PDHonline Course C182 (4 PDH)

Practical Design of Water Distribution Systems

Instructor: Jeffrey A. Gilbert, P.E.

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

An Approved Continuing Education Provider

Practical Design of Water Distribution Systems

Jeffrey A. Gilbert, P.E.

Course Content

INDEX

1.0 MATERIALS

1.1 DEFINITIONS

Ductile Iron Pipe (DIP)- Pipe which is manufactured from ferrous material in which a major portion contains carbon occurring as a free graphite in substantially nodular or spheroidal form. (Reference: ANSI/AWWA C110/A21.10).

ANSI-American National Standards Institute

AWWA-American Water Works Association

Flanged Joint- A pipe joint that has a flared flange made into the pipe end to receive bolts to couple an adjoining flanged pipe or fitting.

Gray Iron Pipe- Pipe which is manufactured from ferrous material in which a major portion contains carbon occurring in the form of flakes interspersed throughout the metal.

Mechanical Joints- Mechanical joints are pipe joints that are gasketed and bolted together. See ANSI/AWWA C111/A21.11.

Push on Pipe Joints- Single rubber gasket pipe joints where the pipe sections are pushed together and not restrained. See ANSI/AWWA C111/A21.11.

1.2 DUCTILE IRON PIPE

ANSI/AWWA C110/A21.10.
DIP from 3” to 24” with mechanical joints or push-on joints is pressure rated for 350 psi. DIP with flanged joints is rated for 250 psi except that sizes 12” and smaller with special gaskets can be rated for 350 psi. Gray iron fittings for this standard are rated at 150 psi or 250 psi for all joints. See Table below.

DIP 30” to 64” pressure class 150 to 350

DIP Outside coatings to be petroleum asphaltic, 1 mil thick. This material adheres to raw DIP and does not become brittle in any condition, buried or exposed.

Size in.	Outside Diameter in.	Pressure Class				
		150	200	250	300	350
		Nominal Thickness in inches				
4	4.8	-	-	-	-	0.25
6	6.9	-	-	-	-	0.25
8	9.05	-	-	-	-	0.25
10	11.1	-	-	-	-	0.26
12	13.2	-	-	-	-	0.28
14	15.3	-	-	0.28	0.3	0.31
16	17.4	-	-	0.3	0.32	0.34
18	19.5	-	-	0.31	0.34	0.36
20	21.6	-	-	0.33	0.36	0.38
24	25.8	-	0.33	0.37	0.4	0.43
30	32	0.34	0.38	0.42	0.45	0.49
36	38.3	0.38	0.42	0.47	0.51	0.56
42	44.5	0.41	0.47	0.52	0.57	0.63
48	50.8	0.46	0.52	0.58	0.64	0.7
54	57.56	0.51	0.58	0.65	0.72	0.79
60	61.61	0.54	0.61	0.68	0.76	0.83
64	65.67	0.56	0.64	0.72	0.8	0.87

ANSI/AWWA C104/A21.4, DIP inside coatings are cement-mortar lined for use under normal conditions. Sleeves plugs or caps generally are cement-mortar lined.
Sleeves, plugs and caps may be specified with petroleum asphaltic coating, 1 mil thick.

Under special conditions, other types of coatings are available.

ANSI/AWWA C150/ A21.50. This is the standard for DIP pipe thickness. AWWA C150 specifies the wall thickness for various working pressures. For example, an 8” pipe with a working pressure of 150 psi, requires a wall thickness of 0.18 inches and requires the use of Pressure Class 350. A working pressure of 150 psi for a 24” pipe requires a wall thickness of 0.30 inches and the use of Pressure Class 200 pipe. Table 13 of the ANSI/AWWA C150/ A21.50 standard lists nominal pipe sizes from 3” to 64-inch for working pressures from 150 psi to 350 psi.

The table below provides the designer with ANSI/AWWA trench and cover criteria. Since some of these depths are generally impractical for most applications, rarely would a designer be concerned about depth of trench when using DIP.

Size in.	Pressure Class	Thickness in.	Working Pressure (1) psi	Laying Conditions Maximum Depth of Cover in Feet(2)				
				Type 1	Type 2	Type 3	Type 4	Type 5
4	350	0.25	350	53	61	69	85	100(3)
6	350	0.25	350	26	31	37	47	65
8	350	0.25	350	16	20	25	34	50
10	350	0.26	350	11**	15	19	28	45
12	350	0.28	350	10**	15	19	28	44
14	250	0.28	250	*	11**	15	23	36
16	250	0.3	250	*	11**	15	24	34
18	250	0.31	250	*	10**	14	22	31
20	250	0.33	250	*	10	14	22	30
24	200	0.33	200	*	8**	12	17	25
30	150	0.34	150	*	-	9	14	22
36	150	0.38	150	*	-	9	14	21
42	150	0.41	150	*	-	9	13	20
48	150	0.46	150	*	-	9	13	20
54	150	0.51	150	*	-	9	13	20
60	150	0.54	150	*	5**	9	13	20
64	150	0.56	150	*	5**	9	13	20

Flanged Fittings 3" - 48"

Unless otherwise specified flanged fittings will be supplied in accordance with ANSI/AWWA C110/A21.10. They may have the following ratings:

Table 1.1

Size	Working Pressure	Material	Flange Drilling
3" - 12"	250 psi	CI & DI	Class 125*
14" - 48"	150 psi	CI	Class 125*
14" - 48"	250 psi	CI	Class 125*
14" - 48"	250 psi	DI	Class 125*

1.3 PLASTIC PRESSURE PIPE

ANSI/AWWA C900
Polyvinyl Chloride (PVC) under this standard is an alternative to DIP. Some government bodies may not accept this material in their systems for several reasons. The product itself is a proven alternative to DIP, yet there are weaknesses that a designer should consider.

ANSI C900 PVC pipe is produced by an extrusion procedure that elongates the grain of the material matrix. This method creates an inherent weakness in pressure pipe. When a water main breaks in a DIP, the break is generally isolated and can be selectively repaired with glands and sleeves. With C900 PVC, a pressure break in the pipe can propagate the length of the pipe *(with the grain)* which may result in a significant increase in excavation and repair costs.

Governments also reject PVC pipe because it must have detector tape or wire laid along with it in order to locate the pipe in the future. Generally the detector ribbon, tape, or wire, is placed above the pipe approximately 18 inches below the surface grade. The long-term integrity of the detection material is the problem. Any excavation traversing a water main of this design will most likely break the detection material and is rarely repaired leaving the system partially undetectable.

When C900 PVC first arrived as a pressure pipe there were concerns about the material holding up to cycles of pressure change, or fatigue failure. Testing has proven that C900 PVC does have the necessary tensile strength to ultimately result in a service life of more than 20 years.

The cost differential depends on economic factors such as steel versus PVC pipe material prices. Labor prices don't necessary play a factor in the bidding.

ANSI/AWWA C909 Standard for Molecularly Orientated Polyvinyl Chloride (PVCO) is an alternate option to C900 PVC. PVCO is manufactured with stock pipe made from ASTM D1784 cell class 12454 material. The pipe is produced by oriented circumferential expansion to provide a hydrostatic design basin (HDB) of 7,100 psi (49.0 Mpa). Basically this means that instead of extruding the stock to produce a given wall thickness and diameter, PVCO is expanded circumferentially. The resultant pipe does not have longitudinal grains susceptible to longitudinal failures. PVCO has cast iron pipe equivalent outside diameter dimensions and wall thickness designed for pressure classes 100, 150, and 200 psi, 4" through 24".

1.4 PROTECTION

Selection of material is important for water distribution and service lines. Depending on soil conditions, or in the case of exposed elements of a system, a designer must choose the appropriate material. For instance, consider the case where there is the likelihood of exposure to concentrations of low molecular weight petroleum products, organic solvents, or their vapors. Polyethylene, polybutylene, polyvinyl chloride, asbestos cement and elastomers used in jointing gaskets and packing glands, can be subject to permeation or deteriation by the lower molecular weight petroleum products. Consider in this case using DIP or gray iron mechanical joint materials.

When selecting a material for your design, soils should be tested for ionic activity as well as for other corrosive conditions. An ion active soil will inherently attack ferrous materials. The part or portion which is under the most stress will be the most affected. This usually means the bolts on flanged components are the first to decay. These areas are where most failures are found. DIP that is stressed in a bending moment (due to bridging) becomes affected more than other portions of a pipe.

If DIP is to be used in active soil, the use of sacrificial anodes are used to protect the system. When mechanical joints and fittings are used, stainless steal bolts and/or mega lugs are used.

ANSI/AWWA C105/A21.5 Polyethylene encasement is another method of protection often used. Polyethylene encasement has been used since 1958. It is generally used in corrosive soils throughout the United States. It is used on system sizes from 3” to 64”. The useful life of polyethylene with use on gray and ductile cast iron pipe is 30 years. Polyethylene is very resistant to bacteriological deterioration. However, the material is sensitive to prolonged light exposure and should be stored appropriately. There is more discussion on this in the design section.

NOTE: This material is difficult to install properly. Diligent inspection should be made and carefully specified in the contract.

1.5 FITTINGS

DIP fittings are generally available in 90 degree, 45 degree and 22.5 degree angles. Simply assuming angels to fit the plan when designing systems, is unwise. In the era of computer aided drafting, designers should have these fittings drawn and made as blocks or cells for assuring the system can be placed as drawn. Water distribution systems of substantial size and complexity should avoid using 90 degree angles due to the head losses they cause and the force they exert on connections during peak demand or demand spikes such as when fire fighting.

ANSI/AWWA C116/A21.16
PROTECTIVE FUSION-BONDED EPOXY COATINGS FOR THE INTERIOR AND EXTERIOR SURFACES OF DUCTILE IRON AND GRAY IRON FITTINGS FOR WATER SUPPLY SERVICE

Specifications found in this standard are more directly applicable to the manufacturer. When purchasing fittings for water supply applications, the supplier is considered the

purchaser since he generally orders directly from the manufacturer. The manufacturer, the purchaser, and the contractor all have responsibility for quality assurance. The contractor can reject any materials that don't meet the standard.
Section 6 of the standard allows for field repair of any fittings that have been damaged as long as the requirements of Section 4 are met. Section 4 covers the standards of materials, surface preparation, coating application, and coating systems qualifications. Meeting these requirements in the field is very difficult.

Generally as a designer a choice must be made while specifying fittings, valves, etc. Normally fittings are furnished with cement-mortar linings in accordance with ANSI/AWWA C104/A21.4 and exteriors protected by use of polyethylene encasement in accordance with ANSI/AWWA C105/A21.5. In the age of Fusion-Bonded epoxy coatings, it seems the cement-mortar lining and polyethylene encasement is a less likely product to specify especially where PVC pipe is used and no other portion of the pipe will be encased with polyethylene.

1.6 VALVES

Several varieties and manufactures of valves are available to the designer. Most incorporated municipal or governmental agencies, which eventually own and operate a system, specify the type and manufacturer of items such as corporation stops, curb stops, meters, valves, and fire hydrants. The most common type valve used for pipe sizes 3" to 12" is the resilient wedge gate valve. Most municipalities won't accept these valves for larger pipes. Butterfly valves are generally used for pipes larger than 12".

1.7 BOLTS, NUTS and GASKETS

Bolts shall be square or hex head conforming to ASME/ANSI B1.1
The UN or UNR thread form is used and the fit class is 2A for external and Class 2B for internal threads.
Bolts and nuts are low carbon steel conforming to ASTM A307, 60ksi tensile strength Grade B. Carbon steal bolts should only be used with gray iron flanges with flat gaskets extending only to the bolts. High strength bolts may be used with gray iron flanges when full-face gaskets are used.

Gaskets are synthetic rubber only. Either ring gaskets or full-face gaskets should be used. It is important that proper lubricants are used during construction. Lubricants containing petroleum products will dissolve synthetic rubber gaskets.

2.0 DESIGN

2.1 WATER DEMAND

There are three basic questions to answer to begin designing your system.

1. How much water will be used: peak and daily average?
2. Where are the water consumption locations and major branch nodes?
3. What is the water use as a function of time?

When designing new systems, calculating demands is not a straightforward process. You need to know the expected demands, possible fire demands, and future expansions.

There are several publications that provide average demands for residential, commercial facilities, and production/industrial facilities. Different demands need to be accounted for:

1. Customer demand ~ Average use needed to meet non-emergency needs.
2. Fire flow demand ~ The computed system capacity required for ensuring minimum fire protection while maintaining a minimum working pressure in the system.
3. Ultimate expansion to the system.

Peak factors

Peaking factors can be determined by dividing the maximum daily usage rate by the average daily usage rate as below.

$$P_f = Q_{max} / Q_{avg}$$

Where P_f is the peaking factor, Q_{max} the maximum daily demand, and Q_{avg} is the average daily demand. This peaking factor can be applied to a system as a whole or specific peak factors can be developed and applied at a specific node. A peaking factor for an overall system can be determined and is reliable since records are taken from source data. Peak factors at nodes are less reliable and less consistent since a peak demand from unknown sources readily affects the node location but not necessarily the system as a whole. Fire flows are usually accounted for in maximum daily flow. There are several time related demands that should be considered in the model such as seasonal demands, weekly demands, population growth and industrial demands, etc. Seasonal demands such as hot dry summers cause increase lawn watering. Small agricultural operations or nurseries may rely on municipal water supplies to irrigate. Some of these demands can be estimated from a community's comprehensive plan, zoning maps, regional expectations for industrial use, etc. Another critical event to check is the peak hour demand. During steady state model runs the modeler can assign specific peak factors to different nodes.

The typical municipal system is very unsteady due to varying demands. A 24 hour simulation period should be analyzed in order to provide reasonable results. Designing a system requires a minimum system pressure during peak hour demands and a reasonable working pressures during average demand periods. The design minimum and working average pressure depends on the level of service required by the community. A minimum peak demand pressure should not fall below 35 psi anywhere in the system. A good average daily pressure is 50 psi or a range between 45 psi and 55 psi.

Data Sources

Pre-existing Compiled Data-Research a specific utility's existing data.
System Operating Data – Production Charts from wells or plants.
Customer Billing Records-Customers are billed volumetrically. This could provide fairly adequate data, usually within 10% to 15%.

The designer must meet with the local public agency or owner of the water supply. Usually a governmental agency that will eventually own the system, owns the water supply as well.

Many smaller communities will purchase bulk water from larger neighboring cities or county governments. The designer will need to find out the maximum amount of water that is available to a proposed system and the projected demands. This amount is usually defined in the water agreement between the buyer and the whole seller. There is a possibility that the source is not adequate to supply an expanded service area.

Upgrades may be necessary to existing transmission lines. There may be legal restraints to providing new water service to expanded areas. The designer must determine the demand, the system service area, any future expansion, and demands to the planned system, then compare these to the water supply that is available.

2.2 WATER DISTRIBUTION SYSTEMS

Sources of water

- Ground water- Series of municipal wells usually requiring chemical treatment, at least to the extent of chlorinating.
- Surface water- Drawn from lakes or rivers below the surface. Ocean-desalination plants on or near coastal regions.
- Precipitation- Large municipal reservoirs collecting rain run off and snow melt.

Transmission and Distribution Mains

Transmission lines are categorized as mains that carry large volumes of water, great distances, such as between a treatment plant and local storage facilities.

Distribution lines are smaller pipes including valves, hydrants, fittings, and appurtenances, that deliver treated potable water to the customers.

System Types

The two types of distribution systems are looped and branched.

Looped systems have pipes that are interconnected throughout such that water can move through the entire system back and forth, depending on the points of largest demand.

Branched systems or *dendritic* systems have only one path to follow from the source to the customer. Think of the system as *one-way* flow.

Looped System Advantages
- Fluid velocities are lower, reducing head losses, resulting in greater capacity.
- Main breaks can be isolated to minimize loss of service to customers.
- Fire protection is greater due to greater capacity and ability to isolate breaks.
- Looped systems usually provide better residual chlorine content due to inline mixing and fewer dead ends.

Looped System Disadvantages
- Looped systems generally cost more because there are pipes that become inadvertently redundant in order to create the loops.

Branched System Advantages
- Lower costs – Avoiding construction of pipes and appurtenances just to create a looped system reduces the cost.
- In smaller rural communities, branched systems may be the only type that is feasible, logistically and monetarily.

Branched System Disadvantages
- Main breaks take all downstream customers out of service.
- Branched systems cause poor chlorine residuals in low demand areas and may require periodic flushing of hydrants in order to pull chlorinated water into the system.
- Velocities are faster, head losses greater and capacity reduced especially during high demand.
- Fire protection is at risk due to inability to isolate a break.

2.3 WATER DISTRIBUTION MODELING

Critical Elements

Most models allow for large amounts of input variables; not all are necessary. There is a level of input intensity that is determined depending on the system size. The designer must determine how much information is needed to accurately model the system. These are important in considerations of the model. Some elements, such as small local demands, may not affect the model. Below are several considerations that should be weighed while assembling your model components and developing your schematics.

- Potential large water consumption.
- Important loops.
- Large diameter pipes.
- Pumps, towers, tanks, SCADA (Supervisory Control and Data Acquisition).
- Existing utility crossings and other conflicts.
- Travel times
- Topography

Large water consumptions should be looked at carefully. The modeler should test the peak demands from these consumers on the model. Make sure the peak demands do not deplete the capacity or pressure in any part of the system. If these consumptions do have such an adverse affect on the overall system, or even the potential to do so, then the system must be designed accordingly. In many cases when a consumer, such as a cannery or other manufacturing facility, requires a demand that exceeds the public's interest, then the consumer will be required to provide secondary facilities such as a tank or elevated tower on site or provide the public system with funds to add booster pumps or storage tanks in the primary system.

Loops and where they are placed, are important because they can change the overall dynamics of a system. Sometimes trial and error in a model is the best way to determine the significance of a loop. The proper method is to find a weak point in the system (low-pressure or supply), then tie it to a loop and see if there is a significant improvement.

Large diameter pipes are critical because they have a big effect on the overall system. These are economic and logistical considerations when designing large elements.

Sometimes when there is insufficient pressures or supply to adequately and safely pressurize a system, at least during peak demands, booster stations, elevated tanks, or other devices are needed to make the system work. Even an upgrade to the water plant may be proposed. SCADA (Supervisory Control and Data Acquisition) may need to be upgraded or added if the owner feels it is necessary to maintain and monitor the system. Far reaching expansion may require booster pumps or even chlorine injection.

Existing conditions such as other utilities and structures must be considered. The schematic of a model generally is laid out with pipe lengths, sizes and node locations. Even scaled or direct input doesn't necessarily account for all conditions that may require larger pipe diameters, grade changes, or additional valves and fittings.

Once a model is built and running and the results are satisfactory, the system can be drafted for construction. It is a good idea to analyze the actual plans for inconsistencies in the model input. Significant changes from the model should warrant the model to be edited and tested with the accurate input from actual plans.

Head Losses and Gains

The energy within a fluid in part depends on its flow under pressure. Friction head loss is a function of velocity and type of pipe materials used. Potential energy is dependent on the gradient at a particular point. Finally, there is pressure energy introduced from a mechanical source. There are several friction loss algorithms that may be applied depending on the software. Darcy Weisbach uses the well-known Reynolds number and Moody Chart. Hazen Williams is another popular method and finally there is the Manning equation.

Modeling software may offer the user the option of the friction loss equation. Minor losses are those contributing cumulative losses from valves, fittings etc. Valves, fittings, bends, and pipe material all affect the head losses. Ninety degree bends should not be used in small systems, especially branched systems. Unnecessary valves add to the head losses. There are also simple algorithms developed for these minor losses.

Booster pumps are used to add energy to the system. Total dynamic head is reduced as the fluid travels through the system, encounters raised gradients, while typical demands pull out energy. If the supply is adequate, booster pumps can be placed to energize the system some distance from the source. Pressure switches generally trigger booster pumps. If the system detects a pressure loss below the normal minimum, the pump will engage and pressurize the system. Once the normal high dynamic pressure is detected, the pump will disengage.

Elevated tanks are used to provide a more consistent supply and pressure. For example, elevated tanks provide supply to strategic zones in large systems or an entire supply for a smaller community. A small community may purchase bulk water from a larger city. For example, the source may provide bulk water to the tank through master meters; the tank then energizes the small municipal system. The water elevations in the tank would automatically determine when the source valves would open and close at the master meters. Elevated tanks are also used in larger systems in order to maintain more consistent pressure. The source would use the off-peak times to fill the tanks. Generally it is during the overnight and early morning hours, when there is very little demand, that the system can fill the tanks adequately, because system pressures are high enough.

Strategically locating booster pumps and tanks are important elements of the schematic and the modeling procedure. Since these are large, visible attributes, geographical and demographic considerations have to be considered.

Conflicts and Separation

Crossing existing utilities usually requires that the water main avoid the conflict. Rarely will an existing utility be moved. However, in many communities the franchise agreements with gas, electric, telephone, cable TV, etc., requires the franchise utility to relocate their facilities if they are in conflict with a proposed public utility. For this reason, utility companies are now requiring exclusive easements in proposed subdivisions. It is not uncommon to see a signature block on final plats for the utility company's easements.

Crossing existing utilities can be done by pipe deflection or mechanical joint offsets. Pipe manufacturers provide maximum allowable pipe deflection. Generally it is very slight, 2% possibly. For minor conflicts where only a few inches are needed to avoid the conflict, deflection is a possible solution. These situations are in most cases discovered in the field where plans do not account for the conflict. It is an option the contractor may use to avoid a mechanical joint offset.

When a conflict is found in the design phase to be unavoidable, the designer will specify an offset. He should calculate the grade differential so the contractor will know what the cost will be, both in time and material. If an error in the offset is made and the contractor has to make extensive changes from the plan, he will be entitled to compensation for the error.

2.4 PUMPS

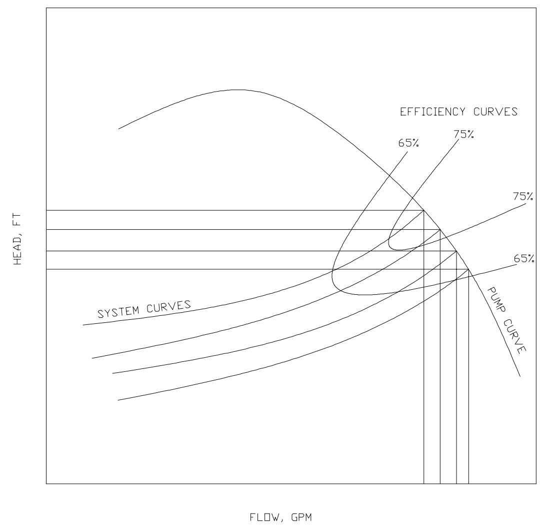
Pumps are used infrequently to add energy to the system. Because pumps add energy and maintenance costs to the owner, they should be used only when absolutely necessary. A pump failure or power loss could affect large service areas. Grade changes and friction losses may require the addition of pumps when a tower or tank cannot be used. Pumps may be needed to fill elevated tanks. Centrifugal pumps generally are the type used. Variable speed pumps are more useful when used as a booster, not to fill a tank or reservoir. Variable speed pump performance is altered by changing the power to the pump, thereby changing the pump speed. There is a direct relationship between total dynamic head (TDH) and pump discharge expressed as gallons per minute (GPM) or cubic feet per second (CFS). Manufacturers design and build pumps by discharge size, impellers shape, fin angle, etc. each having a pump curve graphically shown and associated with its operating parameters. As a designer and modeler it is your responsibility to specify a pump and design the pump system. The pump system includes the site, foundation, vault or housing, power source, valves, piping, warning system and other associated appurtenances.

Choosing a pump manufacturer may depend on the type already in use for a particular system. A municipality may require a certain manufacturer. The pump model is selected based on required TDH versus required GPM or CFS. Every point along the pump curve represents the operating parameters of that pump. Below is a simple typical pump curve as you might see from a pump manufacturer. Efficiency is a third parameter associated with pump selection from the pump curve. Most pump curves have a parabolic efficiency curve or series of curves overlaying the pump curve. You will want to choose a pump with the highest efficiency for the specific performance parameters. The pump efficiency is estimated (interpolated if necessary) based on the point where the system curve (explained below) intersects the pump curve (TDH versus GPM). As a matter of due diligence, the designer should consult with the manufacturer regarding the pump selection. The pump manufacturer can guide you to the model which best fits your conditions and operating parameters.

In order to begin choosing a pump model you need to develop a system curve. The system curve is developed by the associational relationship between flow rate and friction losses. As the flow rate is increased the friction losses increase at an exponential rate. When a series of calculations are made incrementally increasing the theoretical rate, there is a resultant head loss. The system curve is developed by adding the original static head above the discharge and plotting the TDH versus GPM on the pump curve. There is a point where the system curve intersects the pump curve. If this intersection crosses too far below the overlaid efficiency curve you need to choose a different pump. In consideration of a tank filling pump there will be a family of system curves in a design that has been determined to require a pump to fill an elevated tank. A series of curves is developed as the water elevation in the tank changes. Each system curve will represent a static elevation in the tank. The series of curves must include the lowest allowable elevation in the tank and the maximum elevation in the tank. At the very least you will need to develop curves for the high tank, low tank during low demand periods, and high tank and low tank during high demand periods. The series of curves intersecting the pump curve represents the pump operating range. As discussed earlier, there are several friction loss computational methods available. To determine the TDH for each system curve, add the frictional losses and the particular point of static head.

$$TDH=\Sigma h_L+h_l$$

Where Σh_L is the summation of friction and minor losses and h_l is the static head or the tank elevation for that system curve. To repeat, the friction losses are a function of flow rates. Note the four system curves intersecting the pump curve. The highest curve is the high tank levels during low demand and the bottom line is the low tank level during high demands. This is the operating range of the theoretical pump system.



As mentioned in the beginning of the pump discussion, energy use is a concern that requires consideration and calculation. There must be a conversion from water energy to electrical energy. The pump efficiency can be determined by the equation below.

$$E_p = W_p / P_p \; x \; 100\%$$

where E_p is pump efficiency, Wp is water power out and P_p is pump power in. The motor efficiency is determined by

$$E_m = P_p \,/ P_e \; x \; 100\%$$

where $E_{m\ is}$ motor efficiency, Pp is pump power in and P_e is electric power in.

Water power is expressed by the equation

$$W_p = Qh\gamma C$$

Where Q is flow in GPM, h is net static head at pump, γ is the specific weight of water, and C is a conversion factor equal to 4.058E–06. W_p is expressed in horsepower. The conversion from horsepower to watts is 1hp = 0.746 kW.

Example: A pump system design includes a static head of 90 feet, and a flow of 540 gpm. Specific gravity of water is 62.4 lbs/f^3*. This pump would require*

$$W_p = 540 \; x \; 90 \; x \; 62.4 \; x4.058E\text{-}06 = 12.31HP \text{ or } 9.18 \; KW$$

Assume the power rating for the 3 phase pump motor selected is 17.5 KW.

The efficiency of the pump selected is 67% based on where the particular system curve intersected the pump curve and the efficiency curve. The equation $E_p = W_p/P_p \times 100\%$ *is solved for* P_p.

$$P_p = W_p / E_p = \frac{9.18KW}{0.67} = 13.7\ KW \quad \text{Required pump power}$$

Now from equation $E_m = P_p / P_e \times 100\%$ *we have* P_p, *and from the example, power in is 17.5 KW. Therefore,*

$$E_m = \frac{13.7KW}{17.5\ KW} x100 = 78.3\% \quad \text{motor efficiency}$$

Combining the efficiency of the pump and the efficiency of the motor to arrive at the wire to water efficiency we get,

$$E = 0.78 \times 0.67x\ 100\% = 52.26\%.$$

Finally the net positive suction head (NPSH) must exceed the pump rated NPSH, otherwise the pump will cavitate. When a pump cavitates the fluid undergoes negative pressure and causes damage in the pump housing and impellers. By design, each pump has a unique minimum NPSH. This is known as NPSH required. In contrast, available NPSH is a function of flow and head. NPSH available is calculated by summation of atmospheric pressure + static head ahead of pump + water vapor pressure + head losses from source to pump.

$$NPSH = H_{atm} + H_h + H_{vap} + H_L$$

Once the available NPSH is calculated it must be compared to the NPSH required for the selected pump. If it is equal or less than the required NPSH of the pump, the following adjustments to the model can be made and re-calculated:

1) Select a pump with a lower NPSH required;
2) Raise the source tank or reservoir;
3) Lower the pump gradient;
4) Increase the pipe diameter of the suction line.

Pumps can be used in parallel or series. Pumps can be used to fill elevated tanks and to energize a system. Power and maintenance are considerations to be examined. As you have seen, when selecting pumps there are many variables to consider. A series of pump models may very only slightly by fin angle, throat size, or impeller diameter. The manufacturers are very helpful to the designer in selecting the correct or optimum pump for your system. Rely on the manufacturer and consult the available data for a given pump or series of pumps.

2.5 VALVES

Isolation Valves

The use of valves serves several purposes. Valves are most commonly used in the lines of distribution systems in order to isolate zones or pipe runs. In looped systems they are placed strategically to isolate main brakes or service other appurtenances. Isolation valves can be gate valves, butterfly valves, or plug valves.

In modeling, the placement of isolation valves is not necessarily needed except to account for special circumstances when they are closed. The frictional loss due to flow through fully open gate or butterfly valves is generally minor enough to be inconsequential in modeling.

System Check Valves

System check valves are very important for public health as well as to protect pumps in certain situations. When we discussed pumps, one of the elements of the system is valves. There are valves to isolate the pipe system from the pump system for maintenance, and there are check valves, sometimes referred to as direction valves, that protect pumps from headwater flowing back into the pump, causing damage or loss of energy in the system.

Altitude Valves

Tank levels are generally controlled by the use of altitude valves. Altitude valves are pressure sensitive and are adjustable. They are set to open when a tank level falls below a certain elevation and close when a tank's elevation level reaches a certain point. When modeling your system, you may have to specify the use of an altitude valve; however, you may only have to specify the tank elevations to complete your model.

For more information on altitude valves and their specifications it is advisable to speak with manufacturers.

Pressure Reducing Valves

Pressure reducing valves (PRVs) are used when there are significant grade changes in a system. They are intended to reduce the pressure exerted on a system at the lowest points. Consider that every 1 foot of water is equal to 0.433 psi of hydrostatic pressure. For example, a grade change of 100 feet is 43.3 psi in addition to the operating pressures of the highest elevations, which might be 40 psi. The total static pressure at the lowest point in this example would be about 83 psi. In most systems, that pressure is dangerously high and could cause damage to distribution systems and residential services or plumbing. In systems with several service areas of various elevations, PRVs may be needed to reduce the pressure to reasonable operating levels.

If PRVs are warranted, they need to somehow be represented in the modeling process. Most models balance hydraulic grade lines; therefore, this valve would be represented as such. Determining the setting of the PRV will require knowledge of the PRV's elevation as well as the elevations of service areas above and below the PRV.

Similar to PRVs are pressure sustaining valves (PSVs), which are intended to maintain pressures at the higher elevations above the valve.

Air Release Valves

Air release valves are used to allow air to leave the system as well as to allow air in for certain circumstances. Like certain other elements in a system, air release valves are not significant in a model. Air release valves are usually placed at high points of a system and are designed to open and bleed accumulated air. Air vacuum valves are designed to let air into a system when negative pressure is present. They are generally placed at the higher elevations as well. On grade systems usually cannot experience negative pressure; however, negative pressure is possible where a system may have a significant grade change.

For example, assume a closed system (no air vacuum release valve) with a grade differential of 200 feet. Also assume that at the bottom of the system a large water main brake begins to drain the system quickly, causing a vacuum at the upper elevations. The negative pressure created at 200 feet is 0.433 psi/ft x -200' = -86.6 psi. Most pipes are designed for positive pressures but may not withstand the same negative pressure and could collapse under extreme negative pressures. This collapse of the pipe could continue down the line until the elevation differential is no longer great enough to collapse it. The addition of an air vacuum release valve allows air into the system to protect the infrastructure from damage.

2.6 TANKS AND RESERVOIRS

In terms of the model parameters, reservoirs are considered an infinite source of water with a constant head elevation. In contrast, a tank element is modeled with a fluctuating water elevation or hydraulic grade. A reservoir is practically either a water plant wet well of finished water, or in the terms of a smaller community purchasing from a large producer, the point of connection at the master meter. In terms of modeling these are defined as boundary nodes.

There are several types of tanks. A hydro-pneumatic tank is basically a ground level tank or a buried tank that is pressurized with large compressors. There are elevated tanks that are filled by pumps or from the source itself. Pumps can take by suction from storage tanks at ground level or that are buried. Ground level or buried tanks are generally found in communities that will not allow an unsightly elevated tank.

A model run can demonstrate the rate of inflow or outflow of water in the tank, given a specified tank level or hydraulic grade line (HGL). In order to simulate a typical cycle, usually a 24 hour simulation, the volume and tank shape must be identified. The tank shape determines the rate the elevation changes, given a steady rate of discharge. In other words, the relationship of the flow and tank elevation may not be linear. In a spherical tank for example, at the elevation of the largest diameter of the tank, the elevation changes at the slowest rate given a constant rate of discharge. In a cylindrical tank the rate of change of elevation would be linear to a constant discharge. The importance of this dynamic relationship and the need to model it over an extended duration to provide accuracy cannot be overstated. The model is dependent on the hydraulic grade line. These parameters will also be used to set controls for tank operation and alarms. Because some models may not recognize spherical tanks, some assumptions may have to be made to a cylindrical tank model to simulate an actual spherical tank. Because there are risks involved in these assumptions steady state runs can be made to check the resulting approximations. There are important operating parameters to the model. These are maximum tank elevation fill level; low level tank elevation (when filling begins); and overflow elevation.

Designing the tank location, tank height, and high water elevations is very important to the process because it establishes pressure zones and operating parameters of the system. The topography of the service area generally is needed to choose possible locations unless the terrain varies only by a few feet. A tank within the flight control space of airports must have FAA approvals as well. Most customers prefer a consistent pressure or a range that does not change noticeably. The tank design must be such that even at times of an unlikely overflow the HGL does not exceed a working pressure. Besides the distribution system, some household plumbing (depending on local codes) has a limit before things start to break. If you have never designed a system or specified the mechanical equipment you should make an appointment to visit some of the systems that are in place. A typical system incorporating an elevated tank filled through a master meter could have the following elements: A large underground vault with a hatch or double hatch; a small 100 amp electrical panel; the main water line from a supplier; a check valve; a master meter; an altitude valve; a second check valve; a smaller bypass line with a check valve; the tank discharge line; and a sump pump to keep the vault dry. The electric power will provide lights, the sump pump, the SCADA or warning systems, and programmable controls.

2.7 CONTROL DEVICES

Control switches are used to control elements of a system such as pumps and valves. Some models allow you to enter switches as elements and others consider them as attributes of elements such as pumps and valves.

2.8 EPA

The EPA (Environmental Protection Agency) writes federal regulations for construction, maintenance, treatment and operation of potable water facilities. State's EPAs are charged with regulating the standards and permitting. States may write more stringent regulations if they do not violate the intent of the federal code.

The federal regulation for water main separation and protection is:

Section 653.119
Protection of Water Main and Water Service Lines

a) *Water Mains:*

1) *Horizontal Separation:*

A) *Water mains shall be laid at least ten feet horizontally from any existing or proposed drain, storm sewer, sanitary, combined sewer or sewer service connection.*

B) *Water mains may be laid closer than ten feet to a sewer line When:*

i) *local conditions prevent a lateral separation of ten feet*

.

ii)the water main invert is at least 18 inches above the crown of the sewer; and

ii) *the water main is either in a separate trench or in the same trench on an undisturbed earth shelf located to one side of the sewer.*

C) *Both the water main and sewer shall be constructed of slip on or mechanical joint cast or ductile iron pipe, prestressed concrete pipe, or PVC pipe meeting the requirements of Section 653.111when it is impossible to meet (A) or (B) above. The drain or sewer shall be pressure tested to the maximum expected surcharge head before back filling.*

2) *Vertical Separation:*

A) *A water main shall be laid so that its invert is 18 inches above the crown of the drain or sewer whenever water mains cross storm sewers, sanitary sewers or sewer service connections. The vertical separation shall be maintained for that portion of the water main located within ten feet horizontally of any sewer or drain crossed. A length of water main pipe shall be centered over the sewer to be crossed with joints equidistant from the sewer or drain.*

B) *Both water main and sewer shall be constructed of slip on or mechanical joint cast or ductile iron pipe, prestressed concrete* *pipe, or PVC pipe when meeting requirements of Section 653.111 when:*

- *i) it is impossible to obtain the proper vertical separation as described i9n (A) above; or*
- *ii) the water main passes under a sewer or drain line.*

C) A vertical separation of 18 inches between the invert of the sewer or drain and the crown of the water main shall be maintained where a water main crosses under a sewer. Support the sewer or drain lines to prevent settling and breaking the water main.

D) Construction shall extend on each side of the crossing until the normal distance from the water main to the sewer or drain li9ne is at least ten feet.

b) Water Service Lines:

1) The horizontal and vertical separation between water service lines, and all storm sewers, sanitary sewers, combined sewers or any drain or service connection shall be the same as water main separation described in (a) above.

2) Water pipe described in (a) above shall be used for sewer service lines when minimum horizontal and vertical separation cannot be maintained.

c) Special Conditions – Alternative solutions shall be presented to the Agency when extreme topographical, geological or existing structural conditions make strict compliance with (a) and (b) above technically and economically impractical. Alternative solutions will be approved provided watertight construction structurally equivalent to approved water main material is proposed.

d) Water mains shall be separated from septic tanks, disposal fields and seepage beds by a minimum of 25 feet.

e) Water mains and service lines shall be protected against entrance of hydrocarbons through diffusion through any material used in the construction of the line.

3.0 LAYING OUT A PROJECT

A designer would typically use the following steps in setting up a model to design a new water distribution system:

1. Set up the system grid on the area plan. Aerial photo plots to scale are excellent tools;

2. Allocate average daily demands at nodes;
3. Determine the peak factors;
4. Estimate fire demands;
5. Project demands for future expansion of the service areas.

A node is considered a junction point in a system where a demand can be attributed. Models use the nodes to calculate the system demands, pressures, etc.

The practical design of a water system without the use of water distribution modeling software requires a logical, economical approach of laying out the system.

3.1 EXISTING DATA

As mentioned earlier in section 2.1, there are several reliable sources to determine demands. Obviously a discussion with the owners is critical but the actual quantities will have to be calculated for a design situation. A land use plan or zoning map will help to determine the future demands. Use standards developed by the American Water Works Association for typical demands for a particular land use, such as industry, residential density, etc. These need to be compiled and situated on the area map. Once complete this method can help you determine node locations and assume pipe diameters. Fire flows that can spike demand can be assumed. Local fire departments can provide specifications on nozzle flow.

3.2 SCHEMATICS

When an existing system is modeled the process is known as analysis. Modeling during the course of designing a project is much more difficult. While modeling an existing system requires input of available of existing data. The level of accuracy and detail of data depends on the available data and map accuracy. When a system is being designed and modeled there is a trial and error process involved. Topographic maps, general routes, and pipe sizes are assumed. The process of developing a schematic for modeling is very dynamic. A schematic of a proposed system for an existing community may be changed several times based on public input, political divisions, and cost comparisons.

Much like an electrical schematic or roadway system layout, a pipe network will have nodes (junctions). Small systems can be greatly affected by small changes in demand and design. Large metropolitan systems are less affected by local demand changes at nodes.

Pipe Diameter

The selected pipe diameters can affect the model significantly. There are economic considerations in choosing the pipe diameters. Designers need to determine the proper pipe size in order to meet peak demands and fire protection while maintaining an adequate dynamic pressure in the system. During design, once a model is built using good reasoning or assumptions, model runs will give results and demonstrate pipes that are too small either by hydraulic grade line or by low pressure. If you review the model output and see a significant drop in pressure, increase the pipe diameter and try another run. Finding the correct pipe to increase may not be an easy task. *(see section 3.6)*

3.3 PRESSURE ZONES

Pressure zones are set up to regulate pressure in locations where large grade changes will create too much pressure at the lower end of the system and not enough pressure in the higher ends. A differential of less than 60 feet (25.4 psi) does not require a new pressure zone. More than an 80 feet differential generally will require a pressure zone. In areas of even larger grade differentials, such as hill country or mountain communities, several consecutive pressure zones may be needed. The following equations can assist you in determining the HGLs for the pressure zones.

$$HGL_{MIN} = \text{Highest Elevation} + (2.31x \text{ Minimum Working Pressure})$$
$$HGL_{MAX} = \text{Lowest Elevation} + (2.31x \text{ Maximum Working Pressure})$$

It is important to converting pressures to the HGL because most models are based on the HGL. In the case of multiple pressure zones, it is important to use the service connection datum instead of the pipe elevation or valve elevation, in these equations. Use of accurate topographic maps is very important in setting up pressure zones. As the designer you must layout the zones in order to determine the corridors so that survey field crews can be sent out to collect accurate data for the design phase.

Location and Elevation of Junctions

Location of junctions will depend more upon the planned layout of the project site than the affect they will have upon the model. In general grid distribution node locations have little affect upon the overall model since there are customer demands along the system between nodes. Node locations and their elevations are more relative in large transmission mains.

Nodes generally should be placed at the lowest elevation of a looped system where the grades fluctuate significantly. This is not always possible. When junctions are put at lower elevations, the distribution and capacity are improved. In systems were pressures are expected to fluctuate or are generally low, it would be good practice to relate system node elevations to the highest point of service. Other choices of datum could be relative to the ground, or to the center of the pipe. Be consistent in order to accurately represent the model once a relative datum is chosen.

3.4 COMPILING DATA

When modeling an existing system there should be information readily available for analyses and compilation. Fire flows can be calibrated, pipe roughness can be determined based on material and age, leak or loss percentages can be retrieved from annual reports, etc. When designing a new system and creating the model to validate its performance, much of the data for input is achieved based upon your desired level of service and good engineering practice. For example, you will know from your charge what the minimum and maximum demand parameters are and then it is up to you to design the system to meet these criteria. Other known parameters that should be given are the service area boundaries, possible points and areas for future expansion, possible tank locations, control centers, and a projected budget. Soil investigations may be needed to determine the pipe material or protection needed. Topographic surveys will be needed, and zoning maps or comprehensive plans need to be examined. Since there will be opportunity for public involvement, you should be as prepared as possible. The less prepared you are the less confidence the public will have in the project. You will have to graphically demonstrate your proposal and provide alternative routes or locations for the less desirable elements of the system. The public will put you and the public officials to task. Missing data essential to the construction plans need not be available in order to develop your first system models.

New designs will require several models with alternate routes or tank locations etc., in order to validate your alternatives on a technical level and to again provide the level of confidence needed in a public forum. There is no need to present an alternative unless you know it is viable. Data can be developed for new systems by studying similar systems from the same geographic areas. Cross comparisons of the required parameters, and the working parameters of similar existing systems, can provide some time saving preliminary work. Studying elements of existing systems can also provide some interesting working data that can be modeled into your system or just brought up for discussion. For example, if a neighboring community has recently built an at-grade hydro pneumatic tank, you could compare that with an elevated tank by cost, aesthetics, function and maintenance. Additionally, flow charts can be obtained from neighboring like systems to capture certain events such as fires, draughts, industry activities, etc. When acquiring data just keep in mind that the more information you have to build your models and create alternatives, the more confidence the public will have that you have done your homework, and that there are options available.

3.5 BUILDING THE MODEL

Building the model will require all the knowledge provided here and then some. The approach to building the model is to first sketch out the system practically on existing topographic maps. From previous discussions you will already have an understanding of how demands are determined. Large service customers can have demand nodes specific to their use. This of course will depend on the capabilities of your model software. There is no way you can accurately calculate or determine the actual demands unless you use control valves that limit flow to a set rate. A common error in developing a model is rushing through the planning stage. With today’s technology and expedient software packages, we are able to model a system relatively quickly. This saves us from the repetitive iterations that determine the flows and pressures. However, these production tools cannot replace the time and ground work of good planning. It is essential that you collect as much data as possible, as much public input as possible and have in writing as much as possible, the wishes of your client. Also, since most new systems are now designed as an add-on to existing systems, you must know the available flows to the proposed system as well as the pitfalls of the parent system. For example, if a plant or water provider cannot guarantee a specific demand at a specific time, you need to design your system to overcome that flaw.

It is interesting to encounter construction projects that are failures for one reason or another . The engineer blames the contractor-the contractor blames the engineer-subcontractors blame everyone. Regardless of the blame game somebody usually pays more and reputations are marred. Many times projects are given to inexperienced engineers to design and the engineer in responsible charge or the project engineer are not checking the work sufficiently. My advice to engineers is simple: There are three ways to look at a project throughout the planning and design phases. First, it has to be technically sound; second, an engineer has to step into the mindset of a contractor and ask "how would I build it"? Finally, a look at the project from an end user's perspective should be made. The technical aspect is one that engineers usually have a good handle on. Even less experienced engineers understand basic hydraulic design and models can sometimes identify bad data. To think like a contractor and understand what it takes to get equipment in and out of tight spaces, excavate near or around structures or other fixed obstacles takes much more experience, although some young engineers are very good at this as well. Spending time at construction sites or seeking advice from experienced contractors can offer a world of knowledge not obtainable from academia. Many engineering firms have experienced contractors on their staff for the sole purpose of reviewing plans for practical application before they are submitted for approval. If you design a project full of impractical tasks the contractor can pick your pocket or that of your client's through change orders. Finally, envision a completed project and how it will function and be used by the general public. This is very important in the planning stage. Water distribution is a matter of providing customers with service. Locating curb stops and placing certain facilities in areas that will not obstruct views or impede line of site for traffic, are important considerations in water distribution systems.

Once you have "covered your bases" and compiled all the information, you can begin to sketch out your system assigning designated demands at specific nodes. Remember that peak demands will dictate your ultimate system; the average daily demands can then be run through the model once it is designed to peak demands. Assuming your layout is being drawn on a topographic map, account for large grade changes in case you may need to use PRVs or special treatments. Look closely at providing loops. Depending on the community or street, grid loops may or may not be efficient. Generally a looped system is used to isolate a break and provide redundant service in case of a break. Place hydrants in accessible locations. Draw 150 foot radii around them to ensure 300 foot coverage *(check local codes)*. Identify possible tank locations. Scrutinize these locations by possible obstructive views, proximity to airports, available space, and public input. A water tank can be a "big pill to swallow" for some people. After all of the initial layout is complete, look at pipe sizes. Generally the grid areas that are branched off the transmission main for general distribution are assumed to have pipe diameters from 6" to 8". These can be determined more accurately with some additional handwork. Look at the intermediate and transmission lines that actually carry the bulk of the water and that are directly associated with the system elements such as master valves, master meters, tanks, pumps, altitude valves, control valves, etc. Assuming a maximum velocity of 5 to 10 feet per second is reasonable. Do some rough calculations with this velocity range to determine if the selected pipe sizes will be sufficient. Adjust them as needed and you are ready to add them to your model. Use the same theory for the remaining elements. Make your gross assumptions with the available compiled information and build your first model. The rest is elementary. Do your simulation runs, debug the input data until you have a clean run, and analyze the output data. You may have to make several simulations adjusting pipe sizes, tank elevations etc until your peak demand system is adequately designed.

3.6 TROUBLE SHOOTING A MODEL

Low Pressure

Identifying system problems may not be as easy as you might anticipate. For example, a low-pressure zone could be evident from simulation runs and you might think correctly "pipe diameter", but which one? You might identify a pipe with a high velocity and assume that is the culprit. So you increase the pipe diameter and find the problem has been worsened or is unchanged. With large complex systems you could literally chase the low-pressure zone problem "around in circles" and still not find the solution. Sometimes the least obvious is the most suspicious. A large diameter pipe may have a low velocity but considering the amount of water it is transporting and delivering, it could still be sized too small. Conduct a fire flow simulation to test the larger pipe. A fire flow simulation will cause velocity increases in the system that may not be evident under normal or even peak demands.

Low-pressure zones may also occur when increase in grade is shown. Remember that for each foot of grade increase, 0.43 psi is lost. A 25-foot increase in grade will cause 11 psi loss.

If a pump is integrated into the system, check the pump capacity. Increase the HGL at the pump node and test the model.

High Pressure

As with low pressure caused by increased grade, a high pressure zone may be present if the grade falls. The pressure then increases 0.43 psi with each foot of fall. Pipe materials and systems in general use today can operate at pressures in the range of 75 to 85 psi. However, present day customer plumbing may be less tolerant than it was years ago. Newer plumbing materials such as PVC, PE, etc. with glued joints, should not be tested beyond 80 psi. An operating pressure of 80 psi may experience water hammer or surges well above 80 psi, damaging household plumbing or plumbing fixtures. Check your system and make necessary adjustments either lowering the high tank elevation or using a PRV.

In the case of high pressure problems, pipe diameters that are too large cannot be identified. There are fiscal considerations for using the correct pipe diameters. In fact, as the design engineer it is your obligation to design a system with the optimum pipe diameters. In addition to the cost associated with oversized pipes, there is the concern for chlorine dissipation from long travel times. There really is no room for factors of safety especially when considering the cost of capital improvements and your ability with modeling software to substantially simulate real world conditions. If you suspect your pipe diameters are too large, reduce them and run the simulation again. Continue the process throughout the system until the system is at its optimum design.

3.7 FINAL NOTES

In addition to this course, which is a general overview of the types of material that are available, acquiring books on this subject to obtain more detail about water distribution systems is recommended. Other topics for this discussion are:

Well Pumping
Pumps in series
Customer systems
Metering
Cost benefit Analysis
Chemical Reactions
Chlorine Residuals
Water losses
Maintenance
Calibration
Operations

Software

There are several pipe network modeling software systems available on the market. Most of the algorithms use the well-known equations taught in college course work: Darcy – Weisbach, Reynolds Number, Bernoulli energy equation, Hazen-Williams, etc. Mass balance and HGLs are the basis for the calculations.

Modeling software saves the designer the time and unpleasant exercise of crunching numbers and performing mathematic iterations to solve a pipe network system. No specific software is described in the discussion. Designers still need to understand the concepts of hydraulic engineering in order to make assumptions, accurately input data fields, and understand the model output.

Depending on state or local laws, the engineer or the engineering firm may claim proprietary rights to the model. A system model service agreement can be negotiated for an indefinite time which could include mapping services, system expansion and reports.

4.0 SUMMARY

Designing water distribution systems may appear to be a fundamental geometric exercise. Pressurized pipe systems have a high degree of dynamic relevance. Choosing the proper materials for a given environment and specifying the protection methods are important to the design process and project costs.

Applying enough time to the planning process is the key to successful projects. Sizing the system is as important as any other aspect of the design. Sizing for the expected consumer and fire demands as well as possible future expansion must be undertaken. Layout of the system begins after the designer determines the demands, meets with the local agency, or acquires real data to determine demands, level of service, hydraulic capacity and volume available.. Materials must be chosen depending on local codes, soil types and economic factors. These are all relevant to most modeling software used.

5.0 RELATED LINKS

For additional technical information related to this subject, please visit the following web sites or web pages.

www.epa.gov *Environmental Protection Agency*
www.awwa.org *American Water Works Association*
www.dipra.com *Ductile Iron Pipe Research Assoc.*