A SunCam online continuing education course

Water Storage Tanks

by

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Course Outline:

Purpose and Function of a Water Storage Tank
Regulations and Industry Standards
Types of Storage Tanks
Tank Sizing
Mixing Considerations
Tank Features
Water Quality Concerns
Helpful References
Examination

Purpose and Function of a Water Storage Tank

Water storage tanks serve a critical role in ensuring the reliable supply of high-pressure potable water to communities. They are also financially beneficial as they decrease the size of required pumping facilities and reduce energy consumption. Water storage tanks are located in nearly every water distribution system around the world. It is important that engineers understand the different functions of water storage tanks.

This course focuses on water storage tanks that hold "finished water". Finished water means water that has been treated and disinfected and is ready for distribution to the community as potable water.

The following table provides a summary of the different purposes and functions of a finished water storage tank.

Table 1 – Typical Purpose and Function of a Water Storage Tank

Purpose	How it Functions	Comments
1. Increase Reliability of Drinking Water	Store potable water so it is available during system failures	System failures include power outages, storm damage, flooding, and pipe breaks
2. Store Water for Fire Demands	Store a large volume of water reserved for fire protection systems and fire fighting	Some water systems have separate fire protection water tanks
3. Normalize Flow Rates	Tank fills during low demand and drains during high demand, thereby keeping influent flows consistent	Similar to an equalization tank; see the Tank Sizing section for details
4. Provide High-Pressure Water Without Pumping	Height of water surface above grade results in high pressure in the distribution system	Applies to elevated tanks only (not ground storage tanks or standpipes)

Regulations and Industry Standards

Storage tanks are considered one of the most vulnerable components of a water supply system. Storage tanks are to be carefully designed and regularly inspected to minimize security risks and water quality risks. To help protect the public from potential risks, a variety of regulations and standards have been developed for the design, operation, and inspection of storage tanks in potable water supply systems.

The *Recommended Standards for Water Works*, also known as the *Ten States Standards*, is the most commonly recognized industry standard for the design of water storage tanks, as well as for other water system components. Most states in the United States and most provinces in Canada have adopted and enforce the *Ten States Standards*. Section 7 of the *Ten States Standards*, entitled “Finish Water Storage”, includes about six pages of specific recommendations for the design of water storage tanks.

Some municipalities have additional requirements for the design and inspection of storage tanks. Local building codes may also affect aspects of a new tank, such as the required height above the base flood elevation, maximum tank height, maximum impervious area for the site, minimum setback from the property line, and architectural requirements.

For an engineer tasked with the design of a new storage tank, local regulations should be reviewed during each stage of the design process to ensure compliance. The design will likely require a permit submittal to the environmental agency with jurisdiction for making modifications to the potable water system. After construction of the tank, a final submittal may be required to confirm the tank has been properly disinfected in accordance with AWWA Standard C652 and bacteriological testing has shown an absence of fecal coliform.

Additional guidelines for the design, operation, and inspection of storage tanks have been published by the AWWA and EPA. See the References Section for a list of key documents.

Types of Storage Tanks

There are three main types of water storage tanks: ground, elevated, or standpipe. Each of these is explained below. Note that buried tanks and hydropneumatic tanks are not covered as they are relatively uncommon for water distribution applications.

1. Ground Storage Tanks

The most common type of water tank is the ground storage tank. This is a tank with the floor at ground level. Ground storage tanks are also called ground level reservoirs. However, the term reservoir implies that the tank may not be covered, and for finished water tanks, a watertight roof is required per Section 7.0.2.b of the *Ten States Standards*. Therefore, the term ground storage tank is more commonly used.

Figures 1 and 2 show examples of finished water ground storage tanks.

Figure 1: A stainless steel ground storage tank

Figure 2: A concrete ground storage tank with pleasant architectural features.

A ground storage tank requires pumping out of the tank to provide sufficient pressure in the distribution system. This in contrast to an elevated tank which can provide pressurized water to the distribution system.

Ground storage tanks are the most economical type of storage tank because they are constructed at ground level. The construction cost of a ground storage tank is often stated as a cost per unit volume (dollars per gallon or dollars per cubic meter). To calculate the unit cost, simply divide the cost be the volume. For example, a 2 million gallon tank that costs 1 million dollars to construct, has a unit cost of $0.50 per gallon. Unit costs are handy for initial capital budget planning purposes and for comparing alternative storage tank arrangements and materials of construction.

Ground storage tanks have a low surface area to volume ratio, which can be calculated as follows:

$$sa/vol = \frac{2(r+h)}{r*h}$$

where:

sa/vol = surface area to volume ratio

r = tank radius

h = sidewall height

A low surface area to volume ratio provides the following advantages:

- Lower construction cost due to minimized total area of floor, walls, and dome,
- Decreased risk of a security breach since there is a smaller area of walls and dome to protect,
- Decreased risk of external contamination due to minimized total area of floor, walls, and dome,
- Best configuration for water quality due to a more homogenous mixing, decreased dead zones, and decreased likelihood for thermal stratification.
- Avoids both an excessive footprint and an excessive height.

2. Elevated Storage Tanks

Elevated storage tanks have the floor of the tank above ground. They are often called water towers. Examples of different types of elevated storage tanks are shown in Figures 3 and 4.

Figure 3: A conical bottom water tower (left) and spherical bottom water tower (right).

Figure 4: A multi-leg water tower (left) and a fluted column water tower (right).

An elevated storage tank has the ability to provide stored water at high pressure to a community. The higher the tank the higher the water pressure. Some tanks are high enough to provide high-pressure water without the need for pumping. The water pressure due to the static head is calculated as follows, based on Bernoulli's principle:

$$p = \frac{h * sg}{2.31} = 0.43 * h$$

where:

$p =$ water pressure (psi)

$h =$ height of water (feet)

$sg =$ specific gravity of the fluid (1.0 for water)

When designing an elevated water storage tank, it is important to calculate the water pressure that will be provide provided by the tank. The water pressure will vary based on the elevations of the different buildings in the community and based on the water level in the tank, as shown in Figure 5.

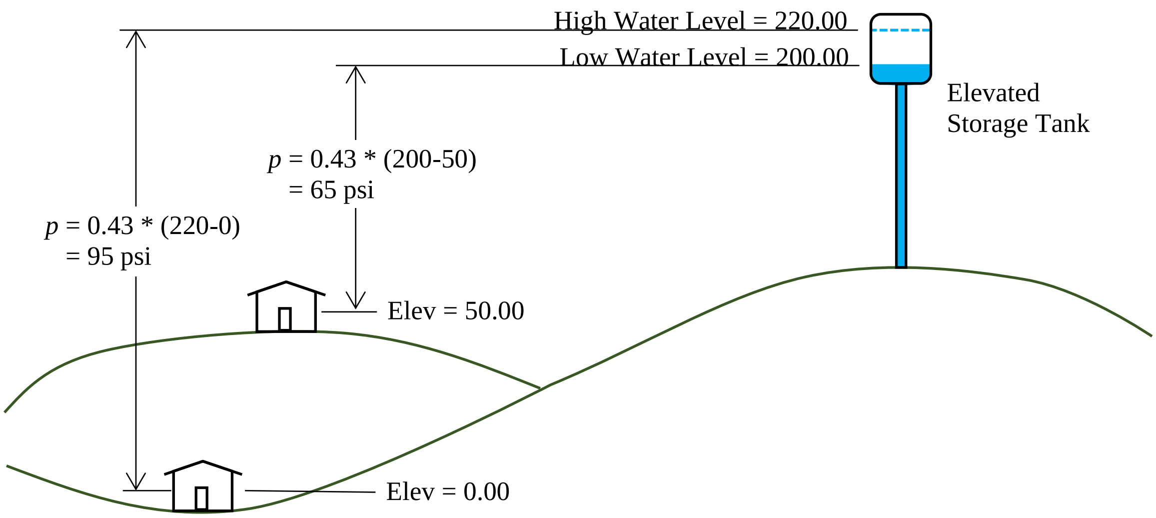


Figure 5: Water pressure (*p*) calculated for the buildings at the lowest and highest elevations in a community with an elevated storage tank.

The highest water pressure is experienced in the lowest elevation building when the elevated storage tank is at the high water level. It should be confirmed that the piping system is designed to withstand the high water pressure. Note that water distribution pipes are typically 3 to 5 feet below ground, so the pressure in the pipes should be calculated at the lowest elevation of the piping. A pressure reducing valve can be installed in the piping system to keep pressures below the design maximum.

The lowest water pressure is experienced in the highest elevation building when the elevated storage tank is at the low water level. It should be confirmed that this pressure exceeds the minimum acceptable water pressure. When calculating the lowest pressure, pipe friction and fitting losses at maximum flow should be calculated and subtracted.

Per the *Ten States Standards*, the distribution system shall be designed with a normal working pressure of approximately 60 to 80 psi (410 - 550 kPa). A minimum pressure of 20 psi (140 kPa) at ground level must be maintained at all points in the distribution system under all conditions of flow. Regulations typically require that a boil water advisory be issued to the public if the pressure drops below 20 psi at any point in the distribution system.

Elevated storage tanks are more common in hilly areas where the tank can be located on top of a hill, thereby reducing the height of the tank required and making it more economical. Elevated tanks are less common along coastlines where hurricane-force wind loads need to be accounted for in the structural design. Similarly, elevated tanks are less common in high seismic zones.

3. Standpipes

A standpipe is a storage tank with the floor at ground level and with a height that is greater than the diameter. Some consider a standpipe to be a type of water tower. In the 1800s and early 1900s, standpipes were very common in water systems in cities around the world. Figure 6 shows examples of standpipes.

Figure 6: Examples of standpipe installations.

A standpipe design produces a fair amount of water pressure, although pumping is still required to achieve more than 60 psi in the distribution system. A standpipe over 50 feet tall can produce enough pressure to keep the distribution system with a pressure over 20 psi if the pumping system fails, and thereby avoiding potential boil water advisories.

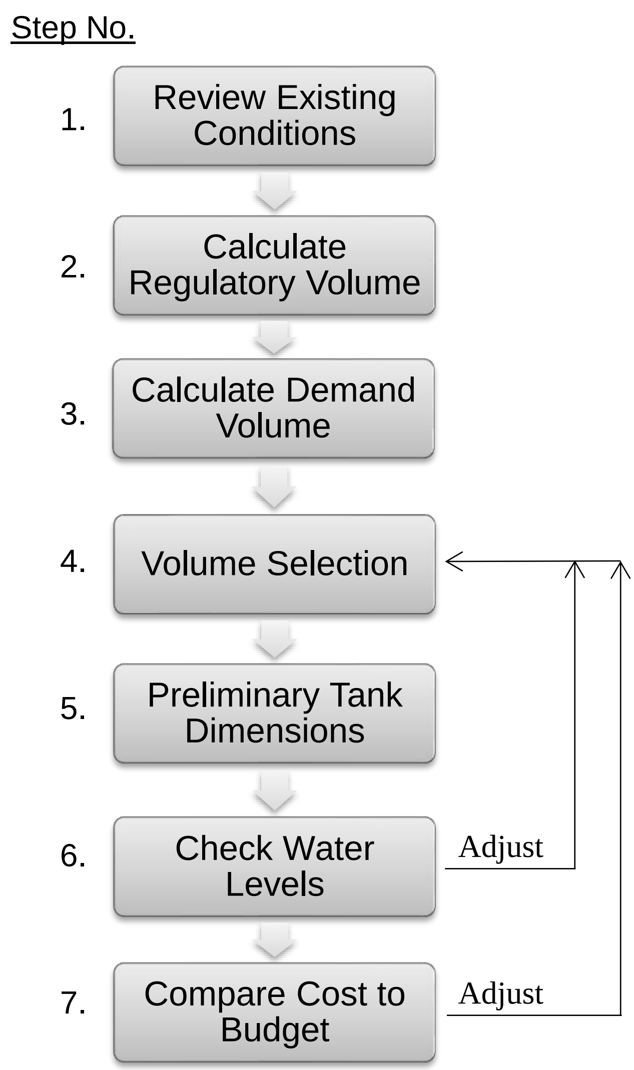
The unit cost of a standpipe is greater than that of a ground storage tank but less than an elevated storage tank.

While there are advantages to standpipes, they are prone to thermal stratification which negatively effects water quality. Thermal stratification is when less dense warm water rises to the top of the tank, thereby creating a temperature differential from the top to the bottom of the tank. Standpipes are prone to thermal stratification for three reasons:

1. A tall and skinny tank geometry naturally promotes thermal stratification. The taller the tank, the greater the potential temperature differential from top to bottom.
2. Standpipes have a higher surface area to volume ratio meaning that more surface area is exposed to heat from the sun.
3. It is more difficult to achieve homogenous mixing with a tall and skinny geometry.

Tank Sizing

A major challenge in designing a storage tank is to determine the optimal size for the tank. The following steps will help guide an engineer through the process of sizing a tank:



Step 1 is to obtain and review the existing conditions. The following information should be gathered, at a minimum:

- Check if there are any existing storage tanks and record their usable storage volume.
- Obtain a site plan or survey for potential tank locations.

- Obtain existing flow rate data including:
    - average hourly flow for each hour of the day,
    - peak hour flow,
    - minimum daily flow,
    - average daily flow, and
    - maximum daily flow.
- Obtain or calculate the future projected demand and peaking factor. This is based on the projected population growth and commercial development in the community.

Step 2 is to calculate the minimum required storage volume according to regulatory requirements. The *Ten States Standards* specifies that the required storage capacity (volume) to be equal or greater than the average daily consumption (demand). This is in addition to any fire flow requirements. For example, if the average daily flow over the last year is 5 million gallons per day (mgd) and no fire flow is required, then the minimum tank volume is 5 million gallons (MG). The designer should also check state and municipal regulations for any additional storage volume requirements.

Step 3 is to calculate the demand storage volume. This takes into account the need for diurnal flow equalization in the tank, fire flow demand, an emergency reserve, and dead storage volume. The demand storage volume (DSV) can be calculated according to the following formula:

$$DSV = EQV + FFV + ERV + DSV$$

where:
$DSV =$ Demand Storage Volume
$EQV =$ Equalization Volume
$FFV =$ Fire Flow Volume
$ERV =$ Emergency Reserve Volume
$DSV =$ Dead Storage Volume

Equalization Volume (EQV) is determined based on a diurnal flow curve, as shown in Figure 7. The average daily flow is the horizontal red line, which represents the relatively constant flow into the tank. In this curve, the tank is filling from 9 pm to 7 am, and the tank is draining, or drawing down, from 7 am to 9 pm.

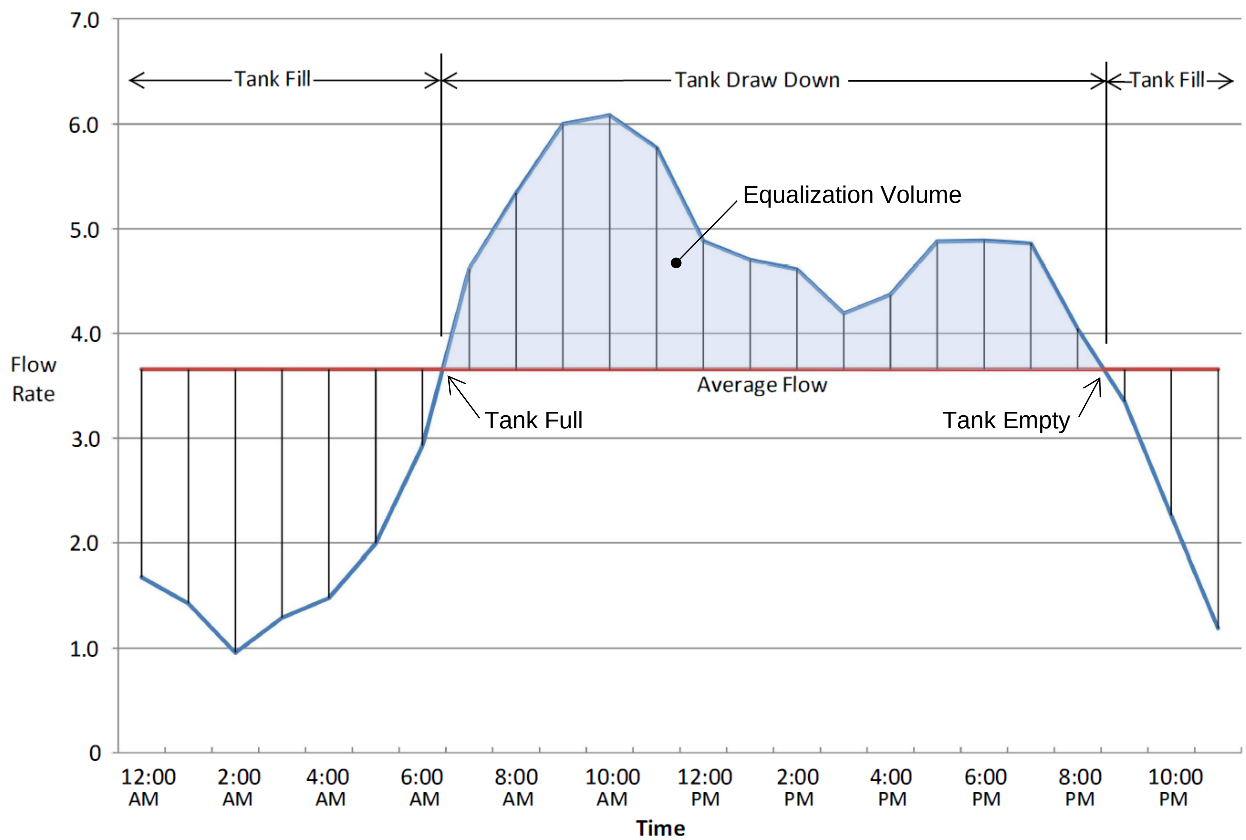


Figure 7: Example equalization curve with diurnal demand in blue and the average daily flow in red.

The area above the red line and below the blue curve represents the required equalization volume. The volume can be calculated as follows:

$$EQV = \frac{\sum |Q_{out} - Q_{in}| \Delta t}{2} = \frac{1}{2} \sum \left| Q_{demand} - Q_{avg} \right| \Delta t$$

where:

Q_{demand} = Hourly Flow Demand (gpm)

Q_{avg} = Average Daily Flow (gpm)

$\Delta t = 1$ hr (60 min)

Note that the required equalization volume is slightly different for each day since water demand in the community varies each day. For example, the flow demand curve during a weekday is different from a weekend and different from a holiday. The designer should review diurnal flow data over a variety of days and pick the day with the highest peaking factor. The peaking factor is the ratio between maximum hourly flow and average daily flow. Days with high peaking factors require the most equalization volume.

Another consideration for equalization volume is the future or projected flow demand. If the flow demand is expected to increase by 50% in the future, a projection factor of 1.50 should be multiplied by the calculated equalization volume. Finally, the required equalization volume should be rounded up by at least 10% to account for unforeseen variations in diurnal flow.

Fire Flow Volume (FFV) may be determined based on the Insurance Services Office (ISO) Method, or another method acceptable to the local governing body. The ISO method involves calculating the Needed Fire Flow (NFF) and multiplying it by the duration. A typical NFF is 2,500 to 3,500 gpm (158 to 221 L/sec) with a typical duration of 2 or 3 hours. This results in a typical FFV of 0.30 to 0.63 MG. For more information on calculating FFV for a storage tank, see AWWA Manual of Practice M31, Distribution System Requirements for Fire Protection.

Emergency Reserve Volume (ERV) is for unusual events such as pipe breaks, equipment failures, power outages, water contamination events, and natural disasters. It is common to have an emergency reserve of 20% to 50% of the maximum day demand. For example, if the maximum day demand is 10 mgd, the ERV would range from 2 MG to 5 MG.

Estimate Dead Storage (DS) is the excess volume at the top and bottom of a tank that is not normally usable. At the top of the tank, there is typically a freeboard of at least a few inches between the maximum water level and the overflow elevation. And at the bottom of the tank, there is a distance between the minimum water level and the floor of the tank to prevent entrained air from entering the outlet pipe and, in some cases, to provide sufficient positive suction head for the high service pumps. DS can be estimated as 10% to 20% of the tank volume, and then checked in Step 6.

Step 4 is to compare the minimum regulatory volume from Step 2 and the demand storage volume in Step 3. The greater volume should be selected as the storage volume requirement. Typically, the selected volume is round up to the nearest 0.5 MG.

Step 5 is to use the selected volume to define the preliminary tank dimensions. The first step is to decide on the number of storage tanks. Ideally, there should be two or more storage tanks in every distribution system for the following reasons:

- Regular tank inspection is best done with the tank empty. With a single tank, it may not be possible to shut down the tank for a full day for inspection.
- There may be a failure in the tank or ancillary components that result in the tank being taken out of service for emergency repair. Without a second tank, the distribution system would be left vulnerable without any storage.
- Having two tanks provides operational flexibility to maintain water quality. For example, if there is a period of low flow demand, one tank may be taken out of service to prevent dead zones or excessive water age that can occur during low flows.

The disadvantages to multiple storage tanks are increased capital cost, additional land area required, and increased system complexity. If there is insufficient funding available for two storage tanks, an option is to construct a single tank based on current demands and plan for a future second tank based on future demands.

If multiple storage tanks are selected, they should be designed to have the same maximum water level and overflow elevation. Ideally, they should be the same volume for ease of operation. For example, a selected volume of 10 MG should be provided with two 5 MG tanks.

If there is already an existing storage tank, then the new tank height should be set with the same overflow elevation, to ensure both tanks can be fully utilized without either tank overflowing. With the height known, the diameter can be calculated using the formula for the volume of a cylinder:

$$V = \frac{\pi}{4} d^2 h \quad \text{In typical English units: } V_{gal} = 5.87\, d_{ft}^2\, h_{ft}$$

where:
V = Volume
d = diameter
h = height

If there are no existing tanks, then a tank supplier should be contacted to provide the most economical diameter and height for the tank based on the selected volume. The designer should utilize the most economical dimensions when possible to minimize construction costs.

For an elevated tank, the height of the tank should be set to provide adequate pressure in the distribution system, as depicted in Figure 5. For a standpipe, a mixing system should be considered in the final selection of the size and shape of the tank.

Step 6 is to check the water levels in the tank. It is helpful to create a profile of the tank(s) with the volumes calculated in Step 3 and the preliminary tank dimensions. See Figure 8 for an example.

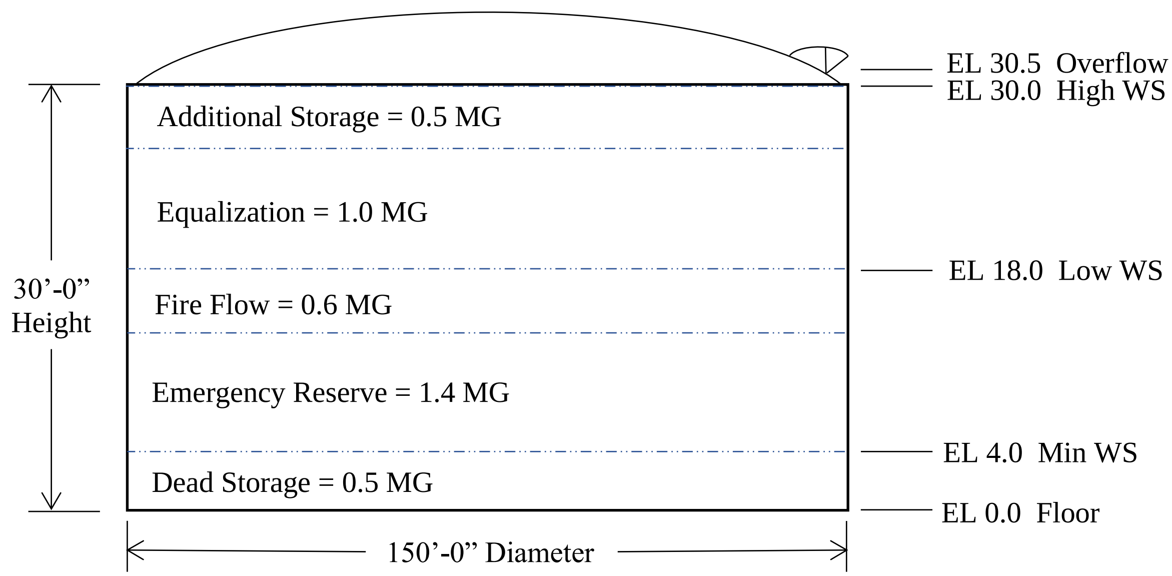


Figure 8: Profile of a 4 MG Tank with elevations and demand volumes.

The Additional Storage represents the difference between the demand volume and the final selected volume and is due to one or more of the following: regulatory volume being greater than the demand volume, rounding up the total tank volume to the nearest even number, to account for future projections, or as a safety margin.

The first water level to check is the minimum water surface (WS) elevation. This is the minimum water depth at which water can be pumped out of the storage tank at the maximum flow rate without the risk of the following: 1) entrained air being sucked through the outlet pipe, and 2) pump cavitation due to inadequate net positive suction head (NPSH). To reduce the potential for entrained air, an anti-vortex plate can be added to the tank outlet pipe. After determining the minimum WS, the Dead Storage volume can be recalculated.

The low WS and high (or maximum) WS elevations define the normal operating range of the tank. It is preferred to keep the water level above the low WS elevation to ensure there is adequate water available for a fire event or other emergency.

The overflow elevation should be at least a few inches above the high WS elevation to account for variation in level sensor readings, wave action at the water surface, and to give time for operators to assess a high water level alarm prior to an overflow event. Clarify with potential tank suppliers that the nominal tank volume is up to the high WS and should not include the freeboard to the overflow elevation.

Step 7 is to calculate the capital cost for the new tank(s). As mentioned in Step 5, if two tanks are desired but the capital cost exceeds the budget, a phased approach can be taken by constructing one tank first and then the second tank in the future.

The following items should be taken into account when performing a cost estimate for a new storage tank:

- Engineering for the design, permit support, and construction management.
- Tank supply and installation.
- Tank features such as ladders, access hatches, vent, and overflows.
- Tank foundation and subgrade.
- Tank grounding and lightning protection.
- Protective coatings and architectural features.
- Yard piping and valves associated with the new tank.
- Site lighting, CCTV cameras, fencing, and other security items.
- Stormwater features to manage drainage from the impervious area of the tank.
- Water testing, disinfection, bacteriological testing, and commissioning.
- Instrumentation, controls, and programming.
- General contractor overhead costs such as permit fees, mobilization, demobilization, temporary facilities, risk management, bonds, profit, etc.
- Escalation to mid-point of construction.

Mixing Considerations

Mixing systems have become common in water storage tanks since they can greatly improve water quality. Mixing systems can perform one or more of the following functions:

- Reduce thermal stratification.
- Improve water circulation and eliminate dead zones.
- Increase uniformity of water age.
- Allow chemicals to be injected directly into the tank.
- Releases volatile organic compounds (VOCs) and thereby reduces the formation of trihalomethane (THM), a disinfection by-product (DBP).

The following table lists common types of mixing systems with advantages and disadvantages.

Table 2 – Comparison of Mixing Systems

Mixing System	Description	Advantages
Hanging Curtains or Baffle Walls	Flow must travel between a series of walls or curtains.	No power consumption or maintenance required.
Mechanical Mixer	A mechanical mixer can be mounted on the tank floor, on a rail, or float on the tank surface.	Effective mixing that is not reliant on influent flow rate. Most compatible with chemical injection.
Passive Mixing System	The inlet pipe is extended into the tank with a series of nozzles designed to mix the tank contents.	No power consumption or maintenance required. Addresses thermal stratification.
Aeration System	Air is added to the water through diffusers with a blower or an eductor with a pump and recirculation piping.	Effective mixing that is not reliant on influent flow rate. Reduces THM formation.

Figures 9 and 10 show examples of tank mixing system installations.

Figure 9: A passive mixing system with several nozzles designed to mix the entire tank.

Figure 10: A rail-mounted submersible mixer which is removable from the hatch above.

Tank Features

Several important tank features are needed for the successful operation and maintenance of storage tanks. Typical tank features for a ground storage tank are shown in Figure 11 for an elevated storage tank and Figure 12 for a fluted column elevated storage tank.

The *Ten States Standards* includes the following requirements for tank features:

- Drain lines and overflow lines shall not connect directly to a sewer or storm drain.
- Overflow pipes shall terminate 12 to 24 inches above the ground surface and include an insect screen. Overflows shall be located so any discharge is visible. The overflow area shall be sufficient for passing water at the filling rate.
- All storage tanks shall have reasonably convenient access to the interior for cleaning and maintenance.
- The vent must be separate from the overflow. Vents shall be covered to prevent the entrance of rainwater and shall have insect screening.
- The roof and sidewalls shall be watertight with only essential openings or penetrations.
- Safety features shall be provided such as ladder guards/cages, guard railings, handholds, and protective bars over riser pipe openings.
- Sample taps shall be provided to facilitate the collection of water samples for bacteriological testing and water quality analysis.

The vent needs to have a large enough area to prevent pressurization of the tank during filling and a vacuum in the tank during drawing/emptying. The following guidelines can be used to size a vent. These values should be confirmed with the tank manufacturer:

- Ventilation area is to be size to release a minimum of 6 standard cubic feet per hour of air for every 42 gallons per hour of water inflow, per API Standard 2000, Section 4.3.2.2, and UL 142.
- Air velocity through the vent should be less than 3.5 ft/s (1 m/s) at peak hourly flow conditions for concrete domes and 8 ft/s (2.4 m/s) for steel or fiberglass tanks.
- Ventilation area shall be a minimum of three times the area of the influent pipe for concrete domes and equal to the inlet area for steel or fiberglass tanks.

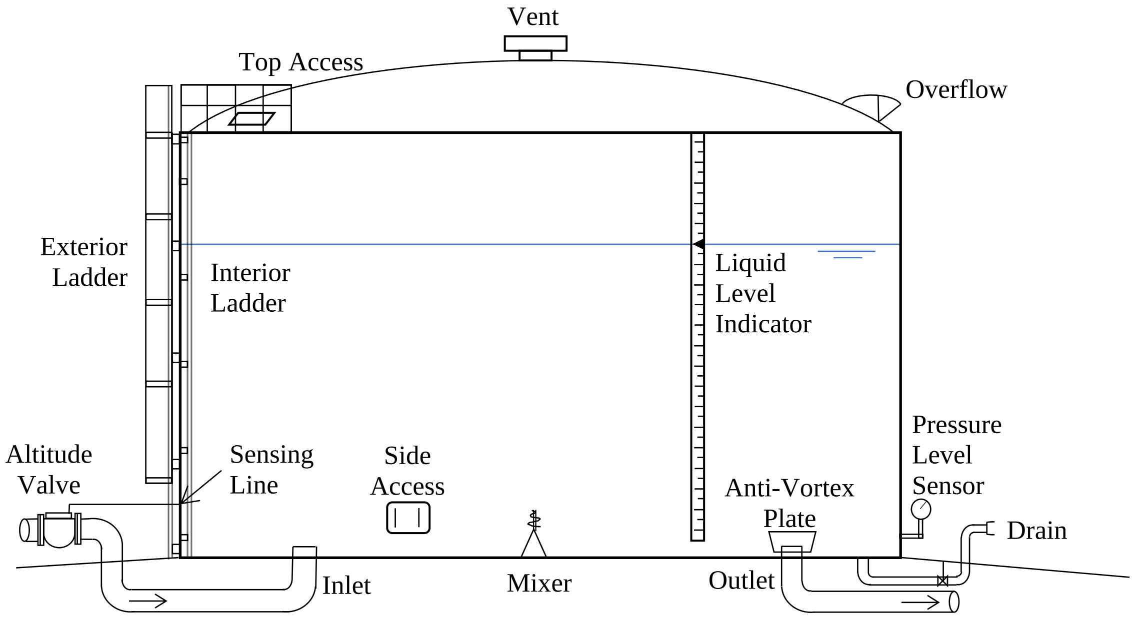


Figure 11: Typical tank features for a ground storage tank.

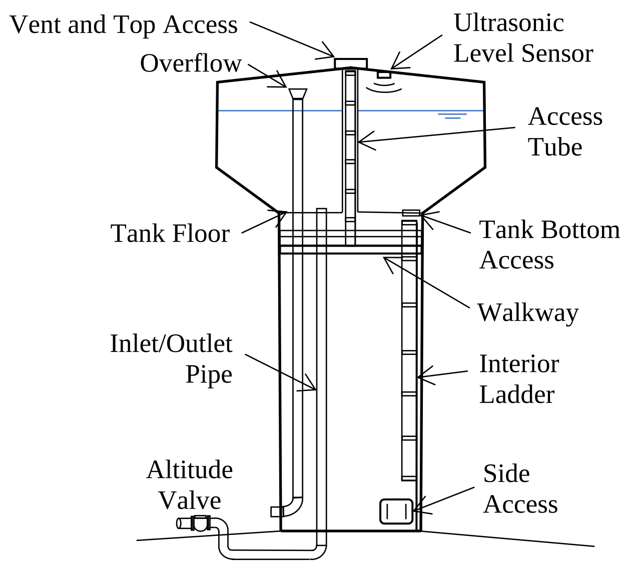


Figure 12: Typical tank features for a fluted column elevated storage tank.

The following table indicates if tank features are required, common, or uncommon for the three main types of water storage tanks.

Table 3: Tank Features for Different Types of Water Tanks

Feature	Ground Storage Tank	Elevated Storage Tank	Standpipe
Beacon Light	Uncommon	Required, Depends on Height	Required, Depends on Height
Vent	Required	Required	Required
Overflow	Required	Required	Required
Top Access Hatch	Common	Common	Common
Exterior Ladder	Common	Only common for Multi-Leg Type	Common
Interior Ladder	Common	Common except for Multi-Leg Type	Uncommon
Access Tube Though Tank	Uncommon	Common except for Multi-Leg Type	Uncommon
Side Access Hatch	Common	Common	Common
Liquid Level Indicator	Common	Uncommon	Uncommon
Level Sensor	Required	Required	Required
Mixing System	Common	Uncommon	Common
Altitude Valve with Sensing Line	Common, One way	Common, One-way & Two-way	Common, One-way & Two-way
Inlet Pipe	Required	Often a Combined Inlet and Outlet Pipe	Often a Combined Inlet and Outlet Pipe
Outlet Pipe	Required		
Drain Pipe	Common	Uncommon, Outlet Pipe Utilized	Uncommon, Outlet Pipe Utilized
Anti-Vortex Plate	Common	Uncommon	Uncommon

Water Quality Concerns

Water storage tanks have been used in pressurized public water systems since the mid-19th century, and are common around the world. However, in recent decades, there has been a growing concern for water quality deterioration resulting from storage tanks in the water distribution system. Potential problems are summarized in Table 1.

Table 4: Potential Water Quality Problems Due to Water Storage Tanks

Physical	Chemical	Biological
Thermal Stratification	Disinfection By-Product (DBP) Formation	Nitrification
Sediment and Sludge	Low Disinfectant Levels	Microbial Growth & Biofilm
Corrosion	Chemical Contaminants	Pathogen Contamination
Taste and Odor		

Excessive water age is considered the most important factor related to water quality deterioration. A long detention time (more than 24 hours) results in "old water" which is more susceptible to low disinfectant levels, microbial growth, and various chemical changes. Distribution systems with remote storage tanks are more prone to water age problems in the most distant tanks. Operational changes can reduce water age to acceptable levels, such as operating a tank at a lower water level.

Thermal stratification and poor mixing can result in excessive water age in certain zones within the tank. This can be prevented with a tank mixing system. A computational fluid dynamics (CFD) model may help indicate if a mixing system is required, as well as helping to select the best mixing system design.

A water storage tank must be an enclosed and sealed structure, with fine mesh insect screens on the overflows and vents. Even so, storage tanks are susceptible to contamination from external debris, biological material, and chemicals. For example, a tank may develop cracks or be damaged.

To help identify potential contamination or structural problems, tanks are to be inspected regularly to review wall penetrations, hatches, vents, overflows, roofs, and walls. Per NFPA 25, tank interiors must be inspected every 3 years for steel tanks without corrosion protection, and every 5 years for all other tanks.

Over time, there may be a buildup of sediment and sludge on the bottom of a storage tank, as shown in Figure 13. Sediment may provide a place for bacteriological material to live and grow, which can result in nitrification, DBP formation, and other water quality problems. The level of sediment should be reviewed during regular tank inspections, and excessive sediment should be removed. It is helpful to completely drain and pressure clean the entire tank interior regularly.


Figure 13: Examples of lime sludge found inside a ground storage tank.
On the left is sludge buildup at a side access port.
On the right is a tank floor with a couple of inches of sludge.

Helpful References

Standards for Tank Design and Operation:

Great Lakes Upper Mississippi River Board of State Public Health & Environmental Managers (2012). "Recommended Standards for Water Works". (Also known as *Ten States Standards)*. Albany, NY: Health Education Services.

EPA and AWWA (2002) "Finished Water Storage Facilities".

Tank Sizing and Design:

Mays, Larry W. (1999) "Water Distribution Systems Handbook". McGraw-Hill.

AWWA (2013) "Steel Water Storage Tanks". AWWA Manual M42.

AWWA (2008) "Distribution System Requirements for Fire Protection". Manual of Practice M31.

API (2014), "Venting Atmospheric and Low-Pressure Storage Tanks", API Standard 2000.

Tank Disinfection:

AWWA (2011) "Disinfection of Water Storage Facilities", AWWA Standard C652.

Tank Inspection:

EPA (2019) "How to Conduct a Sanitary Survey of Drinking Water Systems", EPA 816-R-17-001.

EPA (2017) "Finished Water Storage Tank Inspection/Cleaning Checklist", EPA Region 8.

NFPA (2020) "Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems". NFPA 25.

