Welcome to the course on water conveyance and pumping stations. My name is Nick Georgalis and I will be your narrator for this course. This course was developed by Mr. Craig Moskowitz. Mr. Moskowitz is a registered professional engineer in Connecticut. He received his Bachelors of Science in Civil Engineering from the University of Maine and his MBA from the University of Bridgeport. He has a Masters in Construction Administration from Columbia University. Mr. Moskowitz is also a graduate of the US Army Officers Engineering School and he is the president of CLM Engineering Associates. Mr. Moskowitz has over 14 years of experience as a civil engineer and his experience includes piping design/stress analysis for nuclear power plant containment structures in the State of Connecticut. Mr. Moskowitz has conducted forensic engineering claim investigations and storm damage claim investigations for the insurance industry. He has served as Director of Project Management for water and sewer distribution projects under a contractor to the NYC Department of Design and Construction. Currently, he is involved with construction cost consulting for wastewater treatment plants for the New York City Department of Environmental Protection.
Overview

• Pumping Stations
• Water Conveyance Systems
  – Canals
  – Land Drainage Systems
  – Sewerage Systems
• Packaged Pumping Station
  – Design Considerations
  – Pumping Equipment Selection
  – Pump Characteristics & Types
• Cavitation and Pumping Efficiency
• Pipeline Design Considerations
• Discharge systems
• Engine Selection and Placement Considerations
• Operating and Replacement costs

This course will discuss water conveyance systems and the application, design, and operation of pumping stations. Water systems include canals, land drainage systems, and sewerage systems. Pumping stations are used to supply water to canal systems, to drain land for farming or other uses, and for the operation of sewerage systems. A brief history of canals will be presented as canals were historically one of the earliest applications of pumping stations. We will discuss packaged pumping stations where the engine and pump are contained in a single unit rather than as individual units. We will review design considerations leading to specific equipment selections. Pump characteristics and types will be discussed as well as other pump selection considerations. This will complete the first hour. During the second hour, we will discuss causes of cavitation and how to prevent cavitation. Pumping efficiency is a function of matching pump operating characteristics with system operating characteristics and we will discuss how this is accomplished. We will present pipeline design considerations and provide example calculations of discharge losses and a discussion of discharge systems, including screening methods, gating methods, and ventilation systems. We will also present considerations that should enter into engine selection and placement and offer some insight into determining pumping station operating and replacement costs.
Pumping stations are facilities that include pumps and the associated equipment. They are used for pumping fluid from one place to another. Several engine types are used to drive pumps. These include water engines which operate from the flow of water, wind engines, steam powered engines, diesel engines, and electric motors. Several infrastructure systems use pumping stations. These infrastructure systems include transportation and irrigation canals, which use pumping stations to replenish lost water and sewage renewal systems where pumping stations move and lift effluent. Pumping stations are also used to drain low-lying lands for agriculture. In hydroelectric pumped storage systems, pumping stations fill a reservoir during periods of low demand for hydroelectric power. The stored water is then released during peak periods to handle the increased electrical load. We will discuss these applications in more detail during this hour.
Canals are of two types. The aqueduct is used for conveyance and delivery of potable water for human consumption, municipal uses, and agricultural irrigation. Artificial rills and acequias are small versions of canals. Waterways are large canals used to connect to existing lakes, rivers, or oceans. Examples are the Panama Canal, Suez Canal, Erie Canal and similar canals. Waterways provide transportation in a city network. The most famous city network is the Canal Grande and others of Venice Italy. Other examples of city networks include the gracht of Amsterdam, and the waterways of Bangkok Thailand. We will look at some existing and past canals to illustrate how and when canals are used. Most canals do not employ pumping stations but one of the first applications of the pumping station were irrigation canals so historically canals have stimulated the development of the pumping station.
Canals

- **Simplest Canal**
  - Trench filled with water
  - May be lined with watertight material
    - When clay is used it is known as puddling
- **Must be level**
  - Small irregularities in the lie of the land dealt with through cuttings and embankments
  - Pound lock used to overcome large deviations in the lie of the land.

The simplest canal is a trench filled with water. To prevent absorption the trench may be lined with a watertight material. When clay is used, the lining is called puddling. A canal must be on level ground. Small irregularities in the lie of the land are dealt with through cuttings and embankments. A pound lock overcomes larger deviations in the lie of the land. When there is a hill to be climbed, flights of many locks in short succession may be used. The Falkirk Wheel is a creative method to overcome large variation in the lie of the land and it is used in lieu of a large number of locks. We will discuss Falkirk Wheel later in this hour.
Before we discuss the pound lock, we here provide some examples of existing or past canal systems. One of the earliest canal systems in the United States was the Ohio-Erie Canal and the Miami-Erie Canal. This canal system constructed in the 1820’s and 1830’s connected Lake Erie with the Ohio River. The Erie Canal system enabled the relatively efficient movement of goods in the areas that it served. The system was profitable until the 1850’s when the railroads started to replace it. The system remained operational until about 1911 when it was completed abandoned. One feature of this canal system for our purposes is that it had no pumping stations. The system was fed completely by existing rivers and streams.
Besides Ohio, New York also had an extensive canal system. The 524 mile New York canal system was constructed in the early part of the nineteenth century and parts of it continue to remain in operation. This canal system relied on existing rivers and lakes to supply water for the canals. Like Ohio canals the New York canals spurred economic development in the State of New York during the 1800s. This slide is a list of the canals in the New York canal system. The first canal built in New York was the Erie canal which connected the Hudson River with the Great Lakes. The Erie Canal was completed in 1825 and it cut through 363 miles of wilderness and featured 18 aqueducts and 83 locks, with a rise of 568 feet from the Hudson River to Lake Erie.
## Canals

- **Pound Lock**
  - Developed in China the 10th Century
  - Developed in Europe in 11th Century

- **Boat lifts**
  - Falkirk wheel
    - Caisson of water
  - Inclined plane
    - Caisson of water hauled up a steep railway

- **Flash lock**
  - Allowed navigation around dams
  - Single gate or ramp

There are two techniques used to overcome irregularities in the lie of the land that canals traverse. The pound lock first developed in China in 984 AD and in Europe in the 11th Century is one technique. The pound lock uses the flow of water in the canal to raise and lower boats and barges that are traversing the canal. Boatlifts such as the Falkirk wheel and the inclined plane lift the boat from one level to the next. The Falkirk wheel uses a wheel that supports a caisson of water to lift a boat whereas the inclined plane hauls a caisson of water up a steep railway. The flash lock is a single gate or ramp that allows navigation around dams or weirs constructed to operate mills. The flash lock opens to allow boats to pass and then closed to increase the level of water behind the dam, which enabled the operation of the mill’s water wheel.
Canals

- Crossing a stream or road
  - Use aqueduct
  - Pontcysyllte is a famous example in Wales, England across the River Dee
- Tunneling through hills
  - Harecastle Tunnel on the Trent and Mersey Canal in England
- Contour canals
  - Keep changes in level to minimum
  - Take longer winding routes
- Pump Stations used to replenish water lost

An aqueduct is a canal used to cross a stream or road. A famous example is the Pontcysyllte in Wales, England, which spans the River Dee. Tunneling through hills is another technique for overcoming obstacles to canal construction. The Harecastle Tunnel on the Trent and Mersey Canal in England is an old example of a canal tunnel. Contour canals follow the lie of the land in order to keep changes in level to a minimum. A disadvantage of the contour canal is that it takes longer winding routes so the time to travel the canal is lengthened. While most canal systems use existing rivers and streams to replenish lost water in some cases pump stations are necessary to do this job.
Canals

Pontcysyllte in Wales, England

Here is an example of an aqueduct canal. This is the Pontcysyllte aqueduct in Wales, England. It spans the River Dee. The aqueduct is 1,007 ft or 307 m long, 11 ft or 3.4 m wide and 5.25 ft or 1.60 m deep. It consists of a cast iron trough supported 126 ft or 38 m above the river on iron-arched ribs that are carried on nineteen hollow masonry piers or pillars. Each span is 53 ft or 16 m wide. A feature of a canal aqueduct, in contrast to a road or railway viaduct, is that the vertical loading stresses are virtually constant. According to Archimedes' principle, the mass or weight of a boat and its cargo on the bridge, pushes an equal mass of water off the bridge thus the load of the conveyance on the bridge does not vary the stress on the structure. This is an advantage of this kind of structure.
The pound lock is a widely used method to overcome changes in the level of the terrain. This slide illustrates the operation of the pound lock. For a boat going upstream, the boat enters the lock and the lower gates are closed. The lock fills with water from upstream. The upper gates open and the boat exits the lock. For a boat going downstream, the boat enters the lock and the upper gates are closed. Draining the water downstream empties the lock. The lower gates open and the boat exists the lock. Note that the pound lock operates from the flow of water and requires no external source of power other than the small amount of external power to operate the gates. A pump station is incorporated in those situations where there is a need to replenish the water in a canal and there is no other way to provide a supply of water for this purpose.
Shown here is the Falkirk wheel. It is one of a kind and it is located in Scotland. The difference in height of the two canals served at the wheel is 24 meters (79 ft). The wheel has two carriers, which are caissons that lift the boats from the lower level to the upper level and lowers boats from the upper level to the lower level. A gate at the upper canal opens and closes as the caissons move into place. An advantage of the Falkirk wheel is that it overcomes a high difference in level in a relatively small space. The caissons always weigh the same whether they are just full of water or are carrying their combined capacity of 600 tons of floating canal barges since according to Archimedes' principle floating objects displace their own weight in water. Thus, when the boat enters the caisson, the amount of water leaving the caisson weighs the same as the boat. This keeps the wheel balanced at all times and it is not necessary for a second boat to balance the first. Despite its enormous mass, the Falkirk wheel rotates through 180° in five-and-a-half minutes using very little power. It takes just 22.5 kilowatts (30.2 hp) to power the electric motors, which consume just 1.5 kilowatt-hours (5.4 MJ) of energy in four minutes, roughly the same as boiling eight kettles of water.
Canals

Harecastle North Canal Tunnel

Tunneling through a hill is another technique besides the pound lock for overcoming the hill as an obstacle to canals. The Harecastle Tunnel in England is an early example of a canal tunnel. The tunnel was twelve feet tall at its tallest point and was nine feet wide at its widest. The tunnel built in the later part of the 18th century and early part of the 19th century is over one and one-half mile long. The canal does not employ pump stations although steam pump stations were used during part of its construction to keep the construction site from flooding. An interesting feature of this tunnel is that it did not have a towpath through it. The barge was propelled by men on their backs and pushing on the ceiling of the tunnel. This process was called legging. It took almost three hours of legging for the barge to move through the tunnel.
Canals

- Water Supply
  - Taken from existing rivers or springs
  - Reservoirs
  - Back pumping used to fill the reservoirs
- Canal basins
- Large scale ship canals
  - Panama Canal
  - Suez Canal

Canals have various features to tackle the problem of water supply to the canal. In some cases such as the Suez Canal, the canal is simply open to the sea. Where the canal is not at sea level, a number of approaches have been adopted. Taking water from existing rivers or springs is an option in some cases, sometimes supplemented by other methods to deal with seasonal variations in flow. Where such sources are unavailable, reservoirs, which are either separate from the canal, or built into its course, and back pumping provides the required water. In other cases, water pumped from mines feed the canal. Where large amounts of goods are loaded or unloaded such as at the end of a canal, then engineers often build a canal basin. This would normally be a section of water wider than the general canal. In some cases, the canal basins contain wharfs and cranes to assist with movement of goods. Large-scale ship canals such as the Panama Canal and Suez Canal continue to operate for transporting cargo as do the barge canals of Europe. Due to globalization, such canals are becoming increasingly important, resulting in expansion projects such as the Panama Canal expansion project.
Canals

- Early canals now abandoned to navigation
- Use for recreation or for transportation of untreated water
- Many early canals are still used to provide irrigation for agriculture

The narrow early industrial canals have since ceased to carry significant amounts of trade and many abandoned to navigation and used for transportation of untreated water. In some cases, engineers built railways along the canal route. An example is the Croydon Canal. A movement that began in Britain and France to use the early industrial canals for pleasure boats, such as hotel barges, has spurred rehabilitation of stretches of historic canals. In some cases, abandoned canals such as the Kennet and Avon Canal have been restored, and are now used by pleasure boaters. In Britain, canal-side housing has also proven popular in recent years. The Seine-Nord Europe Canal developed into a major transportation waterway, linking France with Belgium, Germany and the Netherlands. Canals have found another use in the 21st century, as routes along the towing paths for fiber optic telecommunications networks. Canals continue to provide water for agriculture. An extensive canal system exists within the Imperial Valley in the Southern California desert to provide irrigation to agriculture within the area. Engineers frequently drain canals for maintenance by placing stop planks. These consist of planks of wood placed in pre-existing grooves in the canal bank and across the canal to form a dam. By definition (and function) each time a ship passes through the canal, water is lost from the upper section of the canal. Several of the lock gates are not watertight so some water is actually lost as the water seeps from higher to lower levels of the canal. The water must be replaced so that the canal can be properly navigable for future ships/vessels.
Pumping Stations and Canals

- Water for canals usually derived from streams and rivers upstream of the canal
- Pumping stations employed when no water can be obtained from streams or rivers
  - Claverton Pumping Station in Southern England.
  - Supplies water from the nearby River Avon to the canal using pumps driven by the power of the river alone.

The water for canals usually and most economically comes from streams and rivers upstream of the canal. Pumping stations are employed when no water can be obtained from streams or rivers. The Claverton Pumping Station in Southern England supplies water from the nearby River Avon to the canal using pumps driven by the river alone. This is an example of a pumping station using waterpower.
This is a picture of the Claverton Pumping Station. The pump house is the lower profile building straddling the river. The flowing water turns a water wheel, which in turn operates a pump that supplies water from the river to the nearby canal. The pumping station was built between 1809 and 1813 to overcome water supply problems on the canal. It uses a 24-foot wide wooden breastshot water wheel to drive two 18-foot long cast iron rocking beams, which power the lift pumps to raise water 48 feet up to the canal. The Claverton Pumping Station ceased commercial operation in 1952.
Land Drainage

- Usual method is draining ditches
  - Agriculture
  - Improper drainage cause environmental problems
    - Accelerate water contamination
    - Excessively desiccate soils during seasonal drought
    - Financial burden to maintain
  - Flooding control
- Pumps used when the land is below sea level
  - Wind Pumps
  - Steam Power Pumps
  - Diesel Pumps

The usual method to drain low-lying areas is by the digging of drainage ditches or channels. If the particular area in question is below sea level then engineers must use another method to pump the water upward into the channels and then drained. The 19th Century English understood the concept quite well and constructed pumping stations with water pumps powered by steam engines. One area of England called “The Fens” became wonderful farmland because of these efforts. Drainage ditches play a major role in agriculture throughout the world. However, improper drainage systems can cause environmental problems such as accelerated water contamination, and they can excessively desiccate soils during seasonal drought. Improper drainage systems can also become a financial burden to maintain. Sustainable channel design taking advantage of natural geo-morphological equilibrium can result in ditches that are largely self-maintaining. The resulting slowed net siltation and erosion reduce sediment transport. Additionally development of natural stream sinuosity and a multi-terraced channel cross section will maintain peak drainage capacity and minimum pollution and nutrient transport. Flooding can be a major cause of recurring crop loss particularly in heavy soils and can severely disrupt urban economies as well. Subsurface drainage to ditches offers a way to remove excess water from agricultural fields, or vital urban spaces, without the erosion rates and pollution transport caused by direct surface runoff. However, excess drainage results in recurring drought induced crop yield losses, and more severe urban heat or desiccation issues. Controlled subsurface drainage from sensitive areas to vegetated drainage ditches makes possible a more optimal balance between water drainage and water retention needs. The initial investment, allows a community to draw down local water tables when and where necessary without exacerbating drought problems at other times. Pumps used for land drainage includes wind driven pumps, steam power pumps and diesel pumps.
Packaged Pumping Station

- A Packaged Pumping Station provides an efficient way to install a drainage system.
- Best use is for an area where drainage by gravity is not entirely possible or realistic.
- Some of these applications include mechanical building services collection and pumping of liquids such as for wastewater, surface water or sewerage.
- Generally, the package pumping station is constructed in housing from a glass-reinforced plastic or an impact-resistant polyethylene.

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Packaged Pumping Station

- Usually the packaged pumping station is pre-assembled and ready for installation for the specific application.
- The internal pipe-work is fitted for the application and the controls and pumps are fitted and installed once the unit is installed into the ground.
- Some of the features that may be included are:
  - High-level alarm indicator (pump failure)
  - Guide-rail/Auto-Coupling/Pedestal System (easy removal of pumps for maintenance)
  - Controls (fully automation)

Usually the packaged pumping station is pre-assembled and ready for installation for the specific application. The internal pipe-work is fitted for the application and the controls and pumps are fitted and installed once the unit is installed into the ground. Some of the features that may be included are high-level alarm indicator, which results from pump failure, guide-rail/auto-coupling/pedestal system for easy removal of pumps for maintenance, and controls for full automation.
This is a rendition of a typical packaged pumping station. There are three basic components to the packaged pumping station, which include electrical controls and alarm systems as shown on the far left, pumps as shown in the center, and separate valve system, which isolates the pumping station as shown on the right. Packaged pumping stations are pre-configured based on application. Applications include domestic water boosting pumping stations for high rise buildings, packaged fire pumps, package waste water removal, packaged water heaters, and rainwater collection and reuse.
Lift stations are the name given for pumping stations in sewerage collection systems. These lift stations are generally designed to handle raw sewage that is taken from underground gravity pipelines. The wet well is the underground pit where the sewage is stored. This well contains high-level instrumentation and controls to determine the current sewage level. When the sewage in the wet well reaches a designated predetermined level, the pump or pumps will start to do their job by lifting the sewage upwards through a sewer force main, which is a pressurized piping system where the sewerage is discharged into a gravity manhole. This rhythmic cycle continues until all sewage from the wet well reaches the wastewater treatment plant. In other words, the pumping stations for this application move the waste to a higher elevation. Additional pumps handle heavy storms or peak flow periods into the wet wells. Electronic controllers are generally used along with redundancy so that when the flow is too great for one pump to handle and/or one pump is not operating effectively the electronic controllers activate other pumps. Minimizing the retention time in the wet well prevents the sewer gases from transforming into a septic condition. The most common pumps used in sewage applications are of the end-suction centrifugal variety. They have open impellers and a large opening to allow the passage of debris. A four or six pole AC induction motor usually drives the pump. Some solids decompose before passage through pumps impellers making the job easier.
Shown here is a cutaway of a typical packaged pumping station. This is a wet well pump because the pump and motor are submersed in the fluid. This pumping station operates automatically whenever the level of fluid exceeds a preset threshold. The valves from the duplex piping are encased in a separate manhole to allow maintenance access. In this case the fluid flows into the wet well from an inlet on the left and it is pumped out to the sewage system using dual piping on the right. The dual pump design allows for redundancy as well as increased pumping capacity in the event of a high rate of inflow. The check valves prevent backflow during the operation of a single pump.
Lift Station Hazards

- Gaseous accumulation: Methane and Hydrogen Sulfide
- Must have had confined space entry training/certification to enter the wet well
  - Many pumps and appurtenances now maintained from the outside.
- Traditional style sewage pumping stations
  - Wet well
  - Dry well
  - Pumps installed below based on the dry well

A design concern of packaged pumping stations is safety and ease of maintenance. Lift station hazards include gaseous accumulation with methane and hydrogen sulfide. Maintenance personnel must have had confined space entry training/certification to enter the wet well. Due to the hazards, maintenance of many pumps and appurtenances is from the outside. The traditional style sewage pumping stations are a wet well and dry well. Usually they are part of the same structure. The pumps are installed below ground level on the base of the dry well so the inlets are below water level when the pump starts. This allows for priming of the pump and maximizing the available NPSH or Net Positive Suction Head.
The diagram on the left is an example of a wet well in which the submersible pump is easily replaceable. The diagram illustrates how the pump can be lifted from the top of the well along a slotted guide. The slotted guide enables the replacement of the pump while also enabling it to be securely connected to the piping. The diagram on the right illustrates a dry well application. There are two wells in a dry well application. The fluid intake is at the well on the left and the pump is located in a separate and isolated chamber. The piping extends from the wet well through the sealed chamber wall and the pump discharges the fluid to the main sewer line. In the case of the dry well, the pump is easily accessible with no need to enter the wet well. This makes maintenance easier and with much less hazard.
Electronic Controllers

- Function is to control and manage the pumping stations
- Programmable Logic Controller
  - Digital computer used to control pumping stations
- Sensors monitor
  - Fluid levels
  - Rate of flows
  - High concentration of gases
  - Overflow conditions
  - Unauthorized access
  - Temperature
  - Air Pressure
  - Motor or pump failure
  - Ventilation operation
- Housed in a small kiosk above the well

Electronic controls are incorporated to operate pumping stations. The electronic controls use sensors to indicate the level of water, the rate of flow, overflow conditions, the presence of gases, unauthorized access, temperature, air pressure, motor or pump failure, and ventilation operation. A digital program logic controller can be used to turn the pump on and off, run the ventilation system, bring additional pumps into service, and control the operation of valves. The electrical controllers as well as the electrical switchgear are usually housed in a small kiosk above the well.
Pumped-Storage Systems

- A type of power station for storing and producing electricity to supply high peak demands by transporting water from reservoirs of differing heights.
- Turbine generators
- Net energy loss
- Economical due to higher prices at peak demand.
- Generally more efficient than building additional capacity.

Pumped-Storage Systems are a type of power station for storing and producing electricity to supply high peak demands by transporting water from reservoirs of differing heights. Turbine generators are usually employable for this effort. During low demand such as at nighttime, generators are used to power pumps in pushing water back to the top of the reservoir. Water flows back through the turbines when the station is required to produce power during high demand periods. Although the losses of the pumping process makes the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand when electricity prices are highest. Pumped storage is the largest-capacity form of grid energy storage now available. On a present worth basis the construction of the pumped storage facility is more economical than adding additional generating capacity which would remain idle for long periods.
Pumped-Storage Systems
Raccoon Mountain Pumped Storage Facility

- 528 acres of water surface
- Took 8 years to construct
- Dam at upper reservoir is 230 feet high and 8,500 feet in length
- Largest rockfill dam built by Tennessee Valley Authority
- Four (4) generating units for power

The Raccoon Mountain Pumped Storage Facility is a pumped storage system built and operated by the Tennessee Valley Authority. The facility took eight years to construct and was completed in 1978. The dam at the upper reservoir is 230 feet high and 8,500 feet in length. The facility is the largest rockfill dam built by the Tennessee Valley Authority. The plant works like a large storage battery. During periods of low demand, water pumped from Nickajack Reservoir at the base of the mountain fills the 528 acre reservoir built at the top. It takes 28 hours to fill the upper reservoir. When electric power demand is high, water released via a tunnel drilled through the center of the mountain drives the four turbine generators in the mountain’s underground power plant. The power plant has a net generating capacity of 1,652 megawatts.
Design consideration for a pumping station include the following factors: consideration for the least maintenance for pumps and appurtenances and the longest life; making sure that all equipment does not remain idle for extended periods of time during its operational life; consideration for condensation and exposure to sewer gases that will most likely limit life expectancy of equipment; consideration whether additional corrosion-resistant material and sealants are necessary; pumping station equipment that should last for approximately 35 years - any longer is not feasible or economical; all design calculations are to be clear, concise and complete in nature; the design engineer must be totally involved in shop drawing/as-built review and approval; value engineering before final design drawings are submitted.
Contractor Considerations

• Prepare Operations and Maintenance Manuals that tell the whole story from inception to completion of the project.
• This manual should be divided into three sections:
  – Operations/Maintenance/Reference
• The operations manuals should allow the treatment plant operator and staff to effectively inspect equipment, repair and replace defective components of machinery in accordance with the manufacturer’s warranty program
• The plant needs to establish standards for maintenance in accordance with manufacturer’s recommendations
• All records of field tests and maintenance on equipment as well as shop drawings should be maintained.
• In some cases Piping and Instrument drawings are submitted by the Contractor

From the perspective of the contractor the considerations include the preparation of operations and maintenance manuals that tell the whole story from inception to completion of the project. The manual should be divided into three sections: Operations, Maintenance and References. The operations manuals should allow the treatment plant operator and staff to effectively inspect equipment, repair and replace defective components of machinery in accordance with the manufacturer’s warranty program. The plant needs to establish standards for maintenance in accordance with manufacturer’s recommendations. All records of field tests and maintenance on equipment as well as shop drawings should be maintained. In some cases, the contractor submits piping and instrument drawings as well.
Pump Equipment Types

- Mixed Flow Impeller Type
- Fixed-Blade Vertical Type/ Adjustable Blade Vertical Type
- Axial Flow Impeller
- Submersible Pumps
- Fixed-Blade Horizontal
- Volute Type (Centrifugal Volute or Radial Flow)

Pumping equipment consists of six basic types. These are the Mixed Flow Impeller; Fixed-Blade Vertical / Adjustable Blade Vertical; Axial Flow Impeller; Submersible Pumps; Fixed-Blade Horizontal; and Volute Type which includes the centrifugal volute or radial flow types. The next few slides describe these basic types in more detail. The type of pump used depends on the application. The application in turn is defined by requirements which include the head and the rate of flow.
Pump Equipment Types

• Mixed Flow Impeller Type
  – Impellers develop head or discharge pressure through combination of lifting action and centrifugal force.
  – Path of flow through impeller is at angle of less than 90 degrees with respect to pump shaft.
  – N(s) is less than or equal to 9,000 rpm.

The mixed flow type impellers develop head or discharge pressure through combination of lifting action and centrifugal force. The path of flow through the impeller is at angle of less than 90-degrees with respect to pump shaft. The specific speed is less than or equal to 9,000 rpm. We will define the pump specific speed in a few minutes. A diagram of a mixed flow type impeller is shown. Note that the shape of the blades are such that the action of the impeller results in both a lifting and centrifugal force applied to the fluid.
Pump Equipment Types

- **Fixed-Blade Vertical Type/Adjustable Blade Vertical Type**
  - Mostly used in flood control.
  - Use least amount of floor space.
  - Vertical shaft with driver having a vertical or horizontal shaft arrangement.
  - Vertical motor is directly connected to the pump.

The Fixed-Blade or Adjustable Blade impeller Vertical pump is used mostly in flood control. It uses the least amount of floor space. The pump consists of a vertical shaft with driver having a vertical or horizontal shaft arrangement. The vertical motor is directly connected to the pump. The advantage of the adjustable blade impeller is that it is capable of operating at near peak efficiency over a range of operating conditions. The profile of a typical vertical type pump is shown here. The vertical type pump consists of a suction bowl, an impeller bowl, a discharge bowl, a diffuser, a column pipe and the discharge elbow.
Pump Equipment Types

• Axial Flow, Impeller
  – Blades shaped like a propeller.
  – Develops most of head by lifting action of the blades on the liquid.
  – Called axial flow because the pumped fluid travels in a direction parallel to the shaft axis.
  – Used to pump large quantities of water against low heads.
  – Common in sump pump stations in vertical configurations.
  – N(s) is usually greater than 9,000 rpm.

In the Axial Flow Impeller pump type the blades are shaped like a propeller. This pump develops most of the head by the lifting action of the blades on the liquid. It is called axial flow because the pumped fluid travels in a direction parallel to the shaft axis as shown in the diagram. This pump is used to pump large quantities of water against low heads. It is common in sump pump stations in vertical configurations. The pump specific speed N(s) is usually greater than 9,000 rpm.
Pump Equipment Types

- **Submersible Pumps**
  - Stations that have a pumping requirement with each pump having a capacity of less than 200 cfs.
  - Entire pumping unit is submerged in water.
  - Limited by the number of poles in the motor or size of gears in the units.

Submersible pumps are used in pumping stations that have a pumping requirement with each pump having a capacity of less than 200 cfs. The entire pumping unit submerges in water. The number of poles in the motor or the size of gears in the units limits the pump capacity. Submersible pumps should be removable from above the floor without any unbolting of the discharge piping. Their use allows the superstructure of the station to be greatly reduced. Substructure requirements are approximately the same as for vertical pumps. Submersible pumps used for flood control pumping stations are of three different types: axial flow, mixed flow, and centrifugal volute.
Pump Equipment Types

- Fixed-Blade Horizontal
  - Used where total head is less than 6 meters.
  - Large quantity of water to be pumped.
  - More expensive installation than vertical.
  - Needs a separate priming system.

The fixed-blade horizontal pump type is a centrifugal pump for total head less than 6 meters or about 18 feet and there is a need to pump large quantities of water. It is a more expensive installation than vertical type pumps and it requires a separate priming system where vertical pumps are self-priming. Otherwise the selection of a horizontal pump over a vertical pump is based on convenience or preference. An example of a fixed-blade horizontal pump is shown here.
Pump Equipment Types

- **Volute Type (Centrifugal Volute or Radial Flow):**
  - Develop head by centrifugal force on water.
  - Path of flow through impeller is at 90 degree angle with respect to pump shaft.
  - Has a non-clog impeller especially helpful in sewerage applications.
  - Handles small flows in wet wells
  - Generally used in vertical configuration and where dry and/or wet well are used.
  - N(s) is less than 4,000 rpm.

The volute pump type, which is centrifugal volute or in other words a radial flow type, develops head by centrifugal force on water. A volute is a curved funnel increasing in area to the discharge port. As the cross-section area increases, the volute reduces liquid speed and increases liquid pressure. The purpose of volute casings is to balance the hydraulic pressure on the pump shaft. The path of flow through the impeller is at a 90-degree angle with respect to the pump shaft. This type of pump has a non-clog impeller that is especially helpful in sewerage applications. It handles small flows in wet wells efficiently. It is generally used in vertical configuration inside dry or wet wells. The pump specific speed N(s) is less than 4,000 rpm.
In a radial flow pump the liquid enters at the center of the impeller and is directed out along the impeller blades in a direction 90-degrees to the pump shaft. The radial impeller pump has a specific speed of less than 1000 rpm. Note that the physical design of a pump determines the pumps operating characteristics. This is illustrated in the next slide where a comparison of the different types of pumps is made.
This diagram compares the different pump types in terms of the operating characteristics and specific speed. Note that as the physical profile of the pump varies the power, efficiency, and head vs. capacity curves also change. For example, a radial-vane area profile is for specific speeds less than 1000 rpm whereas the Francis-vane area profile is for specific speeds less than 4000 rpm. Thus the physical construction of the impeller is the determining factor in the operating characteristics of a pump.
Pumping Equipment Selection

This chart enables the selection of the most efficient pump type based on operational requirements. Note that the horizontal scale is logarithmic. For example, a required pump capacity between 20 cubic feet per second and 100 cubic feet per second and a pump total head less than 20 feet the pump type is the AFS or the axial flow submersible. Similarly a required pump capacity between less than about 3.5 cubic feet per second will always require a centrifugal volute pump.
Pump Equipment Types

• Type of pump to be used depends on the following three factors:
  – Service conditions
  – Head requirements
  – Station layout

• The impeller designs that are most appropriate for certain specific speeds are as follows:

<table>
<thead>
<tr>
<th>CUSTOMARY US UNIT</th>
<th>IMPELLER TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>500-1,000</td>
<td>Radial Vane</td>
</tr>
<tr>
<td>2,000-3,000</td>
<td>Francis (mixed) Vane</td>
</tr>
<tr>
<td>4,000-7,000</td>
<td>Mixed Flow</td>
</tr>
<tr>
<td>9,000 +</td>
<td>Axial Flow</td>
</tr>
</tbody>
</table>

Additionally the type of pump used depends on the following three factors which are the service conditions, the head requirements, and the station layout. The impeller designs depend on the specific speed as shown in the following table. This table is a summary of the diagram in our earlier slide. A calculated specific speed between 500 rpm and 1000 rpm for example calls for a radial vane impeller whereas a calculated specific speed between 4000 rpm and 7000 rpm calls for a mixed flow impeller.
Pump Characteristics & Types

• Specific Speed
  – This is the speed the pump would have if the geometrically-similar impeller were reduced in size so that it would pump 1 gallon per minute against a total head of 1 foot
  – \( N(s) = N(t) \times Q^{0.50} / H^{0.75} \)
    • \( N(s) \) = pump specific speed
    • \( N(t) \) = pump rotative speed (rpm)
    • \( Q \) = flow at optimum efficiency point (gpm)
    • \( H \) = total head at optimum efficiency point (ft.)

The specific speed is the speed the pump would have if the geometrically similar impeller were reduced in size so that it would pump 1 gallon per minute against a total head of 1 foot. The equation for specific speed is given by \( N(s) = N(t) \times Q^{0.50} / H^{0.75} \) where \( N(s) \) = pump specific speed; \( N(t) \) = pump rotative speed (rpm); \( Q \) = flow at optimum efficiency point (gpm); and \( H \) = total head at optimum efficiency point (ft.). Once the specific speed is determined from the expected operating conditions then the table on the previous slide is used to select the impeller type.
Pump Characteristics & Types

Example:
- A pump that is centrifugal in nature and is powered by a direct-drive induction motor is needed to discharge 150 gallons per minute against a total head of 300 feet when turning at the fully-loaded speed of 3,500 rpm. What type of pump should be selected?
  - Using the equation for pump specific speed as identified above yields:
  - $3,500 \text{ rpm} \times (150 \text{ gpm})^{0.50}/(300 \text{ feet})^{0.75} = 595 \text{ rpm}$
  - Should select a radial-vane pump since the rpm's are between 500 & 1,000
  - If more than one pump is used such as in two stage system, the total head would be 150 feet.

This example illustrates how to select the impeller type. There is a need for a pump that is centrifugal in nature and powered by a direct-drive induction motor to discharge 150 gallons per minute against a total head of 300 feet when turning at the fully loaded speed of 3,500 rpm. What type of pump should be selected? Using the equation for pump specific speed as identified above yields:

$3,500 \text{ rpm} \times (150 \text{ gpm})^{0.50}/(300 \text{ feet})^{0.75} = 595 \text{ rpm}$.

Referring to the earlier table then the engineer should select a radial-vane pump since the rpm’s are between 500 & 1,000

If more than one pump is used such as in two stage system, the total head would be 150 feet.
Pump Characteristics & Types

- Suction Specific Speed
  - Used to determine the maximum permissible speed of the pump.
  - This defines the suction characteristics of a specific pumping system.
  - The suction specific speed available is based on the lowest head pumping condition.
  - \( S = N(t) \times Q^{0.5}/NPSHA^{0.75} \) where
    - \( S \) = suction specific speed available
    - \( N(t) \) = pump rotative speed (rpm)
    - \( Q \) = flow rate (gpm)
    - \( NPSHA \) = Net Positive Suction Head Available (ft)

The suction specific speed determines the maximum permissible speed of the pump. It defines the suction characteristics of a specific pumping system. The suction specific speed available is based on the lowest head pumping condition. It is given by the equation: \( S = N(t) \times Q^{0.5}/NPSHA^{0.75} \) where \( S \)= suction specific speed available; \( N(t) \)= pump rotative speed (rpm); \( Q \)= flow rate (gpm); and \( NPSHA \)= Net Positive Suction Head Available (ft).
The difference between the Net Positive Suction Head Available or NPSHA and Net Positive Suction Head Required or NPSHR is that the NPSHA is a function of the station layout and suction water levels. Whereas the NPSHR is a property of the pump and indicates which suction condition is required for the pump to operate without cavitation. Cavitation is an undesirable condition that leads to premature pump and valve failure and it is the product of poor design as well as maintenance and operation outside the design parameters. We will discuss cavitation more in the next hour.
During hour one, we discussed water systems used for transportation, land drainage and sewerage. We presented several examples of past and present canal systems and their design and operation including the use of the pound lock and the Falkirk wheel. We discussed land drainage systems and the use of such systems in making land available primarily for agricultural purposes. We discussed pumping stations used for supplying water to canals, for draining land and for sewerage systems. One application for pumping stations is for refilling reservoirs used to provide electricity from hydroelectric plants during times of peak demand. The Raccoon pumped storage facility, which is part of the Tennessee Valley Authority, is an example of such an application. We described the six pump types and their application. We discussed the method used to select the pump type based on the specific application. We also discussed how to determine the type of impeller to use. We calculated pump specific speed for a specific application and used the results of the calculation to select the type of impeller. We presented the formula used to calculate the suction speed of a pump. The suction speed is used to determine the maximum permissible speed of the pump. Finally we explained the difference between NPSHA or the Net Positive Suction Head Available and the NPSHR or Net Positive Suction Head Required.
Hour 2

- Cavitation
- Pumping Efficiency
- Prevention of cavitation
- Pump operating characteristics
- Pipeline Design Considerations
- Discharge Systems
- Engine Selection
- Operation, Rehabilitation, and Replacement Costs
Cavitation

- Cavitation is the formation of vapor bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure.

- Inertial cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave.
  - Occurs in control valves, pumps, propellers, impellers, and in the vascular tissues of plants.

- Non-inertial cavitation is the process in which a bubble in a fluid is forced to oscillate in size or shape due to some form of energy input.
  - Observed in pumps, propellers, etc.
Cavitation

Cavitation damage on an impeller

Cavitation damage on valve plate of axial piston hydraulic pump
Preventing Cavitation

• Cavitation caused by vaporization
  – Reduce vaporization by
    • Increase the suction head
    • Raise the liquid level in the tank
    • Raise the tank
    • Pressurize the tank
    • Place the pump in a pit
    • Reduce the piping losses
    • Lowering the pumping fluid temperature
Pump Efficiency

• Pump efficiencies must be considered unless the station meets the following criteria:
  – Flow is less than 500 cfs
  – In operation less than 500 hours per year

• Otherwise go for the highest efficiency for whichever pump is selected for use in the pumping station
Pump Efficiency

- Pump efficiency is defined in general as the ratio of energy output to energy input. Specifically \( \eta = \frac{P_w}{P_s} \)
  - where \( \eta \) is efficiency
  - \( P_w \) is the water power
  - \( P_s \) is the shaft power.
- In the US, \( P_s \) is the power provided to the pump shaft in brake horsepower and \( P_w \) is
  - \( P_w = \frac{(Q \times H)}{3960} \) where \( Q \) is flow in GPM and \( H \) is head in feet.
- For maximum system efficiency the pump flow rate v. pressure characteristics must match the system flow rate v. pressure characteristics.
- Matching and maintaining flow rates and pressure will minimize cavitation and extend the life of the system.
Pump Efficiency
Other Pump Selection Considerations

- Incoming electrical service:
  - May limit the horsepower rating of driver
  - May not permit use of electric motors.

- Available space
  - May limit size of equipment

- Conditions of foundation
  - Cost of excavation

- Low discharge capacity
  - Axial and mixed flow pumps may not allow passage of sewerage as effectively as centrifugal pumps.

- Pumping Capacity and Pumping Head Requirements
  - Determined by the hydrology of the site in question

- Considerations behind the pump selection also include
  - Lowest total head to supply the smallest driver
  - Lowest energy cost

- The optimal pump operation is where the pump is operating at or near the head that occurs at the pump’s best efficiency point.
Pumping Conditions

- Capacity determination
  - based on the hydrology of the area in question
- Head determination:
  - the amount of lift that a pump must overcome when pumping (total head)
  - total head is based on static head
  - losses in the pipeline circuitry
  - the velocity head that develops along the way
  - (note: the losses that occur internally within the pump as supplied by the manufacturer are not a part of this calculation for total head)
- Losses to be determined include:
  - frictional losses
  - intake losses before pump (i.e. trashrack, entrance gates, entrance piping losses, losses in intake channels)
  - discharge losses after pump discharge (i.e. discharge pipes, discharge chamber losses, backflow preventer valves)
  - usually the entrance losses will be negligible except for around the trash rack
Screening

• Screens and trash racks
  – Series of vertical and horizontal bars or wires
  – Trap floatables while allowing water to pass through the openings between the bars or wires
  – Installed at select points within a Combined Sewer System or CSS
  – Capture floatables and prevent their discharge in Combined sewer overflows or CSOs.

• Screens used for CSO control include
  – Mechanically cleaned permanent screens
  – Static screens
  – Traveling screens
  – Drum screens.
Screening

- Screens can also be divided into three categories according to the size of floatable material they are designed to capture.
  - Bar screens (> 2.5 centimeter [1 inch] openings)
  - Coarse screens (0.5 - 2.5 centimeter [0.19-1 inch] openings)
  - Fine screens (0.01-0.5 centimeter [0.004-0.19 inch] openings)

- Screens most commonly used to control CSOs are trash racks and coarse screens.
  - EPA's fact sheet "Screens" (EPA 832-F-99-027) has additional information on screens for CSO control.
Screening

Trash rack used to protect the pumps and appurtenances from damage due to construction debris.
Pump losses

• External losses
  – Start at the sump entrance and point to the pump where pump suction occurs
  – Calculated using “K” factors and multiplying by the velocity head at the location.

• Other losses
  – Exit side of the pump piping
  – Losses in the discharge chamber and its piping system to the point of termination

• Pump Piping losses
  – Losses in connecting pipes to the pump.
  – Include entrance and exist losses in pipe
  – Hazen-Williams formula used to determine the piping friction losses
Pump Piping Losses

• Hazen-Williams formula:
  – $H(f) = 3.022 \times L \times (V/C)^{1.85} / D^{1.17}$
    – $H(f) =$ frictional head loss (ft)
    – $V =$ velocity (feet per second)
    – $L =$ length of pipe (feet)
    – $C =$ roughness coefficient of pipe (unit-less)
    – $D =$ inside diameter of pipe (feet)

  – Roughness coefficient is a function of pipe material
Pump Piping Losses Example

• Given 50 degree Fahrenheit water is pumped through 1,000 feet of 4 inch Schedule 40 welded steel pipe at the rate of 300 gallons per minute. What frictional loss is predicted by the Hazen-Williams equation?

• Other given data includes the following:
  - D (inside diameter of pipe) = .3355 ft.
  - A (area of pipe) = .0884 ft.²
  - Assume Roughness Coefficient C = 100
  - Q (flow rate) = (300 gpm) x (.0002228 ft.³/sec/gpm) = 0.6684 ft.³/sec.
  - V (velocity) =Q/A= 0.6684 ft.³/sec./0.0884 ft.² = 7.56 ft./sec.
  - H(f) =[(3.022) x (1000 ft.)x(7.56 ft./sec.)^1.85 ] / [ (100)^1.85 x (.3355 ft.)^1.17 ]
    = 91.3 feet
Pump Piping Losses

• Other losses occur when the piping diameter changes.
• The head loss in a discharge chamber is usually caused by a constriction in area at its exit.
  – This constriction is usually in the stop log slots used for dewatering the chamber for repair of a flap gate and during high discharge stages.
• Head loss through a trash rack should be less than 6 inches for a rack that is cleaned frequently.
Discharge Pipeline

- The discharge piping to the pumping connections is usually made of a flexible coupling with harness bolts across the connection.
- All buried piping must be connected with flexible couplings with harness bolts
  - Where the piping encroaches a concrete-type structure
  - At bends in the pipelines
  - Where differential settlement may occur
  - Obvious expansion and contraction of the pipe
- When penetrating through concrete walls then use of flanges is appropriate and necessary.
- All pipe should be of a standard wall thickness and a typical and most common size.
- For areas where corrosion can be anticipated as a problem, a thicker pipe may be employed.
Example of Discharge Losses

\[ H_D = 0.0001(m)(Q) + b \]

Where:
- \( m \): Value from table
- \( Q \): Pump capacity in GPM
- \( b \): Value from table
- \( H_D \): Water height above floor in feet

WIDTHS = 1.5D, 2.0D, 2.5D & 3.0D
D = TUBE DIAMETER

**TUBE DIA.**

<table>
<thead>
<tr>
<th>TUBE DIA. (in.)</th>
<th>DISCHARGE WIDTH - VALUES OF ( m ) AND ( b )</th>
<th>TUBE DIA. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5D</td>
<td>2.0D</td>
<td>2.5D</td>
</tr>
<tr>
<td>28</td>
<td>1.65</td>
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<tr>
<td>64</td>
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<td>0.82</td>
</tr>
</tbody>
</table>

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Hour 2 Slide 18
Discharge Chamber

Plan View - Discharge Chamber

Water Profile W/Constriction And Critical Depth Condition

Profile Through Discharge Chamber

Figure A
Discharge Chamber

Parameters

\[ B = \text{Width Between Constriction, Ft.} \]
\[ b = \text{Width Upstream of Constriction, Ft} \]
\[ g = 32.2 \text{ Ft/Sec}^2 \]
\[ A = \text{Area of Flow in Discharge Chamber, Ft}^2 \]
\[ A_C = \text{Area of Flow with Critical Depth Constriction, Ft}^2 \]
\[ H_V = \text{Velocity Head, Ft.} \]
\[ k = \text{Coefficient of contraction = .78} \]
\[ V_C = \text{Velocity of Flow at Constriction with critical depth conditions Ft/Sec} \]
\[ V = \text{Velocity of Flow when Critical Depth Condition does not occur, Ft/Sec} \]
\[ Q = \text{Design Flow Rate (High and Low Head), CFS} \]
\[ Y_C = \text{Depth of Flow at Constriction, Ft} \]
\[ H_C = \text{Water elevation at Constriction in Discharge Chamber Caused by Critical Depth Condition} \]
\[ H_D = \text{Water elevation in Discharge used to determine pumping conditions} \]
Discharge Chamber Critical Depth

- The determination of total head on the pump requires determination of water elevation in the discharge chamber. Three different head conditions are considered.
  - 1. During pump operation back-up water does not exceed the center of the flap gate.
  - 2. Water elevation in drop shaft next to discharge chamber is below elevation of the critical depth water level and the elevation of water back-up is above the center of the flap gate.
  - 3. Water elevation in drop shaft is higher than water elevation due to critical depth condition.
- The total head is then based on the greatest depth at the constriction plus the velocity head required to maintain flow.
Discharge Chamber Critical Depth

- The following is a typical computation to determine total head for discharge chamber type pump station. The computations are based on the layout shown on Figure A.

- **Given Conditions:**
  - Width between constriction \( B \) = 4.5 ft.
  - Width upstream of constriction \( b \) = 5.0 ft.
  - Design Flow Rate Low Head \( Q_L \) = 177 cfs
  - Design Flow Rate High Head \( Q_H \) = 93.4 cfs
  - Coefficient of Contraction \( k \) = 0.78
  - Discharge chamber floor elevation at constriction = 413.0 ft.
  - Drop shaft water elevation due to sewer losses beyond drop shaft with 177 cfs flowing = 417.0 ft.
  - Drop shaft water elevation with 93.4 cfs flowing = 431.0 ft.
  - Elevation of flap gate centerline = 416.75 ft.
Discharge Chamber Critical Depth

- **STEP 1.** Determine ratio of width at constriction (B) to channel width (b) upstream.
  - \( \frac{B}{b} = \frac{4.5 \text{ ft.}}{5.0 \text{ ft.}} = 0.9 \)

- **STEP 2.** Determine depth of flow at constriction \( Y_C \).
  - \( Y_C = \left( \frac{Q^2}{k^2 b^2 g} \right)^{1/3} = \left( \frac{177^2}{(0.78)^2 (5.0)^2 (32.2)} \right)^{1/3} = 3.9 \text{ ft.} \)

- **STEP 3.** Determine velocity of flow at the constriction.
  - \( V_C = \left( \frac{Y_C g}{(g)} \right)^{1/2} = 11.2 \text{ ft/sec} \)

- **STEP 4.** Determine critical area of flow at the constriction.
  - \( A_C = \frac{Q}{V_C} = 177 \text{ cfs/11.2 ft/sec} = 15.8 \text{ ft/sec} \)
Discharge Chamber Critical Depth

• STEP 5. Determine the velocity head based on the velocity occurring at the constriction $H_v$.
  $H_v = \frac{3.9 \text{ ft}}{2} = 1.95 \text{ ft.}$

• STEP 6. Determine the maximum elevation of water in the discharge chamber at constriction with critical depth condition $H_C$.
  $H_C = \text{Elev. of discharge chamber floor} + 1.5Y_C$
  $= 413.0 \text{ ft.} + 1.5(3.9 \text{ ft.}) = 418.8 \text{ ft.}$

• STEP 7. Water elevation in drop shaft and flow rate of 177 cfs is 417.0 ft.
Discharge Chamber Critical Depth

- **STEP 8.** Determine water elevation in discharge chamber with constriction of flow.
  
  = Floor elev. at constriction + depth of flow at constriction + velocity head based on flow at constriction
  
  = 413.0 + Y ÷ Y/2
  
  = 413.0 + 3.9 + 1.95
  
  = 418.8 ft.

- **STEP 9.** This elevation (418.8 ft.) is greater than the water level in the drop shaft (417.0 ft.), therefore it is used to determine head loss if it is higher than the centerline of the flap gate.
Discharge Chamber Critical Depth

• STEP 10. When the elevation of water in the drop shaft is greater than the water elevation as a result of a critical depth condition at the constriction, then the water level in the discharge chamber is only dependent on the drop shaft water elevation and the resultant velocity head.

• The discharge chamber water elevation would equal the drop shaft water elevation + the velocity head.

• Water elevation in drop shaft as given = 431.0 ft.
Velocity at Constriction

• Velocity at constriction, \( V_C \)
  \- \( V_C = \text{Flow rate (cfs)} / (\text{Drop shaft elev.} - \text{Floor elev.})(\text{Width of Constriction}) \)
  \= 93.41 / (431.0 - 413.0)(4.5)
  \= 1.15 \text{ ft/sec}

• Velocity Head = \( (V_C)^2 / 2g \)
  \= (1.15)^2 / (2)(32.2) \text{ ft.}
  \= 0.02 \text{ ft.} \Rightarrow \text{Negligible}

• Therefore elevation 431 ft. would be used for head computations.
The Discharge System

- Used to convey the pumped water from the pumps to the receiving body of water.
- Two types of discharge
  - Over-the-levee
    - Discharge lines over the protection consisting of individual lines for each pumping unit or
    - A manifold discharge with one discharge lines running from the station over the protection.
  - Through-the-protection
    - Individual pump discharge lines ending in a discharge chamber or wall of the protection.
    - Flow from the discharge chamber would then be carried by conduit to the receiving body of water.
Over the Levee
Pump Station Installation
Preventing Backflow

• Preventing backflow in over-the-levee system
  – Air release and siphon breaker at the crest

• Preventing backflow in through-the-protection system
  – Stop logs
  – Emergency gates
  – Shutoff valves
Preventing Backflow

- Siphon breaker at the crest
- Discharge piping
- Pumping station
- Channel Inlet
- River Flow
Vent Formula

- \( D(v) = 0.25D(p) \times (2/h)^{0.25} \)
  - \( D(v) \) = diameter of vent (feet)
  - \( D(p) \) = diameter of pipe (feet)
  - \( h \) = minimum submergence over outlet (feet)
Type of Discharge
Selection Criteria

• Type of discharge sometimes set by location of station
• Study of alternatives
  – Over the levee
    • Pump
    • Siphon
  – Through the protection
• Life-cycle cost analysis
  – Operating costs
  – Equipment costs
  – Structure cost
Pump Station Example
Pipeline Design Considerations

- Twenty-five percent increase in wall thickness is customary for steel pipes.
  - Specific stresses to take into account:
    - Tensile from internal water pressure
    - Excess stress due to water hammer
    - Stress by external loading
    - Stress due to temperature changes
    - Stress due to differential settlement
- The material consideration should lean towards ductile iron or stainless-steel pipe in accordance with the American Water Works Association.
- All piping of 12 inches or less should be composed of ductile iron while all the rest should be steel pipe.
Engines & Gears

- The engines for pump drivers should be of the diesel or natural gas-fueled type.
- Two or four-cycle variety.
- Natural Gas is preferred where conducive to construction.
- Diesel-operated is used otherwise.
- Skid-mounted should be incorporated with all appurtenances connected on the skid excluding the fuel storage tank.
Engines & Gears

- CP 300i self-priming compressor pump
- Powered by CAT 3126TA Diesel Engine on a basic skid
- 1200m³/hr max flow
- Head height of 70 meters
- 95mm solids.
- Fuel usage: 32 ltrs per hour.
- Tank size: 625 ltrs.
- Weight: 7900kg.

DV300i 12" x12" Skid Mounted Diesel Engine Pump
Engine Speed v. Horsepower

• The engine rated for 10 percent in excess of the maximum operating requirements including pump horsepower requirements and losses through the drive system.
• Operate at 110 percent full-load rating at the rated speed with permissible operating temperatures for 2 consecutive hours in a 24 hour cycle.

<table>
<thead>
<tr>
<th>Horsepower (hp)</th>
<th>Speed (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,400 and over</td>
<td>900</td>
</tr>
<tr>
<td>600 to 1,400</td>
<td>1,200</td>
</tr>
<tr>
<td>Less than 600</td>
<td>1,800</td>
</tr>
</tbody>
</table>
Engine Cooling

• Two types of cooling systems: Radiator and Heat Exchanger
  – Radiator
    • Radiator mounted on the engine base or remotely-mounted
    • Needs to be where there is a decent amount of cool air
  – Heat exchanger
    • Employ a cooling fluid and separate pumping system
Engine Mounting

• In some cases the ability to mount on an engine base is not practical. In those cases locate the engine based on the following considerations:
  – Degree of noise
  – Heat produced
  – Sizing requirements
  – Heat Exchanger should be closed type

• Control Equipment required
  – All engines should be designed for manual starting.
  – For over-speed, an automatic engine shutdown device will be necessary.
  – Visible alarms
  – Audible alarms
  – High Jacket Water Temperature
  – High and Low Lubricating Oil Temperature
  – Gear Reducer Low Lubricating Oil Pressure
  – There must be an engine shut-off for low sump levels.
Engine Starting

- A rechargeable battery can be used for systems with less than 400 HP.
- An engine-generator system is necessary for the control system when greater than 400 HP is used.
- These controls should allow for proper cool-down of the engine when required and in accordance with manufacturer’s specifications and recommendations.
- Starting system should be of a pneumatic variety. The associated air system should contain a large enough reservoir to allow for two starts of the unit without recharge being necessary by the air compressor.
- The duration for recharging the air reservoir should not be greater than 2 hours.
- If no standby generating unit is available, two air compressors are needed. One compressor should be engine driven to allow for air pressure build-up during times of low power/outages.
Fuel Oil System

• The system should be in accordance with federally mandated EPA requirements.
• Rule of thumb in design
  – Two continuous days of all units in operation at the maximum horsepower (hp) rating.
• The particular oil to use in operation of the system should be in accordance with manufacturer’s recommendations and/or requirements.
Miscellaneous Equipment

• Sump closure
  – Required at all stations unless the hydrologic conditions provide for long periods where the station entrance is dry and station sump can be made self-draining
  – Purpose is to perform inspections and maintenance on various sections of the sump.

• Two types of sump closure.
  – Stop logs
    • barriers that are placed in the path of flow through wall slots
  – Gates
Gates

- Gates are typically of the slide or roller type
- Slide Gate
  - Frame composed of cast iron with stainless-steel wedges, seats and fasteners
  - Limited to a 10-foot opening width
- Roller Gates
  - Used when the gate opening is too large for slide gates
  - Fabricated steel leaf with cast-iron wheels and rubber seals
  - Higher maintenance cost than slide gates with various difficulties in obtaining a water-tight seal versus slide gates
- Both types of gates are operated via a manual or electric motor-operated hoist.
Gates

Slide Gates
Gates

Roller Gate

Tandem electrically actuated roller gates.
Ventilation

• Should be divided between sump pump and operating areas.
• Gravity ventilation, i.e. natural draft, is deemed acceptable in areas except for where one may be susceptible to an explosion (i.e. sewer adjacent to a sump area).
• Station must be completely ventilated if in or near an “explosion zone”.
• Things to consider when in an “explosion zone”:
  – Electrical-rating of all equipment.
  – Duct equipment specifications.
  – Inlet and outlet locations for fresh air.
  – Understanding and application of ASHRAE guidelines.
Sump Ventilation

• Forced ventilation MUST be provided as to prevent the building up Methane (CH₄) and other toxic gases within the sump. MUST be provided for all wet and dry sumps.
• Accomplished by using motor-driven blowers to remove air from the sump while fresh air is provided through a duct system into the sump location.
• The blower’s discharge should be located so that the recycling of fumes into the operating area is slim to none
• For design purposes:
  – The ventilation rate should provide for at least 15 air changes per hour in an empty sump condition.
  – The fresh air inlet should be 2 times the outlet area inlet to prevent too much fresh air from escaping.
Ventilation
Mechanical and Electrical Equipment

• Operating Area Ventilation
  – Required to remove excess gas accumulation as well as excess heat accumulation from the operation of all mechanical and electrical equipment.

• Design
  – Consideration is to ensure that the interior temperature of all areas is not less than 40 degree Fahrenheit.
  – Six air changes per hour is acceptable for these areas.
Protection of Equipment

1. Heat the interior of motors and switchgear via a central heating plant.
2. Heat the operating room.
3. Provide electric heaters within the motors and switchgear elements.
4. Use a vapor barrier material on interior surface of operating area.
5. Dehumidification systems for motors and switchgear.

For motors used above 2,000 hp, methods 4 & 5 are the most practical to employ.
Pumping Station
Location and Layout

- Factors considered when selecting the location of pumping stations:
  - Sewage Pumping Station Layouts
  - Proximity to rising main discharge point close as possible to minimize rising main length.
  - Depth of incoming gravity sewer - this will influence the pumping station depth.
  - Sites unobtrusive as possible and kept away from houses and built up areas if possible.
  - Sites should have available access and consideration should also be given to construction and maintenance requirements.
  - The order of preference for land choice, is:
    - Land provided within the subdivision by the developer
    - Public reserve
    - Vacant public land
    - Vacant private property
    - Established public land
    - Established private property
Seismic Considerations

• All mechanical and electrical equipment MUST be anchored and supported effectively when located in zones of seismic activity.

• Economic defensive measures.
  – Place pumping station far enough from the protection line to allow the discharge conduits to flex under ground motion without fracturing or shearing.
  – Use additional flexible couplings
  – Pipe bends may be installed at intervals in the discharge lines to allow movement without failure.
Pumping Station Operation Costs

- Cost for Energy + Manpower Expenses
- Must estimate amount of pumping per month for energy consumption purposes.
- Obtain electric power rates from electric supplier
- Total electricity cost: based on the cost for energy used + demand charges
- Maintenance Costs: include manpower and materials for both prevention and making minor to large repairs
- Rule of Thumb for annual maintenance costs
  - Flow is 1 cfs: Maintenance Cost is 0.5% of the installed cost
  - Flow is 530 cfs: Maintenance Cost is 5% of the installed cost
  - Intermediate station sizes can be interpolated from these estimates.
Rehabilitation and Replacement Costs

- Those expenses incurred to keep the station running in good condition for the projected life of the station.
- Most of the equipment to be replaced during the 50-year life span.
- The rehabilitation and replacement schedule may be much more aggressive depending upon operation time of plant.
- Pumps, drivers and switchgear are usually estimated to be replaced during years 20 and 40.
- Rehabilitation costs can be projected as being 35-40% of replacement costs of the station.
Summary

- Pumping Stations – Definition
- Water Conveyance Systems
  - Canals
  - Land Drainage Systems
  - Sewerage Systems
- Packaged Pumping Station
  - Design Considerations
  - Pumping Equipment Selection
  - Pump Characteristics & Types
- Discharge systems
- Pipeline Design Considerations
- Engine Selection and Placement Considerations