

# Calculating Horsepower Requirements and Sizing Irrigation Supply Pipelines

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Pumping costs are often one of the largest single expenses in irrigated agriculture. Table 1 shows typical fuel use and costs of pumping in Texas as measured in irrigation pumping plant tests conducted by the Texas Agricultural Extension Service. Properly sizing pipelines for the particular situation will help minimize these costs. This publication outlines how to calculate the horsepower requirements of irrigation pumps and how to use this information in sizing supply pipelines.

## Pumping Plant Efficiency

An irrigation pumping plant has three major components:

1. a power unit,
2. a pump drive or gear head, and
3. a pump.

For electric powered plants, the pump lineshaft and the motor shaft are usually directly connected, making a pump drive or gear head unnecessary.

The *overall pumping plant efficiency* is a combination of the efficiencies of each separate component. Individual pumping unit components in good condition and carefully matched to the requirements of a specific pumping situation can have efficiencies similar to those given in Table 2. However, many pumping units operate at efficiencies far below acceptable levels (Table 3). Additional details on pumping plant efficiency are given in L-2218, "Pumping Plant Efficiency and Irrigation Costs," (available from your county Extension agent).

## Performance Standards

There are two common methods of determining the efficiency of pumping plants. One is to measure the efficiency of each component of the plant (motor, shaft and pump). Once the efficiencies of the components are

known, the overall efficiency is easily calculated. This requires specialized equipment and considerable expertise.

Another method is to calculate the load on the motor or engine and then measure how much fuel is used by the power unit. The fuel usage can then be compared to a standard. The most widely used standards were developed by the Agricultural Engineering Department of the University of Nebraska (Table 4). The fuel consumption rates in Table 4 indicate the fuel use which can be *reasonably expected* from a properly engineered irrigation pumping plant in good condition. The actual fuel usage of a new or reconditioned plant should not be larger than that shown in Table 4.

## Calculating Horsepower

Horsepower is a measurement of the amount of energy necessary to do work. In determining the horsepower used to pump water, we must know the:

1. pumping rate in gallons per minute (gpm), and
2. total dynamic head (TDH) in feet.

The theoretical power needed for pumping water is called **water horsepower** (whp) and is calculated by:

$$\text{(equation 1)} \quad \text{whp} = \frac{\text{gpm} \times \text{TDH (ft)}}{3,960}$$

Since no device or machine is 100 percent efficient, the horsepower output of the power unit must be higher than that calculated with equation 1. This horsepower, referred to as **brake horsepower** (bhp), is calculated by:

$$\text{(equation 2)} \quad \text{bhp} = \frac{\text{whp}}{\text{(pumping plant efficiency)}}$$

## Total Dynamic Head (TDH)

TDH may be viewed as the total load on the pumping plant. This load is usually expressed in feet of "head" (1 psi, or pound per square inch = 2.31 feet of

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head). TDH can be calculated with the following equation:

$$\text{(equation 3) TDH} = \text{(static head)} + \text{(friction loss)} + \text{(operating pressure)} + \text{(elevation change)}$$

**Pumping lift:** “Pumping lift” is the vertical distance from the water level in the well to the pump outlet during pumping. In areas of falling water table, often the maximum depth to the water table expected during the pumping season is used.

**Friction loss:** Water flowing past the rough walls in a pipe creates friction which causes a loss in pressure. Friction losses also occur when water flows through pipe fittings, or when the pipe suddenly increases or decreases in diameter. Tables with values for friction loss through pipe and fittings similar to Tables 6 and 7 are widely available.

**Operating pressure requirements:** Manufacturers provide recommended operating pressures for specific water applicators in irrigation systems. Operating pressure in *psi* is converted to *feet of head* by the relationship:

$$1 \text{ psi} = 2.31 \text{ ft.}$$

**Elevation change:** Use the total change in elevation from the pump to the point of discharge, such as the end of the pipeline or sprinkler head. This elevation change may be positive (when the irrigation system is uphill from the pump) or negative (when it is downhill from the pump). Use only the difference in elevation between these two points, not the sum of each uphill or downhill section. Do not forget to add the distance from the ground to the point of water discharge, particularly for center pivot systems.

For center pivots, elevation differences caused by slopes in the field usually are accounted for in the computer printout of the design, and are included in the operating pressure requirements. If not, then the elevation change from the pivot point to the highest point in the field should be added to the total elevation change.

## Sizing Irrigation Mainlines

In sizing irrigation water supply pipelines, two factors are important: *friction losses* and *water hammer*; both are influenced by the relationship between flow rate (or velocity) and pipe size.

## Water Hammer

When moving water is subjected to a sudden change in flow, shock waves are produced. This is referred to as *water hammer* or *surge pressure*. Water hammer may be caused by shock waves created by sudden increases or decreases in the velocity of the water. Flow changes and shock waves can occur when valves are opened, pumps are started or stopped, or water encounters directional changes caused by pipe fittings.

## Controlling Water Hammer

To control surge pressure in situations where excessive pressures can develop by operating the pump with all valves closed, pressure relief valves are installed between the pump discharge and the pipeline. Also, pressure relief valves or surge chambers should be installed on the discharge side of the check valve where back flow may occur. Air trapped in a pipeline can contribute to water hammer. Air can compress and expand in the pipeline, causing velocity changes. To minimize such problems, prevent air from accumulating in the system by installing air-relief valves at the high points of the pipeline, at the end, and at the entrance.

Other general recommendations for minimizing water hammer include:

1. For long pipelines sloping up from the pump, install “nonslam” check valves designed to close at zero velocity and before the column of water above the pump has an opportunity to move back.
2. In filling a long piping system, the flow should be controlled with a gate valve to approximately three-fourths of the operating capacity. When the lines have filled, the valve should then be slowly opened until full operating capacity and pressure are attained.

## 5 Feet per Second Rule

To minimize water hammer, especially for plastic (PVC) pipe, water velocities should be limited to 5 ft/s (feet per second) unless special considerations are given to controlling water hammer. Most experts agree that the velocity should never exceed 10 ft/s. Also, the velocity of flow in the suction pipe of centrifugal pumps should be kept between 2 and 3 ft/s in order to prevent cavitation. Table 5 lists the maximum flow rates recommended for different ID (internal diameter) pipe sizes using the 5 ft/s rule. Many friction loss tables give both the friction loss and velocity for any given gpm and pipe size.

Velocity (V) in feet per second (ft/s) can be calculated based on the flow rate in gallons per minute (gpm) and pipe internal diameter in inches as:

$$\text{(equation 4) } V \text{ (ft/s)} = \frac{\text{Flow (gpm)}}{2.45 \text{ ID}^2 \text{ (inches)}}$$

## Friction Loss

Pumping plants must provide sufficient energy to overcome friction losses in pipelines. Excessive friction loss will lead to needlessly high horsepower requirements and correspondingly high fuel usage for pumping. Often the extra cost of a larger pipe will be recovered quickly from lower fuel costs. Both undersized and oversized pipe should be avoided.

Smooth pipe produces less friction loss and has lower operating costs than rough pipe. Plastic pipe, such as PVC, is the smoothest, followed by aluminum, steel and concrete, in that order. Table 6 lists typical friction losses in commonly used pipe. The friction

losses shown are for pipes of these internal diameters. This table is presented for information purposes only. Actual pipe diameters vary widely and more precise figures from manufacturers' specifications should be used for design purposes.

## Selecting PVC Pipe

Polyvinyl chloride (PVC) or thermoplastic pipe is exactly manufactured by a continuous extruding process which produces a strong seamless pipe that is chemically resistant, lightweight, and that minimizes friction loss. PVC pipe is produced in many sizes, grades and specifications.

### PVC Terminology

**Low pressure pipelines** – underground thermoplastic pipelines with 4- to 24-inch nominal diameter used in systems subject to pressures of 79 psi or less.

**High pressure pipelines** – underground thermoplastic pipelines of 1/2- to 27-inch nominal diameter that are closed to the atmosphere and subject to internal pressures (including surge pressures, from 80 to 315 psi).

**Class or PSI designation** – refers to a pressure rating in pounds per square inch (Table 8).

**Schedule** – refers to a plastic pipe with the same outside diameter and wall thickness as iron or steel pipe of the same nominal size (see Table 9).

**SDR (Standard Dimension Ratio)** – is the ratio of the outside pipe diameter to the wall thickness. Table 9 gives the pressure rating for pipes of various SDR.

**IPS** – refers to plastic pipe that has the same outside diameter as iron pipe of the same nominal size.

**PIP** – is an industry size designation for plastic irrigation pipe.

### Working Pressure

Tables 8 and 9 show the recommended maximum operating pressures of various classes and schedules of PVC pipe. Actual operating pressure may be equal to these pressure ratings as long as **surge pressures** are included, but be sure to account for **all** surges.

To determine which pipe to use, simply combine the total head in the pipe with the surge pressures, and select the closest larger class. However, surge pressures should not exceed 28 percent of the pipe's pressure class rating.

**When surge pressures are not known**, the actual operating or "working" pressure should not exceed the maximum allowable working pressures given in Table 11.

### Estimating Surge Pressure

As discussed above, keeping the velocity at or below 5 ft/s will help minimize surge pressure (or water hammer). However, the sudden opening and closing of valves will produce a surge pressure, which increases with higher velocities. The maximum surge pressure that will be produced in a PVC pipe with the sudden opening or closing of a valve can be determined with Table 10. For example, the surge pressure from a sudden valve closure with a water velocity of 7 ft/s in a SDR 26 PVC pipe is:

$$7 \times 14.4 = 100.8 \text{ psi}$$

This pressure then is added to the operating pressure to determine which class of PVC pipe to use.

# Example Problem #1 – Complete Analysis

Determine the difference in horsepower requirements and annual fuel costs for 6-inch and 8-inch mainlines (plastic pipe) for the following system:

## System Data

1. type of power plant	diesel
2. cost of energy	\$0.65 per gal.
3. pumping lift	250 ft.
4. pump column pipe distance to pump in column pipe	8-in. steel pipe 350 ft. (or 3.5 x 100-ft. sections)
5. system flow rate	750 gpm
6. yearly operating time	2000 hrs.
7. distance from pump to pivot	4000 ft. (or 40 x 100-ft. sections)
8. required operating pressure	45 psi
9. elevation change from pump to pivot	+37 ft.
10. types of fittings in system	check valve, gate valve, two standard elbows

## Step One - Calculate Total Dynamic Head (equation 3)

$$\text{TDH} = (\text{pumping lift}) + (\text{elevation change}) + (\text{operating pressure}) + (\text{friction losses})$$

1. **Pumping lift** (item 3) = 250 ft.

2. **Elevation change** (item 9) = + 37 ft.

3. **Operating pressure** (item 8) = 45 psi x (2.31 ft./psi) = 104 ft.

4. **Friction loss: Pump column pipe**

a. friction loss in 8-in. well casing (from Table 6) = 1.8 ft./100 ft.

b. total friction loss = 1.8 x 3.5 = 6.3 ft.

5. **Friction loss in plastic mainline (Case 1: 6-in. pipe)**

a. friction loss in pipe (from Table 6) = 3.4 ft./100 ft. x 40 = 136 ft.

b. friction loss in fittings (from Table 7)  
equivalent pipe length = 30 + 3.5 + (2 x 16) = 65.5 ft. of pipe  
friction loss = 3.4 ft./100 ft. x (65.5/100) = 2.2 ft.

c. total friction loss = 136 + 2.2 = 138.2 ft.

6. **Friction loss in plastic mainline (Case 2: 8-in. pipe)**

a. friction loss in pipe (from Table 5) = 0.8 ft./100 ft. x 40 = 32 ft.

b. friction loss in fittings  
equivalent pipe length = 40 + 4.5 + (2 x 14) = 72.5 ft. of pipe  
friction loss = 0.8 ft./100 ft. x (72.5/100) = 0.6 ft.

c. total friction loss = 32 + 0.6 = 32.6 ft.

7. **TDH (Case 1)** = (1) + (2) + (3) + (4) + (5) = 250 + 37 + 104 + 6.3 + 138.2 = 535.5 ft.

8. **TDH (Case 2)** = (1) + (2) + (3) + (4) + (6) = 250 + 37 + 104 + 6.3 + 32.6 = 429.9 ft.

## Step Two - Calculate Water Horsepower (equation 2)

$$\text{(Case 1) whp} = \frac{(750 \text{ gpm}) \times (535.5 \text{ ft.})}{3,960} = 101 \text{ whp}$$

$$\text{(Case 2) whp} = \frac{(750 \text{ gpm}) \times (429.9 \text{ ft.})}{3,960} = 82 \text{ whp}$$

Note: The output of the power plant must be larger than the water horsepower due to the pump's efficiency. Usually a pump efficiency of 75 percent is used in design. However, actual pump selection is based on pump performance curves available from manufacturers. Do not buy a pump on the basis of its horsepower rating alone. For more information see L-2218, "Pumping Plant Efficiency and Irrigation Costs," available from your county Extension agent.

## Brake horsepower (equation 2)

$$\text{(Case 1) bhp} = 101 / .75 = 135 \text{ bhp}$$

$$\text{(Case 2) bhp} = 81 / .75 = 108 \text{ bhp}$$

## Step Three - Calculate Annual Fuel Use

Note: The Nebraska Performance Standards (Table 4) may be used to estimate annual fuel use. From Table 4, each gallon of diesel fuel will provide 12.5 water horsepower-hours.

$$\text{fuel use} = \text{whp} \times \frac{1}{(\text{performance criteria})} \times (\text{hours of operation})$$

$$\text{(Case 1) fuel use} = 101 \text{ whp} \times \frac{\text{gal.}}{12.5 \text{ whp} \cdot \text{hrs.}} \times \frac{2,000 \text{ hrs.}}{\text{yr.}} = \frac{16,160 \text{ gals.}}{\text{yr.}}$$

$$\text{(Case 2) fuel use} = 81 \text{ whp} \times \frac{\text{gal.}}{12.5 \text{ whp} \cdot \text{hrs.}} \times \frac{2,000 \text{ hrs.}}{\text{yr.}} = \frac{12,960 \text{ gals.}}{\text{yr.}}$$

## Step Four - Calculate Annual Fuel Costs

$$\text{(Case 1) } \frac{16,160 \text{ gals.}}{\text{yr.}} \times \frac{\$0.65}{\text{gal.}} = \$ 10,504 \text{ per year for diesel fuel}$$

$$\text{(Case 2) } \frac{12,960 \text{ gals.}}{\text{yr.}} \times \frac{\$0.65}{\text{gal.}} = \$ 8,424 \text{ per year for diesel fuel}$$

$$\text{DIFFERENCE} = \$10,504 - \$8,424 = \$2,080$$

## Step Five - Calculate Total Water Pumped per Year

Note: The conversion rate used is 325,851 gal. = 1 ac.-ft.

$$\frac{750 \text{ gals.}}{\text{min.}} \times \frac{60 \text{ mins.}}{\text{hr.}} \times \frac{2,000 \text{ hrs.}}{\text{yr.}} = 90 \text{ million gals.} = 276 \text{ acre-feet of water}$$

## Example Problem 2: Simplified Analysis

In the above example, we found that the friction losses in the pump column pipe and through the fittings are minor. The only other difference between Case 1 and Case 2 was the friction loss in the pipeline. Thus, the difference in horsepower requirements and annual fuel costs between the 6-inch and 8-inch pipelines in the above example can be *approximated* by considering only the friction loss in the pipe.

### Step One - Calculate Pipeline Friction Loss Difference

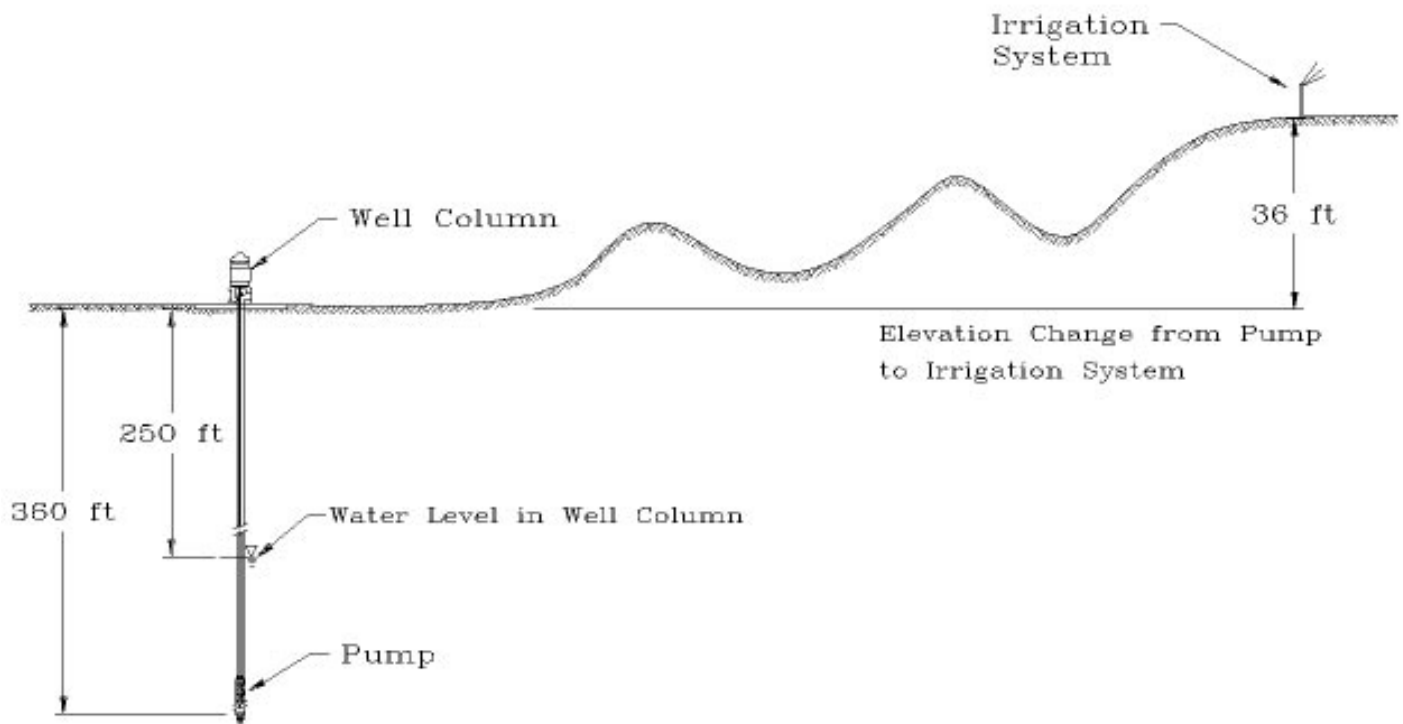
$$(\text{friction loss in 6-in.}) - (\text{friction loss in 8-in.}) = 136 - 32 \text{ ft.} = 104 \text{ ft.}$$

### Step 2 - Calculate Increase in Horsepower and Annual Fuel Use

$$\text{whp} = \frac{750 \times 104}{3,960} = 19.7 \text{ whp}$$

$$\text{fuel use} = 19.7 \text{ whp} \times \frac{\text{gal.}}{12.5 \text{ whp} \cdot \text{hrs.}} \times \frac{2,000 \text{ hrs.}}{\text{yr.}} = \frac{3,151 \text{ gals.}}{\text{yr.}}$$

Note: This means that 3,151 more gallons of diesel would be required if a 6-inch mainline was used instead of an 8-inch mainline.



Drawn By: Ed Wilson

**Table 1. Pumping costs in the Texas High Plains (THP) and in South/Central Texas (SCT) per acre-inch of water at 100 feet total head from irrigation pumping plant efficiency tests conducted by the Texas Agricultural Extension Service.**

Type and price <sup>1</sup>	Region <sup>2</sup>	Cost (\$) per ac.-in. per 100 ft. head		
		lowest	highest	average
Natural Gas @ \$3.00 MCF	THP	0.40	3.93	0.81
	SCT	0.31	1.96	0.76
Electricity @ \$0.07/KWH	THP	0.49	3.10	1.35
	SCT	0.29	20.20	1.49
Diesel @ \$0.65/gal.	THP	0.57	1.91	0.77
	SCT	0.36	3.43	0.83

<sup>1</sup>Assumed price—actual prices varied in each region.

<sup>2</sup>THP (Texas High Plains) results are from more than 240 efficiency tests. SCT (South/Central Texas) results are from 240 efficiency tests.

**Table 2. Irrigation pumping equipment efficiency.**

Equipment	Attainable efficiency, percent
Pumps (centrifugal, turbine)	75-82
Right-angle pump drives (gear head)	95
Automotive-type engines	20-26
Industrial engines	
Diesel	25-37
Natural gas	24-27
Electric motors	
Small	75-85
Large	85-92

**Table 4. Nebraska performance criteria for pumping plants. Fuel use by new or reconditioned plants should equal or exceed these rates.**

Energy source	Water horsepower-hours <sup>1</sup> per unit of energy	Energy units
Diesel	12.5	gal.
Gasoline <sup>2</sup>	8.7	gal.
Natural gas	66.7 <sup>3</sup>	1,000 ft. <sup>3</sup>
Electricity	0.885 <sup>4</sup>	kwh

<sup>1</sup>Based on 75 percent efficiency.

<sup>2</sup>Includes drive losses and assumes no cooling fan.

<sup>3</sup>Assumes natural gas content of 1,000 btu per cubic foot.

<sup>4</sup>Direct connection—no drive.

**Table 3. Typical values of overall efficiency for representative pumping plants, expressed as percent.\***

Power source	Recommended as acceptable	Average values from field tests†
Electric	72-77	45-55
Diesel	20-25	13-15
Natural gas	18-24	9-13
Butane, propane	18-24	9-13
Gasoline	18-23	9-12

\* Ranges are given because of the variation in efficiencies of both pumps and power units. The difference in efficiency for high and low compression engines used for natural gas, propane and gasoline must be considered especially. The higher value of efficiency can be used for higher compression engines.

† Typical average observed values reported by pump efficiency test teams.

**Table 5. Approximate maximum flow rate in different pipe sizes to keep velocity ≤ 5 feet per second.**

Pipe diameter	Flow rate (gpm)
1/2	6
3/4	10
1	15
1 1/4	25
1 1/2	35
2	50
3	110
4	200
5	310
6	440
8	780
10	1225
12	1760
16	3140

**Table 6. Friction losses in feet of head per 100 feet of pipe (for pipes with internal diameters shown).**

Pipe size	4-inch			6-inch			8-inch			10-inch			12-inch		
	Steel	Alum.	PVC	Steel	Alum.	PVC	Steel	Alum.	PVC	Steel	Alum.	PVC	Steel	Alum.	PVC
Flow rate (gpm)															
100	1.2	0.9	0.6	--	--	--	--	--	--	--	--	--	--	--	--
150	2.5	1.8	1.2	0.3	0.2	0.2	--	--	--	--	--	--	--	--	--
200	4.3	3.0	2.1	0.6	0.4	0.3	0.1	0.1	0.1	--	--	--	--	--	--
250	6.7	4.8	3.2	0.9	0.6	0.4	0.2	0.1	0.1	0.1	0.1	--	--	--	--
300	9.5	6.2	4.3	1.3	0.8	0.6	0.3	0.2	0.1	0.1	0.1	--	--	--	--
400	16.0	10.6	7.2	2.2	1.5	1.0	0.5	0.3	0.2	0.2	0.1	0.1	0.1	--	--
500	24.1	17.1	11.4	3.4	2.4	1.6	0.8	0.6	0.4	0.3	0.2	0.1	0.1	0.1	0.1
750	51.1	36.3	24.1	7.1	5.0	3.4	1.8	1.3	0.8	0.6	0.4	0.3	0.2	0.1	0.1
1000	87.0	61.8	41.1	12.1	8.6	5.7	3.0	2.1	1.4	1.0	0.7	0.5	0.4	0.3	0.2
1250	131.4	93.3	62.1	18.3	13.0	8.6	4.5	3.2	2.1	1.5	1.1	0.7	0.6	0.4	0.3
1500	184.1	130.7	87.0	25.6	18.2	12.1	6.3	4.5	3.0	2.1	1.5	1.0	0.9	0.6	0.4
1750	244.9	173.9	115.7	34.1	24.2	16.1	8.4	6.0	4.0	2.8	2.0	1.3	1.2	0.9	0.6
2000	313.4	222.5	148.1	43.6	31.0	20.6	10.8	7.7	5.1	3.6	2.6	1.7	1.5	1.1	0.7

NOTE: Flow rates below horizontal line for each pipe size exceed the recommended 5-feet-per-second velocity.

**Table 7. Friction loss in fittings. Friction loss in terms of equivalent length of pipe (feet) of same diameter.**

Type of fitting	Inside pipe diameter (inches)					
	4	5	6	8	10	12
45-degree elbow	5	6	7	10	12.5	15
Long-sweep elbow	7	9	11	14	17	20
Standard elbow	11	13	16	20	25	32
Close return bend	24	30	36	50	61	72
Gate valve (open)	2	3	3.5	4.5	5.5	7
Gate valve (1/2 open)	65	81	100	130	160	195
Check valve	100	110	30	40	45	35



**Table 8. Pressure rating for class and SDR non-threaded PVC pipe.\***

Pipe designation	Maximum working pressure including surges (psi)
Class 80	80
Class 100	100
Class 125	125
Class 160	160
Class 200	200
Class 250	250
Class 315	315
SDR 81	50
SDR 51	75
SDR 41	100
SDR 32.5	125
SDR 26	160
SDR 21	200
SDR 17	250
SDR 13.5	315

\*For pipes of standard code designation: PVC 1120, PVC 1220, and PVC 2120.

**Table 10. Maximum surge pressures associated with sudden changes in velocity in psi per ft./s. water velocity (for 400,000 psi modulus of elasticity PVC materials).**

SDR	Maximum surge pressure (psi) per each ft./s. of water velocity
13.5	20.3
17.0	18.0
21.0	16.1
26.0	14.4
32.5	12.9
41.0	11.4
51.0	10.2
64.0	9.1
81.0	8.1

Example: The surge pressure from a sudden valve closure with a water velocity of 7 ft./s. in a SDR 26 PVC pipe is  $7 \times 14.4 = 100.8$  psi.

**Table 9. Pressure rating for schedule 40 and schedule 80 PVC pipe.\***

Diameter (inches)	Maximum operating pressure (psi)	
	Schedule 40	Schedule 80
3	840	1200
4	710	1040
6	560	890
8	500	790
10	450	750
12	420	730

\*For Type I, Grade I at 73.4 degrees F.

**Table 11. Maximum allowable working pressure for non-threaded PVC pipe when surge pressures are not known and for water temperatures of 73.4 degrees F.**

SDR	Maximum working pressure (psi)
13.5	227
17.0	180
21.0	144
26.0	115
32.5	90
41.0	72
51.0	58
64.0	45
81.0	36

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