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Pump Station Design Series

Article 1: Capacity Considerations

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**Lots of Choices**

Pump station design is a common municipal project. Being common, however, should not be confused with being simple.

There is no single best design for pump stations. Capacity of pumps, station type, control strategy, and a multitude of other factors contribute to variations in design. Operators and managers should be aware of the considerations of station design to provide guidance and oversight for the designers.

Pump stations should be considered as systems. Pumps may be the most critical items, but they won't function without electrical, structural, and HVAC components. For the pump station to be successful, the relationships between them must be coordinated.

There are similarities between potable water, stormwater, and wastewater pump stations, but there are also differences. This article will concentrate on wastewater pumping.

**Identifying Flow Rate**

The first design task is determining the flow rate the pump station must deliver. This generally means defining a range of flows since pump stations must accommodate considerable variability in demand. Capacity is usually expressed as gallons per minute (gpm). (1 gpm = 3.8 L/min = 0.23 $m^3$/hr)

The design generally starts with an Average Daily Flow (ADF). This is the nominal flow rate that the station is expected to deliver at the end of its design life. Few pump stations operate at ADF for an extended period of time. Most stations are designed for capacity exceeding the current ADF. The station design is intended to accommodate growth in capacity requirements – often twenty years into the future. During the early years of operation the flow required will necessarily be much lower - most pump stations operate at 1/3 of the design flow rate.

Diurnal flow variations are a fact of life in water and wastewater pumping. The peak dry weather flow is typically twice the average daily flow. The flow variations for water pumping stations are generally less than for wastewater or stormwater pumping.

Rain and snow melt obviously dictate sizing for stormwater pump stations, but they are also a major consideration in wastewater pumping. Infiltration and inflow (I & I) usually dictate the maximum pumping capacity. The ratio between average daily flow and peak pumping capacity is called the peaking factor. Factors of four or five are common, and in communities with older or combined sewers factors as high as eight are used.

Capacity turndown, or the minimum flow that the system can deliver as a percentage of maximum flow, can be critical. The flow evaluation should include ADF, daily minimum and maximum, and peak hourly flow. Variations can be accommodated by intermittent pump operation. However, oversized pumps should be avoided because they result in excessive start/stop cycles. Large pumps are more prone to damage from frequent starting.

**Number of Pumps**

Regulatory agencies require that the pump station include standby (redundant) pumps. This means that with the largest pump out of service the remaining pumps must have the capacity to meet peak hourly flow rates. Because a single pump is generally unable to achieve the needed turndown, most designs use a number of small pumps instead of a large pump and identical standby. The cost of multiple pumps is offset because each pump is less expensive than a large one.

Small pump stations are often “duplex”, with two constant speed pumps. Each pump is capable of handling peak hourly flow.

**Head**

The second characteristic for pump sizing is the pump head or discharge pressure. The term “head” derives from the height of water that the pump can overcome at a given flow, generally expressed as feet of water. (1 foot water = 0.43 psi = 6.3 bar). Operators often think of head as the discharge pressure at the pump, but many different aspects of head influence pump performance (Figure 1).

The difference in head from suction to discharge determines the pump performance and power. This is referred to as Total Dynamic Head (TDH).

$$\mathrm{TDH} = \mathrm{h_{fs}} + \mathrm{h_{fd}} + \mathrm{h_t}$$

$h_{fs,d}$ = friction head loss in suction and discharge piping, ft

$h_t$ = total static head; the difference in elevation of water on the discharge and suction sides of the pump, ft

It is important to remember that pumps produce flow, but the system resistance to flow creates head. A pump with the discharge pipe disconnected will produce lots of flow but no pressure!

The two components of TDH receiving the most attention in pumping are static head and discharge friction head. Static head is the elevation of the water on the discharge side of the pump minus the elevation of water on the suction side of the pump. For most applications the static head is nearly constant.

Friction head results from the resistance to water moving through pipe and fittings. Friction loss occurs on both the suction and discharge sides of the pump. Friction losses vary with water velocity squared and with the inverse of the pipe size to the fifth power.

In some applications, such as the headworks of a treatment plant, static head is the largest component of TDH. In other cases, such as pumping through a long force main, friction head is more important. The relative proportions of static head and friction head will affect the pump control strategy and the energy consumption characteristics of the system.

Two commonly neglected but important components of head on the suction side of the pump are the Net Positive Suction Head Required (NPSHR) and the Net Positive Suction Head Available (NPSHA). NPSHR is a function of the pump design. It is established by the manufacturer's tests and is displayed on the pump curve. NPSHA and NPSHR are absolute pressures – relative to a vacuum.

Most municipal pumping applications have a flooded pump suction. That means that the water level in the wet well is above the pump suction connection. This is one components of NPSHA. Another is barometric pressure. At sea level this equals 14.7 psia (14.7 psia = 1.01bar = 33.9 ft. $H2O$ = 10.3 m $H2O$). As the site elevation increases barometric pressure decreases. Vapor pressure is the pressure at which water will boil at a given temperature. Vapor pressure increases as the water temperature rises, with a corresponding decrease in NPSHA.

$$\text{NPSHA} = \frac{p_a \cdot 144\frac{\text{in}^2}{\text{ft}^2}}{\gamma} - h_{fs} \pm h_{ts} - \frac{p_v}{\gamma}$$

$p_a$ = barometric pressure, psia

$\gamma$ = water specific weight, 62.4 $lb_f/ft^3$

$h_{fs}$ = friction loss in suction piping, ft

$h_{ts}$ = height of water above (+) or below (-) pump suction, ft

$p_v$ = vapor pressure of water at suction temperature, psia

Operating a pump when the NPSHA is lower than the NPSHR can result in pump damage. A margin of safety between the calculated NPSHA and the manufacturer's NPSHR values should always be provided.

**Pump Performance Curve**

The pump performance curve summarizes the capabilities and requirements of a given pump (Figure 2). There are a variety of formats used by manufacturers, but all pump curves show the most critical parameters. These include the head, NPSHR, and power requirement over the available flow range. Most pump curves show the performance at several speeds or impeller diameters.

The pump curve does not identify the actual operating point of the pump. This requires plotting the system curve (TDH vs. flows) on the pump curve. The intersection of the two identifies the actual flow.

When two pumps operate in parallel the result is not twice the flow. The static head remains constant. However, the friction head increases, which "pushes" the operating flow lower. Plotting a system curve with the friction loss at twice the flow identifies the new operating point.

Identifying the pump capacity and performance is the first and most critical step in pump station design. Once the pump requirements have been determined it is possible to continue the design process for the station and its ancillary components. These will be covered in future articles.

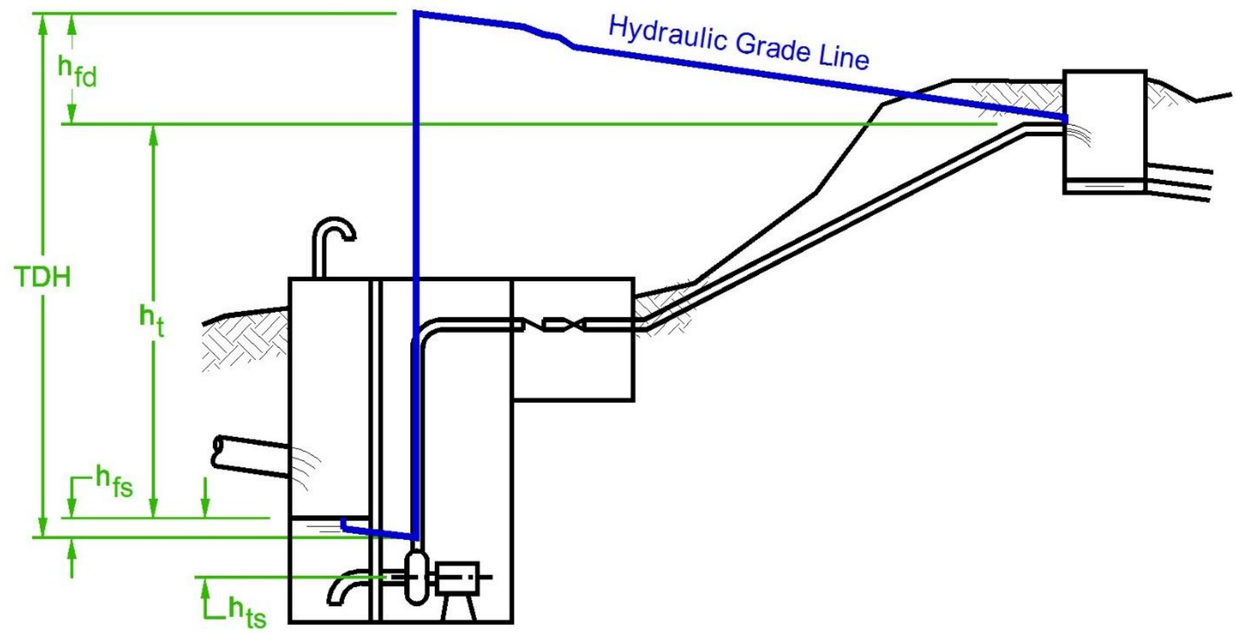


Figure 1: Pump Head

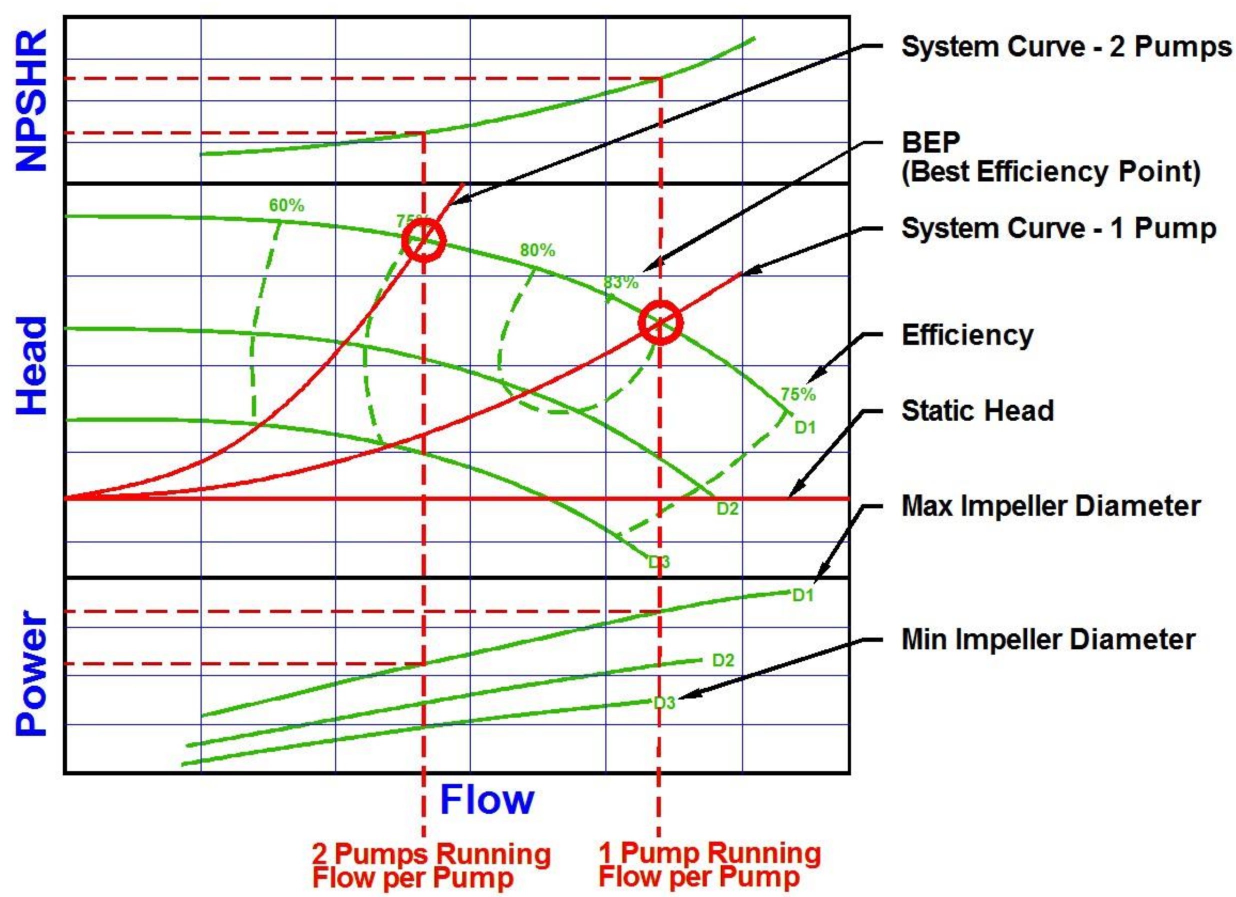

Figure 2: Example Pump Curve