
SECTION 9.3

DRAINAGE AND IRRIGATION

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DRAINAGE PUMPS

Drainage pumps are used to control the level of water trapped in a protected area. Entrapment occurs when high lake levels, stream stages, and tides preclude the normal discharge of streams, storm runoff, and seepage from the protected area. These high-water conditions are created by floods and hurricanes or impoundment.

Floods and hurricanes occur infrequently and are relatively short-lived. However, as normal drainage is not possible at such times, all interior drainage that cannot be ponded must be pumped over the protective works if the protective works is a levee or through it if it is a concrete flood wall. Pumps for this purpose are strategically located at the edge of pending areas and streams, in sewer systems, or in the protective works. These pumps are operated continuously or are cycled on and off as necessary to maintain the water level in the protected area below the elevation at which damage would be experienced. As their use is required only during emergency situations and usually under adverse weather conditions, reliability of operation is essential.

Where valuable low-lying areas must be protected against inundation due to backwater, gravity drainage from the area is generally not possible. In such situations, all seepage and storm-water runoff entering the protected area must be pumped. The pumping of seepage is often a continuous operation, whereas the pumping of storm-water runoff is intermittent. Both can occur simultaneously because inflow due to seepage does not stop during a rainstorm. It therefore is necessary to provide pumps that can handle seepage and storm water simultaneously.

IRRIGATION PUMPS

Irrigation pumps play an important part in making vast areas of arid and semiarid land agriculturally productive. These pumps take water from surface sources, from subsurface

sources, and in ever-increasing amounts from sewage treatment facilities and pump it to the point of application.

Water from surface sources, such as streams, lakes, and ponds, is pumped directly into the distribution system or into a conveyance system. If pumped into a conveyance system, it flows either by gravity or under pressure to the distribution point or to a booster pumping station. Most of the pumps used in these installations are mounted permanently and are arranged to operate as necessary without constant attendance during the growing season.

Water from subsurface sources is usually pumped directly into the distribution system. In such installations, a well is drilled in the vicinity of the area to be irrigated and is fitted with the proper size pump. In many instances, more than one well is needed to provide the required capacity.

Effluent waters from different types of sewage treatment facilities are sometimes used for irrigation on a year-round basis in land disposal systems. In these systems, the treated effluent is temporarily stored in holding tanks or ponds and is applied to the disposal area at predetermined rates via sprinkler systems. As the disposal area may be a considerable distance from the storage area and as pressure is needed for operation of the sprinkler system, pumping is required.

PUMP TYPES

Centrifugal pumps are used almost exclusively in drainage and irrigation installations. Because of the large selection of propeller, volute, turbine, and portable pumps manufactured today, there is little difficulty in finding a pump that will meet the conditions encountered in these fields. Pumps in the sizes needed to meet the requirements of the majority of installations are available as standard items. Specialized pumps and extremely large pumps are designed and built to meet the needs of individual projects.

Propeller Pumps These units are used for low-head pumping. As most of the pumping in drainage and irrigation is low-head, the propeller pump is the most widely used type. In general, vertical single-stage axial- and mixed-flow pumps are used; however, there are instances where two-stage axial-flow pumps should be considered for economic reasons.

Horizontal axial-flow pumps are used for pumping large volumes against low heads and usually employ siphonic action when not of the submersible type. When higher heads are involved, these pumps can be arranged to operate with siphonic action until the back pressure places the hydraulic gradient above the pump.

Variable-pitch propeller pumps rotating at constant speed can be operated efficiently over a wide range of head-capacity conditions by varying the pitch of the propeller blades. These pumps are used when the head-capacity conditions cannot be met with the more economical fixed-blade pumps and where the pumps will be operated often enough and long enough to warrant the expense. The blade-control system needed for such pumps is more sophisticated than in any of the systems usually provided on drainage and irrigation projects. As a consequence, operation and maintenance must be performed by organizations employing competent and experienced personnel.

Volute Pumps Volute pumps are used when pumping from surface sources and in general when the total head exceeds approximately 45 ft (14 m). Such pumps are available in many types, such as vertical and horizontal shaft, end suction, bottom suction, and double suction with semi-open or closed impellers, and so on. These pumps are mounted in dry pits when located below grade and on slabs or floors when located above grade. The particular type used depends on the capacity and kind of service to be performed.

Deep-Well Turbine Pumps Deep-well turbine pumps (vertical-shaft, single-suction pumps having one or more stages) are used in irrigation primarily to pump water from a subsurface source into a distribution system. The head against which the pump will operate determines the number of stages that must be provided. For large capacities, more than one pump will be needed.

Submersible Turbine Pumps In these deep-well units, the motor is close-coupled to the pump and submerged in the well. This type of pump is used for high-head applications where long intermediate shafts are undesirable.

Portable Pumps In drainage work, portable pumps are used as emergency equipment to control ponding elevations where mobile equipment, such as tractors and trucks, having power takeoffs are available to drive them. In irrigation work, they are usually used to irrigate from a surface source. Such pumps are small-capacity, low-head, economical pumps that must be submerged in order to be used.

PUMP SELECTION

A pump selection study should always be made, and its importance cannot be emphasized enough. Such studies permit selection of the type of pump and discharge system best suited to the project and provide the information needed to proceed with the design of the installation.

In many cases, the type of pump required will be obvious. If more than one kind of pump would be satisfactory, the specifications should permit the pump manufacturer to make the choice. This is particularly advantageous when competitive bidding is involved. The practice of the Corps of Engineers in this regard is to write a performance specification and allow the pump manufacturer to determine the type, size, and speed of the pump.

Before initiating such a study, all previous studies made to determine the total pumping requirement or station capacity, pertinent water-surface elevations, terrain, utility locations, proposed station or well locations, points of discharge, and the proposed method of operation should be reviewed. Also to be considered is the experience of the personnel that will be responsible for the operation and maintenance of the installation.

Number of Pumps First costs are generally of more concern than operating costs in drainage and irrigation work because the operating period for the majority of installations is relatively short and occurs only once a year. Costs can be minimized by using as few pumps as possible. However, one-pump installations are seldom used except in the case of wells. For reliability, a minimum of two pumps should be installed in drainage pumping stations, where the loss of even one pump during an emergency situation could result in considerable damage. Three or more pumps are preferred. Standby units are provided only in those installations where continuous operation precludes taking a pump out of service for maintenance.

The number of pumps ultimately used should be consistent with the demands of the project. For instance, when the installation is located in an agricultural area or is a part of an urban sewer system, a standby pump should be provided because these installations must always be capable of discharging project requirements during periods of blocked drainage. In this way, considerable damage may be avoided. When the installation is used to pump storm water from pondage or irrigation water from a lake, the loss of a pump is not critical and so a standby pump is not needed.

If during pump selection it is found that the rated power of the prime mover exceeds the maximum power requirements of the pump by a considerable amount, the contemplated number of pumps should be increased or decreased, provided the change results in a better power match without increasing the overall cost of the installation. By increasing the number of pumps and thereby reducing the required power, there is a possibility that the size of the prime mover can be reduced and that the pump power will approach the rated power of the prime mover. On the other hand, decreasing the number of pumps will increase the power requirements. This increase may be sufficient to either utilize most of the excess capacity in the prime mover or require the use of a larger one.

For installations requiring the use of large pumps, foundation conditions become important. To prevent the installation from being relocated to a less desirable site or the necessity of providing a more expensive pile foundation because the bearing pressures at

the selected site exceed the allowable limit, the number of pumps should be increased, provided the loading can be reduced to an acceptable amount and the resulting installation continues to be the most economical.

Inadequate depth on the suction side of the pumps may necessitate the use of more pumps. Should the water not be deep enough to provide the submergence needed by the contemplated pump, more pumps of a smaller size may have to be used or the sump and approach channel may have to be excavated to the needed depth. The latter alternative could cause operational and maintenance problems and might be the more expensive solution.

Capacity The capacity of a pump is a function of the total pumping requirement, the number of pumps, and, in the case of wells, the capacity of the well. Whenever possible, all pumps in a multiple-pump installation should be of the same capacity. This is advantageous from a cost standpoint as well as from a maintenance standpoint. In drainage installations, three pumps are generally provided in order to have the capability of pumping not less than two-thirds of the project requirement with one pump inoperative. Each pump would then have a capacity equal to one-third of the total capacity. When more than three are used, the capacity should be the total required capacity divided by the number of pumps being used. If two pumps are used, each pump should be sized to pump not less than two-thirds of the total capacity.

In irrigation installations utilizing multiple pumps, the capacity of each pump should be the same. In single-pump installations, the pump should be sized to meet project requirements. When wells are involved, the capacity of the pump will be determined by the capacity of the well. Often several wells are needed to give the capacity to satisfy the established requirements.

When a standby pump is to be provided, its capacity should be equal to that of the largest pump being furnished.

Head Total head is the algebraic difference between the total discharge head and the total suction head. In drainage and irrigation work total suction head can usually be determined, but this is not always the case for the total discharge head. The losses in the discharge systems often must be determined by hydraulic model test rather than by calculation and therefore must be estimated for preliminary selection purposes. The head specified will have to be some head other than total head; generally pool-to-pool head is used.

Total discharge head is defined in the Hydraulic Institute Standards, and its value is to a great extent determined by the type of discharge system used. A number of the many possible discharge systems used are shown in Figure 1. The losses in systems *A*, *B*, *C*, *D*, and *E* can be calculated. Thus the performance for pumps discharging into these systems can be put on a total head basis.

System A is an "over the levee" siphonic discharge line, the use of which can seldom be justified. However, continuous operation over long periods could effect a savings that would be sufficient to justify the additional cost of the installation and the taking on of the operational hazards usually encountered with such lines. The total discharge head for this system is equal to the height of the discharge pool, stream, or lake above the impeller plus the exit loss and the discharge line losses from the pump discharge nozzle to the line terminus. The absolute pressure at the high point of the line should be not less than 9 ft (2.7 m). Lower values have been used successfully, but this should be the exception rather than the rule. For additional information on the determination of heads in a siphonic system, refer to "Siphon Head" in Section 8.1.

Flap valves should be installed on the discharge end of all lines subjected to a cycling operation. The closing of these valves following pump shutdown prevents reverse flow into the protected area and permits development of the pressures needed to keep the lines full (primed) during those short periods when pumps are idle. These pressures will be less than atmospheric pressure, with the minimum pressure (absolute) being at the high point. Should there be significant leakage at the joints or in the valves, the pressures will rise and the water level at the high point will drop. If the water level drops below the invert of the line at the high point, the two legs of the line will be separated by an air space and priming will be necessary when the pump is started.

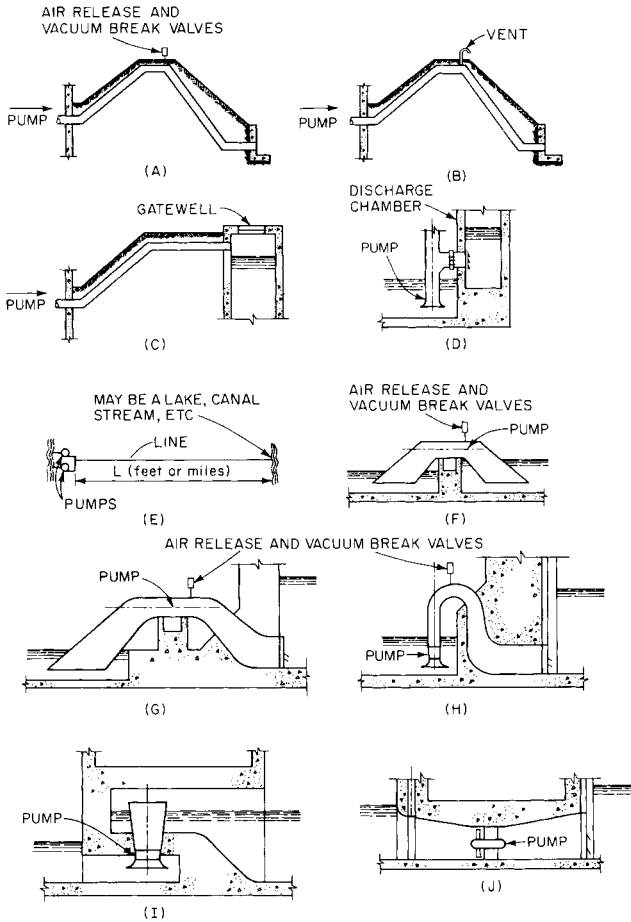


FIGURE 1A through J Discharge systems (adapted from Department of the Army, "Mechanical and Electrical Design of Pumping Stations," EM 1110-2-3105, Washington, DC, 1962)

Air-release valves should be installed at the high point of all siphonic discharge lines to provide an escape for the air being compressed as the water rises in the line during priming, and vacuum-break valves should be used to prevent reverse flow into the protected area. For lines equipped with flap valves, the vacuum-break valve should be manually operated and used when the flap gate fails to seat properly or to provide a rapid means of draining the line when pumping is no longer required. Units for almost any size line can be obtained from manufacturers who specialize in such equipment or they can be assembled, using swing check and angle valves.

System B in Figure 1 is an "over the levee" nonsiphonic discharge line. To preclude siphonic action, this line should be vented at the high point with a vent having a diameter that is approximately one-fourth that of the line. The invert of this line at the high point should be placed at the same elevation as the top of the protective works so the pumped flow can discharge from the down leg of the line under gravity without backwater effects for all discharge pool elevations up to maximum. Thus the total discharge head

will have a constant value because it will not be affected by changes in the level of the discharge pool. To ensure adequate prime mover capacity when using this system, it is the practice in all cases to use the top of the line at the high point in lieu of the hydraulic gradient when determining the total discharge head. Therefore, total discharge head is the height of the top of the line at the high point above the impeller plus the velocity head in the line at the high point based on a full pipe and the losses in the line from the pump discharge nozzle to the beginning of the down leg of the line.

System C is used when there is a conduit carrying the normal gravity discharge under the levee adjacent to the station that must be valved off against reverse flow into the protected area during periods of high water. The closure gate is located in a gate well constructed on the stream or lake side of the levee to prevent subjecting the gravity conduit to high-water conditions. The pump discharge lines go over the levee and terminate in the gate well above the maximum water level. This shortens the lines and reduces the cost. The total discharge head for this system is equal to the height of the top of the line at the terminal end above the impeller plus the exit loss and the losses in the line between the pump discharge nozzle and the terminal point. The total discharge head for this system, as in system *B*, is independent of the discharge pool and therefore constant. Neither flap valves nor vents are required on these lines.

System D is used when the pumping station is constructed as an integral part of the levee or flood wall. The invert of the pump discharge line is placed at an elevation that is above the stream or lake level that will prevail approximately 70% of the time or as is dictated by the physical dimensions of the pump. Owing to the extreme turbulence in the discharge chamber, gates with multiple shutters, which are less likely to be damaged, should be used instead of flap gates on discharge lines that are larger than 36 in (914 mm) in diameter. When the water level in the discharge chamber is below the top of the discharge line, the total discharge head is determined in the same manner as for system *C*. For higher discharge water levels, the total discharge head is equal to the height of the water level in the discharge chamber above the impeller plus the exit loss and the losses between the pump discharge nozzle and the chamber side of the flap valve.

System E is perhaps the most common discharge system in use today. It is used to connect one pump or several manifolded pumps with a lake, canal, stream, ditch, reservoir, or sprinkler system. For short lines and low static heads, valve and fitting losses, frictional losses, and exit losses are very important, whereas in long lines or very high static head installations only frictional losses are given consideration. In manifolded installations using propeller pumps, a check valve and gate valve are installed immediately downstream of the pump. The gate valve should always be opened before the pump is started because the motors provided are not usually sized to operate against shutoff head. Positive shutoff valves are placed immediately downstream of volute or turbine pumps because these pumps are usually started and stopped against a closed valve. They also prevent reverse flow into the sump when one of the pumps is inoperative.

Pool-to-pool head is the difference in elevation between the sump and discharged-water surfaces and is used instead of total head in drainage work because the losses in the discharge system are not easily determined. Installations of this type are exemplified by systems *F*, *G*, *H*, *I*, and *J* in Figure 1. For such installations, it is best to specify the pumps on a pool-to-pool basis, to have the pump manufacturer design the pump and the discharge system, and to verify the predicted performance by model test. It should be noted that in such installations the discharge systems are usually constructed within the confines of the pumping station structure.

System F is operated as a siphon with the pump supplying energy equivalent to the pool-to-pool head plus the system losses. The invert of the pump discharge pipe at the highest point is located above the maximum river stage, and vacuum pumps are generally used to aid in priming the pump. This system is used for pool-to-pool heads of up to approximately 6 ft (1.8 m) and where the physical dimensions of a vertical pump would make it necessary to operate against higher heads. In estimating the losses, entrance losses, which are small [approximately 0.14 ft (4 cm)], should be neglected. The centerline of the suction piping should be assumed to make an angle of 45° with the horizontal, and the diameter of the discharge piping as measured at the discharge flange of the discharge elbow should be such that the velocity at maximum discharge is approximately 12 ft/s (0.037 m/s) or less.

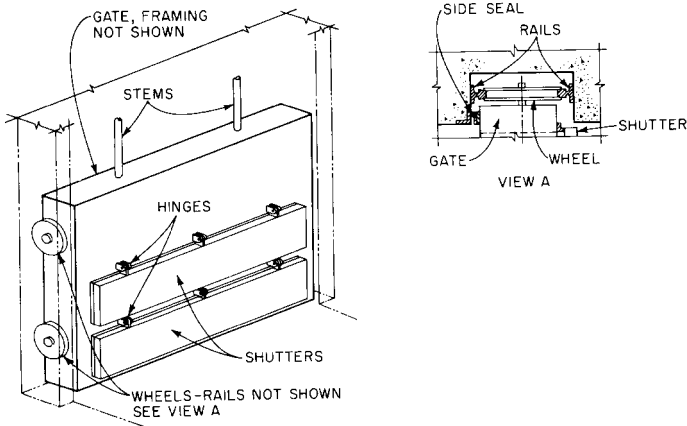


FIGURE 2 Multiple-shutter gates

System G is used for pool-to-pool heads of up to approximately 15 ft (4.6 m). The water passages change in cross-section from round at the pump bowl to rectangular at each end. The width at the suction end is the same as or less than that of the suction bay, and the height is such that the entrance to the suction passage is always submerged when the pump is in operation. The discharge velocity should be kept to approximately 6 ft/s (1.8 m/s). Multiple-shutter gates (Figure 2) arranged to be raised when the pump is in operation are provided to prevent prime mover overload when the pump is started and to prevent reverse flow when the pump is stopped or inoperative. These pumps are usually large and slow and require substantial prime movers. Vacuum priming equipment is used so additional power will not be required for priming.

System H is essentially the same as system *G*, except that the former is used for pool-to-pool heads up to approximately 26 ft (7.9 m). Also, a splitter may be required in the discharge water passage for structural purposes as well as for keeping the multiple-shutter gates to a reasonable size. The pumps used with this system are vertical and in general smaller than those used with system *C*.

System I can be constructed with the lip of the pump column either above or below the design flood elevation or the maximum surge, if it is being provided for hurricane protection. If the lip of the pump column is above and the chances of reverse flow through the pumps are extremely remote, gating of either the pump column or the discharge water passage is unnecessary. If the lip of the pump column is below, a decision of whether to gate both the pump column opening and the discharge water passage or just the water passage must be made. In general, if the pumps will be in operation continuously during high-water conditions and if reverse flow through an inoperative pump will not have substantial detrimental effects, only the multiple-shutter gate at the end of the discharge water passage need be provided. Reverse flow could occur should the flap for some reason fail to close. Like system *C*, splitter walls may be required if pumps are large. Also, the clearance between the lip of the pump column and the ceiling of the discharge water passage is critical and should be determined by model test.

The shape of the pump column lip will also affect pump efficiency and should be determined by test.

System J could have many configurations but, regardless of arrangement, would have to be gated on the suction side with a positive shutoff gate, such as a pressure-seating slide gate, and on the discharge side with a positive shutoff gate and a multiple-shutter gate or a flap gate if the installation is small and a pipe is used in place of formed water passages. When formed water passages are used, transition sections between the pump and the gates sections will be needed and should be designed by the pump manufacturer.

Total Suction Head The practice for propeller pump installations is to dimension the station sump or sump bays in accordance with Hydraulic Institute standards and to make the distance between the sump floor and the lip of the suction bowl conform to the standards or the recommendations of the pump manufacturer. The approach and entrance velocities resulting therefrom are small enough to be disregarded when calculating total suction head. Total suction head in vertical propeller pump installations is the height from the centerline or eye of the propeller to the water surface in the sump. For drainage installations using vertical propeller pumps, a total suction head of zero is not uncommon. In submerged horizontal propeller pump installations, total suction head is the height from the centerline of the propeller shaft to the water surface in the sump, and the minimum value should be not less than $1.2D$, where D represents the diameter of the propeller.

Volute pumps equipped with a formed suction or suction piping may operate with either a suction lift or a suction head, depending on the suction water level. In either case, all the losses between the entrance and the eye of the impeller should be included in any calculation. Approach velocity is not a consideration in these installations, but entrance losses are.

TOTAL SUCTION LIFT Approach and entrance velocities can be disregarded in suction lift installations by proper dimensioning of the station sump or sump bays and by proper setting of the suction bell. The sump or sump bay dimensions used, as in suction head installations, should conform to the Hydraulic Institute standards or to the recommendations of the pump manufacturer. The suction bell for both horizontal propeller pump and vertical volute pump installations should be set with the lip located approximately $0.5D$ above the sump floor. For horizontal propeller pump installations, the minimum submergence of the suction bell should be approximately $0.25D$, where D is the diameter of the suction pipe; for volute pump installations it should be $1.5D$, where D is the diameter of the suction bell. In determining the total suction lift for these installations, it is assumed that the suction piping is a part of the pump and that the approach and entrance velocities can be disregarded. Total suction lift therefore is the height from the water surface in the sump to the centerline of the propeller shaft or to the eye of the impeller.

Setting The setting of the pump or the locating of the centerline or eye of the propeller or impeller with respect to the water surface should be given careful consideration when selecting the pump to be used. Some installations offer few if any problems in this regard, whereas in others setting may have a considerable effect on the size and number of pumps selected.

TURBINE PUMPS Drawdown is a consideration in any well installation. In setting the pump to prevent cavitation, sufficient NPSH at the eye of the first-stage impeller and/or sufficient depth over the suction bell lip or tailpipe to prevent vortexing should be maintained when maximum draw-down is being experienced.

VOLUTE PUMPS Volute pumps may operate with either a suction head or a suction lift. If with a suction lift and of the horizontal type, the pump should be set above the maximum anticipated elevation of the suction water source in order to avoid inundation. As priming will be necessary when starting, a suction lift would be considered a satisfactory arrangement when long periods of continuous operation are anticipated.

Suction head installation is the preferred practice (because priming is unnecessary) and should be used whenever conditions permit. In drainage work, vertical volute pumps are used for pumping small amounts of rainfall runoff and seepage flows. These pumps are usually located in a dry sump adjacent to the storm water pump sump, with motors and valve operators located on the operating floor above. The submergence of these pumps should be such that when discharging at maximum capacity, the total suction head is zero or above. In many instances, water surface fluctuations of just a few feet occur. When small volumes are involved, a cycling operation occurs. For this type of operation, the pumps are usually started at the maximum water level and stopped at the minimum level.

PROPELLER PUMPS Sufficient water depth does not always exist or cannot always be provided to give the submergence needed to permit the smallest and perhaps the most efficient pump to be used. Excavation is one answer. However, depending on the soil type, the location of the installation, the kind of construction used, the silt-carrying characteristics of the stream, and the frequency of operation, excavation may be an operational and maintenance headache and is impractical when sumps are to be made self-draining. Another alternative—and the one most frequently used in drainage work—is to set the centerline or eye of the propeller at or slightly below the minimum sump elevation and select a pump that will operate at this setting with little or no cavitation damage. This means that a larger pump operating at a lower speed should be used.

PRIME MOVERS The prime movers used in drainage and irrigation installations are electric motors and diesel and gas engines. The one to be used in any particular situation must be determined before the pump can be selected.

Electric motors are the most economical installations; they should be used when a reliable source of electric power is available and when the cost of bringing it into the pumping station is not unreasonable. A reliable source of electric power is a source that historically has not suffered outages under the climatic conditions that will prevail during the time the pumps will be required to operate. Two feeders of separate origins and not subject to simultaneous outages are sometimes provided to ensure the reliability needed for drainage installations. Such an arrangement has been satisfactorily employed in urban areas but would not be a practical solution in remote areas not yet electrified. The cost of constructing and maintaining even one transmission line in such an area could be prohibitive.

The motors in all but the largest installations should be of the squirrel-cage induction type. In those installations where the motor rating is numerically larger than the speed, the type of motor used should be the one having the lowest overall first cost. It may be either a squirrel-cage induction or a synchronous motor.

All motors should be full-voltage starting except in those instances where the local power company indicates that reduced-voltage starting is necessary. For unattended operation and for drainage stations pumping seepage or pumping from a sewer system where frequent cycling is usually necessary, control devices set to start and stop the motors automatically at predetermined sump or discharge pool levels should be provided. In drainage pumping stations not subject to a cycling operation, motors are started manually by the operator and stopped automatically by a control device.

Engines are used to drive pumps when it is not feasible to use electric motors. They are more expensive than motors but reliable if properly maintained and serviced. They are also variable-speed drives that should be operated at constant speed whenever possible. The requirements of most installations can be met with constant-speed operation. However, for those that cannot, the number of speeds used should be held to a minimum.

Engines should not be cycled on and off but should be operated on a continuous basis. For those installations where the inflow is not sufficient, continuous operation can be obtained by returning a part of the pumped discharge back to the sump. This is accomplished by connecting the pump discharge line and the sump with a valved line.

Gas engines are seldom used, but their use should be considered when the installation is close to a natural gas main.

Right-angle reduction gears are used to transmit the power from the engine to the pump shaft of vertical propeller pumps. For horizontal pump installations where the engine shaft parallels the pump shaft but is at a different elevation and off to one side, silent chain drives are used. For other horizontal installations, parallel-shaft gear units may be used. A service of 1.50 should be used when determining the equivalent power of these units. Right-angle units should be of the hollow-shaft type only if vertical adjustment of the pump impeller is required.

Adequate fuel storage in addition to the day tanks should be provided. Storage facilities should be sufficient to provide fuel at the maximum rate of consumption for a period of 48 hours or less, as demanded by the anticipated pumping requirements. Larger fuel storage installations may be needed if replenishment supplies are not readily available. The design of the facilities should be in accordance with the standards of the National Board of Fire Underwriters and local agencies having jurisdiction.

PUMPING STATION

Sump The sump is perhaps the most important element in the structure of the pumping station. Unless it is properly located, designed, and sized, the flow conditions within could have an adverse effect on the operation of the pump. There are many variations in sump arrangements that are acceptable; however, best results are obtained when the sumps or sump bays are oriented parallel to the line of flow. Flows approaching from an angle create dead spots and high local velocities, which result in the formation of vortices, nonuniform entrance velocities, and an increase in entrance losses. The flow to any pump should not be required to pass another pump before reaching the pump it is meant for. When sumps or sump bays are normal to the direction of flow, such as in sewer systems, the distance between the sump or sump bay entrance and the pump must be sufficient for the flow to straighten itself out before reaching the pump. For additional information relative to sump design and sizing, refer to Chapter 10. If the installation is large enough to warrant it, modeling of the sump to permit the best design to be determined is advocated.

Sumps in drainage installations pumping storm water should be either located above normal water levels, in which case they would be self-draining, or isolated from normal flows by gates. In small installations, motorized pressure-seating gates should be used; in large installations, roller gates raised and lowered with a crane or by some other suitable system should be used. These gates should be sized so the velocity through them will not exceed 5 ft/s (1.5 m/s) for any condition of flow. One gate should be located directly opposite each pump when all pumps are installed in a common sump or should be located at the entrance to each sump bay when pumps are separated.

Frequent cycling of pumps is encountered in installations that pump from sewer systems and that pump seepage. In such installations, the sump should be sized so the volume stored in it and in the ponding area or the sewer lines, as the case may be, within the limits of the operating range, will be sufficient to prevent the starting of the pumps more often than once every four minutes.

Superstructure A superstructure is provided on practically all drainage pumping stations but not on all irrigation pumping stations. The type of superstructure provided should be consistent with the surrounding area and should have a minimum number of windows and openings. In rural areas, corrugated sheet metal structures, which are inexpensive, have been used extensively. These provide adequate protection from the elements and from vandalism. To eliminate the need for an indoor crane, hatches in the roof over each pump can be provided to permit a truck crane to remove motors and pumps as a unit. For engine-driven pumps and larger pump installations, indoor cranes of the appropriate size and type should be provided for installation, removal, and maintenance.

Corrosion The corrosion of electrical and mechanical equipment in housed and unhoused stations can be controlled by painting exterior surfaces with a good paint and by installing strip heaters in all electrical enclosures. In large housed installations, heating of the operating room area in addition to the use of strip heaters should be considered. All equipment below the operating room floor level should be coated with a paint that is suitable for the exposure. In dry sump stations, enamels should be satisfactory. In wet sumps that are kept dry during inoperative periods, cold-applied coal tar enamel, which is easily repaired, is preferred. In installations where the equipment is continuously immersed, coal tar epoxy paint or vinyl paint should be used. If the water is extremely corrosive, consideration should be given to mounting galvanic anodes on the pumps in addition to painting.

FURTHER READING

Department of the Army, Office of the Chief of Engineers. "Interior Drainage of Leveed Urban Areas: Hydrology." EM 1110-2-1410, Washington, DC, 1965.

Department of the Army, Office of the Chief of Engineers. "General Principles of Pumping Station Design and Layout." EM 1110-2-8102, Washington, DC, 1962.

Department of the Army, Office of the Chief of Engineers. "Mechanical and Electrical Design of Pumping Stations." EM 11102-3105, Washington, DC, 1962.

Hicks, T. G. *Pump Selection and Application*. McGraw-Hill, New York, 1957.

Houk, I. E. *Irrigation Engineering*. Wiley, New York, 1951.

Hydraulic Institute ANSI/HI 2000 Edition Pump Standards, Hydraulic Institute, Parsippany, NJ, www.pumps.org.

Israelson, O. W. *Irrigation Principles and Practices*, 2d ed., Wiley, New York, 1950.

U.S. Department of the Interior, Bureau of Reclamation. *Turbines and Pumps, Design Standard 6*. Denver, CO, 1960.