CHAPTER 10

HYDRAULIC DESIGN OF WATER DISTRIBUTION STORAGE TANKS

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10.1 INTRODUCTION

Water storage tanks are a commonly used facility in virtually all water distribution systems. Methods for sizing and locating these facilities to provide equalization and emergency storage have changed little over the years. Recent years, however, have seen an increased awareness of water-quality changes that can occur in storage tanks. Because water-quality problems are usually worse in tanks with little turnover, no longer it is safe to assume that a bigger tank is a better tank. There is increased emphasis on constructing the right-sized tank in the right location.

Water-quality concerns will not radically change tank design, but they do call for a reassessment of some design practices, This chapter summarizes the state-of-the-art in tank design.

10.2 BASIC CONCEPTS

Water distribution storage is provided to ensure the reliability of supply, maintain pressure, equalize pumping and treatment rates, reduce the size of transmission mains, and improve operational flexibility and efficiency. Numerous decisions must be made in the design of a storage tank, including size, location, type, and expected operation. This chapter focuses on the hydraulic aspects of design as opposed to structural, corrosion, safety, contamination, or instrumentation aspects. (In this chapter, the word "tanks" will be used to describe treated water-storage facilities, although the term "reservoirs" is preferred by some, whereas others use the word "reservoir" to describe only ground-level and buried tanks.)

The key considerations in the hydraulic design of water storage tanks are described in the following sections and procedures for design of the tanks are described in the remainder of the paper.

10.2.1 Equalization

One primary purpose for construction of storage facilities is *equalization*. Water utilities like to operate treatment plants at a relatively constant rate, and wells and pumping stations generally work best when pumped at a steady rate. However, water use in most utilities varies significantly over the course of the day, These variations in use can be met by continuously varying source production, continuously varying pumping rates, or filling and draining storage tanks. The process of filling and draining storage tanks is much easier operationally and is generally less expensive than other methods. Facilities serving portions of a distribution system with storage tanks generally need to be sized only to meet maximum daily demands, with storage tanks providing water during instantaneous peak demands.

10.2.2 Pressure Maintenance

To a great extent, the elevation of water stored in a tank determines the pressure in all pipes directly connected to the tank (i.e., not served through a pressure-reducing valve or pump). Ignoring headloss, which is usually small most of the time, the pressure can be estimated as

$$p = (H - z)w \tag{10.1}$$

where p=pressure at elevation z, Pa (lb/ft^2), H=water level in tank, m (ft), z=elevation in distribution system, m (ft), and w=specific weight of water, N/m^3 (lb/ft^3). (When pressure is expressed in psi, w is 0.433.) The larger the tank volume, the more stable the pressures in the distribution system will be despite fluctuations in demand or changes in pump operation.

10.2.3 Fire Storage

If distribution storage tanks were not used, larger water transmission mains and larger treatment plant capacity would be required by most utilities to provide water needed for fire fighting. Especially for smaller systems, storage tanks are a much more economical and operationally reliable means for meeting the short-term large demands placed on a water-supply system during fire fighting.

10.2.4 Emergency Storage

In addition to fires, emergencies such as power outages, breaks in large water mains, problems at treatment plants, and unexpected shutdowns of water-supply facilities can cause failure of the water system if sufficient water is not available in storage. Storage tanks can meet demands during emergency situations. The extent to which emergency storage is needed in excess of fire storage depends on the reliability of the supply system. In addition to simply providing storage volume, tanks can provide a form of backup pressurization of the system in case of

a loss of pumping capability (e.g., power outage, major pipe break). Such pressurization helps prevent contamination from cross connections if pumping should be lost.

10.2.5 Energy Consumption

To the extent that water is stored in a distribution at a higher level than the treatment plant, the energy in that water also is stored at that higher level. The existence of tanks enables utilities to store energy as well as water for later use. To the extent that equalization storage slows down the velocity (and friction losses) in the large transmission mains, the energy used to pump water is reduced by having distribution storage tanks that equalize pumping.

Most water utilities pay a demand charge, a capacity charge, or both to the electric utility based on peak rates of energy consumption. To the extent that availability of storage reduces peak energy usage, storage tanks can be helpful in reducing the demand charges for the utility. If time-of-day energy pricing is used, energy can be used during off-peak hours and that energy can be stored with the water in tanks to be used during peak hours.

10.2.6 Water Quality

Tanks may affect water quality in two general ways: (1) through chemical, physical, and biological processes that occur as water ages while stored in the tank and (2) through external contamination of water in tanks.

Sources of contamination may include the tank lining, sediments in the bottom of the tank, and animal or human contamination in either open reservoirs or through breeches in the tank roof, vents, and sides. These should be eliminated by proper design and maintenance. The greatest single change in tank design for water quality is the requirement to cover treated water-storage tanks.

Water ages in a storage facility because of detention times and differential aging caused by incomplete mixing. Common degradation mechanisms that may occur as a result of aging water include loss of disinfectant residual, which can result in microbial regrowth in the tank or distribution system, and formation of disinfection by-products, such as trihalomethanes.

There also is the potential for the escape of volatile organic compounds through the water's surface to the atmosphere, but this is generally considered to be inconsequential because of the low levels of volatile organic compounds that are mandated by the maximum contaminant levels and quiescent nature of the water surface in a tank. Another impact of tanks on water quality may be the decay of radon caused by volatilization and the short half-life of this contaminant. Water also can stratify in tall tanks, thus exacerbating water-quality problems.

Another impact of storage volume on water quality is the fact that storing water in tanks allows for a greater time interval between the occurrence of a distribution system problem (e.g. major pipe break or power outage) and the deterioration of water quality caused by cross-connections. (Water quality in storage tanks is discussed in greater detail in Chap. 11.)

10.2.7 Hydraulic Transient Control

Changes in velocity in water mains can result in hydraulic transients referred to as "waterhammer." (also see Chapter 6) These extremely high or low pressures caused by

transients can be significantly dampened by storage tanks, especially those that "float-on-the-system." (See Sec. 10.3.1 for an explanation of this term.)

10.2.8 Aesthetics

Most people are neutral about storage tanks, considering them an acceptable part of the scenery. However, some individuals believe that tanks are unsightly and detract from views; thus, storage tanks are susceptible to the "NIMBY" syndrome (not in my back yard). Still others see tanks as a resource to promote their community or business. Tanks should be designed to satisfy the aesthetic considerations of stakeholders to the extent possible without sacrificing the purpose of the tank and efficiency of the system's operation.

10.3 DESIGN ISSUES

Design of distribution storage facilities involves resolving numerous issues and trade-offs. Some of these include location, levels, and volume, which are described in the following sections. The subsections immediately below describe some of the preliminary issues that must be resolved. Issues regarding the structural design of storage tanks are given for welded steel tanks in AWWA D100 and AWWA D-102 (AWWA, 1996, 1997a), bolted steel tanks in AWWA D103 (AWWA 1997b), prestressed concrete tanks in AWWA D110 and AWWA D115 (AWWA, 1995a, b) and pressure tanks in the appropriate ASME standard (ASME, 1998). A good overview of steel tank design is provided in AWWA Manual M42 (1998c).

10.3.1 Floating Versus Pumped Storage

For the purpose of this chapter, storage *"floating-on-the-system"* is defined as storage volumes located at elevations so that the hydraulic grade line outside the tank is virtually the same as the water level (or hydraulic grade line for pressure tanks) in the tank. In this type of storage, water can flow freely into and out of the tank. The converse of this is pumped storage, which refers to water that is stored below the hydraulic grade line in ground-level or buried tanks so that the water can leave the tank only by being pumped.

In many cases, storage floating-on-the-system is associated with higher capital but lower operating costs than is pumping from storage, and the trade-off must be made on a case-by-case basis. Capital costs are higher because the tank must be elevated or located at ground level on a hill somewhat removed from the service area. This is usually more costly than the capital costs of pumping equipment associated with the pumped tank. The energy cost associated with the pumped system is, of course, significantly higher.

The trade-offs between an elevated tank that floats on the system and a ground-level tank with pumping can best be illustrated by an example. Consider a 1.88 ML (500,000 gal) tank where 0.94 ML (250,000 gal) enter and leave the tank during the day. (Assume that labor and instrumentation costs are comparable between the alternatives.) The elevated tank (floating-on-the system) would cost $600,000 whereas the ground-level tank would cost $400,000 with the pumping equipment and controls costing $150,000. Based on initial cost, the pumped alternative is more economical in this case. However, the water level in the ground tank will normally be 30 m (100 ft) below the level of the water in the elevated tank. At an energy price of 5 cents per kilowatt-hour and a wire-to-water efficiency of 60 percent, the annual cost to operate the pumps is as follows:

$$\text{Cost (\$\backslash yr)} = [(62.4\ \text{lb/ft}^3)(0.25\ \text{Mgal/day})\ (1.54\ \text{ft}^3\text{/Mgal/day})(100\ \text{ft})$$

$$\frac{(\$0.10/\text{kwh})\ (8760\ \text{h/yr})]}{[(0.6)\ (737\ \text{ftlb/ks}]} = \$4760 \text{ per year.}$$

The extra cost for operations and maintenance labor and supplies may be $3000 per year. The present worth of this value at 5 percent interest over 20 years (present worth factor=12.46) is given by present worth: (energy, labor)=($4760+$3000) (12.46) =$97,000. The total present worth of a ground tank=$400,000+150,000+97,000= $647,000. The elevated tank ($600,000) will be slightly less expensive in this case. The costs, however, are highly site-specific and the comparison must be made on a case-by-case basis.

10.3.2 Ground Versus Elevated Tank

A decision related to whether the tank floats on the system is how the tank is constructed with respect to the ground. If the tank is constructed so that the bottom of the water is at or near ground level, the tank is referred to as a *"ground tank."* If the tank is significantly taller than it is wide, it is usually referred to as a *"standpipe."* Standpipes are usually constructed to float on the system, whereas ground-level tanks may float on the system if they are constructed at a sufficiently high elevation. In some areas, buried tanks are preferred because they are least susceptible to freezing. Figure 10.1 illustrates the different kinds of tanks.

In general, elevated tanks and standpipes are usually constructed of steel, buried tanks are usually constructed of concrete, and ground-level tanks are constructed of either steel or concrete, The risk of freezing increases as more of a tank's surface is exposed to cold weather. Heating of tanks has been addressed by Hodnett (1981).

Elevated tanks usually are the most expensive per unit volume, but they provide most of the storage at the desired elevation and are essential if storage that floats on the system is desired in flat areas. Terrain, aesthetics, seismic considerations, potential for freezing, land availability, budget and experiences with different types of tanks will influence a utility's choice of tank.

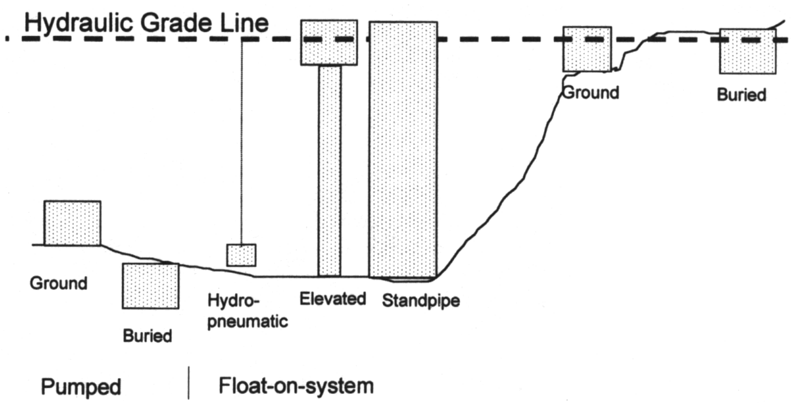

FIGURE 10.1 Tank terminology.

10.3.3 Effective Versus Total Storage

For tanks that float on the system, the tank will drain only if the hydraulic grade line outside the tank drops below the water level in the tank. When the water level in the tank drops too low, the pressures (i.e., hydraulic grade line) provided to customers at higher elevations in the service areas can drop below acceptable levels for customers at the highest elevation. Storage volume located at an elevation so that it can provide acceptable pressure is called "effective storage." Storage located below the minimum acceptable hydraulic grade line is not effective storage, although some individuals may consider that part of "total storage." A standpipe is an example of a tank in which only a small portion of the storage is effective storage.

Storage located below the effective storage zone, which still can provide a minimum pressure [say, 138 kPa (20 psi)], is sometimes referred to as "emergency storage" because a utility would only allow the level to drop to that level during an emergency.

This concept is illustrated in Fig. 10.2, which shows the highest customer located at elevation X requiring 241 kPa (35 psi) during non emergency situations and 138 kPa (20 psi) during emergency situations. The hydraulic grade line and tank water must be kept 25 m (81 ft) above elevation X during non emergency situations and 14.1 m (46 ft) above elevation X during emergencies neglecting headloss.

Water stored below the 14.1 m (46 ft) level can be referred to as ineffective storage (Walski et al., 1990). It does not help in equalization or fire fighting but does increase the detention time in tanks and hence contributes to the problem of disinfectant decay. Tall standpipes also can become stratified, which can contribute further to water-quality problems because the water in the top portion of the tank may have extremely long detention times. Kennedy et al. (1993) documented significantly lower chlorine concentrations in a tall tank. Standpipes with a great deal of ineffective storage should be discouraged for these reasons.

10.3.4 Private Versus Utility Owned Tanks

In most cases it is desirable for the utility to own all water distribution storage tanks. If a large customer needs a great deal of storage, it is usually better for all parties to have that customer contribute to the cost of a utility-owned tank. In some cases, however, a large customer (or a neighboring utility) may choose to construct its own tank. Once water enters the private system (or a neighboring utility's system), it should not be allowed back into the original utility's system unless the private system follows all precautions required to protect water quality. Issues regarding private water tanks are addressed in National Fire Protection Association Standard NFPA 22 (1998).

10.3.5 Pressurized Tanks

The tanks discussed thus far have been non pressurized tanks in which the water surface corresponds to the hydraulic grade line in the tank. If a tank is pressurized, the hydraulic grade line will be higher than the water surface. This can result in a ground-level tank that still effectively floats on the system. To allow the water level in the tank to fluctuate (so that the tank is not simply a wide spot in the pipe), some air is placed in the tank to expand or compress as the volume of water in the tank changes. (Tanks are only worthwhile if the volume of water in storage can change.) Such tanks are referred to as *hydropneumatic tanks*.

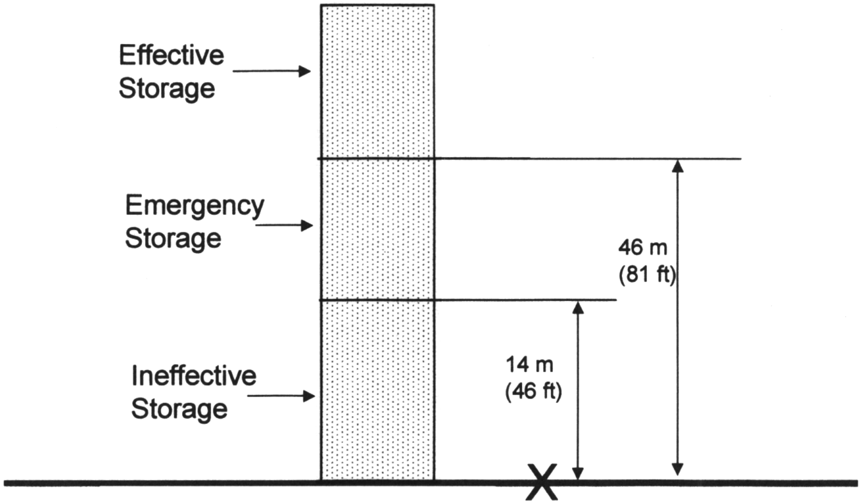

FIGURE 10.2 Definition of effective storage.

Pressurized tanks are much more expensive than non pressurized tanks. Therefore, their use is limited to small tanks that provide limited equalization and emergency storage and virtually no fire protection.

10.4 LOCATION

The location of storage provides an opportunity to make the most of a given volume of storage. However, because of restrictions on availability, terrain, and aesthetics, good storage sites may be difficult to find. Some considerations regarding location are described below.

10.4.1 Clearwell Storage

Clearwell storage at the downstream end of the water treatment plant or the outlet of a well is usually at ground level or in buried tanks that must be pumped. This type of storage can provide time to meet disinfection contact-time requirements. Usually, ground-level tanks are relatively inexpensive. However, because these tanks usually do not float on the system (except when the water treatment plant is on top of a sufficiently large hill), all the water must be pumped and standby power is required, especially if there is limited storage in the distribution system. A large pipe break near the plant also can completely eliminate the effectiveness of clearwell storage. In general, utilities should have some clearwell storage to provide contact time, but they should not rely solely on clearwell storage (unless they are small utilities with clearwell storage that float on the system).

10.4.2 Tanks Downstream of the Demand Center

Storage tanks are best placed on the downstream side of the largest demand from the source. An advantage of this is that if a pipe breaks near the source, or the break will not result in disconnecting all the storage from the customers. A second advantage is that if flow reaches the center of demand from more than one direction, the flow carried by any individual pipe will be lower and pipe sizes will generally be smaller, with associated cost savings. Of course, adequate capacity must be available to refill the tank in off-peak hours. Hydraulic grade lines with storage located opposite the peak demand center are shown in Fig. 10.3.

10.4.3 Multiple Tanks in the Pressure Zone

If there are to be multiple tanks in a pressure zone, the tanks should be placed roughly the same distance from the source or sources. If one tank is very close to the source and other tanks are farther away, it may be difficult to fill the remote tanks without shutting off (or overflowing) the closer tank. Because this is often a problem in systems that have evolved over many years, a tank that was on the fringe of the system years ago is now very close to the plant relative to new remote tanks in the growing service area. In most cases, use of control valves can enable multiple tanks to be used effectively. To make a system easier to operate, it may be desirable in some cases to abandon a small tank in an undesirable location when it needs maintenance.

When there are multiple tanks in a pressure zone, it is essential for all of them to have virtually the same overflow elevation. Otherwise, it may be impossible to fill the highest tank without overflowing or shutting off the lower tanks (thus causing water-quality problems in the lower tanks). Tanks are usually at consistent elevations when they are planned logically. However, when systems grow by annexation or regionalization, some

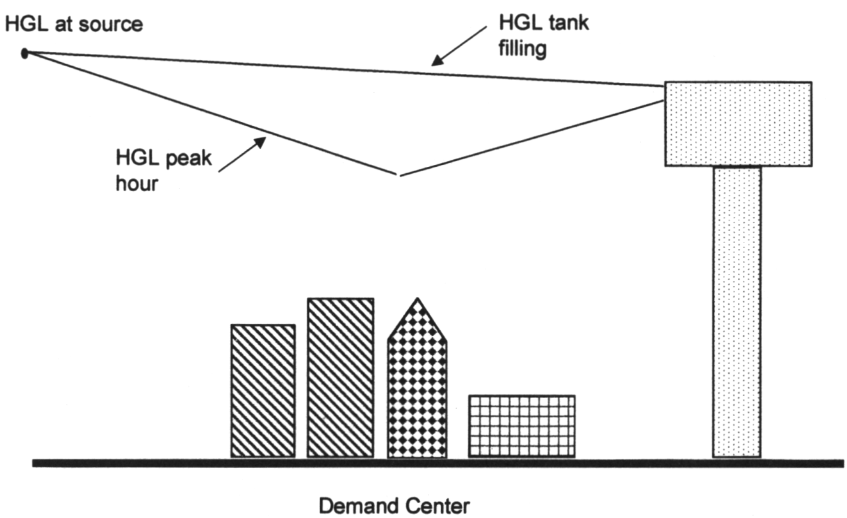

FIGURE 10.3 Hydraulic grade line for tank beyond demand center.

tanks may be at an inappropriate elevation and may need to be abandoned or modified, and pressure zone boundaries may need to be adjusted to operate effectively in the newly configured system.

10.4.4 Multiple Pressure-Zone Systems

In multiple pressure zones, the source is usually located in one of the lowest zones and the system is fed through pumps. In such cases, it is best to place sufficient storage volume in each zone so that each zone can operate almost independently. In this way, only water that is needed in the higher zones will be pumped to those zones. Pumping water to a higher zone only to have it run back down to a lower zone wastes energy and should be avoided if feasible.

In multiple pressure-zone systems where the source is located in the highest zone and lower zones are fed through pressure-reducing valves, most of the storage should be kept in the higher zones. In that way, stored water can feed virtually any zone. Tanks are justified in lower zones to ensure reliability in case of a pipe break and to reduce piping requirements to meet peak and localized large fire demands.

10.4.5 Other Siting Considerations

Because some individuals consider tanks to be an eyesore, it is important to select sites that minimize the visual impact of the tank by having it blend in with its surroundings or by making it attractive. Although the risk of structural failure of an elevated tank is small, setbacks from tanks should be such that the impacts of failure on neighbors will be minimal.

If a tank is planned for a site but is not to be constructed for several years, it is desirable to obtain the land for the tanks and the needed rights-of-way for pipes and roads well in advance. If possible, the zoning should be modified and land subdivision should be approved so that the tank is an accepted land use. In that way, construction will not be delayed because of zoning hearings and appeals.

10.5 TANK LEVELS

10.5.1 Setting Tank Overflow Levels

The most significant decision about a tank in terms of distribution system design is its overflow elevation. This elevation and the associated range (minimum normal day, bottom of tank) will determine the size and boundary of the pressure zone that can be served from the tank, the layout of transmission mains, and the head required at pumping stations. When a tank is being placed in an existing pressure zone, the overflow elevation and operating range should be consistent with existing tanks, as was discussed earlier.

If a tank is being designed for a new pressure zone, it is essential to select an overflow level that will still be acceptable when that pressure zone is built-out in the future and that will be consistent with tank overflows in neighboring utilities to the extent possible in case the systems may be combined into a regional system at some point in the future.

10.5.2 Identifying Tank Service Areas

Consider a tank with overflow elevation Z, as shown in Fig. 10.4. The bottom of its normal operating range is usually about 6 m (20 ft) below the overflow, and the tank bottom is about 12 m (40 ft) below the overflow. The highest customer that can be served is approximately 25 m (81 ft) below the normal low level (point H) or 14 m (46 ft) below the bottom of the emergency storage (point H0[1]).

The lowest customer that can be served is usually determined by customers who will receive excessive pressure 690–550 kPa (100–80 psi) when the tank is full and there is little head-loss in the system. In this example, 690 kPa (100 psi) is the maximum acceptable pressure, and the minimum elevation served is 70 m (231 ft) below the overflow (point L). Anyone above the shaded range will receive too little pressure, whereas anyone below the range will receive excessive pressure. Small pockets of customers with excessive pressure can be served through pressure-reducing valves, either in the system or on individual service lines. Larger groups of customers should be served to the extent possible from a lower-pressure zone to prevent the waste of energy.

10.5.3 Identifying Pressure Zones

Once the overflow elevation and the highest and lowest customers have been identified, it is best to locate all the area that falls between those elevations on a contour map and identify those areas by shading or coloring them. (It is acceptable for there to be some bands of elevations for which customers can be served from either the upper- or lower-pressure zone.) The exact location of the pressure-zone boundary should be consistent with long-term development plans, street layout and supply capability in the respective zones. Figure 10.5 shows the kind of map that can be prepared to identify which customers can be served by

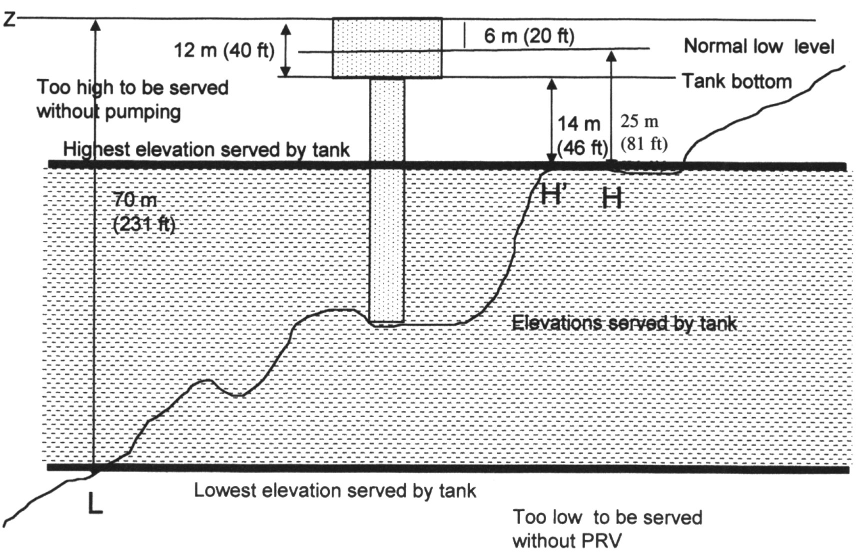

FIGURE 10.4 Elevation drawing showing a tank's service area.

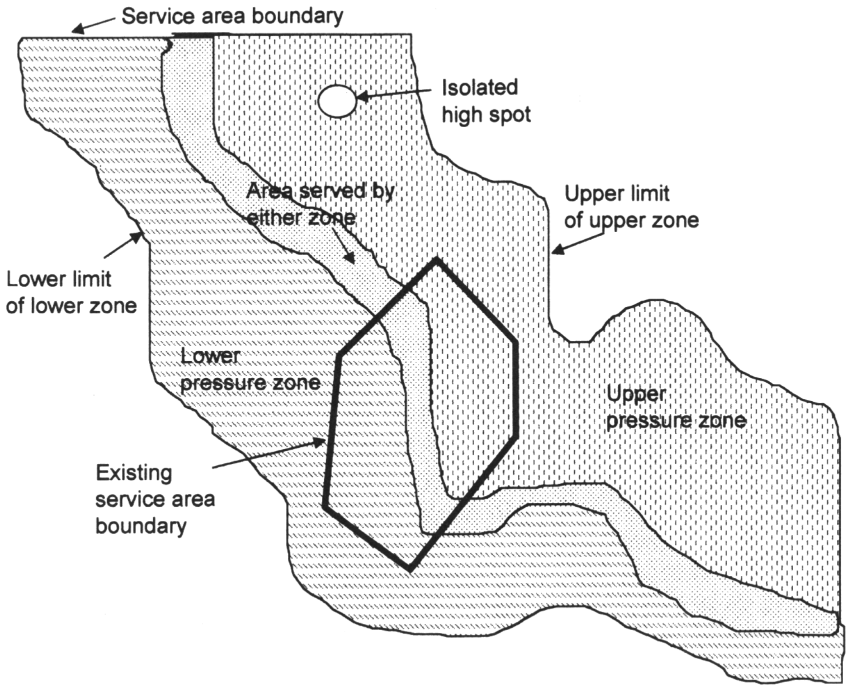

FIGURE 10.5 Plan view of a pressure zone layout.

tanks with various overflow elevations. The map should be prepared before land development occurs and should include land outside of the current service area that may be developed in the future. Isolated high and low points in a pressure zone can cause problems and should be identified in planning studies.

In general, pressure-zone hydraulic grade lines should differ by roughly 30 m (100 ft) from one pressure zone to the next. Significantly larger steps will result in some customers receiving excessively high or low pressure. Smaller steps between pressure zones result in an excessive number of tanks, pump stations, and pressure-reducing valves.

10.6 TANK VOLUME

10.6.1 Trade-offs in Tank Volume Design

Selecting the optimal tank volume involves trade-offs between improved reliability of the system provided by larger tanks and the higher costs and the disinfectant decay problems caused by loss of disinfectant residual in larger tanks. The issue is complicated further by the fact that there are substantial economies of scale in tank construction—doubling the volume of a tank only increases the cost by roughly 60 to 70 percent. Traditionally, the philosophy has been to build as big a tank as possible given long-term

demands, budget limits, and site constraints. This can result in tanks that cause disinfectant residual problems.

Two overall approaches to sizing a tank are available: regulatory-driven design and functional design. Both are illustrated below.

10.6.2 Standards-Driven Sizing

Each state and province has its own standards for sizing tanks. For example, the "Ten State Standards" (Recommended Standards for Water Works, 1992) states the following:

> Fire flow requirements established by the appropriate state Insurance Services Office should be satisfied where fire protection is provided….
> The minimum storage capacity (or equivalent capacity) for systems not providing fire storage shall be equal to the average daily consumption, This requirement may be reduced when the source and treatment facilities have sufficient capacity with standby power to supplement peak demands in the system.

Another example is the Texas State Standards (Texas Department of Health, 1988), which devotes up to four pages of text to a description of volume sizing, depending on the size of the system and the nature of the source. The key points in the Texas standards for systems with more than 50 connections are the following: "Total storage capacity of 200 gallons per connection must be provided… Elevated storage in the amount of 100 gallons per connection is required for systems with over 2,500 connections." If more than 18,800 m^3 (5 million gal) of storage are required, utilities can substitute ground storage, pumping, and auxiliary power.

Hydropneumatic tanks can be sized on the basis of 20 gal per connection (with ground tank available) or 50 gal per connection (no ground tanks at source) (Texas Department of Health, 1988).

Sizing also can be determined on the basis of providing a reasonable number of pump starts: "The gross volume of the hydropneumatic tank, in gallons, should be at least ten times the capacity of the largest pump, rated in gallons per minute" (Ten State Standards, 1992).

Other states and provinces have variations on these standards. All these standards leave considerable discretion to the design engineer to provide storage and to regulators to accept the design.

10.6.3 Functional Design

Although the appropriate regulatory standards must be met, it also is helpful to examine why the volume is required. This involves summing up the storage required for each of the recognized purposes: (1) equalization, (2) fire protection, and (3) emergencies other than fires. Cesario (1995) referred to these three types of storage as supply, fire, and reserve, respectively. Each type is discussed in more detail below.

10.6.3.1 Equalization Storage. *Equalization storage* is used to enable the source and pumping facilities to operate at a predetermined rate, depending on the utility's preference. Some options for operating pumping facilities include the following:

1. Operate at a constant rate to simplify operation and reduce demand charges.

2. Adjust flows to roughly match demand and minimize use of storage.
3. Pump during off peak hours to take advantage of time of day energy pricing.
4. Match the demand exactly with variable speed pumps and have no storage.
5. Have a reasonable number of starts per unit time for hydropneumatic pumps.

A comparison of these pumping (or production) rates with a typical time-of-day demand pattern is shown in Fig. 10.6. The variable-speed pump alternative is not shown because it would correspond to the case where the demand and pumping are identical.

The amount of equalization storage required is given by the area between the demand and pumping curves on a peak day. The fraction of daily water production that must be stored depends on the individual community and the type of operation. Some typical values are summarized below.

Type of Operation	Equalization volume needed as a fraction of maximum daily demand
Constant pumping	0.10–0.25
Follow demand (constant speed)	0.05–0.15
Off peak pumping	0.25–0.50
Variable speed pumps	0

The higher values in the list are for systems with fairly peaked demands, and the lower values are for those with a flatter daily demand curve. For example, a utility with 7.5

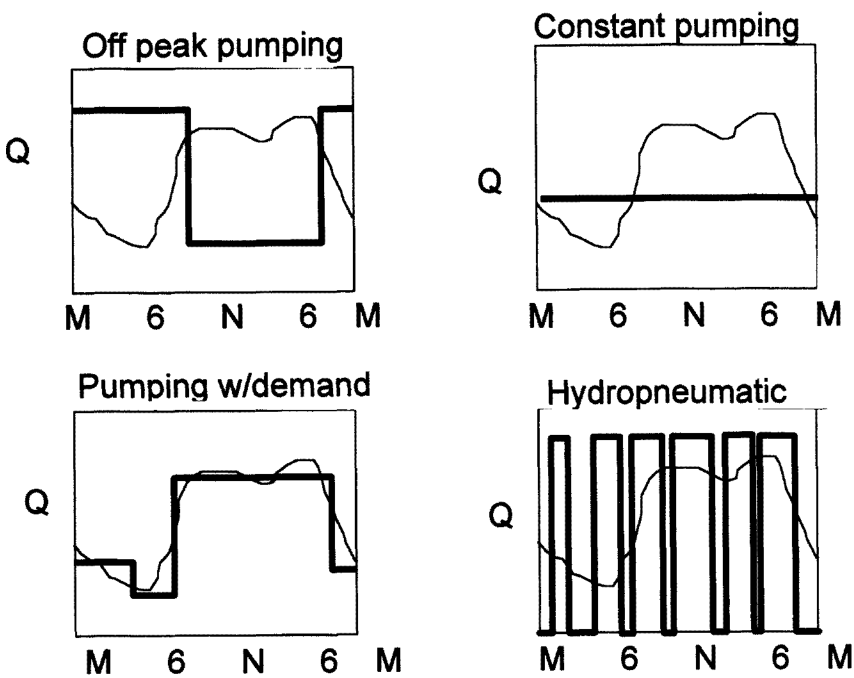

FIGURE 10.6 Comparison of pumping rate and demand for equalization sizing.

ML/day (2 Mgal/day) of maximum daily demand, would need roughly 1.5 ML (0.4 Mgal) of equalization storage (using a value of 0.2). Equalization storage can be checked using extended-period simulation models pipe networks.

10.6.3.2 Fire Storage. Fire storage requirements are based on the need for water to supplement the capacity of the water supply. If the capacity of the water supply is such that it can provide fire flow while still meeting maximum daily demand, no fire storage is required. This is sometimes the case in extremely large systems where fire demands are a tiny fraction of maximum daily demands.

The flow from fire storage required (in excess of equalization storage) can be given by

$$\mathrm{SSR} = \mathrm{NFF} + \mathrm{MDC} - \mathrm{PC} - \mathrm{ES} - \mathrm{SS} - \mathrm{FDS} \tag{10.2}$$

where SSR=storage supply required, NFF=needed fire flow, MDC=maximum daily consumption, PC=production capacity, ES=emergency supply, S=suction supply, and FDS=fire department supply.

All the above quantities are in flow units (volume per time), and the equation is based on the Fire Suppression Rating Schedule (Insurance Services Office, 1980). The storage supply required is water that must be delivered from storage. The needed fire flow is determined by the size and occupancy of the structure with the largest fire demand. The emergency supply is the water that can be brought into the system from connections with other systems. The suction supply is the supply that can be taken from nearby lakes and canals during the fire and cannot exceed the needed fire flow. The fire department supply is water that can be brought to the fire by tracks. The production capacity is either based on the capacity of treatment plant, the well capacity, or the pump capacity, depending on the system, as is shown in an example below. Except for the largest systems, it is usually safe to assume that only one major fire will occur at any given time.

The amount of water delivered to a fire can be analyzed best using pipe network models. Brock (1993) provided a graphical method for determining the amount of water that will flow from storage as opposed to the system source.

In large systems, where needed fire flow is small compared with treatment capacity, little fire storage is required. On the other hand, large amounts of fire storage, compared with equalization storage, are required for small- to medium-sized utilities with a structure that has a large needed fire flow.

Once the storage supply requirement is determined in flow units, the actual volume of fire storage must be established multiplying the requirement by the duration of the fire. For modest-sized fires, the duration is given below (AWWA, 1998):

Needed fire flow (gpm)	*Needed fire flow* (L/s)	*Duration* (h)
Less than 250	Less than 157	2
3000 – 3500	189 – 220	3
4000 – 12,000	251 – 755	4

In the United States, needed fire flows are usually rounded to the nearest 500 gpm (31.4 L/s) for flows in this range.

Multiplying the duration by the storage supply requirement gives the fire storage needed. This is compared with the available storage for flre protection, which is storage below the normal low level of equalization storage. For example, if a tank holds 0.5 ML (0.133 MG) and, at the normal low level, the stored volume is 0.3 ML (0.080 MG), only 0.3 ML (0.088 MG) is available for fire protection.

The calculations for a simple system are illustrated in Fig. 10.7. (The 0.5 ML is the existing volume in storage at normal low level.) The clearwell storage can be counted as available storage when one considers the plant as limiting, but the clearwell storage does not

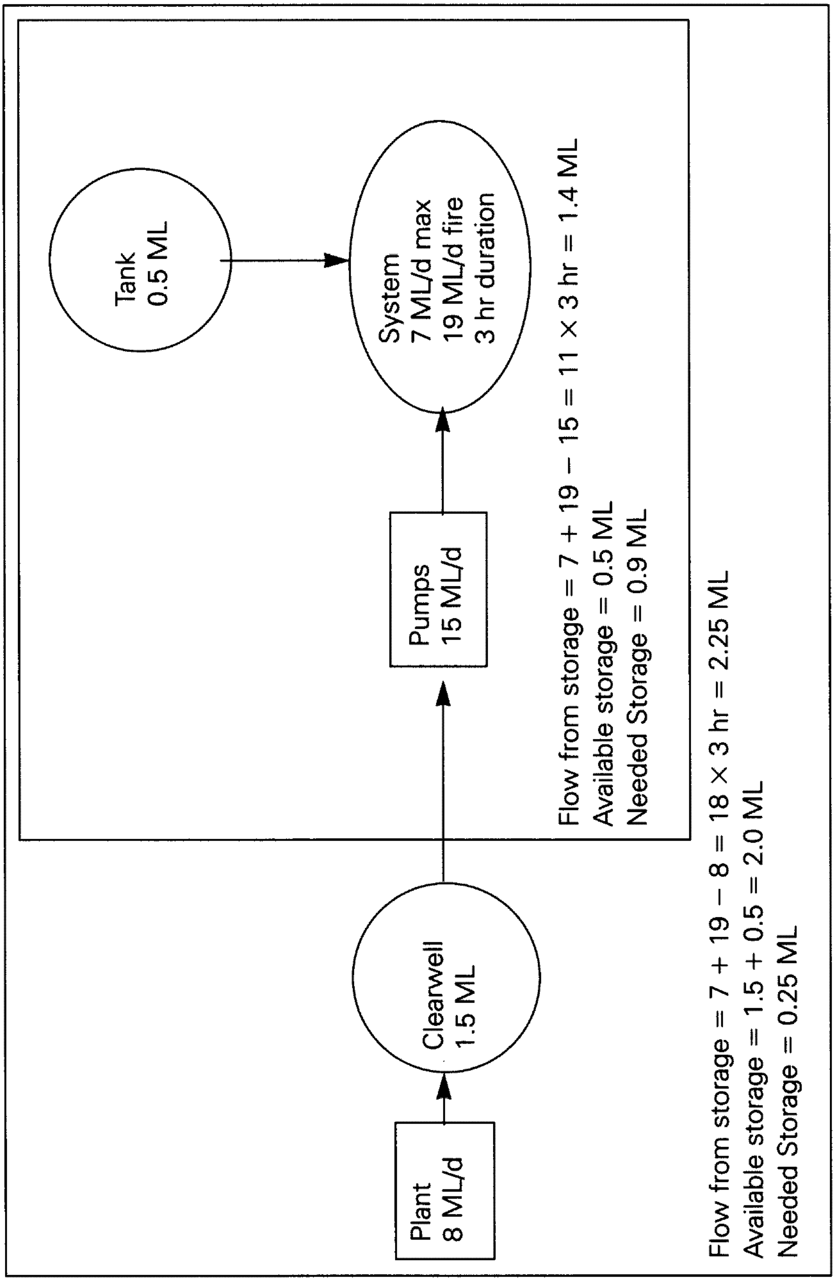

FIGURE 10.7 Sample calculation for fire storage.

count toward available storage when the pump station is considered to be limiting. In this case, the plant is the limiting factor. When you look only at the overall system, you might conclude that only 0.25 ML of storage is needed. However, because the pumping system only can deliver 15 ML/day, it therefore cannot move water out of the clearwell fast enough and, actually, 0.9 ML of storage is needed.

Although the above calculation appears to be fairly simple, several decisions must be made. For example, maximum daily consumption (MDC) changes over time with growth of the utility. Selecting the year corresponding to the MDC can make a significant impact on volume required. Some would argue that MDC=PC (production capacity) is a good conservative assumption. Needed fire flows can be affected by use of fire resistant building materials, fire, walls and fire sprinkler systems in buildings. The extent to which these factors are required by the local building code can make a difference in storage requirements.

10.6.3.3 Emergency Storage. No formula exists for determining the amount of emergency storage required. The decision will have to be made on a judgment about the perceived vulnerability of the utility's water supply.

If a utility has several sources and treatment facilities with an auxiliary power supply (or power supplied from several sources), the need for emergency storage is small. Some storage should be available to handle a catastrophic pipe break that cannot be isolated easily.

If a utility has a single source without auxiliary power and a relatively unreliable distribution system, a significant volume of emergency storage is prudent.

10.6.3.4 Combination Equalization, Fire, and Emergency Storage. The volume of effective storage required should be based on a combination of equalization, fire, and emergency storage. Some engineers use the sum of the three types of storage, whereas others base design on the sum of equalization storage plus which is larger fire or emergency storage. The logic in such cases is that the fire is not likely to occur at the same time as a critical pipe break or power outage. The total storage can be summarized by equalization+maximum (fire, emergency).

The most economical tanks are constructed in standard sizes, so the number above is rounded (usually upward) to a standard size.

10.6.3.5 Summary of Functional Sizing. The results from an analysis of storage requirements, based on functional sizing should yield storage requirements similar to regulatory-based sizing. If there are significant differences, the utility and the regulatory agency need to work together to determine the appropriate storage requirement. No volume of storage can protect a utility from every possible emergency (e.g., several catastrophic fires and pipe breaks during a plant outage). However, the guidance above should provide for reasonable amounts of storage.

10.6.4 Staging Requirements

If a utility has a fairly slow rate of demand growth, then the volume required in storage should not increase dramatically over time. However, for fast growing utilities, there are significant questions concerning how tank construction should be staged.

For example, the typical question is whether a utility, which will ultimately need 1.88-ML (500,000 gal) of storage, should construct a 1.88-ML (500,000 gal) tank today or a 0.94-ML (250,000 gal) tank today and another 0.94-ML (250,000 gal) tank later. The key to the problem is the expected number of years the first, smaller tank will be adequate before

the second is required. Suppose that the cost of the 1.8-ML tank is $500,000 and the cost of the smaller tank is $350,000. The present worth cost of the two smaller tanks for an interest rate of 7percent is:

$$\frac{\$350{,}000 + \$350{,}000}{(1+0.07)^n} \tag{10.3}$$

where n=the number of years before the second tank is needed. If n is 5, the present worth is $600,000 and the single large tank is best. If n is 12 years, the alternatives are equal. If n is 20 years, the present worth is $440,000 and the two-tank alternative is superior. The break-even year will become larger as the interest rate decreases.

Economics is not the only consideration in the staging of storage tank construction. Having two properly located tanks in the system gives the utility more flexibility in its operations (e.g., if a tank must be taken off-line for painting and inspection). Figure 10.8 shows an example of two tanks located at a single site.

10.6.5 Useful Dead Storage

Some utilities may find that they need additional fire or emergency storage, but have a tall standpipe with only enough storage for equalization. One approach for converting the dead storage in the bottom of the tank into useful storage is to install emergency pumps that can withdraw water from the bottom during a fire or other emergency. In this way, the dead storage in the bottom of the tank can be used.

In such a situation, the tank should be refilled through a pressure-sustaining valve to prevent a localized drop in pressure when the tank is refilled. If the tank is the only storage in the system, backup power for the pump will be required, controls will be needed to

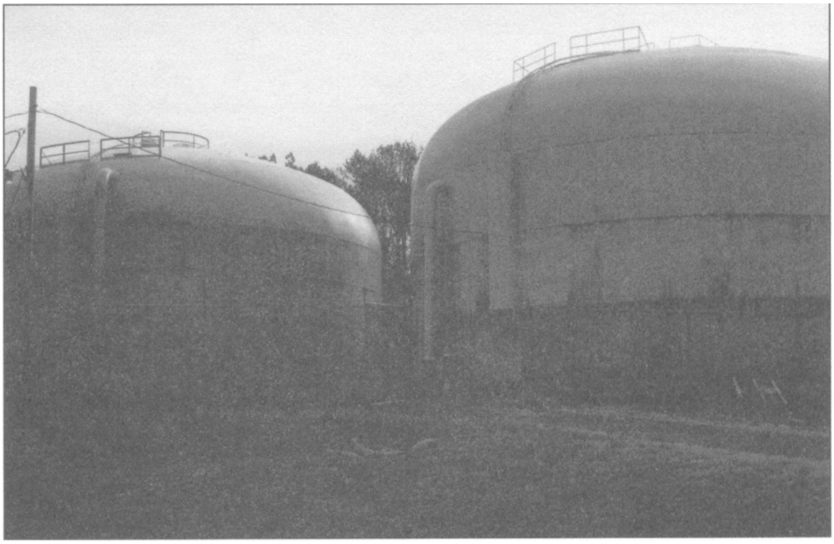

FIGURE 10.8 Use of two tanks at a site. (Photograph by T.M Walski).

prevent overpressurizing of the system, and a surge analysis will need to be performed to ensure that the pumping will not cause waterhammer.

10.7 OTHER DESIGN CONSIDERATIONS

10.7.1 Altitude Valves

Altitude valves are used to prevent tanks from overflowing by shutting off inflow to the tank when the water level in the tank approaches a high level. These valves are usually located in a vault at the base of a tank. Appropriate valving should be installed to enable the tank to function while the altitude valve is being serviced.

The two main types of altitude valves are single acting and double acting. The former type only allows water to flow into the tank; the latter type allows water to flow both into and out of the tank. When a single-acting valve is used, there must be a parallel line with a check valve that allows water to flow out of the tank. Although a double-acting valve is less expensive than a single-acting valve plus a check valve, there is usually a small risk that the double-acting valve may fail to open during an emergency. Therefore, a single-acting valve with a check valve is considered to be more reliable.

Although altitude valves provide some protection against overflow, they are not used when conditions that would cause an overflow are unlikely to occur: for example, when the tank level is monitored through a Supervisory Control And Date Acquisition (SCADA) system, with appropriate alarms and the impact of an overflow is minimal. Closing an altitude valve on the last tank in a pressure zone when pumps are running and demand is low could cause pressure to increase dramatically in some systems.

10.7.2 Cathodic Protection and Coatings

The presence of water and air in metal tanks causes the tanks to corrode rapidly if not protected adequately. Numerous types of paints and coatings are available. These coatings must be approved by the appropriate state regulatory agency and applied in accordance with AWWA D102, (AWWA, 1997a). Different types of paints are required for the interior and exterior of the tanks. Because new types of coatings are introduced and approved regularly, it is important for the design engineer to keep in contact with coating suppliers. Good inspection of the painting and frequent follow-up inspections are needed to prevent failure of the coating (Drisko, 1980; Dubcak, 1994; Knoy, 1983; Roetter, 1987).

Many metal tanks also are equipped with cathodic protection systems that further protect metal on the inside of the tank by offsetting the natural corrosion currents that set up when metal is in contact with an electrolyte (water). Cathodic protection of tanks involves passing direct current through a system of electrodes suspended in the water. Although benefits of cathodic protection have been documented, significant problems can develop in tanks in areas where formation of ice damages the cathodic protection system. Installation of cathodic protection systems is described in AWWA D104 (AWWA 1998a).

10.7.3 Overflows and Vents

Tanks should have an overflow pipe capable of handling the maximum potential overflow volume from the tank (e.g., failure of altitude valves with pumps running). The pipe

should have an air gap at its discharge and a check valve that can prevent birds and insects from entering the pipe. Depending on the applicable environmental regulations and the potential for flooding downstream, a detention basin and erosion protection may be required at the tank.

The draining and filling of tanks also requires that a large volume of air enters and leaves the tank during each cycle. These vents should be screened to prevent birds and insects from entering the tank. In climates subject to freezing, a frostproof design is needed to prevent ice from blocking the vents.

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