A SunCam online continuing education course

Lift Station Design

by

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Course Outline:

Purpose and Function of a Lift Station
Regulations and Industry Standards
Design Criteria and Steps
Design Flow Rates
Types of Lift Stations
Wet Well Design
Intake Design
Discharge Design
Pump Selection
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Purpose and Function of a Lift Station

The purpose of a lift station is to transfer wastewater through a pressure pipe to a designated discharge location. A lift station functions by storing a small amount of wastewater and using pumps to "lift" the elevation and pressure of the wastewater, thereby moving the wastewater along to the destination. Lift stations also help ensure that wastewater flows only in the forward direction and not back into the gravity sewers.

Lift stations serve a critical role in moving wastewater (also called sewage) from local communities to designated wastewater handling facilities. A typical wastewater collection system is comprised of private laterals and gravity sewers that move wastewater by gravity from each property to a local lift station. The lift stations then pump the wastewater to a wastewater treatment plant (WWTP). See Figure 1 for a typical example.

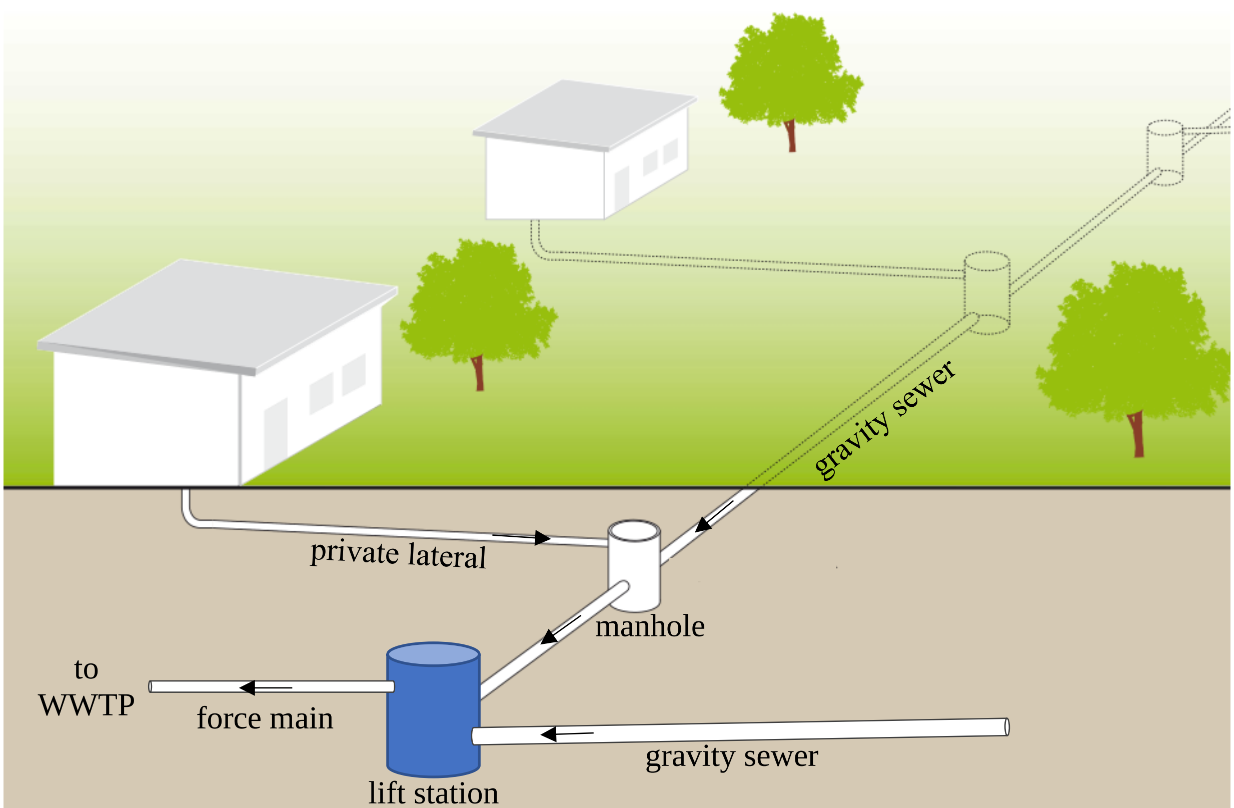

Figure 1: Schematic of a wastewater collection system with a lift station in blue.
Source: https://commons.wikimedia.org/wiki/File:Schematic_of_the_Conventional_Gravity_Sewer.jpg
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This course focuses on the design of lift stations in public sewer collection systems (also called conveyance systems). This falls under the field of sanitation engineering (to use an old term) and civil engineering.

It is possible to design a collection system with only gravity sewers and no lift stations. However, the gravity sewers require a consistent downward slope, and as the sewer pipes get longer, the deeper down the pipes need to be installed. Large deep tunnels can be utilized to collect and convey the flow by gravity. These deep pipes are expensive to construct and are difficult to maintain.

So, engineers utilize lift stations to allow for the conveyance of wastewater in shallow pipes of a smaller diameter. Lift stations also provide flexibility in routing pipes around or over features such as rivers, lakes, mountains, valleys, landmarks, and sensitive environmental areas. See Figure 2 for an example.

Figure 2: A force main crossing over a canal with an air relief valve in blue.

Normally multiple lift stations will pump wastewater into a common force main pipeline rather than keeping the force mains separate since a single pipeline is more economical. The pipe size grows in diameter as it picks up the flow from additional lift stations until reaching the destination, which is often the headworks of the WWTP.

In large collection systems, there may be a regional pumping station that accepts flow from multiple lift stations and boosts the force main pressure to convey the wastewater to the WWTP. It is common to use the term Master Pump Station or Booster Pump Station. An example of a network of lift stations is shown in Figure 3.

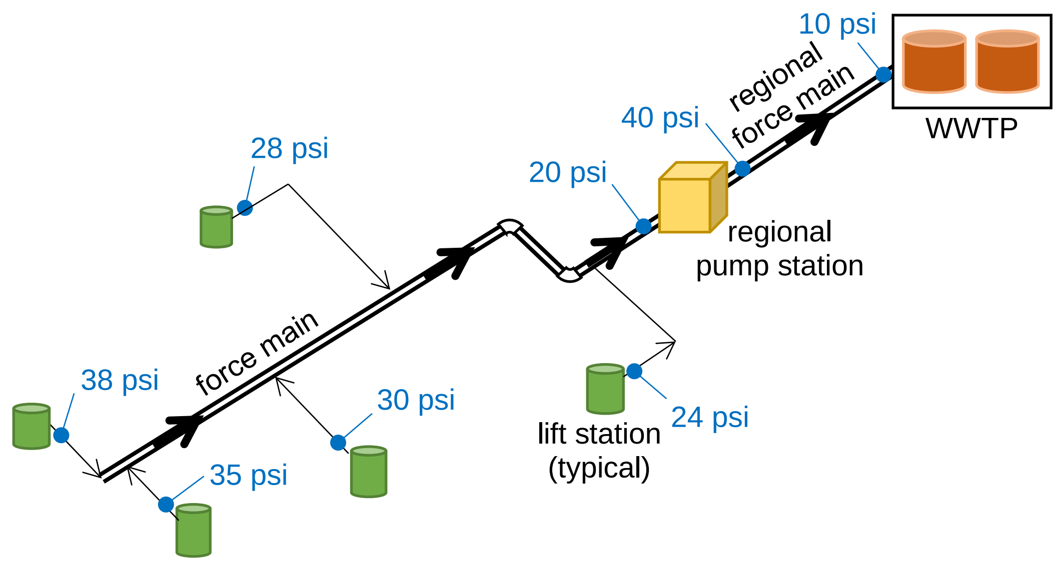

Figure 3: Force main schematic showing design pressures at each facility.

Note how the lift station that is furthest from the regional pump station experiences the highest force main pressure (38 psi in Figure 3), as the flow needs to overcome the greatest amount of friction losses from the long pipeline and its many fittings. A computer model is typically used to calculate the pressure at each lift station, especially when the collection system is being expanded or significantly modified.

Regulations and Industry Standards

A variety of regulations and standards have been developed for the design and operation of lift stations. For an engineer tasked with the design of a new lift station, or a rehabilitation of an existing lift station, state and local regulations should be reviewed during each stage of the design process to ensure compliance.

The *Recommended Standards for Wastewater Facilities*, also known as the *Ten States Standards*, is a commonly recognized industry standard for the design of lift stations, as well as for other wastewater system components. Most states in the United States and most provinces in Canada have adopted and enforce the *Ten States Standards*. Chapter 40 of the *Ten States Standards*, entitled “Wastewater Pumping Stations”, includes about 15 pages of specific recommendations.

Most municipalities and utility agencies have requirements for the design of lift stations within their system. Often there are standard drawings and specifications that are to be used and modified based on the application. The engineer is expected to incorporate the standards into the project drawings and specifications. The municipality then reviews the design to confirm it conforms to the requirements.

Private lift stations are located on private property and only accept flow within the property, such as for an apartment complex or gated community. These lift stations are typically held to the same design standards as the lift stations owned and operated by the municipality.

Approval is typically required from a state or local environmental agency, to confirm compliance with state regulations for wastewater collection systems. Also, local building codes may affect aspects of the overall design, such as the required elevation of the top of the wet well which is often required to be higher than the crown of the adjacent road and above the base flood elevation.

Guidelines for the design and operation of pump stations have been published by the Hydraulic Institute (HI), AWWA, and EPA. See the Helpful References Section for a list of key documents.

Design Criteria and Steps

The following design criteria are important to keep in mind throughout the design process and to confirm when the design is near completion:

1. Match pump capacity and type with wastewater quantity and quality;
2. Provide reliable and uninterruptible operation;
3. Allow for easy and safe operation and maintenance of the equipment;
4. Accommodate future capacity expansion;
5. Avoid septic conditions and excessive release of odors;
6. Minimize environmental and landscape impacts on surroundings; and
7. Avoid flooding/overflow of the lift station.

The design of a new lift station is typically done in the following steps:

1. Design flow rates
2. Lift station type
3. Pump quantity and speed control
4. Wet well configuration, size, and volume
5. Intake design
6. Discharge design
7. System curves
8. Pump selection
9. Quality review of calculations
10. Ancillary features

The order of these design steps can be modified. Lift station design requires an iterative approach, where an initial sizing and selection of components is assumed and then checked and modified as the design progresses. For example, after an initial pump selection, the wet well volume, intake design, and discharge design should be checked. If any of those items change, the system curve should be modified, and the pump selection checked. These inter-dependencies raise the chance for oversights and mistakes and make the final quality review of high importance. Calculations should be kept well organized to assist in this effort.

The following sections provide a general guide to each of these design steps. Additional guidance can be found in the reference documents in the Helpful References section.

Design Flow Rates

This is a common first step as it impacts most other aspects of the lift station design. It is essential to define the average and peak design flow rates since this helps in choosing the lift station type and to size the wet well, pumps, and force main. Each lift station has a unique combination of flow sources that should be identified and reviewed when defining these flow rates.

When designing a lift station for a new community, the average design flow (ADF) is based on adding the estimated flow rates of each flow source. Source design flows may be defined in municipal or state standards. For example, a single-family dwelling may be defined as 100 gpd. This single-family flow rate is sometimes referred to as one Equivalent Residential Connection (ERC) or one Equivalent Residential Unit (ERU). Other types of flow sources such as apartment buildings, offices, and shopping centers can be defined by a number of ERCs, to simplify the summation of all the source flows.

The peak design flow (PDF), or peak hourly flow (PHF), is calculated by multiplying the ADF by a peak factor, which typically ranges from 2 to 4. The peak factor accounts for the following:

- uncertainty in estimating flow rates,
- the sporadic peak flows which occur in sewer systems, and
- the inflow and infiltration of groundwater and stormwater.

Combined sewer systems accept both sewer and stormwater flows, which adds a small amount to the average flow and a large amount to the peak flow. For combined sewer systems, a larger peak factor should be used, or peak storm flows calculated. Storm flow is commonly calculated with a computer model using predefined design storm events for the watershed, such as the 25-year, 3-day storm. Check local codes for design storm requirements.

Pumps should be designed so that the “firm capacity” of the lift station meets or exceeds the PHF. The firm capacity is the discharge flow rate with all the pumps running except one of the largest pumps.

An “ultimate” design flow (UDF) can also calculated by adding the potential flow from properties to be developed in the future. Important permanent features, such as the wet well and force main, should be designed to ensure the lift station can accept the UDF.

Example 1:
Engineer Howard is designing a lift station with the following wastewater sources: (100) houses with three bedrooms, (40) houses with four bedrooms, a small office with ten daytime employees, and a 24/7 gas station with one restroom for men and one for women. State design requirements are listed in Table 1. What is ADF in gallons per minute (gpm) for the lift station?

TABLE I
For System Design
ESTIMATED SEWAGE FLOWS

TYPE OF ESTABLISHMENT	GALLONS PER DAY
Office building	
per employee per 8 hour shift or	15
per 100 square feet of floor space, whichever is greater	15
Service stations per water closet	
(a) Open 16 hours per day or less	250
(b) Open more than 16 hours per day	325
Shopping centers without food or laundry	
per square foot of floor space	0.1
Residences	
(a) Single or multiple family per dwelling Unit	
1 Bedroom with 750 sq. ft. or less of building area	100
2 Bedrooms with 751-1200 sq. ft. of building area	200
3 Bedrooms with 1201-2250 sq. ft. of building area	300
4 Bedrooms with 2251-3300 sq. ft. of building area	400
For each additional bedroom or each additional 750 square feet of building area or fraction thereof in a dwelling unit, system sizing shall be increased by 60 gallons per dwelling unit.	

Answer:

ADF = 100 x 300gpd + 40 x 400gpd + 10 x 15gpd + 2 x 325gpd
= 46,800 gpd x 1day/1,440 min
= 32.5 gpm

When designing for the rehabilitation of a lift station, or when adding a lift station to an existing community, it is helpful to measure the actual wastewater flow rate to confirm the ADF and PHF. This should be done over a long period of time, ideally a year or more since wastewater flow often varies by the season and may peak during holidays or other special events.

The following methods can be used for measuring the flow on an existing lift station:

1. Install a flow meter in the force main.
2. Use water consumption data by summing the water meter totals for each property discharging to the lift station. This approach assumes the wastewater flow is equal to or less than the water utilized, which is nearly always the case for residential and commercial properties.
3. Use pump run times and known pump flow rates. The pump flow rate can be confirmed by a draw-down test (measuring the change in level in the wet well) or by checking the discharge pressure and finding the corresponding operating point on the pump curve. See Figure 4 for an example. Note to subtract any elevation difference or significant head loss between the pump and gauge. The measured ADF equals the pump run time (total number of minutes the various pumps were "on") multiplied by the pump flow rate (most common flow rate from pump curve) divided by the measuring time period.

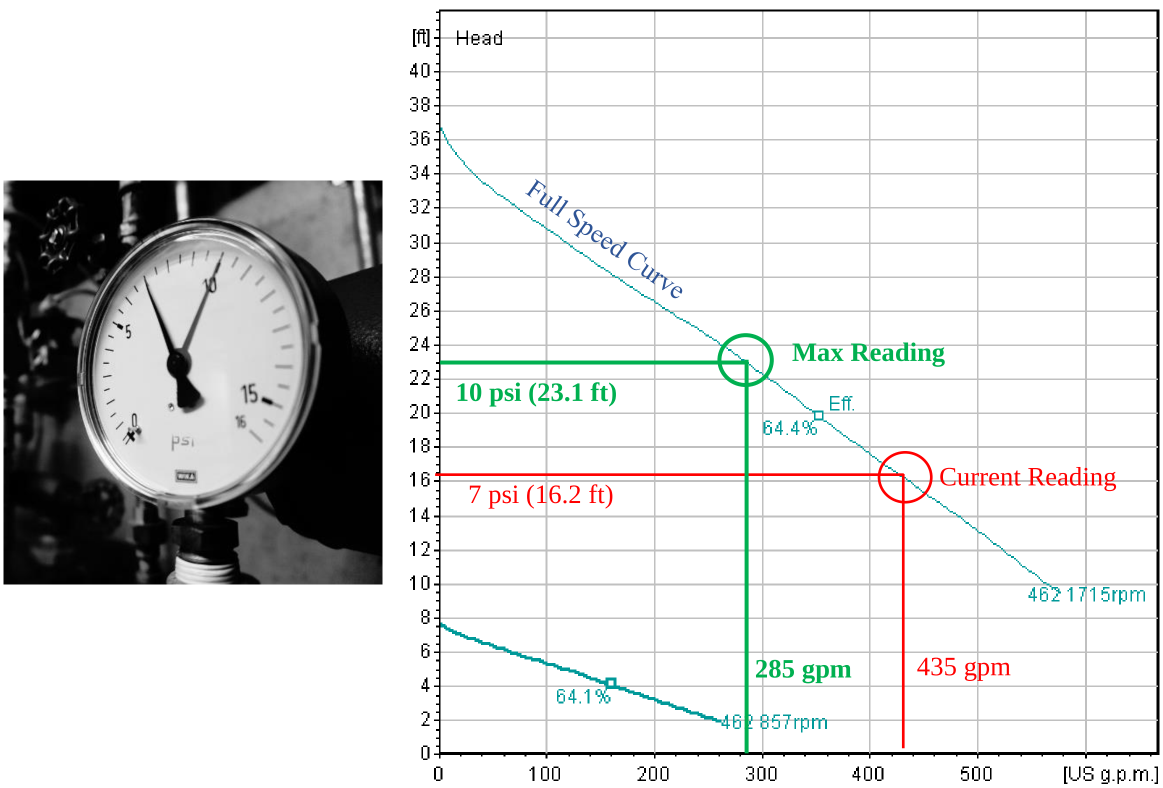

Figure 4: Left: A force main pressure reading of 7 psi (16.2 ft) and a max pointer reading of 10 psi (23.1 ft). Right: Pump curve with corresponding operating points. These pressure readings also help define the force main pressure range, which is needed later for producing the system curve.

Types of Lift Stations

The four most common types of lift stations are discussed as follows.

1. Submersible Lift Station

Submersible type lift stations are by far the most common for collection system applications. The main feature is the buried wet well which contains submersible type pumps. The discharge pipes from each pump penetrate the wall of the wet well. The valves are often located in a separate dry vault at grade for easy access. Electrical panels are mounted aboveground near the wet well. See Figures 5 through 9 for typical arrangements.

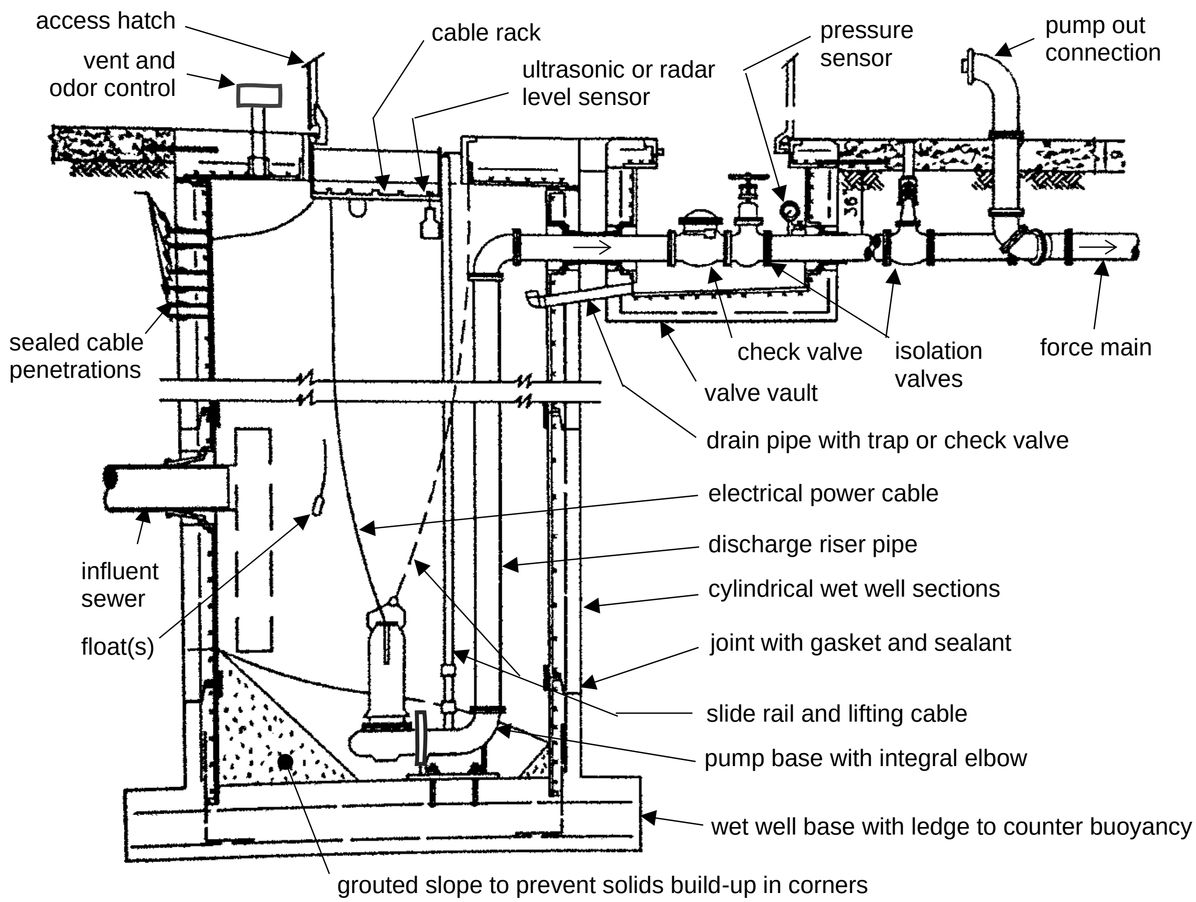

Figure 5: Section of a submersible lift station with a precast concrete wet well and valve vault. Important features are labeled.

Figure 6: Schematic of a prefabricated submersible lift station. This is a duplex station since it has two pumps. Triplex stations have three pumps.

Figure 7: A valve vault with two check valves (blue), plug valves (red), a pump-out connection on a riser, and a pressure gauge on the force main (to right).

Figure 8: Looking down inside a rectangular wet well with two pumps on slide rails. The tops of the two pump motors are visible in the wastewater. Floats are hanging from a cable rack on the right.

Figure 9: Top, wood forms for a concrete slab to surround the wet well (left) and valve vault (right). Final installation with vent (red), control panel, and communications antennae.

Submersible pumps have a water-tight enclosure that allows the motor to operate submerged in the wastewater. Pumps can be removed to the surface and reinstalled using the guide rails and a hoist. The wet well is a permit-required confined space with hydrogen sulfide gas and low oxygen, so maintenance should be done from the surface whenever possible. Entering the wet well requires following confined space safety procedures. The following items can be included in the design for safety:

- Safety grating below the access hatch to prevent falling into the wet well,
- Confined space signs on the top and/or bottom of the hatch doors, and
- A davit crane base installed next to the hatch.

Advantages of a submersible lift station are as follows:

- Less expensive than other types of lift stations for flow capacities less than 10,000 gpm (38,000 liters per minute).
- Less maintenance than other types of lift stations.
- Simplest design as there is no aboveground structure is required.
- Easier to blend in with the surrounding environment in residential areas.

Disadvantages are as follows:

- Maintenance of submersible pumps requires exposure to wastewater.
- The electrical control panel is exposed to the elements.
- Potential for sewer gases to enter the control panel through conduits.

2. Dry Well Lift Station

Dry well type lift stations have a separate pump room, which is also called a dry pit or a dry well. The pumps and valves are housed in the pump room and are is easily accessible. The wet well is a separate chamber adjacent to the pump room. Dry well configurations are common for regional pumping stations and booster stations. See Figures 10 through 12 for common arrangements.

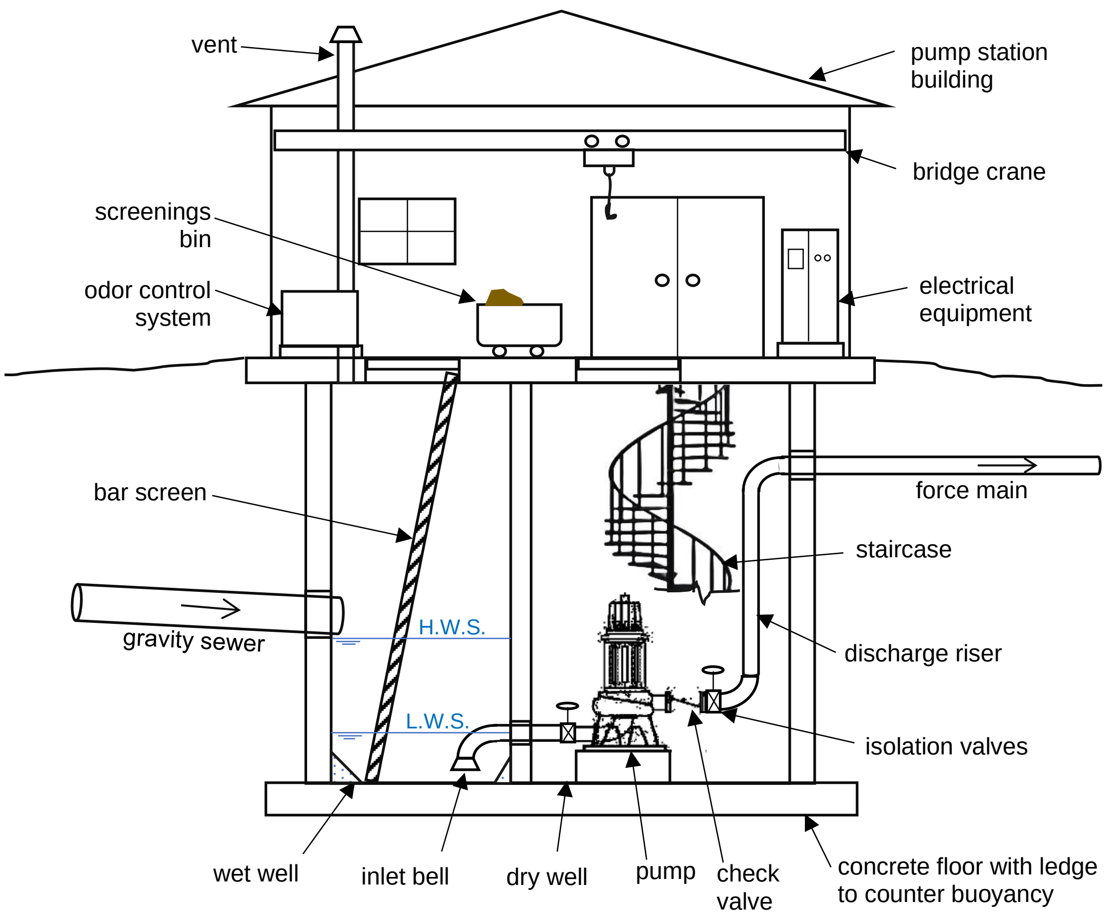

Figure 10: Section of dry well lift station with a buried wet well and dry well below a small building. Important features are labeled.

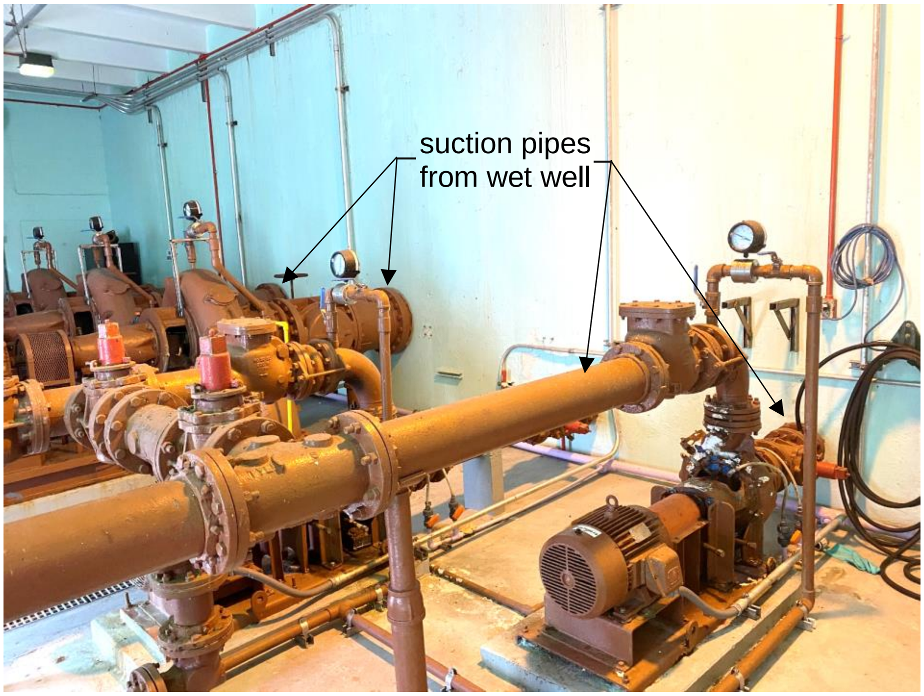

Figure 11: A dry well pump room with the wet well on the other side of the wall.

Figure 12: A pump station building with an architectural design intended to blend in with the surrounding neighborhood.

Advantages of dry well lift stations are as follows:

- Easy access to pumps for routine visual inspection and maintenance. Operators tend to prefer dry well pumps for this reason.
- Integrate indoor facilities such as an electrical room with air conditioning, an engine generator, a chemical feed system, a bathroom, sampling equipment, and a laboratory.
- Option to convert to an in-line booster station by routing feed pipes directly to the suction end of the pumps.

Disadvantages are as follows:

- More expensive than a submersible lift station for wastewater flow capacities less than 10,000 gpm (38,000 liters per minute). However, can be less expensive for large flow rates, such as regional pumping stations.
- The pump room has a high fire and explosion hazard rating according to NFPA 820. The room requires explosion-proof motors and instruments, a fire protection system, a ventilation system, and other safety features.
- Larger footprint.
- May need to own the property rather than using an easement.
- Typically requires a building which results in a long complex permit process with site plan and architectural reviews by the local municipality.

3. <u>Suction Lift Station</u>

Suction type lift stations have a pump room above grade while the wet well is below grade. The pumps need to pull a lift on the suction end. The lift height is equal to the distance from the pump suction flange to the water surface in the wet well. There are three common options for pulling a lift:

1) Self-priming centrifugal pumps,
2) Air diaphragm pumps with an air compressor, and
3) Centrifugal pumps with a vacuum priming system.

All these options are considered less reliable and more maintenance-intensive compared to other lift station types. For this reason, suction lift stations are uncommon. See Figures 13 through 16 for possible arrangements.

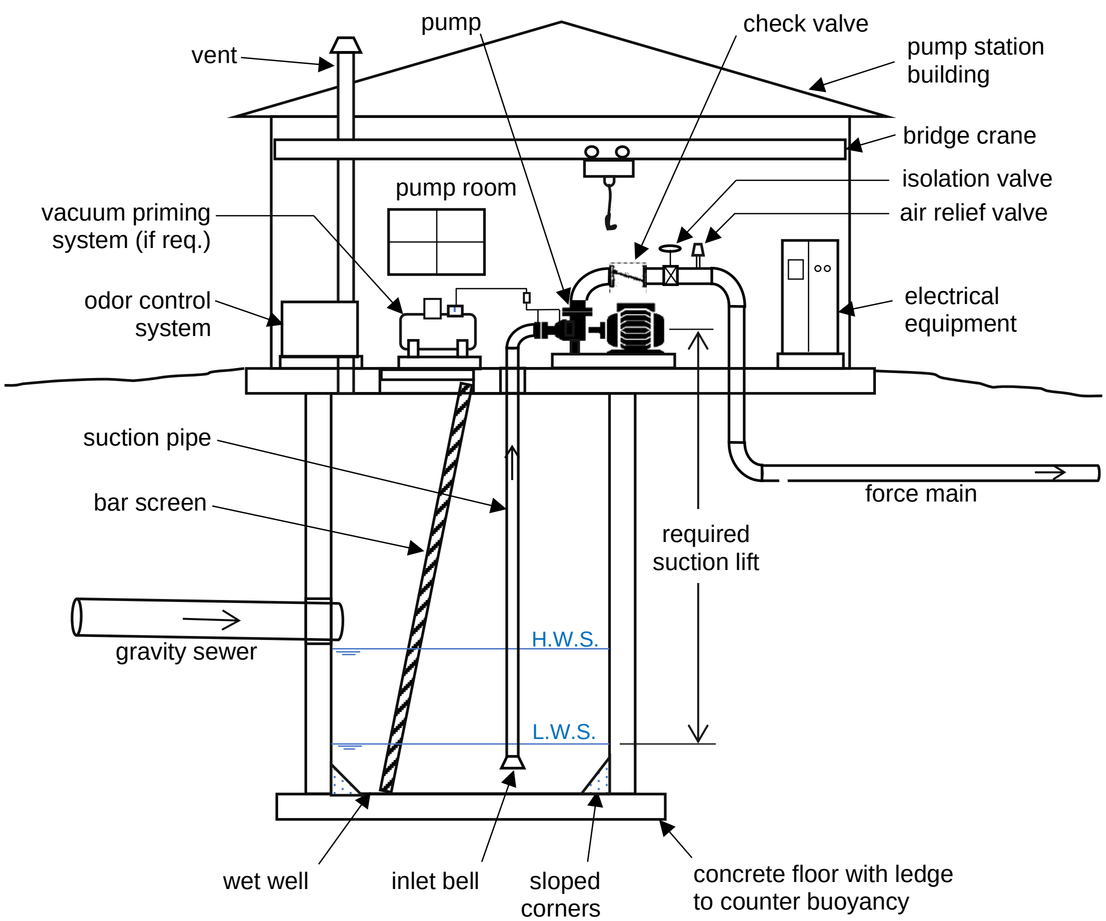

Figure 13: Section of suction lift station with the pump room above and well below. Important features are labeled.

Figure 14: A self-priming, solids handling centrifugal pump, which has a maximum lift height of around 20 feet. Note that these pumps are less efficient than typical end suction centrifugal pumps.

Figure 15: A suction lift station with self-priming pumps mounted on an outdoor slab.

Figure 16: Air diaphragm pumps with compressed air hoses in black, red, and yellow.

4. Vertical Lift Station

Vertical lift stations use vertical-style pumps that mount at grade and hang down into the wet well. See Figure 17 for an example arrangement.

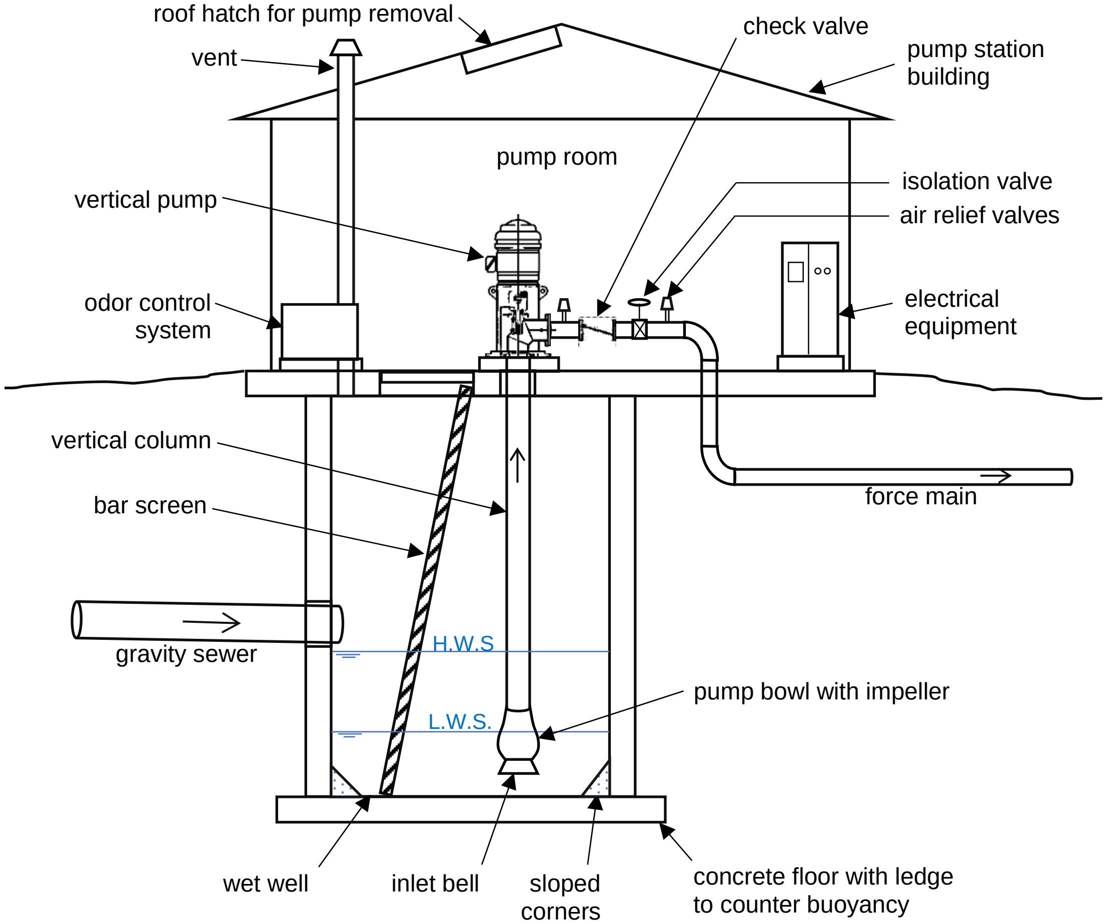

Figure 17: Section of a vertical lift station with important features are labeled.

Vertical lift stations tend to be more reliable than suction lift stations since the impeller is submerged in the wet well and therefore no priming device is needed. Vertical pumps are typically more energy-efficient and have a steeper pump curve which provides greater flow stability. Vertical turbine style pumps are a common choice as the bowl can handle solids and stringy material. A disadvantage is that vertical pumps require a crane for removal. The impeller is not accessible for removing rags.

5. Vacuum Sewer Station

The vacuum sewer station is the most interesting type of lift station. Wastewater is sucked from each source instead of flowing by gravity. A wastewater collection sump is attached to each house, and the wastewater from multiple sumps is transferred by a vacuum force to a collection tank in the vacuum station. From the tank, the wastewater is pumped to a force main. See Figure 18 for an example.

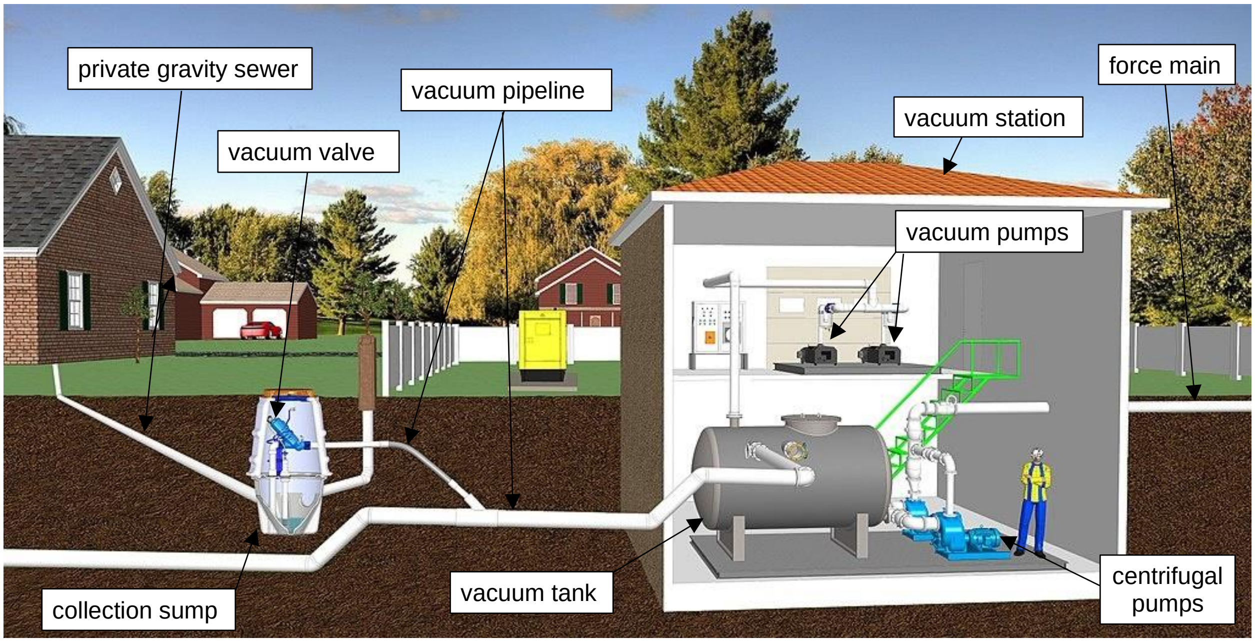

Figure 18: Schematic of a typical vacuum station.
Source: https://commons.wikimedia.org/wiki/File:Vacuum_Station_Layout.jpg
(c) by Srstevens3; used under CC BY-SA 4.0 (labels added)

Wastewater collects in the sump until it reaches a high level; then a vacuum valve opens, and the wastewater is transported with a stream of air to the vacuum tank. The vacuum pipes can route up and down, with low and high points, without problems. Vacuum pumps maintain the vacuum in the vacuum pipes.

Advantages of a vacuum sewer system are as follows:

- Shallower depth pipes with flexible routing to minimize disruption to sensitive ecosystems, structures, and other important features.
- Vacuum pipes can route through unstable soil in a high water table.
- No manholes are required.
- Smaller diameter pipes.
- Significant reduction in infiltration.

Disadvantages of a vacuum sewer system are as follows:

- Vacuum valves are installed at each property, and they require periodic maintenance.
- Vacuum stations are larger and more expensive than conventional submersible lift stations.
- An uncommon system requiring special training of operations and maintenance staff.
- Problems require more complex troubleshooting.

Pump Quantity

Small lift stations are typically designed with two pumps (duplex arrangement). There is one duty (or lead) pump and one standby (or lag) pump. Each pump is the same and each pump can operate across the full range of flow conditions including the peak hourly flow.

A duplex pump arrangement has the following advantages:

- Simplicity in design, construction, and maintenance,
- Lowest construction cost, and
- Smallest diameter wet well and therefore the smallest footprint lift station.

Using three or more pumps is beneficial under the following conditions:

- Large flow rates, such as a PHF greater than 5,000 gpm,
- Peak factor great than 4 (such as for combined sewer systems), and
- Force main pressure range greater than 20 psi.

Three or more pumps offers the following benefits:

- Ability to maintain the water level for variable speed control applications,
- Ability to cover a greater range of flows and pressures,
- Can still pump at average flow if two pumps are out of service,
- Increase in pumping efficiency with associated energy savings,

Large pumping stations, and especially booster stations, may have a combination of small pumps and large pumps. The small pumps stay in the high-efficiency range during low flow events, while the larger pumps can efficiently handle flows during large events. This combination of small and large pumps requires a more complex control logic. Also, a redundant small and redundant large pump may be required. It is unusual for local lift stations to be designed with a combination of small and large pumps.

Speed Control

A decision needs to be made if the pumps will be constant speed or variable speed controlled. Constant speed pumps mean the pump will output a relatively constant discharge regardless of the influent sewage flow. This means the water level in the wet well will fall when the pump is on and rise when the pump is off. The pump on and pump off levels need to be defined based on pump cycle calculations. Sometimes the wet well volume will need to be larger than a variable speed control scenario.

Variable speed controls are used to maintain a fixed water level in a wet well by varying the speed of the pump(s). By carefully adjusting the speed of the impeller, the output of the pump can closely match the influent sewage flow. The following are benefits to variable speed control:

- For large flow applications, variable speed pumping may allow a given flow range to be achieved with fewer pumps than a constant speed alternative.
- Variable speed pumping is often used to optimize pump performance and minimize power use.
- Variable speed pumping can reduce the size and cost of the wet well.

Several types of variable speed pumping equipment are available, including variable voltage and frequency drives, eddy current couplings, and mechanical variable speed drives. The most common is the variable frequency drive (VFD). This equipment adds a small amount of energy loss (typically 3% to 5% for VFDs).

Submersible lift stations typically have constant speed controls for the following reasons:

- Simplicity in maintenance and operation,
- Lower construction cost,
- VFD equipment has a shortened life when installed outdoors.

Wet Well Design

Wet Well Configuration

It is important to consider the overall wet well configuration, which includes the shape of the well, baffles, and slope of the floor. The main goal is to avoid concentrated flows and large eddies, which can lead to pump problems such as sucking entrained air and cavitation. Pump intakes (also called inlets) should be equally spaced from one another and centered about the center of the wet well.

HI Standard 9.8 entitled *Pump Intake Design* provides guidance on the wet well configuration. When the flow is greater than 5,000 gpm per pump the following is recommended: baffles between each pump intake, special geometry to distribute the flow between the intakes, and 3D modeling. Local lift stations are typically below this flow limit, so baffles are not required between the pumps.

The wet well floor should be sloped towards the pump with a flat area directly below the inlet or pump, to avoid an accumulation of solids and prevent areas with no water movement. The *Ten States Standards* recommends a minimum slope of 1 to 1, although a steeper slope of 2 to 1 will provide self-cleaning, if there is space. If the slope enters the level control zone, the impact on the usable wet well volume needs to be considered.

Wet Well Dimensions

The interior horizontal dimensions of the wet well are based on the following:

- Spacing between intakes (or pumps) and the distance from the intakes to the wall, all of which is part of the intake design.
- Space for baffles, bar racks, or other features, if required.
- For submersible lift stations, the hatch at the top needs to be large enough to remove all the pumps, as shown in Figure 19. Other types of lift stations also need a hatch for inspection and access.
- Consider increasing the dimensions to account for a potential future upgrade to larger pumps with greater flow rates.

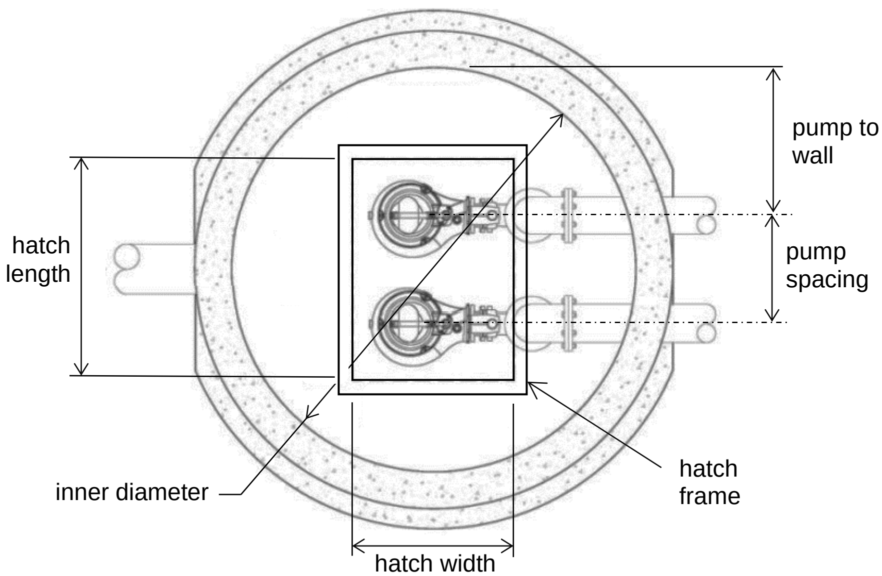

Figure 19: Plan view of a duplex submersible lift station.

The depth of the wet well is dependent on the following:

- Defining the top of the wet well elevation, which is often required to be higher than the crown of the adjacent road and above the base flood elevation.
- Defining pump control levels. See Figure 20 for an example.
- Defining the elevation of the inlet (or pump) so the depth from the pump off level to the inlet bell (or bottom of the pump) is greater than the minimum inlet submergence.
- Defining the elevation of the bottom of the wet well so the distance between the inlet bell as part of the intake design.

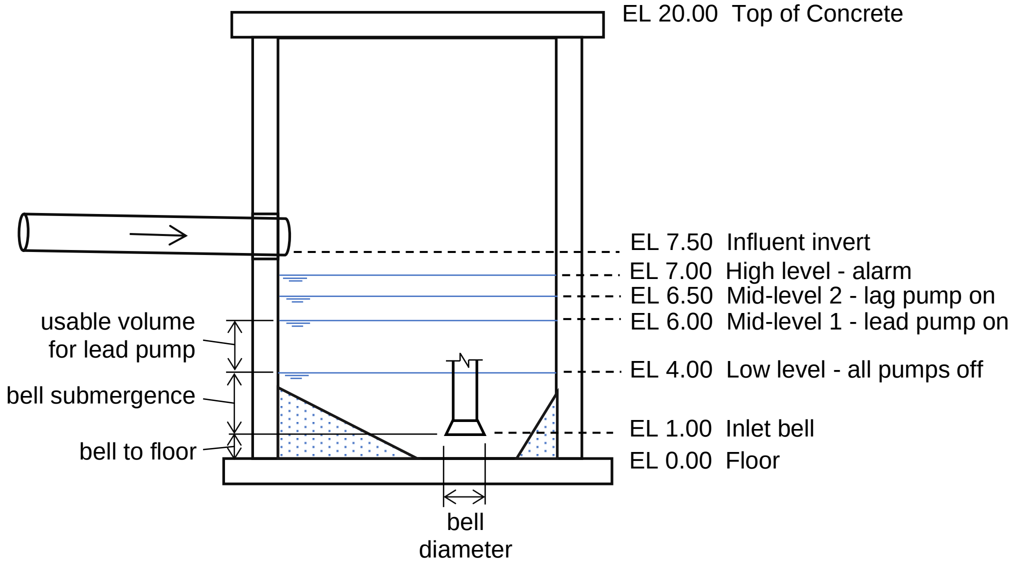

Figure 20: A 20-foot deep wet well with important elevations defined.

Usable Volume

The usable volume (also called effective volume) of a wet well can be calculated as the area of the wet well times the distance between the on and off operating levels of the pump(s). Wet wells should be sized with a large enough volume to prevent excessive pump cycling. Submersible pumps typically allow up to 15 starts and stops per hour, which equals a cycle time of 4 minutes. This should be confirmed with the pump manufacturer.

Constant speed pumps will cycle the most when the influent flow is half the pump capacity. Based on this condition, the minimum usable wet well volume (V_{min}) can be determined with the following formula, where (T_{cyc}) is the minimum cycle time between starts for the selected pumps and (Q_{pump}) is the maximum pumping rate of a single constant speed pump:

$$V_{min} = \frac{T_{cyc} * Q_{pump}}{4} \qquad \text{(constant speed)}$$

For variable speed pumps designed to hold a constant water surface elevation, the minimum volume can be based on providing sufficient time for pumps to start or stop. When a pump is started, the motor must be ramped to the desired speed, and the pump currently online must be reduced in speed. The time required for this is usually 1 to 2 minutes. However, experience has shown that having a storage time of 4 minutes provides an additional safety factor for unforeseen conditions and potential drive control settings.

$$V_{min} = Q_{pump} * 4min \quad \text{(variable speed)}$$

There is also a maximum volume since a long detention time results in septic conditions, intense odors, and solids buildup on surfaces. Typically, a maximum detention time of 30 minutes is acceptable under average influent flow conditions. The maximum usable wet well volume (V_{max}) can be calculated with the following formula, where (T_{det}) is the allowable detention time and (Q_{avg}) is the average influent flow rate:

$$V_{max} = Q_{avg} * T_{det}$$

Example 2:
The city has contracted with ABC Design Company to design a new submersible lift station. Mary is the project engineer, and she has determined a PHF of 650 gpm and an ADF of 200 gpm. She has selected two constant speed pumps, each with a maximum flow of 700 gpm (complete redundancy) and a maximum of 15 starts per hour. The City standards require an 8 ft diameter wet well with a maximum detention time of 20 minutes. The City has asked for the depth of the well to be kept at a minimum to avoid excavation in bedrock. The pump on float is set at an EL 4.00 which is 12” below the influent gravity pipe. Choose an elevation for the pump off float.

Solution:
Start by calculating the minimum cycle time of the pumps, since that is required for calculating the minimum usable volume:

$$T_{cyc} = \frac{60min}{15\ starts} = 4\ min$$

$$V_{min} = \frac{T_{cyc} * Q_{pump}}{4} = \frac{4\ min * 700\ gpm}{4} = 700\ gallons$$

$$V_{max} = Q_{avg} * T_{det} = 200gpm * 20min = 2000\ gallons$$

Mary selects a volume of 750 gallons which is above the minimum required while also keeping excavation depth to a minimum. The distance between floats is calculated as the height of a cylinder:

$$Height = \frac{V}{Area} = \frac{750gal}{\pi r^2} = \frac{100.3ft^3}{\pi(4\ ft)^2} = 2.0ft$$

Therefore, the low float should be at EL = 4.00 – 2.0 ft = **2.00**.

Mary wants to check the starts per hour of the pump at various flow conditions, so she creates Table 2. At average flow, the cycle time is 4.8 minutes with 12.5 starts per hour. This is close to the limit of 15 starts per hour, which concerns her. Mary defines the control logic so the two pumps alternate starts, which doubles the cycle time per pump to 9.6 minutes and reduces the starts per hour to 6.3 starts per hour.

Table 2: Cycle time calculations based on a usable wet well volume of 750 gallons

Label	A	B	C	D	E	F
Equation	Given	Given	750 / A	750 / (B-A)	C + D	60 / E
Condition	Influent Flow (gpm)	Pump Flow (gpm)	Fill Time (Pump Off) (min)	Drain Time (Pump On) (min)	Cycle Time (Drain+Fill) (min)	Starts /Hour
Low Flow	100	700	7.5	1.3	8.8	**6.8**
Avg Flow	200	700	3.3	1.5	4.8	**12.5**
Most Cycles	350	700	2.2	2.2	4.4	**14.0**
Max Flow	650	700	1.2	15.0	16.2	**3.7**

When designing for multiple pumps of different sizes, the minimum volume required for the large pump will control the sizing of the wet well. However, it is helpful to calculate the minimum volume for each pump and make a diagram of the pump on and off levels to visually confirm the design. See Figure 21 for an example.

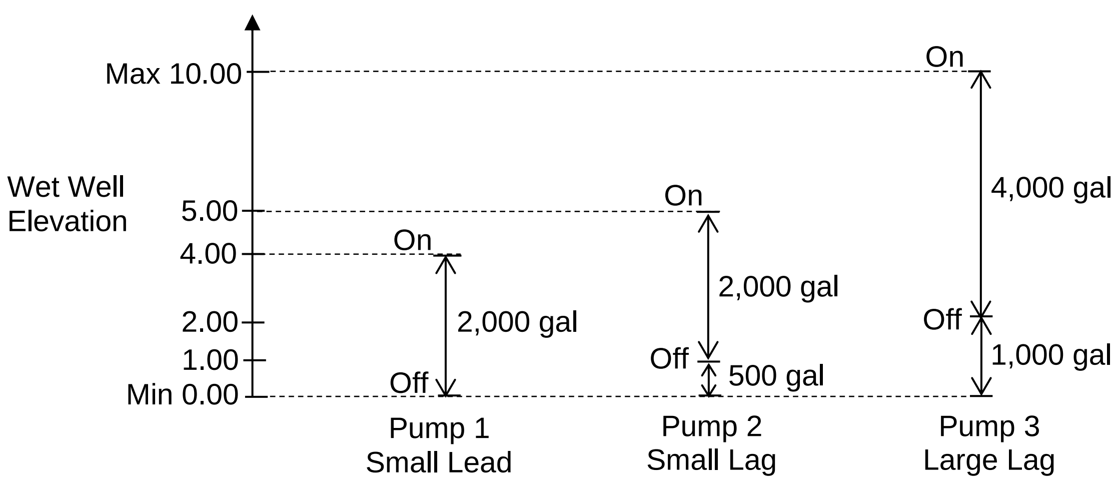

Figure 21: Pump on and off levels with associated usable volumes for three pumps.

Lining

Most wet wells are designed of concrete which is generally resistant to corrosion. However, the wet well is designed to last the longest of all components of the wet well as it cannot be replaced like mechanical or electrical items. A coating or lining on the *interior* of the wet well is essential to protect it from raw sewage and corrosive gases. A coating on the *exterior* is an option for protecting the concrete from corrosive soils and groundwater. And the *concrete itself* can have an antimicrobial admixture where superior corrosion resistance is desired.

The following are common options for lining the interior of the wet well:

- Plastic liner fixed to the concrete surface, with holes cut and welded for pipe and conduit penetrations. Liner material may be PVC, polypropylene (PP), PP with random copolymer, or fiberglass reinforced plastic (FRP).
- High Solids Epoxy applied in multiple thick coats.
- Vinyl-ester applied in multiple thick coats.
- Cementitious composite system, often with calcium aluminate included in the cement/grout mixture, with a minimum thickness of 1-inch.
- Coal tar epoxy apply with a minimum dry film thickness of 16 to 20 mils. Note that this product contains chemicals known to cause cancer, so is no longer commonly used.

Intake Design

A proper intake design protects the pump from vortices, entrained air, and cavitation. The intake design concerns the shape of the wet well as it guides flow into each pump or inlet bell. In the cases of submersible pumps and vertical pumps, the inlet is the opening in the bottom of the pump. The pump manufacturer should provide recommendations for the intake design, although the following principles should still be reviewed during design. Important intake dimensions are as follows, per *HI Standard 9.8* on intake design:

- Bell diameter sized so velocity at maximum pump flow is approximately 5.5 ft/s (1.7 m/s).
- Clearance between multiple inlet bells (or pump volutes) to be a minimum of 0.25 times the bell diameter. For submersible pumps, confirm the minimum pump spacing and wall distance with the manufacturer.
- Distance from the center of the inlet bell to the nearest wall of the wet well should be a minimum of 0.75 times the bell diameter.
- Distance from the inlet bell to the flat floor should be from 0.3 to 0.5 times the bell diameter.
- Minimum inlet submergence (S), which is the depth in inches below the minimum water surface, based on bell diameter (D) in inches and maximum flow rate (Q_{max}) in gpm:

$$S = D + \frac{0.574 * Q_{max}}{D^{1.5}}$$

Discharge Design

The discharge design consists of the following:

- Sizing the discharge piping,
- Selecting a material, thickness or class, and lining for the piping,
- Selecting the type of check valve and isolation valve,
- Determining the route of the piping, including all fittings (can estimate fittings for potential utility crossings at this point and confirm during final design), and
- Defining the tie-in design to the force main, including the tie-in elevation.

The main tool for sizing the discharge piping is the velocity at the maximum pump rate. The following are *Ten States Standards* recommendations for sizing discharge and force main pipes:

Minimum velocity: 2 fps, to prevent solids buildup and clean the pipe

Maximum velocity: 8 fps, to avoid high head loss and prevent damage to valves and pipe lining.

For force mains in the right-of-way, many municipalities require a maximum velocity of 4 or 5 fps (rather than 8 fps), to account for the possibility of additional lift stations being tied into the force main in the future.

If there are more than two pumps, the branches to each pump will be smaller than the force main downstream of the tee or cross-connection. Each pump branch should be sized based on the maximum flow of the corresponding pump. And downstream of the point the branches combine, the force main should be designed based on the overall firm capacity of the lift station, or the UDF, whichever is greater.

Pipe material options are as follows:

- Ductile iron (DIP) – most common for inside the wet well.
- PVC (Schedule 80) – easy flange connections inside the wet well and vault.
- PVC (C900) – not suitable inside wet well; thrust restraints to be considered.
- HDPE – fused joints to be used whenever possible instead of couplings.

Pipe and joint designs are typically the same as used for water mains. The force main designed must withstand water hammer pressures and associated cyclic reversal of stresses that occur when pumps turn on and off.

System Curves

Creating system curves is the most technically difficult part of lift station design. An engineer should perform system curve calculations for each application since it is unlikely that any two lift stations will the same system curves. A system curve is a plot of the total dynamic head (Y-axis) versus the flow rate (X-axis).

The "system" is the designed portions of the lift station and discharge piping in which the wastewater must move to get to the destination, which is assumed to be a tie-in to an existing force main. The total dynamic head (TDH) represents the energy required (called loss) to move the wastewater to the destination at a given flow rate. Engineers use the unit of feet (or meters) for TDH for simplicity.

A system curve is created by calculating the system losses at several different flowrates and then plotting the points. The following are typical steps for creating a system curve:

1. Gather the following information:
   a) Average daily flow (ADH) and peak hourly flow (PHF),
   b) Number and type of duty pumps,
   c) Water level elevations for pump on and pump off,
   d) Suction pipe dimensions (not required for submersible pumps),
   e) Discharge pipe size, route, and tie-in elevation, and
   f) Force main tie-in pressure range.
2. Select the two most extreme operating conditions, which are typically as follows:
   a) Lowest static head: high water level and low force main pressure.
   b) Highest static head: low water level and high force main pressure.
3. Tabulate the following headloss values for the extreme operating conditions:
   a) minor losses,
   b) pipe friction losses, and
   c) static losses
4. Plot the TDH versus Flow for the two conditions. See Figure 22 for an example.

Most engineering firms have standard excel templates or programs for calculating headloss values. Please download the Free Software that comes with this course for a template for performing headloss calculations. The Hazen Williams Equation is by far the most used formula for calculating pipe friction losses for pumping applications. Not only is it simple and easy to use, but its use is also required by many regulatory agencies. Coefficients for friction losses and K values for minor losses can be obtained from *Flow of Fluids Through Valves, Fittings & Pipe* by Crane, *Cameron Hydraulic Data* by Flowserve, or other documents listed under Helpful References.

Example 3:
Engineer Beatrix is creating system curves for a submersible lift station. The water level varies from EL 4.0 to 6.0. The force main pressure varies from 9 to 13 psi with pipe centerline EL 12.0. The PHF is 550 gpm. Calculate the static head and plot example system curves.

Answer:
Beatrix calculates the static head at the two extreme operating conditions:

- Lowest static head:
  - Water level from 6.0 to 12.0, plus low FM pressure of 9 psi
  - Head = (12.0' – 6.0') + 9 psi * 2.31 ft/psi = 26.8 ft
- Highest static head:
  - Water level from 4.0 to 12.0, plus high FM pressure of 13 psi
  - Head = (12.0' – 4.0') + 13 psi * 2.31 ft/psi = 38.0 ft

Beatrix calculates the friction and minor losses at 100 gpm intervals, then adds the two static losses to create system points, which are plotted as system curves in Figure 22.

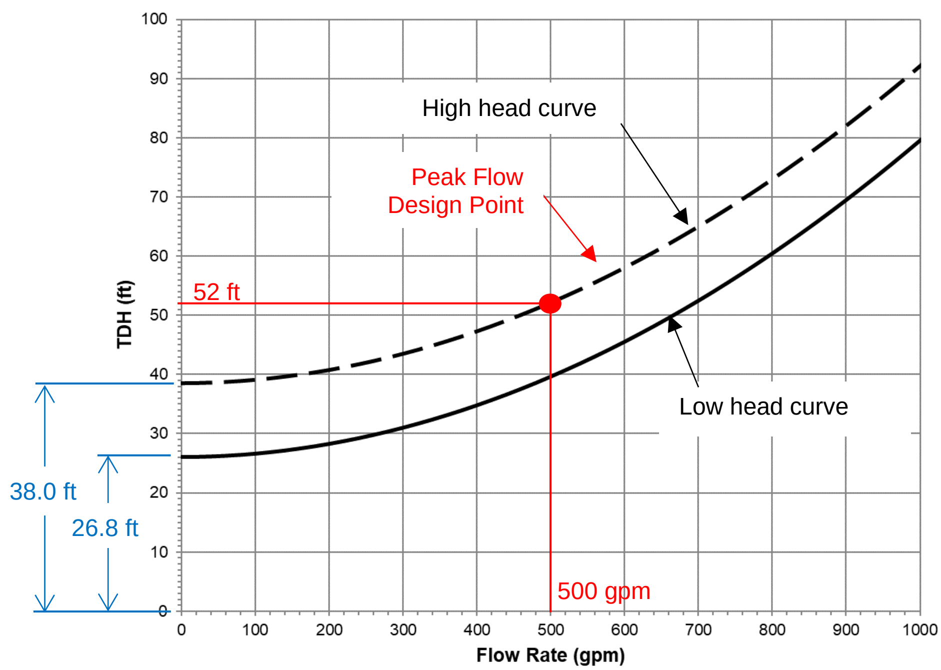

Figure 22: System curves with the operating point in red.

Pump Selection

The importance of making a good pump selection cannot be understated. The main goal is to choose pumps that meet the flow demands while staying within the operating range with acceptable efficiency. However, the pumps also need to be of reliable construction as they will be expected to move wastewater for many years.

The following are typical steps for the pump selection process:

1. Select the type of pump
2. Identify and contact pump manufacturers
3. Make preliminary pump selections using design points
4. Compare and chose a pump
5. Plot pump curve on the system curve
6. Identify pump capacity at high and low head conditions
7. Review net positive suction head (NPSH)
8. Select motor HP
9. Design pump connections, mounting, rails, hatches, etc.
10. Check and adjust wet well dimensions, intake dimensions, and pipe sizes.

Advice on performing these steps is provided in this section. For further details, consult the Helpful References Section.

Type of Pump

Often the type of pump is chosen based on the type of lift station or municipal design standards. Many municipalities specify the type of pump, some important features, and acceptable manufacturers. Per the *Ten States Standards*, pumps handling raw wastewater shall be capable of passing solid spheres of at least 3 inches (80 mm) in diameter. Pump suction and discharge openings shall be at least 4 inches (100 mm) in diameter. An exception to these requirements is if a grinder pump is chosen or if a macerator/grinder is installed in the influent line to the wet well.

Increasingly in recent years, pumps that can pass 3-inch solids are still becoming clogged due to rags and wipes. The following pumps have shown good performance when rags are present in the wastewater:

- Chopper pumps or cutter pumps with cutting bars adjacent to the vane edges.
- Screw impeller pumps that can pass rags and achieve high efficiency.
- An adaptive self-cleaning impeller that can move axially (i.e. Flygt N-pump).

Preliminary Pump Selection with Pump Curves

Preliminary pump selection is the process of reviewing pump curves and choosing the best fit for the design conditions. Although many pump curves are available in catalogs or websites, it is still a good practice to request the curves from the pump supplier. Typically, catalogs will show the various impellers available in full size, but trimmed impeller curves may not be shown. To get a pump that exactly hits the design point, the impeller needs to the “trimmed” so the pump curve hits the design point.

In reviewing pump curves that meet the design point, consider which curve provides the following:

- The best efficiency at the average operating condition, which will be between the high and low head conditions.
- All operating points in the preferred operating range, which is between 70% to 120% of the flow rate at the best efficiency point.
- The curve is not excessively flat, excessively steep, and is smooth without hills or valleys.
- The flow rate at the intersection of the low head system curve and the pump curve is not excessive (typical of a flat pump curve).
- The lowest maximum shaft power across the full recommended operating range, which is the boldened part of the pump curve.

It may be helpful to plot more than one pump curve with the system curves, to help make a pump selection decision.

Example 4:

After producing systems curves in Example 3, Engineer Beatrix has selected a pump that meets the design condition of 500 gpm at 52 ft TDH. Plot the pump curve with the system curves, identify the pump operating flow range, confirm the best efficiency point is within the range, and select the motor HP using a service factor of 1.15.

Answer:

See Figure 23 for the manufacturer pump curve and Figure 24 for a plot including both the pump curve and the system curves using excel.

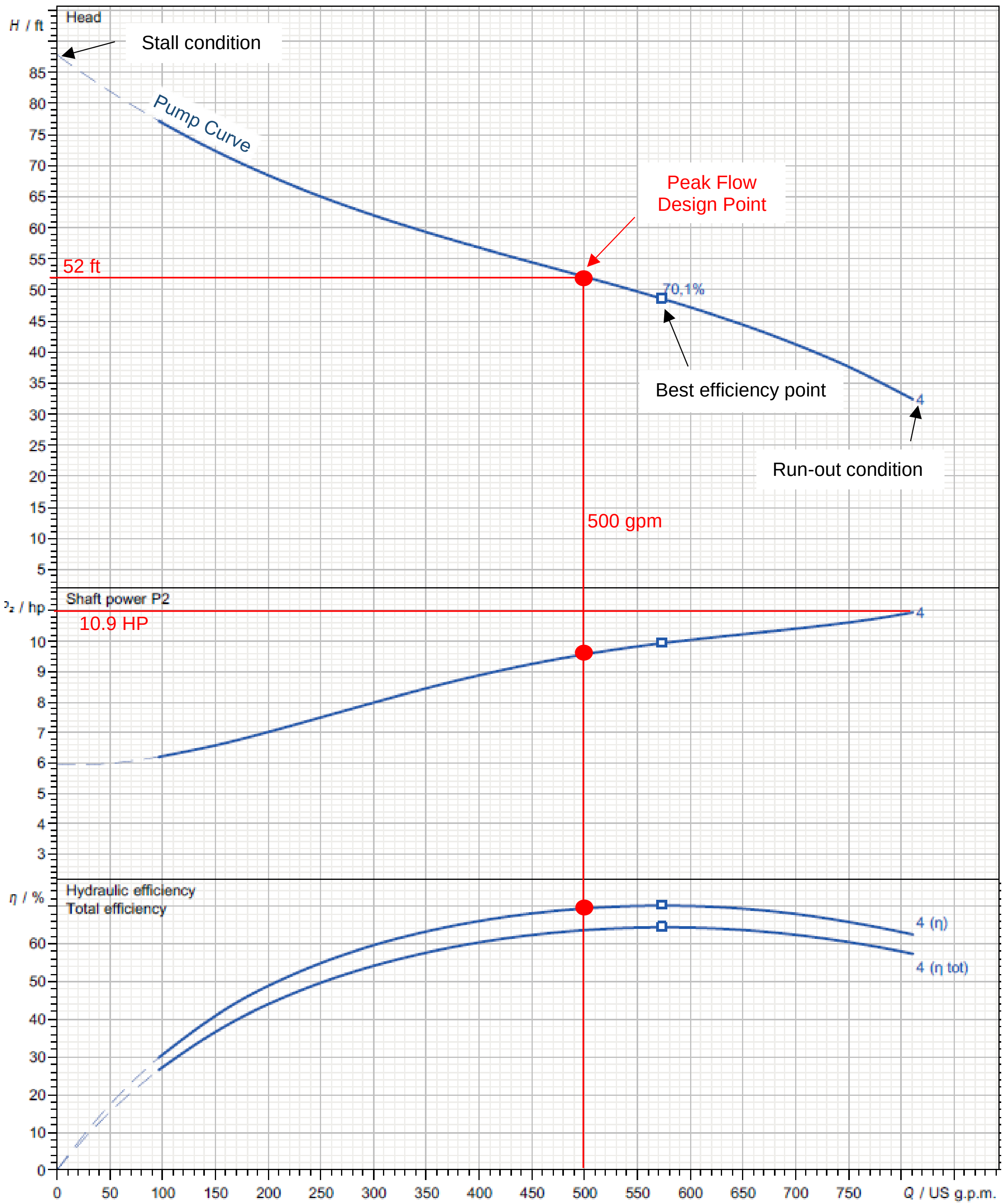

Figure 23: Manufacturer pump curve.

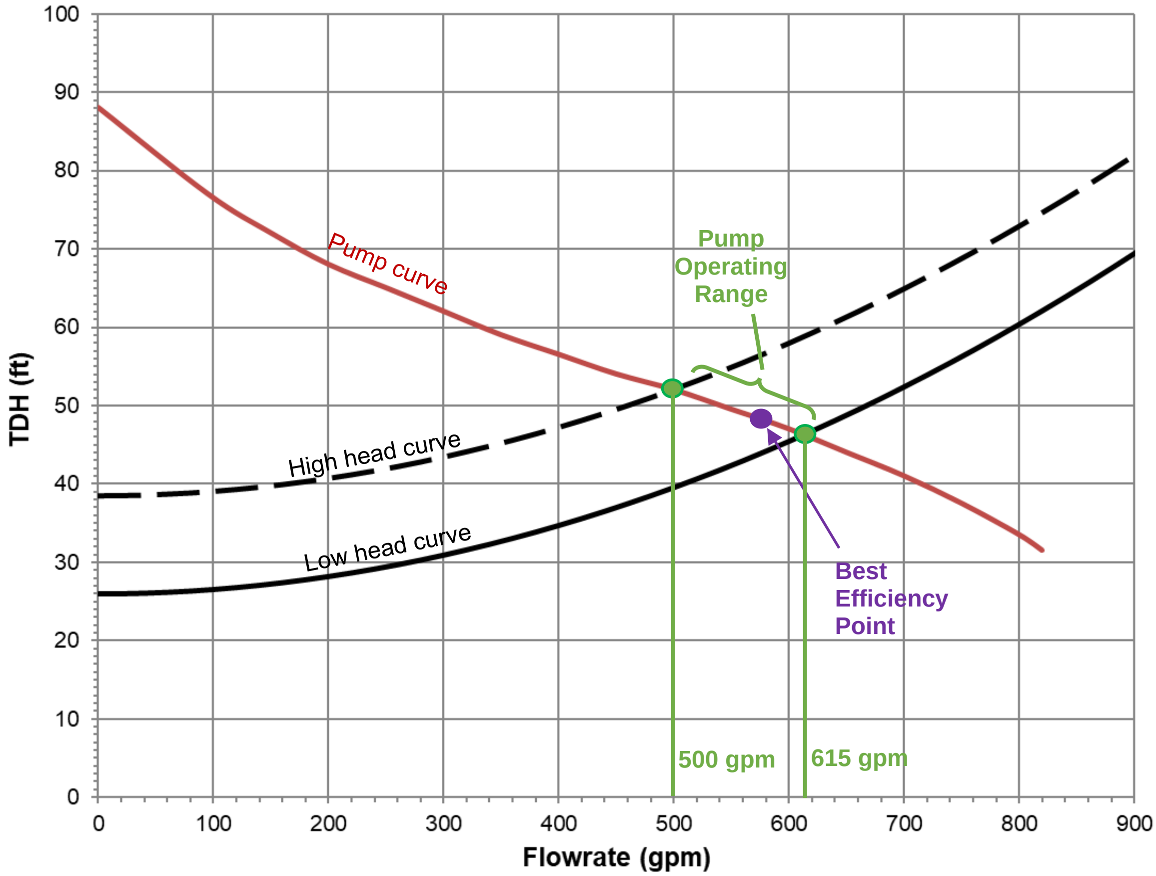

Figure 24: Plot of the pump curve and the system curves, showing the best efficiency point within the pump design operating range of 500 to 615 gpm.

The shaft power (HP) curve is shown in the center region of Figure 23. The greatest power is 10.9 HP at the far right of the curve. This is divided by the motor efficiency of around 90%, and multiplied by a service factor, which gives the minimum motor HP:

$$Minimum\ Motor\ HP = \frac{Line\ shaft\ HP * 1.25}{motor\ eff} = \frac{10.9\ HP * 1.15}{0.90} = 13.9\ HP$$

This is rounded up to the next nominal motor size, which is a **15 HP** motor.

NPSH

To avoid cavitation, the net positive suction head available (NPSHa) should be greater than the net positive suction head required (NPSHr). The NPSHa is based on the details of the intake design, while the NPSHr is from the pump manufacturer. The NPSHa formula is as follows with definitions and an example in Table 6:

$$NPSHa = H_{bar} + h_s - h_{vap} - h_{fs} - h_m - h_{vol} - h_a - FS$$

Table 3: NPSHa Definitions and Calculation		
Term	**Example (ft)**	**Definition**
H_{bar}	+33.96	Atmospheric pressure, which is 14.7 psi (33.96 ft) at sea level.
h_s	+2.50	Minimum static head (from pump impeller to low water level).
H_{vap}	-1	Vapor pressure of water, at 75 deg F, expressed in feet.
h_{fs}	-0.50	Suction pipe friction losses at the max pump operating flow rate (intersection of the pump curve and low head system curve).
Σh_m	-1.96	Suction pipe minor losses at max pump operating flow rate.
h_{vol}	-2	Partial pressure of dissolved gases such as air in water (customarily ignored as insignificant) and organics in wastewater (estimated at 2 ft).
h_a	-0	Acceleration head for positive displacement pumps only. See Section 1 of *Cameron Hydraulic Data* for the formula.
FS	-5	Factor of Safety, which can range from 2ft to 5ft, or 20% to 35% of NPSHr.
NPSHa	**26.0**	**Sum the above terms**

Often the pump curve will include an NPSHr curve. Confirm the NPSHr value at the maximum pump operating flow rate is less than the calculated NPSHa. If the NPSHr is greater than NPSHa, the following options are available to correct the issue:

- Increase inlet submergence,
- Increase suction pipe size,
- Use long radius elbows on the suction piping, or
- Choose a different pump.

Note that checking the NPSH is different than checking the minimum inlet submergence, and both calculations should be done for each size pump.

Lift Station Features

Design options and advice is provided for the following common lift station features.

Water Level Instrumentation

Instruments for reading and communicating water level include the following:

- A trapped air column system, commonly called a bubbler system. The transmitter can be mounted in the control panel with the bubbler tubing extending down to the bottom of the wet well.
- Ultrasonic or guided radar level sensors mounted at the top of the wet well.
- Several switches placed at key operating levels and alarm levels. Switch devices include the following:
  - Electrodes,
  - Floats,
  - Mechanical clutches, and
  - Floating mercury switches.

Protection from Clogging

Bar racks (manual course screens) or grinders (macerators) are often installed in or upstream of the wet well to minimize pump clogging problems. The *Ten States Standards* recommends the following based on the type of sewage.

For Combined Wastewater:

- Pumps handling combined wastewater shall be preceded by readily accessible bar racks to protect the pumps from clogging or damage.
- Where a bar rack is provided, a mechanical hoist shall also be provided.
- Where the size of the installation warrants, mechanically cleaned and/or duplicate bar racks shall be provided.

For Separate Sanitary Wastewater:

- Pumps handling separate sanitary wastewater from 30 inch (750 mm) diameter or larger sewers shall be protected with bar racks meeting the above requirements.
- Appropriate protection from clogging shall also be considered for small pumping stations. Examples include a basket screen, macerator, grinder pumps, chopper pumps, cutter pumps, screw impeller pumps, and self-cleaning pumps.

Wet Well Ventilation
Either permanent or portable ventilation is required for wet wells. The *Ten States Standards* recommends the following:

- Wet well ventilation may be either continuous or intermittent.
- Ventilation, if continuous, shall provide at least 12 complete air changes per hour; if intermittent, at least 30 complete air changes per hour.
- Air shall be forced into the wet well by mechanical means rather than solely exhausted from the wet well.
- The air change requirements shall be based on 100 percent fresh air.
- Portable ventilation equipment shall be provided for use at submersible pump stations and wet wells with no permanently installed ventilation equipment.

Dry Well Ventilation
Ventilation is required if the lift station includes an area routinely entered by personnel. Ventilation is particularly important to prevent the collection of toxic and explosive gases. Air fan wheels should be fabricated from non-sparking material.

Dry well ventilation codes typically require six continuous air changes per hour or 30 intermittent air changes per hour. All continuous ventilation systems should be fitted with flow detection devices connected to alarm systems to indicate ventilation system failure. Gas detection equipment can be installed, and the ventilation rate automatically increased in response to the detection of hazardous concentrations of gases or vapors.

Heating or cooling should also be considered. The minimum temperature should be 13 degrees C (55 degrees F) whenever chemicals are stored or used.

Dry Well Sump
A sump is required to collect spilled water and wastewater in the dry well pump room. The *Ten States Standards* recommends the following details:

- A sump pump equipped with dual check valves shall be provided in the dry well to remove leakage or drainage with discharge above the maximum high water level of the wet well.
- All floor and walkway surfaces should have an adequate slope to a point of drainage.
- Pump seal leakage shall be piped or channeled directly to the sump.

- The sump pump shall be sized to remove the maximum pump seal water discharge that could occur in the event of a pump seal failure.

Odor Control

Odor control systems are frequently required for lift stations, especially for large lift stations and if the lift station or upstream manholes are in sensitive public areas.

A relatively simple way to reduce odors is by minimizing wet well turbulence. Another simple approach is to attach a replaceable container to the wet well vent with odor absorbing media, such as activated carbon.

More effective odor control systems include the collection of odors generated at the lift station and treating them in scrubbers or biofilters. Another option is the addition of odor control chemicals to the sewer upstream of the lift station. Chemicals typically used for odor control include chlorine, hydrogen peroxide, metal salts (ferric chloride and ferrous sulfate), potassium permanganate, oxygen injection, and aeration.

Power Supply

The reliability of power for all the pumps is of extreme importance. Commonly used methods of emergency power supply include the following:

- Electric power feed from two independent power distribution lines,
- An on-site standby generator,
- Adequate portable generator with quick connection,
- Stand-by engine-driven pump, and
- A portable pumping unit and appropriate connections.

Electrical Equipment

The *Ten States Standards* recommends the following design consideration for electrical equipment:

- Electrical systems and components (e.g., motors, lights, cables, conduits, switch boxes, control circuits, etc.) in raw wastewater wet wells, or in enclosed or partially enclosed spaces where hazardous concentrations of flammable gases or vapors may be present, shall comply with the National Electrical Code requirements for Class I, Division 1, Group D locations.
- Equipment located in the wet well shall be suitable for use under corrosive conditions.

- Each flexible cable shall be provided with a watertight seal and separate strain relief.
- A fused disconnect switch located above ground shall be provided for the main power feed for all pumping stations.
- When such equipment is exposed to weather, it shall meet the requirements of weatherproof equipment NEMA 3R or 4, at a minimum.
- Lightning and surge protection systems should be considered.
- Lift station control panels located outdoors shall be provided with a 110-volt power receptacle inside the control panel to facilitate maintenance.
- Ground Fault Circuit Interruption (GFCI) protection shall be provided for all outdoor outlets.

See Figure 25 for an example of a control panel that uses a radio antenna for communication. Other options are a cellular modem, copper wire, or fiberoptic cable.

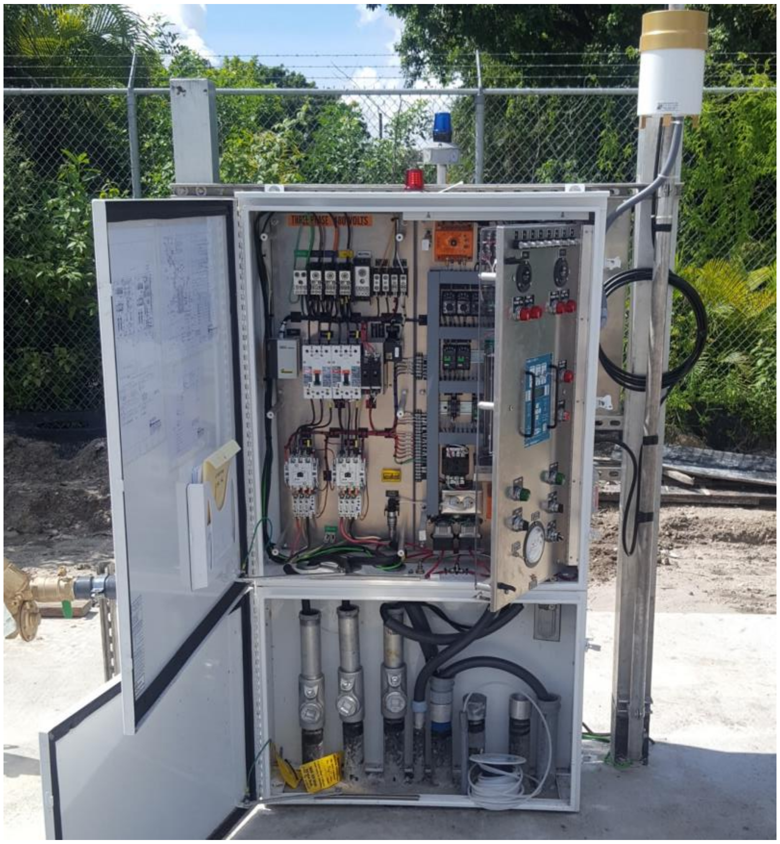

Figure 25: Interior of a control panel for a submersible lift station. The white column in the upper right is an omni-directional radio antenna.

Water Supply

It is common to design for a water line with a backflow preventer and above ground connection near the lift station, but not connected in any way directly to the station. Maintenance staff often use the water to fill buckets or spray with a hose. If the water line is brought to the lift station, local code requirements must be followed. And the *Ten States Standards* recommends the following:

- There shall be no physical connection between any potable water supply and a wastewater pumping station which, under any conditions, might cause contamination of the potable water supply.
- If a potable water supply is brought to the station, a break tank, pressure pump, and pressure tank shall be provided.
- Water shall be discharged to the tank through an air gap at least 6 inches (150 mm) above the maximum flood line or the spill line of the tank, whichever is higher.
- A sign shall be permanently posted at every hose bib, faucet, hydrant, or sill cock located on the water system beyond the break tank to indicate that the water is not safe for drinking.

Helpful References

Crane (1942) "Flow of Fluids Through Valves, Fittings & Pipe". Crane Company.

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