

Chapter 12 - Pump Stations

Stormwater pump stations move stormwater from highway sections where elevation and topography prohibit gravity flow. Compared with gravity drainage, pump stations involve high life-cycle costs and present several potential design and operational challenges discussed in this chapter. Therefore, designers only consider stormwater pump stations where gravity flow systems are not feasible. Gravity alternatives to pump stations include deep conduit trenches, tunnels, siphons, and groundwater recharge basins, although recharge basins are often aesthetically unpleasing and can create maintenance problems. This chapter provides an overview of stormwater pump stations for highway applications. The FHWA publication *Highway Stormwater Pump Station Design* (HEC-24) provides more in-depth information (FHWA 2001). The Hydraulic Institute also prepared several publications which provide information for the successful design of pump stations (Hydraulic Institute n.d., AASHTO 2014).

Design of stormwater pump stations can differ from design of pump stations for other applications. For example, stormwater management requirements from an applicable jurisdiction may limit the maximum discharge from stormwater pump stations. Designers often meet such requirements by providing additional storage as discussed in Section 12.4.

Designers make many stormwater pump station design decisions based on engineering judgment and experience. To enhance cost effectiveness, the designer may compare annual or life-cycle costs of alternatives. The decision to install a pump station involves long-term commitment of funds and personnel. This chapter provides information to minimize construction, operation, and maintenance costs of highway stormwater pump stations, while remaining consistent with the functional goals for the pump stations.

Unusual Features

Pump stations are some of the more unusual and complex features that may be encountered in highway drainage design. Their design involves knowledge of electrical, mechanical, and control systems as well as building design and construction that may be unfamiliar to most highway and drainage designers. The drainage designer will likely call on designers of other disciplines to assist with the complete design of a pump station.

12.1 Pump Station Types and Pumps

Designers choose from several stormwater pump station types and numerous pump types. Selection of both depends on the operational requirements of the pump station, the number and size of pumps, hydraulic conditions, and frequency of operation.

12.1.1 Station Types

Designers can categorize pump stations as wet-pit or dry-pit. In **wet-pit stations**, the pumps are submerged in a **wet well** or sump, with the motors and the controls located overhead. With this design, stormwater arriving in the wet well is pumped vertically from the well through a "riser" pipe. Commonly, the motor connects to the pump by a drive shaft located in the center of the riser pipe.

Another type of wet-pit design involves using submersible pumps. A submersible pump commonly involves less maintenance because it does not use a long drive shaft. Submersible pumps also allow for convenient maintenance in wet-pit stations because the pumps may be removed

relatively easily. Submersible pumps come in many sizes and have many applications. Rail systems are available which allow removal of pumps without entering the wet well.

Dry-pit stations consist of two separate elements: a storage box or wet well and a dry well. Stormwater arrives in the wet well, which is connected to the dry well by a horizontal suction pipe. The dry well contains the stormwater pumps. Designers often use radial flow pumps in this configuration. Either motors mounted in the dry well or drive shafts with overhead motors may provide power.

Since dry-pit stations cost more than wet-pit stations, designers most often use wet-pit stations. The hazards associated with pumping stormwater usually do not warrant the added expense of dry-pit stations, and available space within the highway right-of-way may be a limiting factor. However, dry-pit stations offer some advantages, including ease of access for repair and maintenance, the protection of equipment from fire and explosion, and adaptability for storage volume.

For both wet-pit and dry-pit stations, the station depth influences the cost and functionality of the pump station. Engineers minimize station depth with designs that use only the depth that will allow pump submergence and hydraulically necessary clearance below the inlet invert. HEC-24 (FHWA 2001) provides additional information on station types.

12.1.2 Pump Types

One or more pumps provide the capacity to move water from a lower to higher elevation for discharge. The most common stormwater pump types are rotary pumps of the **axial flow**, **radial flow**, or **mixed flow** types.

Axial flow pumps move water in the direction along the axis of rotation of the pump. The impeller of an axial flow pump usually looks like the propeller on a boat or a ship. These pumps operate in open water rather than within a confined space. Axial flow pumps perform best where they can move large volumes of fluid against relatively low head.

Axial flow pumps lift the water up a vertical riser pipe; water flows parallel to the pump axis and drive shaft. Designers commonly use axial flow pumps for low head, high discharge applications. Axial flow pumps do not handle debris particularly well because the propellers may be damaged if they strike a relatively large, hard object. Also, fibrous material will wrap itself around the propellers.

Radial flow pumps take water into the pump casing in the direction of the pump's axis of rotation. The impeller then changes the direction of the water's movement by "flinging" the water outward from the inlet direction, perpendicular to the impeller's axis of rotation, and imparting rotational motion in the direction of the impeller's rotation. The pump case is scroll-shaped, and water leaves the pump perpendicular to, and offset from, the impeller's axis of rotation, with greatly increased energy head.

Radial flow pumps use centrifugal force to increase head and move water up the riser pipe. They will perform in any range of head and discharge but perform best for high head applications. Some

Modern Pumps and Controls

Many pumps have synchronous, AC electric motors and simple on/off switches. Modern technology allows the consideration of variable-speed pump motors with computer control in place of the traditional type. The pumps themselves still fall within the same classifications (axial, radial, or mixed-flow), but variable motor speed may allow pumping rate to vary with inflow rate and needed outflow rate, controlled by a computer, based on sensor information.

forms of radial flow pumps handle debris quite well. A single vane, open configured impeller handles debris best because it provides the least interference with the passage of debris through the pump. The debris handling capability decreases the number of vanes, since the size of the openings decreases.

Mixed flow pumps represent a physical transition from axial flow to radial flow and have some attributes of each. Unlike with an axial flow pump, inside a mixed flow pump, the water flow direction changes from along the impeller's axis of rotation to some angle away from that axis. But, unlike in a radial flow pump, the change in direction is not perpendicular to the axis of rotation. As in a radial flow pump, the impeller "flings" the water outward and adds energy, but the pump case then redirects the water back along the axis of rotation.

Very often, mixed flow pumps are multi-stage. This design stacks together several impellers inside of several cases and drives them by a common shaft. Water passes through the impellers progressively, with each stage imparting more energy to the water. The impellers of a mixed flow pump can be designed to shed and pass debris better than an axial flow pump. Mixed flow pumps work best for intermediate head and discharge applications. Because they are easily configurable for multiple stages, and because of the physical configuration of mixed flow pumps, most submersible pumps are of this type.

All pumps can use motors or engines housed overhead or in a dry well, or submersible motors located in a wet well. Submersible pumps frequently provide the advantages of simplified design, construction, and maintenance and, therefore, lower associated cost. Designers rarely use anything other than a constant speed, single suction pump.

12.1.3 Pump Selection and Sizing

Designers select pumps by establishing criteria, characterizing operating requirements, and then selecting a combination that meets the design criteria. They consider cost, reliability, and operating and maintenance requirements. Because stormwater pump stations have relatively short annual operating periods, initial cost usually influences selection more than operating costs. Designers typically minimize initial pump costs by providing as much storage as possible.

The designer can obtain an approximate range of pump and motor sizes for consideration by reviewing the design of existing pump stations, pumps, and their performance curves. Pump manufacturer information provides further information on the performance characteristics of available pumps. The designer can narrow down pump type and size by considering pump **specific speed** because each pump type performs best in certain ranges of specific speed.

12.1.3.1 System Curve

Designers select and size pumps by referring to the system requirements expressed in the form of a system curve. The system curve relates the head required of the pump station as a function

Getting the Right Pump

The procurement process in some jurisdictions may not allow the designer to specify a particular brand, type, or style of pump or pump motor for reasons of fairness and competition. The designer of a pump station may find it necessary to specify certain aspects of pump performance within acceptable ranges, allowing contractors bidding on projects to select equipment within that range, with the agency retaining the right of approval of shop drawings after bidding and award of a contract and before purchase of the equipment. For such reasons, the final configuration and equipment of a pump station may differ from the initial design.

of discharge as shown in Figure 12.1. Since changes in head influence pump performance, designers calculate the head required as accurately as possible including all “minor losses” attributed to valves and bends. Designers can minimize these various head losses by carefully selecting discharge line size and other components such as check valves and gate valves.

Designers select the discharge pipe size by considering the manufactured pump outlet size, either matching the outlet size or, to reduce the loss in the line, by using a pipe larger than the outlet. Generally, this approach allows the designer to identify a reasonable compromise in balancing cost but would involve inclusion of an expansion loss in the calculations.

The static head represents the vertical lift required of the pump station, that is, the difference between the head at the pump station outlet and inlet. It varies depending on the water levels in the storage at the inlet and may also vary if the outlet water surface elevations fluctuate.

The total head required of the pump station combines static head, friction head, velocity head, and minor losses (through fittings, valves, pipe expansions, pipe contractions, etc.). This quantity is called total dynamic head (TDH). It is dynamic because, except for static head, TDH increases with flow. Designers compute TDH as:

$$TDH = H_s + H_f + H_v + H_l \quad (12.1)$$

where:

TDH	=	Total dynamic head, ft (m)
H_s	=	Static head, ft (m)
H_f	=	Friction head (loss), ft (m)
H_v	=	Velocity head, ft (m)
H_l	=	Losses through fittings, valves, etc., ft (m)

Figure 12.1 displays a system curve which determines the energy required to pump any flow through the discharge system. It is especially critical for the analysis of a discharge system with a force main. When overlaid with pump performance curves (provided by the manufacturer), it will yield the pump operating range.

12.1.3.2 Pump Performance Curve

A pump performance curve expresses the capabilities of the pump in terms of both discharge and TDH, as Figure 12.1 shows. The designer selects multiple pumps for a given station to operate together to deliver the design flow (Q) at a TDH computed to correspond with the design water level. Because pumps must operate over a range of water levels, the quantity delivered will vary between the lowest level and the highest level of the range.

Typically, the designer specifies the conditions for the TDH expected over the full operating range of the pump with emphasis on at least three points on the pump performance curve: near the highest head, at the design head, and at the lowest head. Manufacturers always provide a curve of TDH versus pump capacity for every pump. When running, the pump will pump the discharge associated with the actual TDH on the curve. The designer can develop an understanding of the pumping conditions (head, discharge, efficiency, horsepower, etc.) throughout the full range of head under which the pump will operate by studying the performance curves for various pumps.

Pump efficiency, also provided by the manufacturer, influences pump selection. Designers select a pump to operate with the best efficiency at its design point, which corresponds to the design water level of the station. The efficiency of a stormwater pump at its design point will vary, depending on the pump type. HEC-24 (FHWA 2001) provides additional information on pump performance curves.

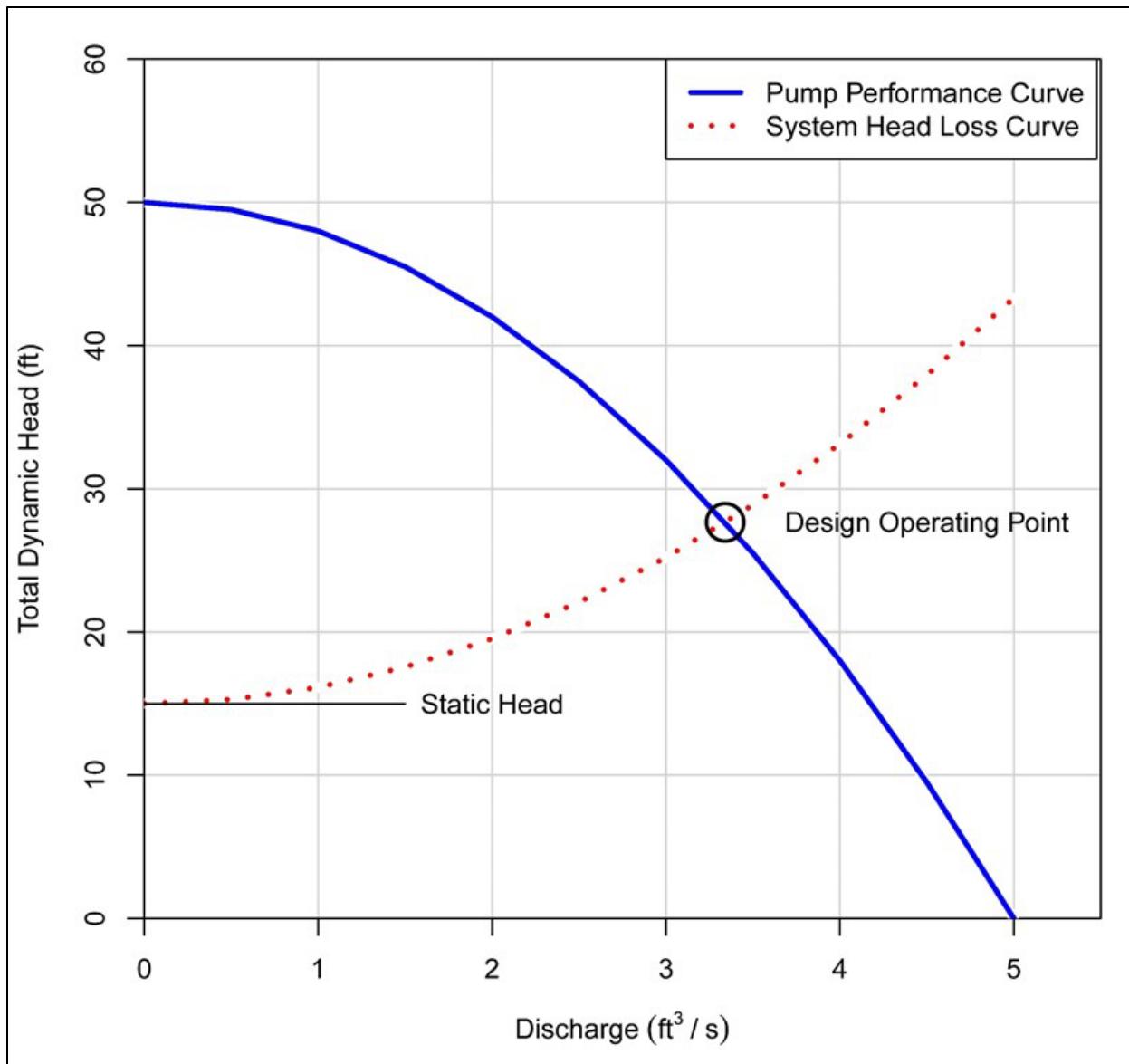


Figure 12.1. System and pump curves.

12.1.4 Number of Pumps

System requirements determine the number of pumps needed. However, two to three pumps generally represent the recommended minimum. When pumping a small total discharge and where the area draining to the station has little chance of increasing substantially, designers typically prefer to use a two-pump station. Designers may consider oversizing the pumps to compensate, in part, for a pump failure. The two-pump system could have pumps designed to pump from 66 to 100 percent of the required discharge, and the three-pump system could be designed so that each pump would pump 50 percent of the design flow. Designers can use the damage resulting from the loss of one pump as a basis for deciding the size and numbers of the pumps.

Limitations on power unit size as well as practical limitations governing operation and maintenance determine the upper limit of pump size. The minimum number of pumps used may increase due to these limitations.

Using pumps of equal size and type has the benefit of enabling all pumps to be freely alternated into service thereby distributing the load between pumps more evenly. Providing an automatic

Equipment Certification and Testing

Testing, certification, and acceptance of equipment is an important element of pump station development. Witnessing equipment testing at the manufacturer's lab or at a suitable facility is ideal, but not always practical. As an alternative, the manufacturer can provide certified test results to the owner. It is good practice to include in the contract specifications the requirement for acceptance testing by the owner, when possible, to ensure proper operation of the completed pump station. Generally, the testing happens in the presence of the owner's representative. If the representative waives the right to observe the test, the manufacturer can provide the owner a written report, signed and sealed by a licensed Professional Engineer or person with other credentials deemed appropriate by the owner, to give assurance that the pump equipment meets all performance and reliability requirements. Any component which fails should be repaired and retested.

alternation system for each pump station allows this approach. This system would automatically rotate the lead and lag pump after each pump cycle so that each pump in turn would become the lead pump. This equalizes wear and reduces needed cycling storage. It also simplifies scheduling maintenance and allows pump parts to be interchangeable. Providing hour and start meters aids in scheduling needed maintenance.

12.1.5 Inlet Water Depth and Net Positive Suction Head

Net positive suction head required is the head above vapor pressure head required to ensure that cavitation does not occur at the impeller. The hydrodynamic phenomenon of cavitation can cause substantial damage to pumps. Cavitation results when the depth of water above the pump inlet (submergence) is too low. Insufficient water depth can also allow vortex formation at the inlet, which reduces pump efficiency.

More precisely, cavitation may occur when the net positive suction head (NPSH), which is a function of water depth, is lower than the required NPSH for the pump. NPSH is the minimum pressure under which fluid will enter the eye of the impeller. It varies significantly with pump type and speed and with ambient atmospheric pressure (a function of altitude). This dimension is provided by the pump manufacturer and is determined by laboratory testing. The available NPSH should be calculated and compared to the manufacturer's requirement.

12.2 Pump Station Components

In addition to the pumps and pits, stormwater pump stations include many other components described briefly in this section. HEC-24 provides additional information on these and other pump station components (FHWA 2001).

12.2.1 Water-Level Sensors

Engineers design stormwater pump stations to operate automatically, without human intervention. They rely on water-level sensors to activate the pumps, making those sensors a vital component of the control system. Available sensor types include float switches, electronic probes, ultrasonic devices, mercury switches, and air pressure switches.

The location or setting of sensors inside of the wet well or storage box controls the starting and stopping of pump motors. Their function is critical because pump motors or engines must not start more frequently than an allowable number of times per hour (i.e., the minimum cycle time) to avoid damage. Designers can prolong motor life by providing sufficient storage volume between the pump start and stop elevations to achieve the minimum cycle time requirement.

12.2.2 Power

Designers choose from several types of power for a pump station. Most commonly, they choose electric motors, which involve the least maintenance and oversight. In some cases, designers choose fuel-driven (gasoline, diesel, or natural gas) engines. When selecting fuel-driven engines, considerations include reliable storage with minimal chance of leakage of liquid fuels and fuel perishability. Fuel-driven engines involve periodic maintenance but must start and run reliably without human oversight. Designers select the type of power that best meets the needs of the project based on an estimate of future energy considerations and overall station reliability. Developing a comparative cost analysis of alternatives helps make this decision. However, when readily available, electric power usually costs the least while being the most reliable choice. Getting input from the maintenance engineer will aid the designer in the selection process. The designer will also benefit from remembering that the same conditions necessitating the pump station—rainstorms—are also the conditions under which electric systems may experience service outages.

Because of the tendency for outages to occur during storms, designers generally consider provisions for backup power. However, if they deem the consequences of failure acceptable, they may choose not to provide backup power. Generally, designers make the decision to provide backup power on economics, serviceability, and safety. For electric motors, two independent electrical feeds from the electric utility with an automatic transfer switch may provide sufficient reliability and affordability when backup power is required.

For extensive depressed freeway systems involving several electric motor-driven stations, mobile generators represent another potential source of backup power. Maintenance staff can store a trailer mounted generator at any one of the pump stations, moving the generator to the affected station in case of power outage.

12.2.3 Discharge System

Designers will want to keep discharge piping as simple as possible. Pump systems that lift the stormwater vertically and discharge it through individual lines to a gravity storm drain as quickly as possible represent a preferred design. Because frozen discharge pipes could damage pumps, designers also consider frost depth when deciding the depth of discharge piping.

Depending on topography, designs may use long discharge lines to pump stormwater to a higher elevation. For efficiency, such a design may combine the lines from individual pump stations into a force main or mains. For such cases, designers provide check valves on the individual lines to prevent stormwater from flowing back into the wet well and restarting the pumps or prolonging their operation time. Check valves are preferably located in horizontal lines. To provide for continued operation during periods of repair, etc., designers include gate valves in each pump discharge line. To determine the most efficient length and type of discharge piping and fittings such as manifolds designers perform a cost analysis. Designers keep the number of valves to a minimum to reduce cost, maintenance, and head loss through the system. Because water remaining in the pipe can develop corrosive and hazardous anaerobic conditions and become a nuisance, designers include some provision for draining or other removal of water stored in the force main (that will not drain by gravity) after a pumping event.

12.2.4 Flap Gates and Valving

Designs use flap gates and various valve types to provide controls and connections for a stormwater pump station. **Flap gates** restrict water from flowing back into the discharge pipe and discourage entry into the outfall line. Because flap gates are usually not watertight, designers set the elevation of the discharge pipe above the normal water levels in the receiving channel. If the design uses flap gates, check valves may not be necessary.

Check valves are watertight; designers use them to prevent backflow on force mains which could store enough water to restart the pumps if backflow were to flow into the wet well or storage box. By preventing backflow, they prevent pump direction reversal and resulting motor rotation, which can cause electrical overloads and tripped circuit breakers. Designers use check valves on manifolds to prevent return flow from perpetuating pump operation. To prevent water hammer in the pipes, designers use spring-assisted silent or “non-slam” configuration check valves or otherwise pay careful attention to design and installation. These include swing, ball, dashpot, and electric.

Gate valves are a shut-off device used on force mains to allow for pump or valve removal. Designers should not use valves in pump stations to throttle flow. Instead, they should be either entirely open or entirely closed.

Air/Vacuum valves allow trapped air to escape the discharge piping when pumping begins and prevent vacuum damage to the discharge piping when pumping stops. They are especially important with large diameter pipe. If the pump discharge is open to the atmosphere, an air-vacuum release valve is not necessary. Designers use combination air release valves at high points in force mains to evacuate trapped air and to allow entry of air during system drainage.

12.2.5 Trash Racks and Grit Chambers

Designers can provide trash racks at the entrance to the wet well if they anticipate large debris. For stormwater pumping stations, simple inclined steel bar screens are adequate. Constructing the screens in standardized modules facilitates removal for maintenance and replacement if damaged. If the screen is relatively small, designers typically provide an emergency overflow to protect against clogging and subsequent surcharging of the collection system. Screening large debris at surface inlets may effectively minimize the need for trash racks. Excluding debris at the surface, and thereby preventing entry into the system, facilitates maintenance and improves hygiene.

If designers anticipate substantial amounts of sediment, they may provide an easily accessible grit chamber to capture settleable solids. This will reduce wear on the pump impellers and cases and reduce the need for regular removal of sediment from the wet well. The optimal design provides convenient access to the grit chamber and removal of sediment by mechanical means (e.g., backhoe tractor or vacuum truck), rather than manual removal.

12.2.6 Monitoring Systems and Maintenance

Pump stations are vulnerable to a wide range of operational problems from malfunction of the equipment to loss of electrical power. Designers traditionally use monitoring systems such as onsite warning lights and remote alarms for pump stations to help minimize such failures and their consequences. The expanding use of Intelligent Transportation System (ITS) elements such as video roadway surveillance, electronic changeable message signs, and active monitoring of urban roadways enhances the possibilities for pump station oversight and monitoring. Cellular and other wireless communications allow regular exchange of information with highway features such as traffic signals; monitoring the status, performance, and maintenance of pump stations is no different. The pump station can transmit operating functions to a central control unit, ITS

monitoring office, or maintenance office, allowing the central control unit to initiate corrective actions immediately in case of malfunction. This approach allows effective monitoring of such functions as power, pump operations, unauthorized entry, explosive fumes, and high water levels. A regular schedule of maintenance conducted by trained, experienced personnel help assure the proper pump station functioning.

The ease of acquisition of information from remote locations allowed by ITS and modern communications presents opportunities not available in the past. Designers may consider including electronic weather monitoring equipment such as temperature and rainfall measurements at pump stations, along with electronic records of operation (start/stop times, water level in wet wells, inflow, and outflow data) over several years or the lifespan of a pump station. Such data can prove invaluable in improving future design, maintenance, and operation of pump stations, as well as in providing real-time data for active traffic management via ITS, active maintenance management, and emergency incident management. Pump stations provide a logical setting for such data collection and transmission equipment.

Since major storm events occur infrequently, the DOT can develop a comprehensive, preventive maintenance, inspection, and recertification program for maintaining and testing the equipment so that it will function properly when needed. Inclusion of instruments such as hour meters and number-of-starts meters on each pump will help schedule maintenance. Soliciting input from maintenance forces will allow designers to improve each new generation of stations.

Periodically testing equipment, instrumentation, and auxiliary features (hatches, doors, etc.) will help ensure proper operation and condition. DOTs will also wish to schedule relatively frequent inspection of the facility for vandalism, deterioration, weather damage, vehicular damage, and unauthorized entry or occupation. In some areas, vegetation, roots, insects, or other creatures can create entry or maintenance problems. Fire ants, in particular, can damage electronic components. Bats, raccoons, skunks, snakes, and other animals can create disease or safety hazards and damage components.

Safety First

For the safety of operation and maintenance, designers review all elements of the pump station. Ladders, stairwells, and other access points facilitate use by maintenance personnel. Designers also ensure adequate space for the operation and maintenance of all equipment, paying particular attention to guarding moving components such as drive shafts and providing proper and reliable lighting. In some cases, air testing equipment can be available so maintenance personnel can check for clean air before entering. Proper ventilation is essential.

Pump stations will likely be classified as a confined space resulting in appropriate access requirements and safety equipment. Designers ensure pump stations are secure from entry by unauthorized persons, providing as few windows as possible.

12.3 Site Planning and Hydrology

Effective stormwater pump station design starts with evaluation of the site and the site hydrology. This section describes stormwater pump station location, site hydrology, and the stormwater collection system that drains to the site.

12.3.1 Location

Practical considerations usually allow designers to locate pump stations near the low point in the highway drainage system they serve. An adjacent frontage road or overpass can often provide easy access to the station. If possible, locating the station and access road on high ground will allow access if the highway becomes flooded. Soil borings made during the selection of the site will reveal the allowable bearing capacity of the soil and identify any potential problems.

Considering architectural and landscaping issues in the location phase of the design process will allow aboveground stations to blend into the surrounding community or fit with the theme of past and future projects. Foregrounding aesthetic, decorative, and community-relevant aspects of highway projects has become commonplace in recent decades, and pump stations can fit into such schemes. Relevant pump station location and design considerations include:

- Providing architecturally pleasing modern pump stations with a minimal cost increase.
- Using screening walls to hide exterior equipment and break up the lines of the building.
- Adding landscaping and plantings to improve the overall appearance of the site.
- Determining if it is necessary or desirable to place the station entirely underground.
- Accommodating maintenance requirements by providing unobtrusive parking and work areas adjacent to the station without encouraging their use by the public.

Consider Construction Experience

Construction methods impact the cost of the pump station. The more a pump station operates, the smaller the fraction the construction cost is of life-cycle cost. With a stormwater pump station, which operates only when needed (during wet weather) operating costs may be insignificant compared to construction costs. One construction option includes caisson construction, in which the station is usually circular, and construction is open-pit construction. Soil conditions are important in selecting the most cost-effective alternative.

Feedback from construction personnel on any problems encountered can improve future designs. "As-built" drawings document any changes. Personnel knowledgeable and experienced with such equipment conduct construction inspections of pump stations.

Hazardous Materials Spills in the Highway Corridor

Pump stations and pumping equipment may be vulnerable to hazard materials spills (of gasoline, other fuels, oils, corrosive chemicals, pesticides, and other hazardous cargo) and associated fire hazards. Commonly, designers have provided a closed conduit system leading directly from the highway to the pump station without any open forebay to intercept hazardous fluids or vent off volatile gases. A closed system depends on a gas-tight seal between the pump pit and the motor room in the pump station. A safer design isolates the pump station from the main collection system and the effect of hazardous spills by placing the storage facility upstream of the station. This may be an open forebay or a closed box (with sufficient grating at each end for ventilation) below or adjacent to the highway pavement.

12.3.2 Hydrology

For traffic safety and to avoid flood hazards, engineers usually design pump stations serving major controlled-access thoroughfares and arterial streets to accommodate a 0.02 AEP event (AASHTO 2014). To determine the extent of flooding and the associated risk, designers also validate the drainage system performance for the 0.01 AEP event. Keeping the drainage area contributing to the station small reduces the size of the pumping station and minimizes negative impacts if the pumping station malfunctions. For the same reasons, designers anticipate future development that could contribute to increases in flow to the pumping station.

Consider the feasibility of providing storage, in addition to that which exists in the wet well, at all pump station sites. For most highway pump stations, the high discharges associated with the inflow hydrograph occur over a relatively short time window. Additional storage, above or below ground, may greatly reduce the peak pumping rate. Designers can use an economic analysis to estimate the optimum combination of storage and pumping capacity. However, once constructed, adding pumping capacity typically involves many additional costs compared to relatively low-cost storage volume. Chapter 10 describes procedures for storage routing.

12.3.3 Collection Systems

Local topography and efforts to minimize depth and associated construction costs often restrict storm drains leading to pumping stations to mild grades. A grade resulting in velocities of around 3 ft/s in the pipe while flowing full typically avoids siltation problems in the collection system. Minimum pipe cover, construction clearance, or local head requirements will usually govern the depth of the uppermost inlets. Designers often use baffles to ensure that inflow to the pump well distributes inflow equally to all pumps. The Hydraulic Institute provides information for pump station layout (Hydraulic Institute n.d.).

Collector lines preferably terminate at a forebay or storage box structure, or they may discharge directly into the station. Under the latter condition, designers calculate and carefully check the capacity of the collectors and the storage volume inside of them to provide adequate cycling time for the pumps. A minimum grade of 2 percent may prevent or control siltation problems in storage units.

Storm drainage systems tributary to pump stations can be quite extensive and costly. For some pump stations, the storage volume within the collection piping itself may be significant. Designers may consider storage volume within the system, especially near the pump station, when designing the collection system.

To prevent large objects from entering the system and possibly damaging the pumps, designers typically use debris screens. Screening at the surface facilitates screen maintenance and debris removal, however debris screening may occur either at the surface or inside the wet well/storage system. Design considers the level, accessibility, and convenience of maintenance and inspection when selecting debris trapping devices.

12.4 Storage and Mass Curve Routing

Stormwater pump stations route stormwater inflows at a low point to a higher discharge point, using storage to provide for effective pump station operation. When determining the volume of storage for a pump station, designers strive to achieve a balance between pump rates and storage volume; as available storage increases, required pump size decreases. Designers use an iterative procedure in conjunction with economic estimation to balance storage volumes and pump sizes. Because of the cost associated with pump station construction and ongoing maintenance and operations, designers consider several viable alternatives as they strive to optimize life-cycle

cost/benefit. This allows comparisons of life-cycle costs and sensitivity to uncertainties of both physical and financial constraints.

During a stormwater event, pump station operations generally include the following series of events:

1. As stormwater flows to the pump station, the wet well or storage box stores the water, and the water level rises to an elevation which activates the first pump.
2. If the inflow rate exceeds the pump rate, the water level will continue to rise until it causes the second pump to start. If not, the water level will diminish until the pump stops.
3. This process continues sequentially for each pump until either the inflow rate subsides, or enough pumps operate to equal or exceed the inflow.
4. After the pumping rate exceeds the inflow rate, the stage in the station recedes until reaching the pump stop elevations (sequentially), eventually stopping all pumps.
5. If inflow continues at a rate lower than the output of one pump, the water level will again rise in the wet well until a pump starts.
6. The static condition after the end of an event has a water level somewhere between the lowest elevation for NPSH and the first pump start elevation.

Evaluation of the relationship between pump station storage and pumping rate involves developing an inflow mass curve and routing the mass curve through the pump station. The following sections outline these elements of the design.

12.4.1 Storage

Storage attenuates the incoming flow and reduces the demands on pump station operation. Using the inflow hydrograph and pump-system curves, designers can try various levels of pump capacity to determine the corresponding required total storage. Designers estimate the required storage volume by comparing the inflow hydrograph to the controlling pump discharge rate. Stormwater management limitations, the capacity of the receiving system, desirable pump size, or available storage may set this controlling pump discharge rate.

Figure 12.2 depicts an inflow hydrograph and an assumed peak pumping rate. Since the inflow hydrograph peak is greater than the pumping rate, the needed storage volume is the shaded area above the last pump turn-on point. Allowing more of the design storm to collect in a storage facility enables use of a smaller pump station, with anticipated cost benefits.

The location of most highway related pump stations near either short underpasses or long depressed sections, often makes aboveground storage impracticable. Designers ensure that water originating outside of the depressed areas does not enter the depressed areas to avoid pumping additional water. Enlarging the collection system or constructing underground storage represent the simplest forms of storage for such depressed situations. State DOTs typically construct these under the roadway area or in the median, so they rarely involve additional right-of-way.

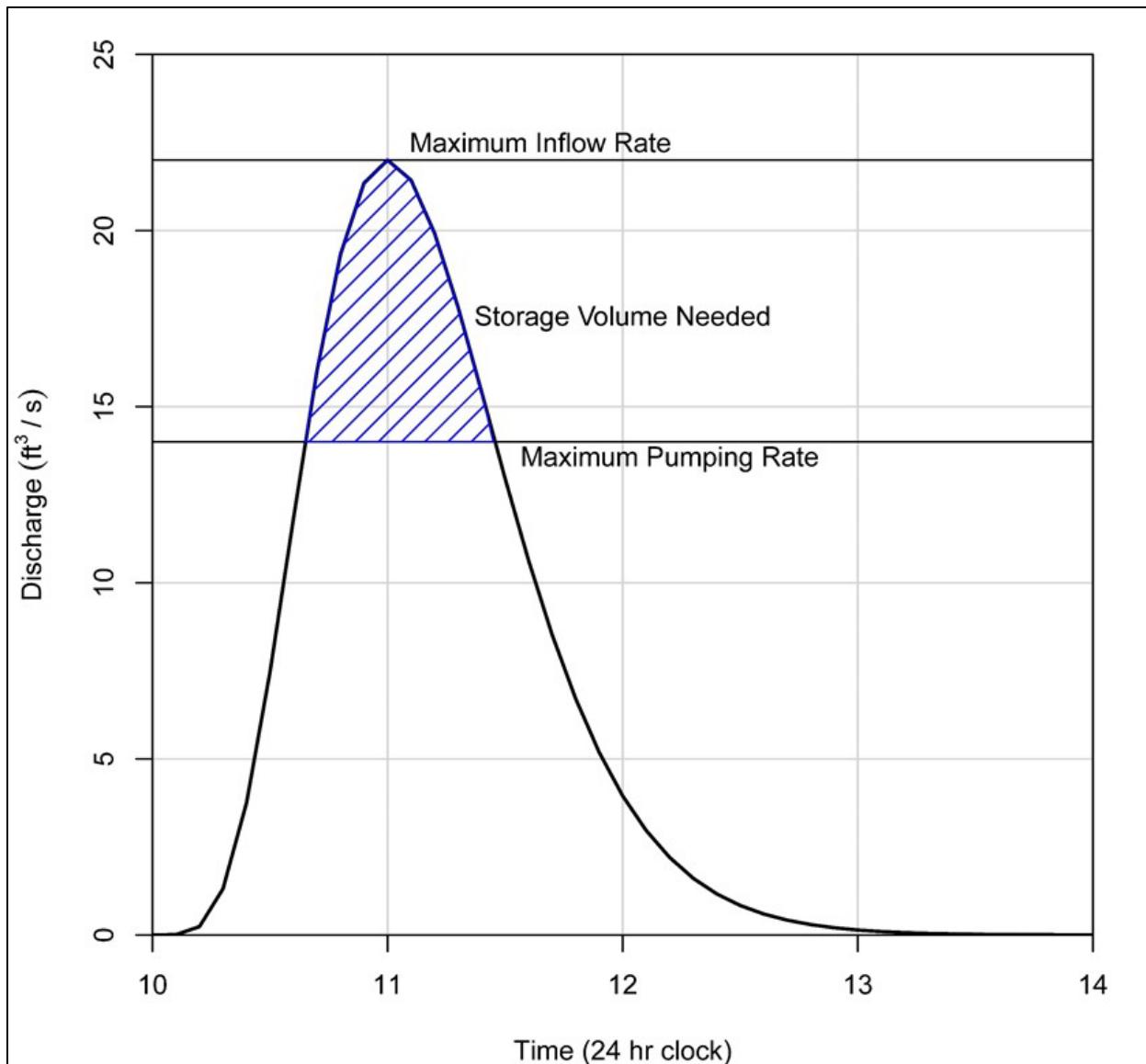


Figure 12.2. Estimated required storage from inflow hydrograph.

12.4.2 Inflow Mass Curve

Designers develop the inflow mass curve by dividing the inflow hydrograph into uniform time increments, computing the inflow volume over each time step, and summing the inflow volumes to obtain a cumulative inflow volume. They then plot this cumulative inflow volume against time to produce the inflow mass curve as shown in Figure 12.3.

12.4.3 Mass Curve Routing

Designers evaluate the relationship between pump station storage and pumping rates using the mass inflow curve in a tabular, computerized form (spreadsheet) or a graphical mass curve routing procedure. Designers can find spreadsheet applications for this procedure online; alternatively, individual designers or agencies can develop them relatively easily. Designers will want to pay close attention to the time steps on the mass inflow curve; sometimes, achieving sufficiently short time steps will depend on curve fitting or polynomial interpolation.

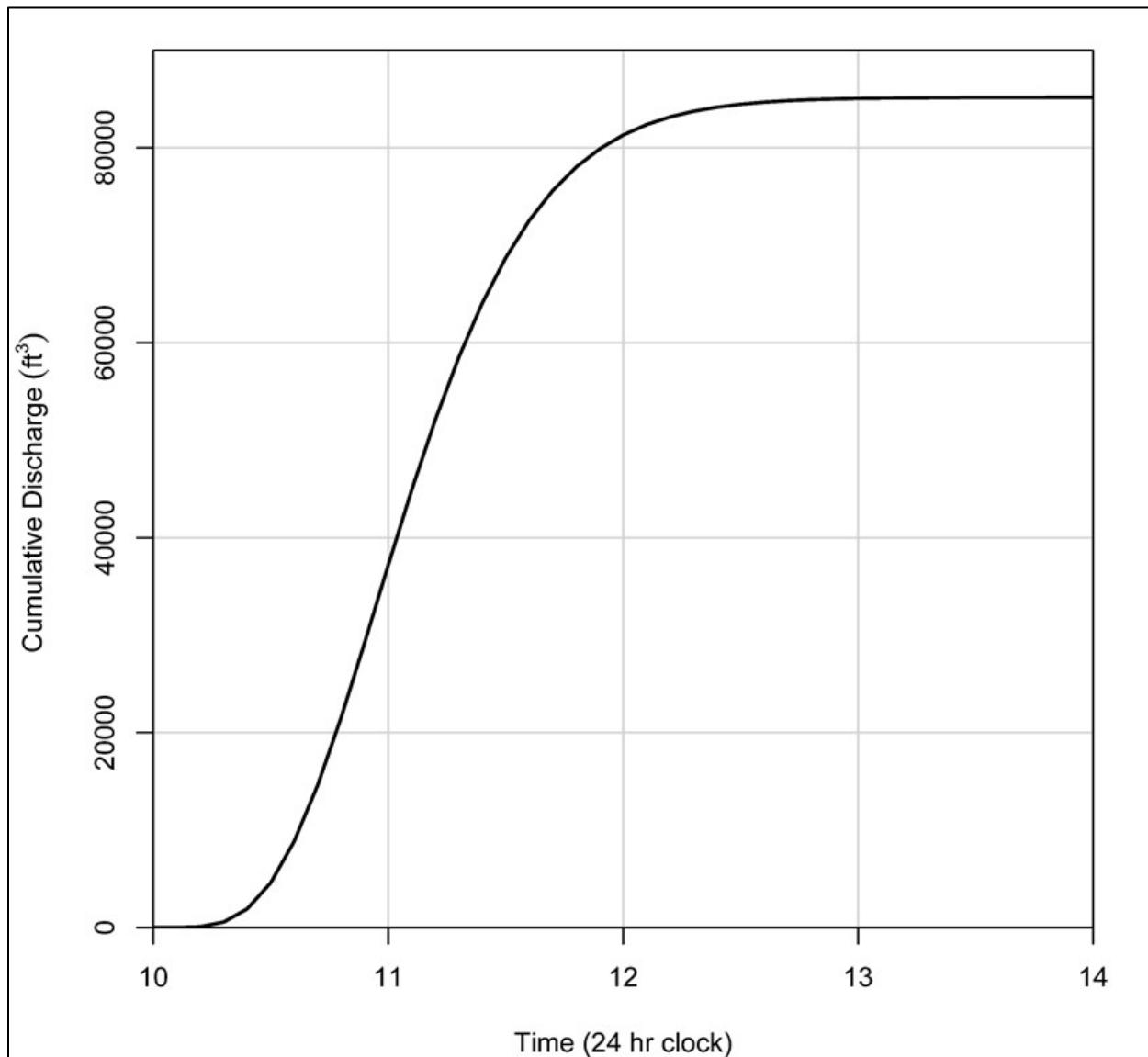


Figure 12.3. Mass inflow curve.

Downstream capacity considerations, limits imposed by local jurisdictions, or other criteria determine an initial maximum pump discharge. With the inflow mass curve and an assigned pumping rate, the designer can determine required storage by various trials of the routing procedure.

Designers use three pieces of information for mass curve routing:

- An inflow hydrograph (Figure 12.2) (from hydrologic evaluation).
- A stage-storage curve (Figure 12.4) (from physical geometry of the storage features).
- A stage-discharge curve (Figure 12.5) (from the pump curve and start/stop elevations).

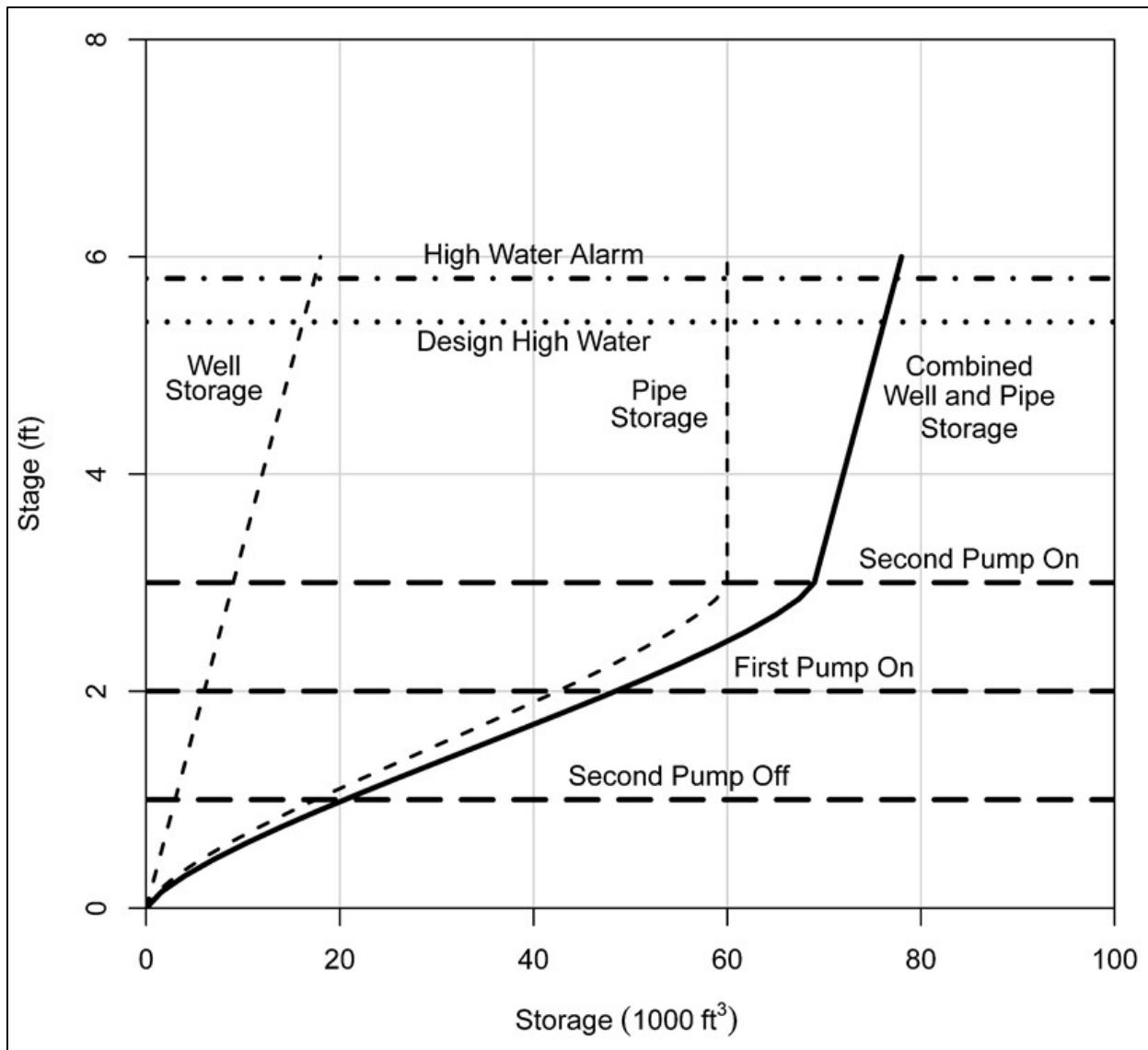


Figure 12.4. Stage-storage curve.

Using this information, designers develop a mass curve routing diagram as shown in Figure 12.6. The letters in the figure note the following sequence of events:

1. The first pump starts at point A and pump at a rate represented by the slope of the line between A and B.
2. At point B, the storage empties and the pump turns off.
3. At point C the start volume has accumulated again, and the lead pump turns on.
4. At Point D the storage has filled to the elevation where the second pump turns on. Since this depicts a two-pump system, both pumps will operate along the pump curve from D to E.
5. Point E represents the elevation where the second pump turns off. At point F, the storage has been emptied and the lead pump turns off.

The vertical lines on Figure 12.6 represent the total volume stored at any given time, such as when a pump starts or stops. The maximum vertical distance between the inflow mass curve and

the pump discharge curve represents the amount of storage needed for that set of conditions. The pump start elevations tie directly to the storage volume at that elevation. The designer tries different start elevations iteratively to find a set of start elevations that minimizes the storage needed.

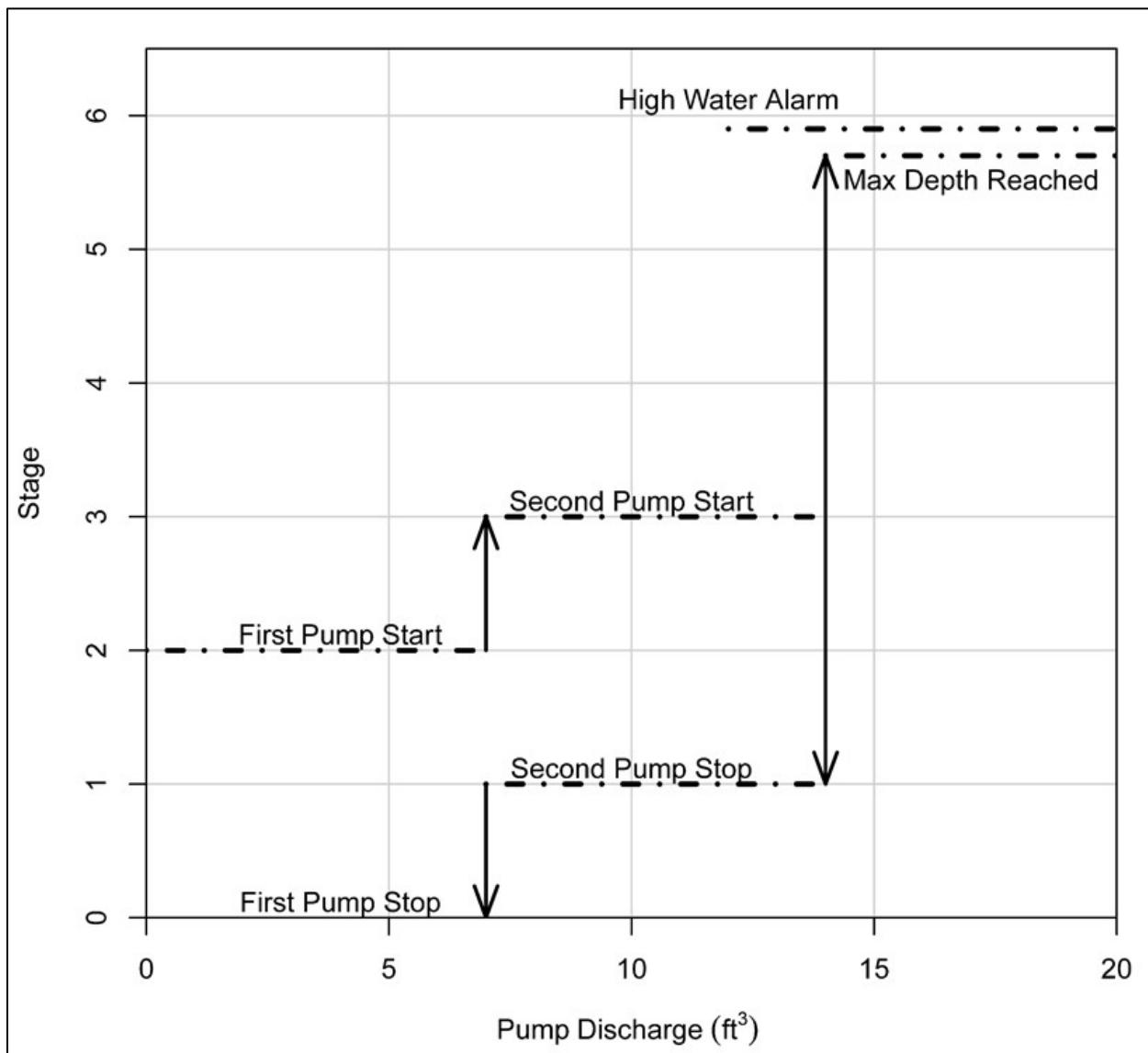


Figure 12.5. Stage-discharge curve.

Designers can use a spreadsheet to perform the calculations. With reasonably short time steps, they can try many different combinations of start/stop elevations. They can try different pump performance curves the same way. HEC-24 provides a detailed example of stormwater pump station design and describes additional design, operations, and maintenance aspects.

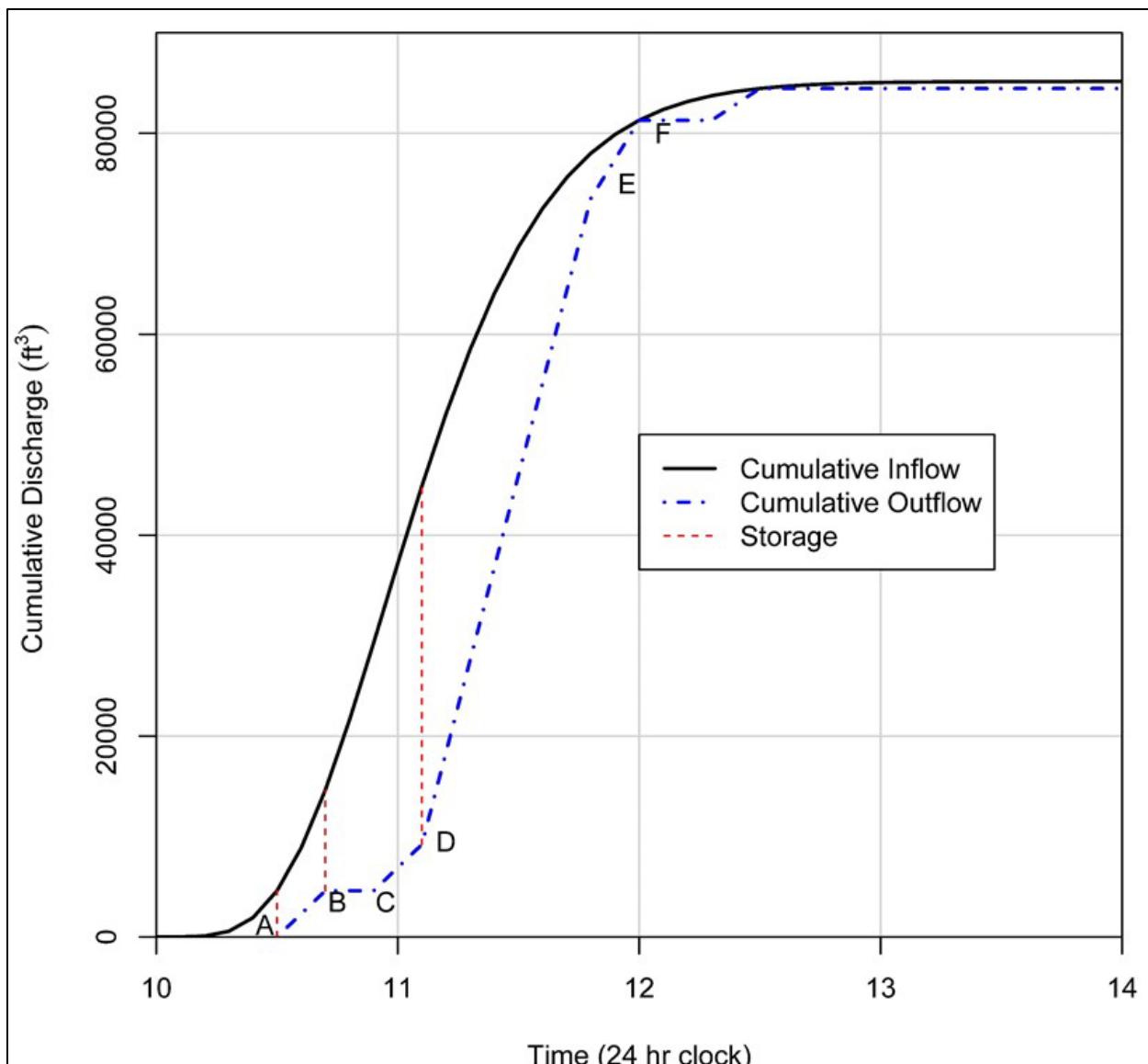


Figure 12.6. Mass curve routing diagram.

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