{Pipe Pressure Class – Total System Operating Pressure}$$

= 200 [5] psi – 130 [13] psi

= 70 [14] psi

b). Determine the flow velocity.

Pipe inside diameter (Appendix Table A.3) 5.995 [1] in

Equation 8.2

$$V = \frac{Q}{2.45\ D^2}$$

$$= \frac{210\ [7]\ \text{US gpm}}{2.45 \times (5.995\ [14]\ \text{in})^2}$$

= 2.38 [14] ft/s

c). Determine pressure increase due to an instantaneous valve closure

Pressure wave velocity, a (Table 8.3) 1,300 [15] ft/s

Equation 8.5

$$P = 0.0135 \times a\ \Delta V$$

= 0.0135 x 1,300 [15] ft/s x 2.38 [14] ft/s

= 42 [16] psi

Since the pressure generated due to instantaneous valve closure does not exceed the maximum allowable surge pressure, the valve may be closed quickly. To reduce pressure surge, care should be taken to ensure velocity changes occur slower than the system critical time.

d). Determine the system critical time

Equation 8.6

$$T_c = \frac{2\ L}{a}$$

$$= \frac{2 \times 1{,}500\ [3]\ \text{ft}}{1{,}300\ [15]\ \text{ft/s}}$$

= 2.3 [17] sec

8.5 Pipeline Design Considerations

As discussed in Section 8.3 and 8.4, the pipe selected must he capable of withstanding the total possible pressure that can be exerted on the system. The following points should be considered in designing mainline systems:

- The flow velocity in the pipe should be limited to 5 ft/sec.
- For PVC pipe systems the operating pressure should not exceed 72% of the stated pipe pressure rating.
- An air-vacuum release valve should be installed at all summits of the pipeline. These valves release air during start up which reduces potential surge pressures. It also allows air to re-enter the pipeline during shut down which prevents the possibility of vacuum collapsing the pipe. Suggested minimum sizes for air-vacuum release valves are shown in Table 8.6, for pipe lines operating with a flow velocity of 5 ft/sec or less.

Table 8.6 Air-Vacuum Release Valve Sizing

Pipe Diameter	Minimum Air-Vacuum Release Valve Diameter
up to 4″	1½″
5″ – 8″	2″
10″ – 12″	3″

- On gravity fed irrigation systems, a vent should be installed at the intake to allow entry of air should the intake become blocked.
- Drains or pump outs should be installed at all low points in regions where freezing is a hazard.
- Check valves should be used to prevent back flow through the pump. Spring loaded check valves are suggested as they will close before flow reversal begins, reducing possible pressure surges.
- If water hammer pressures are excessive, gasket joints should be used to allow for pipe expansion.
- If multiple laterals are being operated at the same time the designer should calculate friction loss at the furthest point.

Pipe Installation

The pipe should be snaked moderately between fixed supports to allow for expansion and contraction. Temperature problems can be minimized by installing pipe when it is within a few degrees of the expected operating temperature. Anchoring of the pipe is required whenever excessive movement due to temperature changes or steep slopes are likely to occur.

Buried pipe should be backfilled (excluding joints) to a one foot depth shortly after laying. This tends to distribute thermal expansion or contraction evenly over the pipe. It also keeps the pipe in alignment during the final backfill process. The pipe should be pressure tested after being partially back filled so that all joints and fittings can be observed.

Trenches

Irrigation trenches should have the following characteristics:

- free from rocks and frozen earth
- deep enough to protect pipe from surface loads or below frost level if drains are not provided. Recommended pipe depths, assuming frost not to be a factor are given in Table 8.7.
- the bedding material on the trench bottom should support the pipe uniformly over its entire length.
- trenches should be free from water.
- trenches should not curve faster than the recommended rate for the specific pipe to be buried.

Table 8.7 Recommended Pipe Installation Depths – Excluding Frost Requirements

Nominal Pipe Diameter		Pipe Depths	
[in]	[mm]	[ft]	[m]
½ – 2	12 – 63	1.5	0.45
2 – 4	63 – 100	2.0	0.60
> 4	> 100	2.5	0.80

Thrust Blocking

Thrust blocks may be required at all changes in pipe direction or where the flow rate changes significantly. The thrust block must support the pipe against forces caused by water pressure and changes in momentum. This is done by increasing the soil bearing area for buried pipe or by the weight of a block or anchoring for surface pipe. The size and location of the thrust block depends on the pipe size, line pressure, and type of fitting, soil type and degree of bend. PVC pipe less than 3" that is solvent welded will usually not require thrust blocking.

The following tables can be used to determine the thrust block size.

Table 8.8 Pipeline Thrust Factors

Nominal Pipe Diameter		Pipeline Thrust [lb/psi]			
[in]	[mm]	Dead Ends Tees	90° Elbows	45° Elbows	22.5° Elbows
1.5	38	2.94	4.16	2.25	1.15
2	50	4.56	6.45	3.50	1.80
2.5	63	6.65	9.4	5.10	2.60
3	75	9.80	13.9	7.51	3.80
4	100	16.2	23.0	12.4	6.31
5	127	24.7	35.0	19.0	9.63
6	150	35.0	49.2	26.7	13.5
8	200	59.0	83.5	45.2	23.0
10	250	91.5	130.0	70.0	35.8
12	300	129.0	182.0	98.5	50.3
16	400	201.1	284.4	153.8	78.6

Source: ASAE Standards 1987

Table 8.9 Bearing Strength of Soils

Soil Type	Safe Bearing Load [lb/ft^2]
Muck	0
Soft clay	1,000
Medium clay – can be spaded	2,000
Coarse and fine compact soil	3,000
Cemented gravel and sand – difficult to pick	4,000
Sound shale	10,000

Source: ASAE Standards 1987

Example 8.9 Thrust Block Sizing

Question: An 8” PVC pipe operating at 125 psi is buried in a compact sand type soil. For a 90^o elbow, what size thrust block will be required?

Information:

Operating pressure	*125*	1	psi
Pipe diameter	*8*	2	in
Elbow degree	*90*	3	degree

Calculation:

Pipeline thrust (Table 8.8) *83.5* **4** lb/psi

Pipeline Thrust = **Pipeline Thrust x Operating Pressure**

= *83.5* **4** lb/psi x *125* **1** psi

= *10,437* **5** lb

For compact sand,

Soil bearing strength (Table 8.9) *3,000* **6** lb/ft^2

Thrust Block Area = $\dfrac{\textbf{Pipeline Thrust}}{\textbf{Soil Bearing Strength}}$

= $\dfrac{10{,}437 \ [5] \text{ lb}}{3{,}000 \ [6] \text{ lb/ft}^2}$

= *3.5* **7** ft^2

A pipeline under pressure exerts an outward thrust at each deflected coupling. Usually well tamped soil is sufficient to prevent any side movement in the pipe. However, if soft soil conditions exist then thrust blocks may be required, especially for gasket joints. Table 8.10 can be used to calculate the thrust block size to limit side thrust.

Table 8.10 Pipeline Thrust Factors

Nominal Pipe Diameter		Side Thrust
[in]	[mm]	[lb/psi/degree deflection]
1.5	38	0.05
2	50	0.08
2.5	63	0.12
3	75	0.17
4	100	0.28
5	127	0.43
6	150	0.61
8	200	1.03
10	250	1.60
12	300	2.25
16	400	3.49

Source: ASAE Standards 1987

For example, the side thrust for an 8" pipe operating at 125 psi with a 10 degree deflection is 1.03 lb/psi/deg x 10 degree x 125 psi = **1,287 lb** (from Table 8.10). The soil conditions should be evaluated to determine if thrust blocking will be required for the side thrust calculated in this example. Table 8.11 can be used as a guide to determine the need for thrust blocking in-line valves.

Table 8.11 Anchoring of In-Line Valves

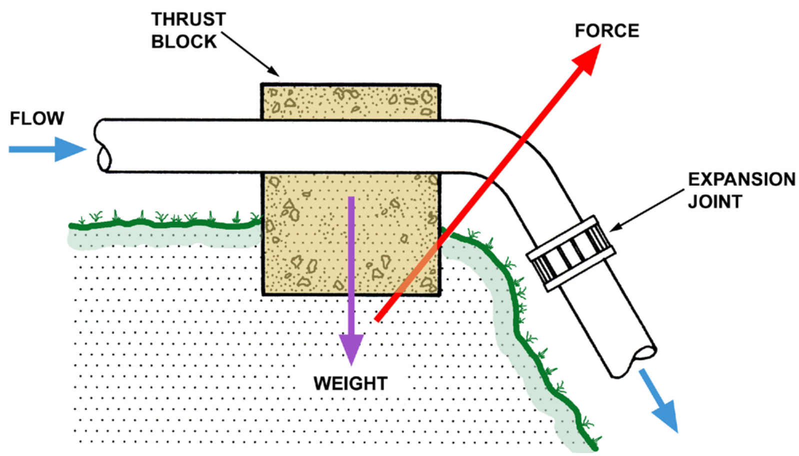
Working Pressure [psi]	Valve Size Requiring Anchorage
50 – 100	12″ and up
100 – 150	8″ and up
150 – 200	all sizes

Thrust Block Installation

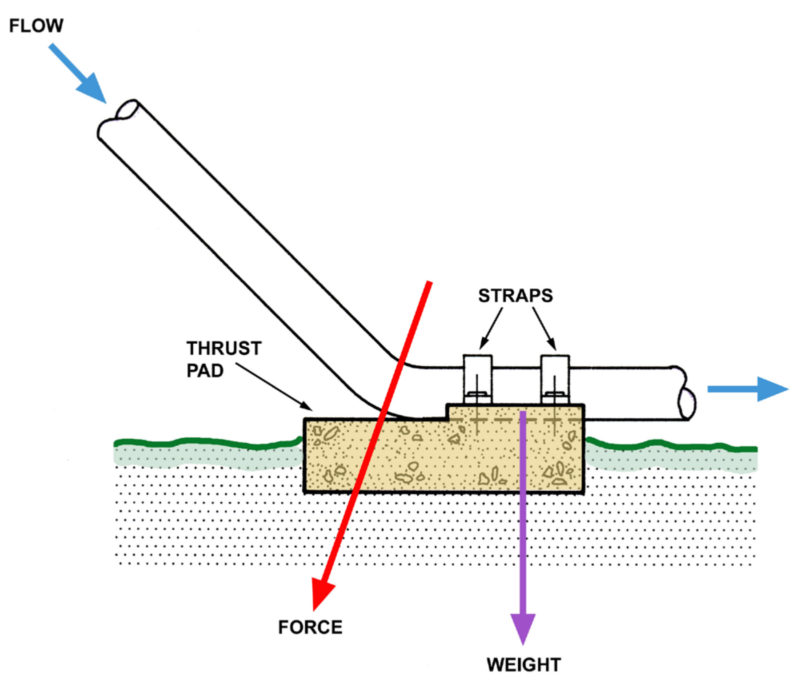
Recommended thrust blocking consists of concrete having a calculated compressive strength of at least 2,000 psi. The concrete mixture suggested is one part cement, two parts washed sand and four parts gravel.

Figure 8.1 indicates how thrust blocks are used for above ground mainline installations.

Figure 8.2 provides details on thrust block positioning for buried pipes.



(a) Thrust block at Vertical Bend. The thrust block must be heavier than the thrust force by at least 50% for vertical bends.



(b) Thrust pad at vertical bend.

Figure 8.1 Thrust Block Positioning for Above Ground Irrigation Pipelines

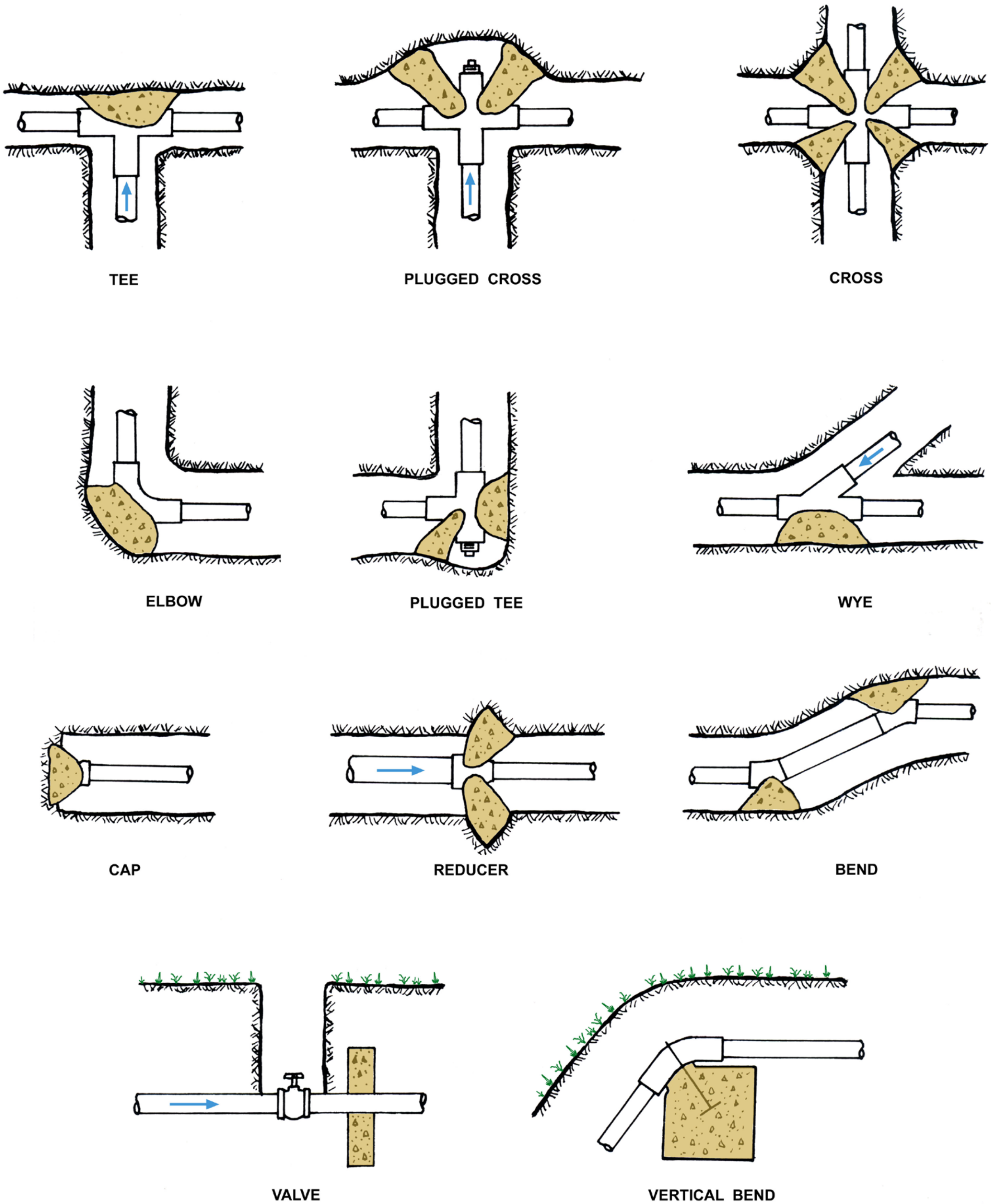


Figure 8.2 Thrust Block Positioning for Underground Irrigation Pipelines