PL Pump Station Design General Principles

General Principles
Propeller pumps are the most sensitive to inlet flow disturbances relative to other types of pumps. Ideally, the flow at the pump inlet should be uniform and steady, without swirl, vortices or entrained air.

- Non-uniform flow at the pump intake can reduce efficiency and cause pulsating loads on the propeller blades, resulting in noise and vibrations.
- Unsteady flow can also cause fluctuating loads, noise and vibrations.
- Swirl in the intake can change the head, flow efficiency and power in undesirable ways. It can also augment vortices.
- Vortices with a coherent core cause discontinuities in the flow and can lead to noise, vibration and local cavitation. Vortices emanating from the free surface can become strong enough to draw air and floating debris into the pump.
- Entrained air can reduce the flow and efficiency, causing noise, vibration, fluctuations of load and consequent physical damage.

Flow conditions at the pump intake are established in the approach-flow region. Three zones are significant: inlet, forebay and sump.

- Inlet: The function of an inlet is to convey water to the pumping station from a supply source such as a culvert, canal or river. Usually, the inlet has a control structure such as a weir with free surface flow or a gate with internal flow. The inlet should normally be perpendicular to the line of pumps and be placed symmetrically with respect to them. The inlet velocity should not exceed 4 ft/s.

- Forebay: The role of the forebay is to guide the flow to the sump, or sumps, in such a way that it is uniform and steady. Although this brochure cannot include all possible forebay layouts, the following recommendations are useful guides:

- Transition to the sump, whether diverging, converging or turning, should result in nearly uniform flow at the sump entrance. High velocity gradients and separated boundary layers should be avoided. No obstacles that generate wakes should be allowed to interfere with the approaching flow. Entrainment of air should be avoided.

- Sump: In practice, only the design of the sump can be standardized for a given pump type. The dimensions of the sump are a function of the pump size and the flow rate. A properly designed sump is a prerequisite for correct presentation of flow to the pumps. However, the proper sump design alone does not guarantee correct flow conditions. A bad approach to the sump can disturb the flow in the sump and at the pump intake.

Recommended Sump Configurations and Dimensions
Flygt’s recommendations adhere to well established principles of hydraulic design, such as those of the American Hydraulic Institute and the British Hydromechanics Group Limited (formerly BHRA). The exact sump dimensions recommended here are based on the results of model and full scale tests with Flygt pumps. These were carried out in order to study the behavior of propeller pumps as a function of the sump size and water depth. The aim was to minimize both without jeopardizing efficient and safe operation of the pump. Tolerances of +/-10% on the sump dimensions are acceptable provided that the combined effect of the departures does not lead to velocities significantly higher than those for the standard sump.

The basic principle of the design is to use a separate sump for each pump. A sump for several pumps always consists of several sump cells. Three basic sump variants are recommended:

1) Configuration “A” - a standard open sump, as recommended by Prosser but adapted to Flygt pumps.
2) Configuration “B” - a compact closed intake.
3) Configuration “C” - a closed intake of the draft-tube type.

The importance of the approach flow varies in the three cases; configuration “A” requires nearly uniform approach flow and the greatest depth of submergence, configuration “C” is the least demanding in both respects.
**CONFIGURATION “A”** is the simplest to build and is often the first alternative considered. However, as it requires more submergence and possibly a longer approach than other configurations, the total cost of a station designed around configuration “A” can be higher than those of the other options.

The basic variant of configuration “A”, marked “A-1”, is the least effective in controlling disturbances in the flow approaching the pump. It is therefore normally recommended only for installations with ideal approach conditions, such as those occurring in a station with only one pump and a straight approach. For stations with multiple pumps, in which various operating conditions will exist, variants “A-2” and “A-3” are preferable. Both include devices such as splitters and divider plates that alleviate the effects of minor asymmetries in the approaching flow. For the low pressure pumps (PL7045, PL7055 and PL7076), configuration “A-1” is not recommended at all.

The minimum required submergence of the pump inlet, in an open sump such as configuration “A”, is a function of the flow rate, the pump inlet diameter and the distribution of the flow at the approach to the pump. To account for differences in the inlet size and the range of the flow rate among the PL-7000 pumps, a separate diagram is shown for each pump size. In turn, each diagram has two curves for various conditions of the approaching flow.

Because vortices develop more readily in a swirling flow, more submergence is required to avoid vortices if the inlet arrangement leads to disturbed flow in the sump. Hence, the upper curve in the submergence diagrams is for a perpendicular approach and the lower one is for the symmetrical approach. The curve appropriate to the inlet situation should be used to determine the minimum water level in the sump for normal operation of the pumps.
PL Pump Station
Configurations & Dimensions

Configuration A-2

ALL DIMENSIONS IN INCHES

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* DEPENDENT ON FLOW – SEE MINIMUM SUBMERGENCE CURVES
PL Pump Station
Configurations & Dimensions

Configuration A-3

ALL DIMENSIONS IN INCHES

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* DEPENDENT ON FLOW - SEE MINIMUM SUBMERGENCE CURVES
PL-7045, PL-7050, PL-7055, PL-7061
Minimum Submergence Curves for Configurations A1-A3
PL-7076, PL-7081, PL-7101
Minimum Submergence Curves for Configurations A1-A3

PL-7076, PL-7081

Lateral approach  
Symmetrical approach

PL-7101

Lateral approach  
Symmetrical approach
PL-7121
Minimum Submergence Curves for Configurations A1-A3
PL Pump Station
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CONFIGURATION “B” is a closed intake which has been adapted so that it can be made of concrete. The geometric features, like the curvature of the front wall, the corner fillets and the benching at the back wall, have been developed to allow smooth acceleration and turning as the flow enters the pump.

Configuration "B"

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* See "Lateral Approach" values on following page.
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P7050, P7045

P7061, P7055

P7101

P7121

P7081, P7076
**PL Pump Station**

**Configurations & Dimensions**

**CONFIGURATION “C”** is a draft-tube intake, (also called a formed suction intake) and can be constructed of either steel or concrete. The intake can reduce inconsistencies and swirl in the approaching flow. This intake is more effective than configuration “B” because of the sloping front wall that is designed to prevent stagnation of the surface flow. The geometrical features of this intake provide for smooth acceleration and turning as the flow enters the pump. The minimum inlet submergence should not be less than 1D.

Configuration "C" - Steel Version

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**NOTE: FOR ALL CONFIGURATIONS**

In some cases the minimum submergence of the pump intake indicated by the diagrams is insufficient to satisfy NPSH requirements. One must, therefore, also ensure that the pump inlet is sufficiently submerged to satisfy the cavitation criterion given in the pump performance data as required by NPSH.
Configuration "C" - Concrete

NOTE: FOR ALL CONFIGURATIONS
In some cases the minimum submergence of the pump intake indicated by the diagrams is insufficient to satisfy NPSH requirements. One must, therefore, also ensure that the pump inlet is sufficiently submerged to satisfy the cavitation criterion given in the pump performance data as required by NPSH.
PL Pump Stations with multiple pumps

Stations with multiple pumps
Pumping stations are usually equipped with two or more pumps. Multiple pump systems provide greater capacity, operational flexibility and increased reliability. Such stations should be designed around individual sump modules. Because the inflow to each module should be as uniform as possible, the design of the forebay feeding the individual modules is critical and should follow the recommended guidelines.

Draft tube intakes are the least sensitive to inconsistencies in the approach flows that occur in sumps at multi pump stations. The inconsistencies can result from diverging or turning flow in the forebay, or from single pump operation at partial load. Therefore configuration “C” is nearly always the preferred choice. Since configuration “A” is the most sensitive to non-uniform approach, it requires a longer forebay and longer dividing walls between the individual sumps than configurations “B” and “C”. If configuration “A” is used for more than three pumps, the length of the dividing walls should be at least 2/3 of the total width of the sump. If flow contraction occurs near the sump entrance, because of screens or gates, the sump length should be increased, to 6D or more, depending on the degree of contraction.

Two typical configurations of multiple pump stations commonly encountered: 1) inlet parallel with the sump centerline, the preferred layout, and 2) inlet perpendicular to the sump centerline.

1) The inlet should be placed symmetrically with respect to the pumps. If the width of the inlet is less than the total width of the sumps, the forebay should diverge symmetrically. The combined angle of divergence should not exceed 40° for Configurations “B” and “C”. For Configuration “A”, the total angle of divergence should not exceed 20°. The bottom slope in the forebay should be less than 10°. If these parameters cannot be met, dividing walls or baffles must be used to improve the flow distribution. Such arrangements, and more complex layouts should be investigated using model tests in order to arrive at suitable designs.

2) If the inflow is perpendicular to the axis of the sump modules (parallel with the line of pumps), an overflow-underflow weir can help to redistribute the flow, as shown below. A substantial head loss at the weir is required to dissipate much of the kinetic energy of the incoming flow. Alternatively, baffle systems can be used to redirect the flow, but model tests are then required to determine their correct shape, position and orientation. The distance between the weir or baffles and the sump modules must be sufficient to allow eddies to dissipate and entrained air to escape before the water reaches the pump inlet.

Experience with designs already in use provides valuable guidelines for the design of multiple pump stations. Adaptations of existing and well proven designs can often provide solutions to complex problems even without model tests. Flygt has extensive experience based on many successful projects, and the services of our qualified engineers are always available to our customers.
PL Pump Station Model Testing

Model Testing
Hydraulic models are often essential to the design of structures that are used to convey or control the flow of water. They can provide effective solutions to complex hydraulic problems with unmatched reliability. Their costs are often recovered through improvements in design that are technically better and yet less costly.

Model testing is recommended for pumping stations in which the geometry differs from recommended standards, particularly if no prior experience with the application exists. Good engineering practice calls for model tests for all major pumping stations if the flow rate per pump exceeds 40,000 gpm or if multiple pump combinations are used. Tests are particularly important if:

- Sumps have water levels below the recommended minimum
- Sumps have obstructions close to the pumps
- Sumps are smaller or larger than recommended
- Multiple pump sumps require baffles to control the flow distribution
- Existing sumps are to be used but with significantly greater discharges

A model of a pumping station usually encompasses a representative portion of the headrace, the inlet structure, the forebay and the sumps. The discharge portion of the flow is seldom included. Testing may encompass the following flow features and design characteristics:

- Inlet structure: flow distribution, vortex formation, air entrainment, intrusion of sediment and debris.
- Forebay and sump: flow distribution, mass swirl, surface and bottom vortices, sediment transport.
- Operating conditions: pump duty modes, start and stop levels, pump down procedures.

Model testing can also be employed to seek solutions to problems in existing installations. If the cause of a problem is unknown, it can be less expensive to diagnose and remedy by model studies rather than by trial and error at full scale.

The pump manufacturers involvement is often required in the evaluation of the results of model tests. Experience is required to determine whether the achieved results are satisfactory and will lead to proper overall operation.

Flygt Systems Engineering
Flygt provides design assistance for any pump project. We have broad experience in design and operation of pumping stations, and we use unique computer programs developed at Flygt. The scope of our assistance includes:

1. Selection of pumps for a pumping station with due consideration of the variations in the flow capacity and the costs involved.
2. Optimization of the sump design for given pumps and specific sites. Dimensional drawings of the pumps and the sump can be provided both as paper copies and as AutoCAD data files.
3. Provision of standard tube fabrication drawings and cable support/protection recommendations.
4. Analysis of complex systems for pumping stations including calculations of hydraulic transients and pump starts.
5. Advice on the need for model tests and arrangements for such tests.

Flygt’s Systems Engineers are always ready to assist you in finding the most suitable solution to your pumping requirements, no matter how small or large.
PL Pump Vertical Discharge
Standard Tube Dimensions*

* Consult Flygt Applications Engineering for fabrication drawings.