CE 3372 WATER SYSTEMS DESIGN

Lecture 06 – Pumps and Lift Stations

Overview

- Pumps
  - Description
  - Suction Requirements
  - System and Pump Curves

Pumps

Pumps

- A mechanical device that transfers mechanical energy to move fluid
  - Lift from lower to higher elevation
    - Lift stations
  - Increase pressure
    - Booster stations

Pumps

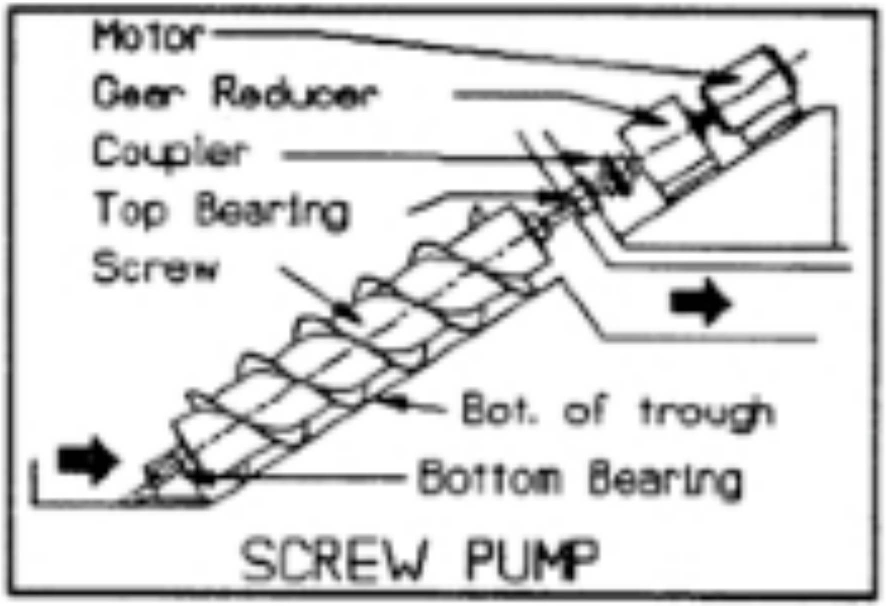
- Positive Displacement Pumps
  - Fixed volume of fluid is displaced each cycle regardless of static head/pressure
  - Lower flow rates and higher head than non-positive pumps
- Non-Positive Displacement Pumps (Centrifugal Pumps)
  - Volume of fluid is dependent on static head/pressure in system (back pressure)

Pumps

- Positive Displacement Pumps
  - Screw Pumps
  - Reciprocating Pumps
- Non-Positive Displacement Pumps
  - Centrifugal (Radial-Flow) Pumps
  - Propeller Pumps (Axial-Flow)
  - Jet Pumps (Mixed-Flow)

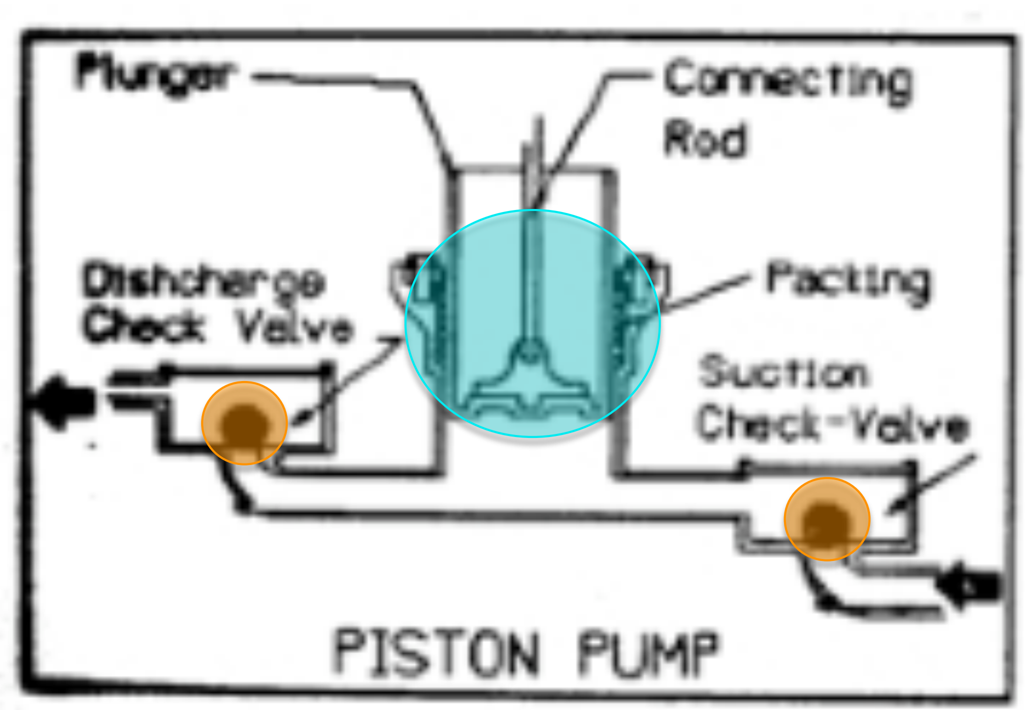
Positive Displacement Pumps

- Screw Pump
  - A revolving shaft with blades rotates in a trough at an incline and pushes water up



Positive Displacement Pumps

- Reciprocating Pump
  - A piston sucks the fluid into a cylinder and then pushes it out



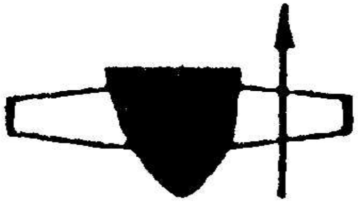
Pumps

- Positive Displacement Pumps
  - Screw Pumps
  - Reciprocating Pumps
- **Non-Positive Displacement Pumps**
  - **Centrifugal (Radial-Flow) Pumps**
  - **Propeller Pumps (Axial-Flow)**
  - **Jet Pumps (Mixed-Flow)**

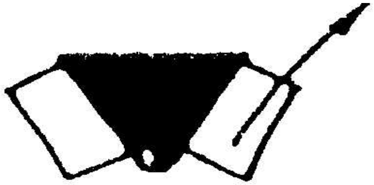
Non-Positive Displacement Pumps

- Classification is based on the way water leaves the rotating part of the pump
  - **Radial-flow pump** – water leaves impeller in radial direction

  - **Axial-flow pump** – water leaves propeller in the axial direction

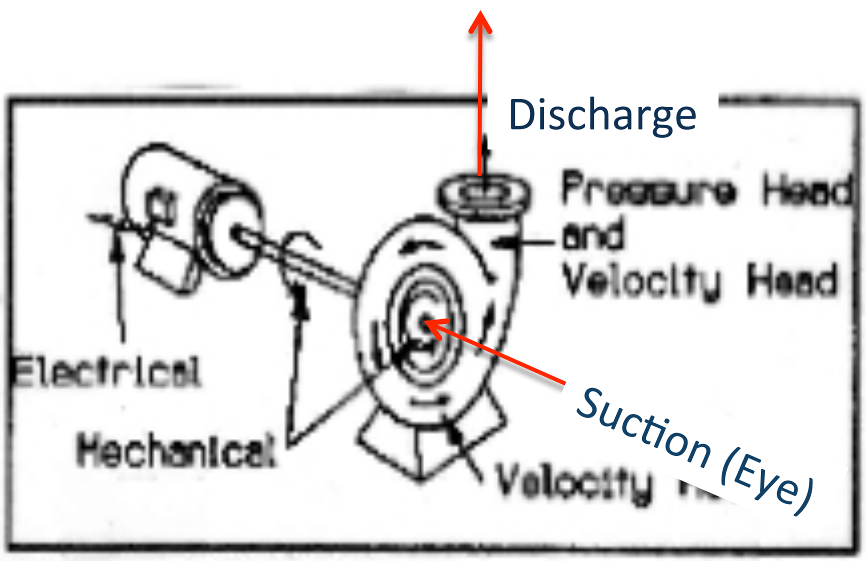


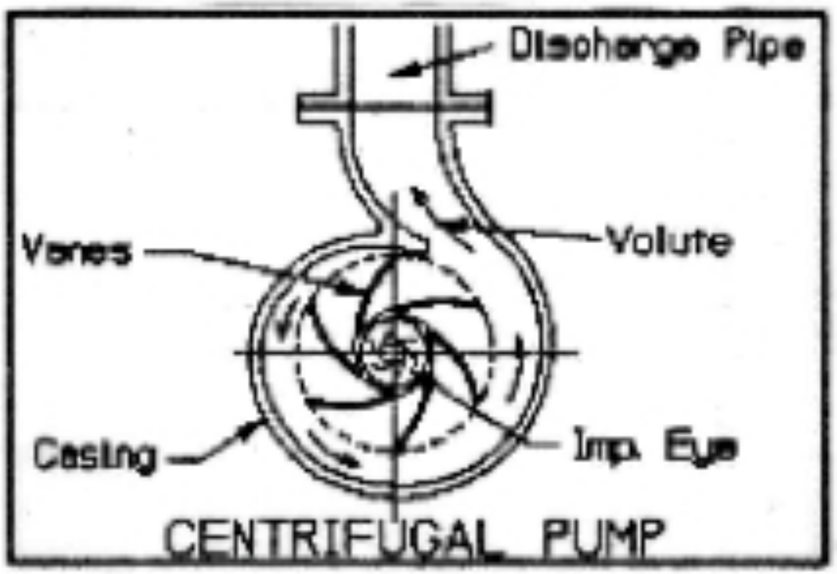
  - **Mixed-flow pump** – water leaves impeller in an inclined direction (has both radial and axial components)



Radial-Flow Pumps

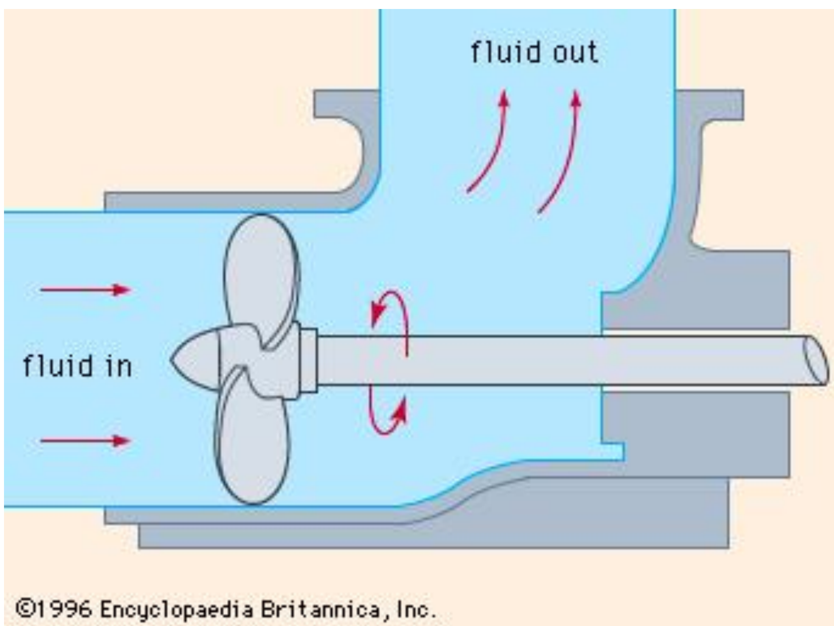
- Centrifugal Pump
  - Accelerates water using an impeller
- https://www.youtube.com/watch?v=BaEHVpKc-1Q
- https://www.youtube.com/watch?feature=player_detailpage&v=ECv1VwW6RTo#t=122

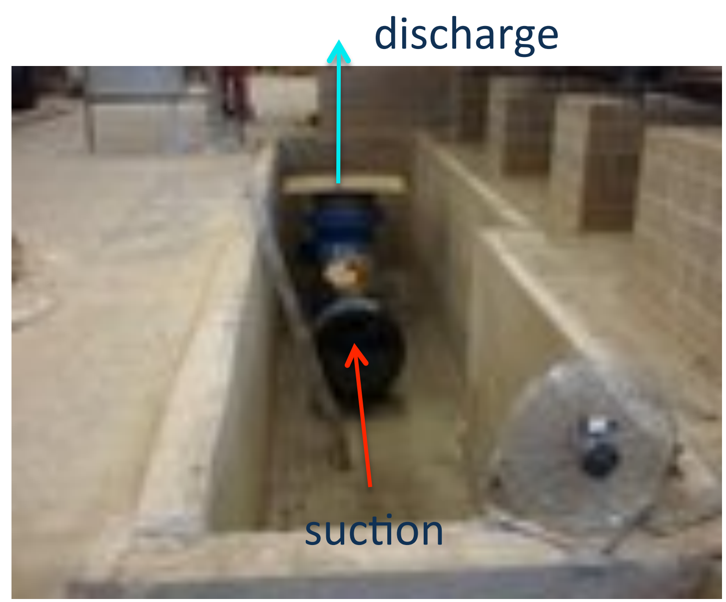




Axial Flow Pumps

- Axial flow pumps have impellers whose axis of rotation is collinear with the discharge
- Used in high flow, low head applications





Suction Requirements

Suction Requirements

- The most common cause of pumping failure is poor suction conditions
- Cavitation occurs when liquid pressure is reduced to the vapor pressure of the liquid
- For piping system with a pump, cavitation occurs when P_{abs} at the inflow falls below the vapor pressure of the water

Suction Requirements

- Liquid must enter the pump eye under pressure; this pressure is called the **Net Positive Suction Head available ($NPSH_a$).**

- A centrifugal pump cannot lift water unless it is primed
  - the first stage impellers must be located below the static HGL in the suction pit at pump start-up

Suction Requirements

- The manufacturer supplies a value for the minimum pressure the pump needs to operate.
- This pressure is the Net Positive Suction Head required ($NPSH_r$).
- For proper pump operation (w/o cavitation)

$$\mathbf{NPSH_a > NPSH_r}$$

Suction Requirements

- Available suction is computed from

Frictional head loss in inlet piping

Absolute vapor pressure at liquid pumping temperature

$$NPSH_a = H_{abs} + H_s - H_f - H_{vp}$$

Absolute pressure at liquid surface in suction pit

Static elevation of the liquid above the pump inlet eye

Suction Requirements

- Example

A 3000 GPM vertical turbine is located 4000-feet above MSL. Water temperature is 90 degrees F. The suction bell is 24-inches diameter, reducing to 12-inches diameter at the first (lowest) impeller stage. Water level is NEVER less than 8 feet above the first impeller. What is the $NPSH_a$ under the worst conditions?

1. Determine anticipated air pressure in feet of water. $\frac{\Delta p}{\Delta z} = -0.5 psi/1000 ft$; Thus $H_{abs.} = 33.9 * (12.7/14.7) * (0.85) = 24.8$feet This result is the product of one atmp-sphere in feet of water, adjusted for the 4000 foot elevation, and adjusted again for a thunderstorm, which typically occurs at 85% of normal atmospheric pressure. This is a "worst case" air pressure estimate for the absolute head.

Suction Requirements

- Example

A 3000 GPM vertical turbine is located 4000-feet above MSL. Water temperature is 90 degrees F. The suction bell is 24-inches diameter, reducing to 12-inches diameter at the first (lowest) impeller stage. Water level is NEVER less than 8 feet above the first impeller. What is the $NPSH_a$ under the worst conditions?

2. $H_s = 8$ feet. This value is given, we are told the water level is always 8 feet or more above the impeller.

Suction Requirements

- Example

A 3000 GPM vertical turbine is located 4000-feet above MSL. Water temperature is 90 degrees F. The suction bell is 24-inches diameter, reducing to 12-inches diameter at the first (lowest) impeller stage. Water level is NEVER less than 8 feet above the first impeller. What is the $NPSH_a$ under the worst conditions?

3. $H_f = KV^2/2g = 0.112$feet. We obtain this from a head loss equation based on the nominal pumping rate of 3000 GPM, and the reduced inlet diameter of 1 foot. The inlet minor loss coefficient is 0.1 (we would get this value from a table). The inlet velocity is around 8.5 ft/sec from the discharge value given.

Suction Requirements

- Example

A 3000 GPM vertical turbine is located 4000-feet above MSL. Water temperature is 90 degrees F. The suction bell is 24-inches diameter, reducing to 12-inches diameter at the first (lowest) impeller stage. Water level is NEVER less than 8 feet above the first impeller. What is the $NPSH_a$ under the worst conditions?

4. $H_{vp} = 1.6$feet. We obtain this value from a table of water properties. We need the vapor pressure in feet of water at 90F.

Suction Requirements

- Example

A 3000 GPM vertical turbine is located 4000-feet above MSL. Water temperature is 90 degrees F. The suction bell is 24-inches diameter, reducing to 12-inches diameter at the first (lowest) impeller stage. Water level is NEVER less than 8 feet above the first impeller. What is the $NPSH_a$ under the worst conditions?

Once the above values are determined the $NPSH_a$ is computed as $NPSH_a = 24.82 + 8 - 0.112 - 1.6 = 31.10$ feet. Using 10% as a margin of uncertainty, we would specify that the pump not require more that 28-feet of NPSH for operation. That is, if this pump has $NPHS_r > 28$ feet on its pump curve, we have a potential pumping problem and either a different pump should be used or the suction conditions must be changed (lower the pump deeper into the pit).

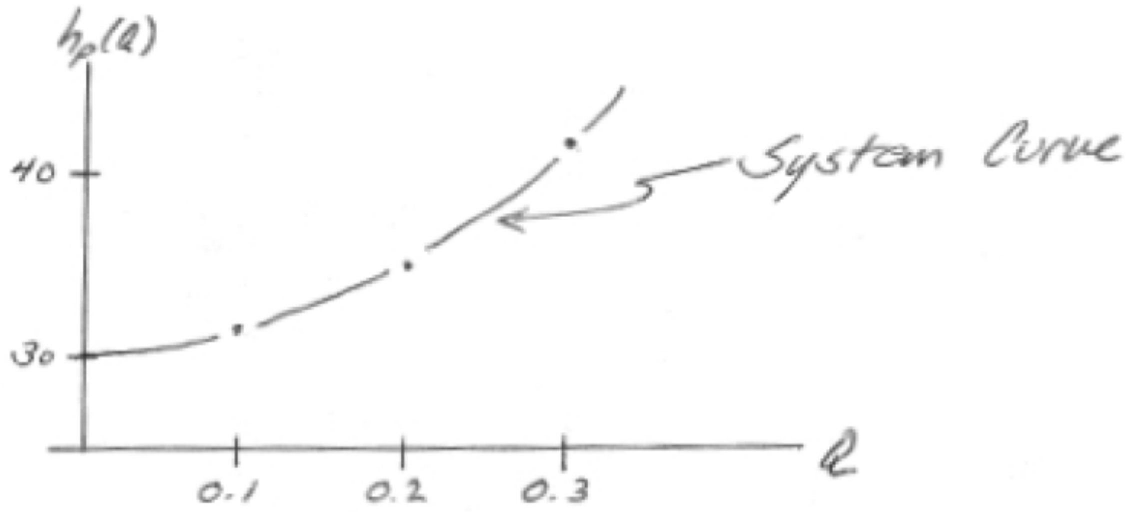
System and Pump Curves

Selecting Pumps

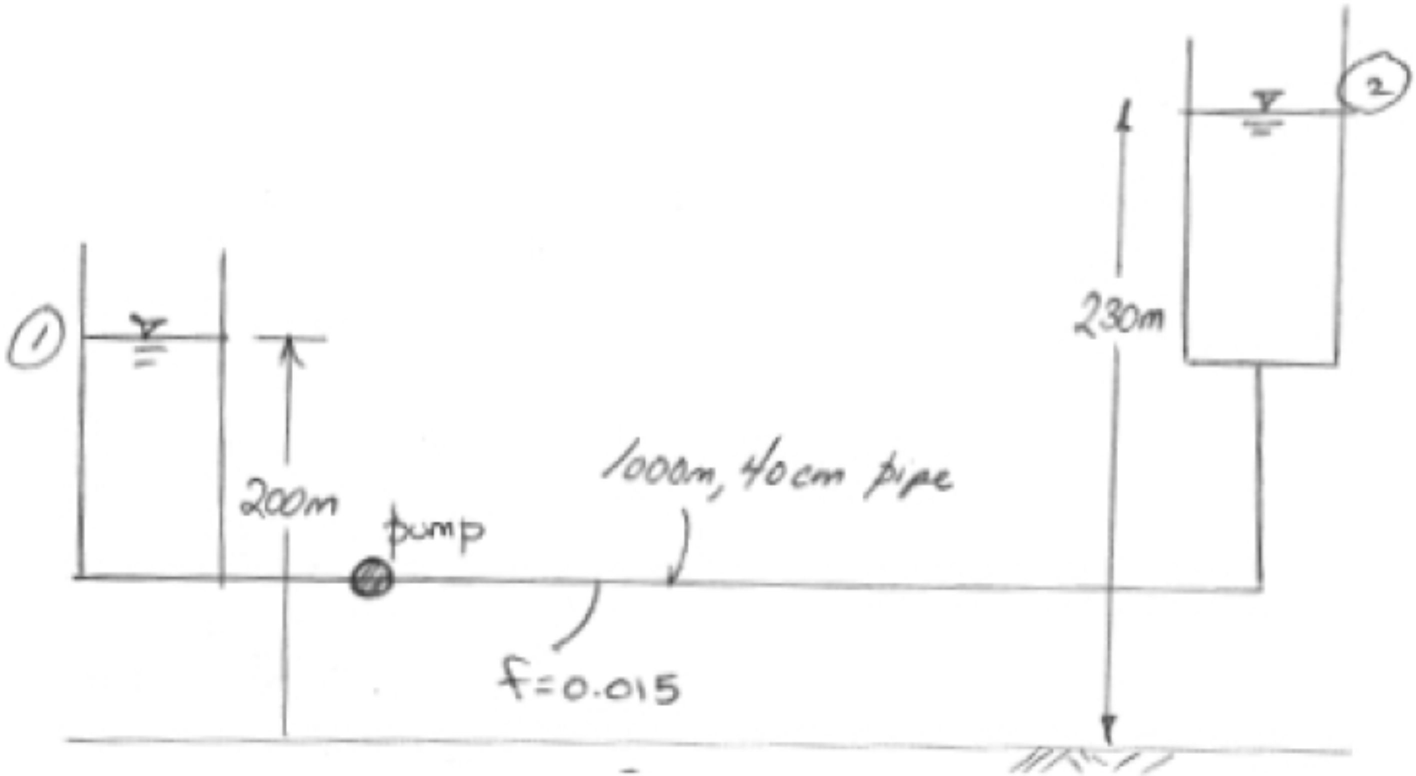
- Design conditions are specified
- Pump is selected for the range of applications
- A System Curve (H vs. Q) is prepared
- System Curve is matched to Pump Curve
- Matching point (Operating point) indicates the actual working conditions

System Curves

- A system (characteristic) curve is a plot of required head versus flow rate in a hydraulic system (H vs. Q)
  - The curve depicts how much energy is necessary to maintain a steady flow under the supplied conditions
  - Total head, H_p, **= elevation head + head losses**



System Curves



$$H_p = (30) + H_{\text{Loss}} = 30 + (f\frac{L}{D} + K_{\text{entrance}} + K_{\text{bend}} + K_{\text{exit}})\frac{Q^2}{A^2\ 2g} = 127Q^2 + 30$$

System Curves

- This relationship tells us that the added head has to be at least 30 meters just to keep the reservoirs at the two levels shown, if any flow is to occur the pump must supply more than 30 meters of head.

$$H_p = (30) + H_{\text{Loss}} = 30 + (f\frac{L}{D} + K_{\text{entrance}} + K_{\text{bend}} + K_{\text{exit}})\frac{Q^2}{A^2\,2g} = 127Q^2 + 30$$

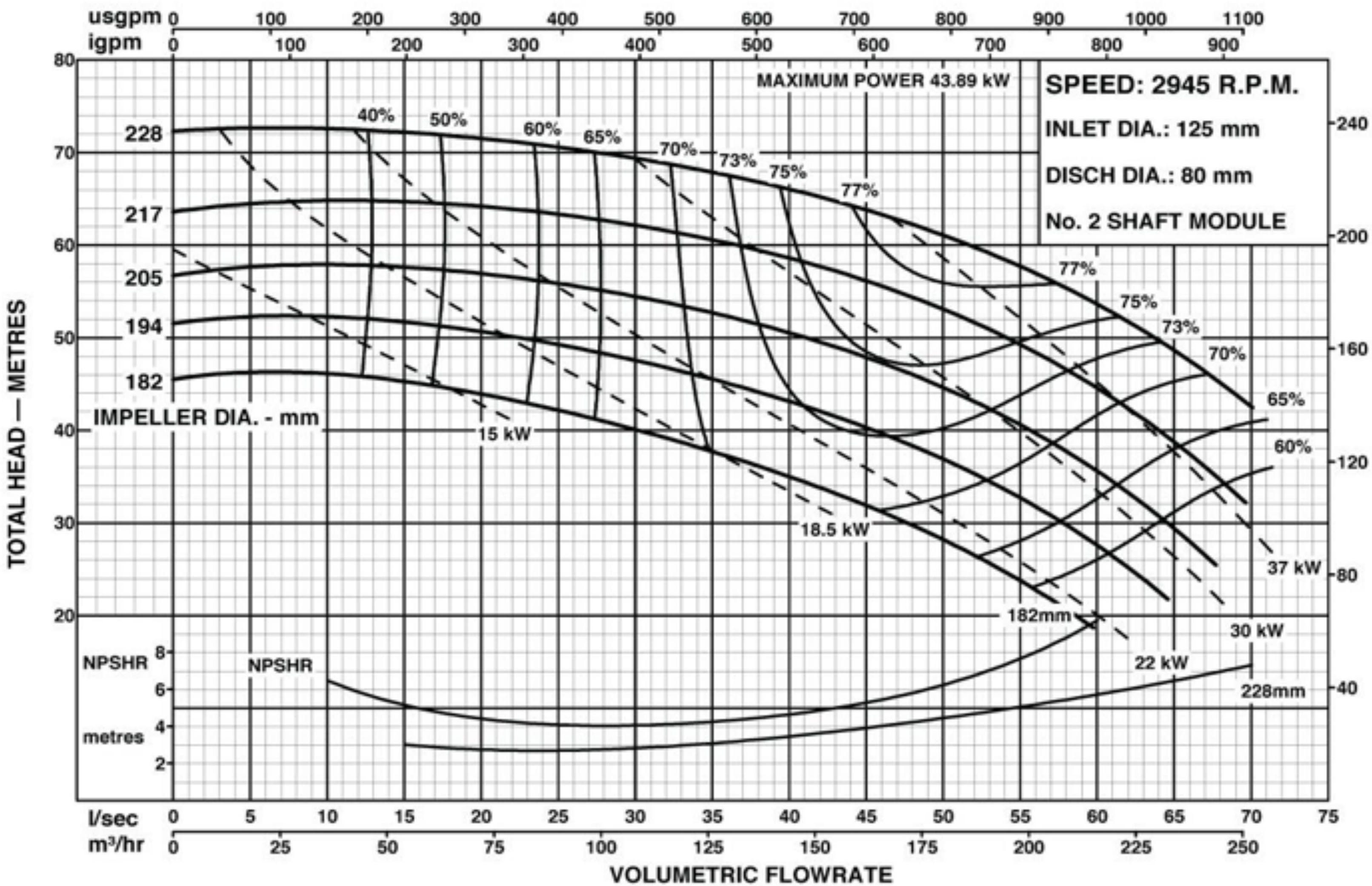
Pump Curves

- Provided information from the manufacturer on the performance of pumps in the form of curves.
- Information may include:
  - discharge on the x-axis
  - head on the left y-axis
  - pump power input on the right y-axis
  - pump efficiency as a percentage
  - speed of the pump (rpm)
  - NPSH of the pump

Southern Cross

CENTRIFUGAL PUMP PERFORMANCE DATA

Sovereign 125 x 80-200



Performance to AS2417 Grade 2 for clean, cold water only.

May 2005

How to

- Provided information from the manufacturer on the performance of pumps in the form of curves.
- Information may include:
  - discharge on the x-axis
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  - pump power input on the right y-axis
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  - speed of the pump (rpm)
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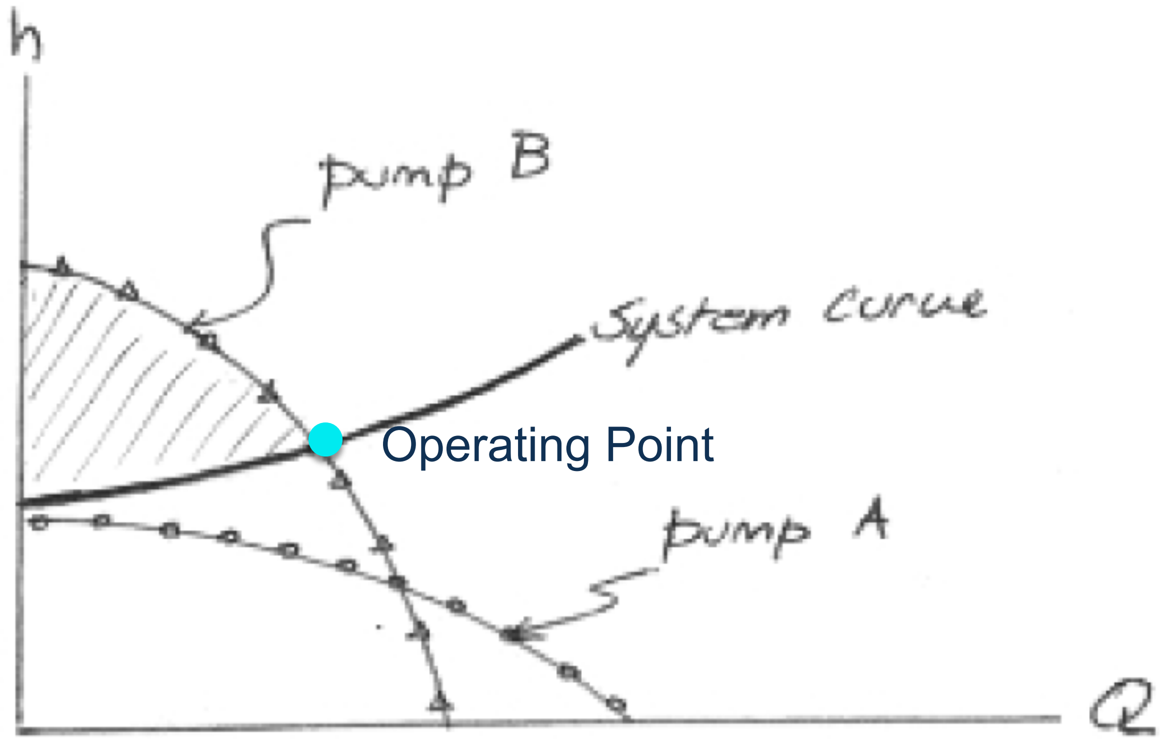
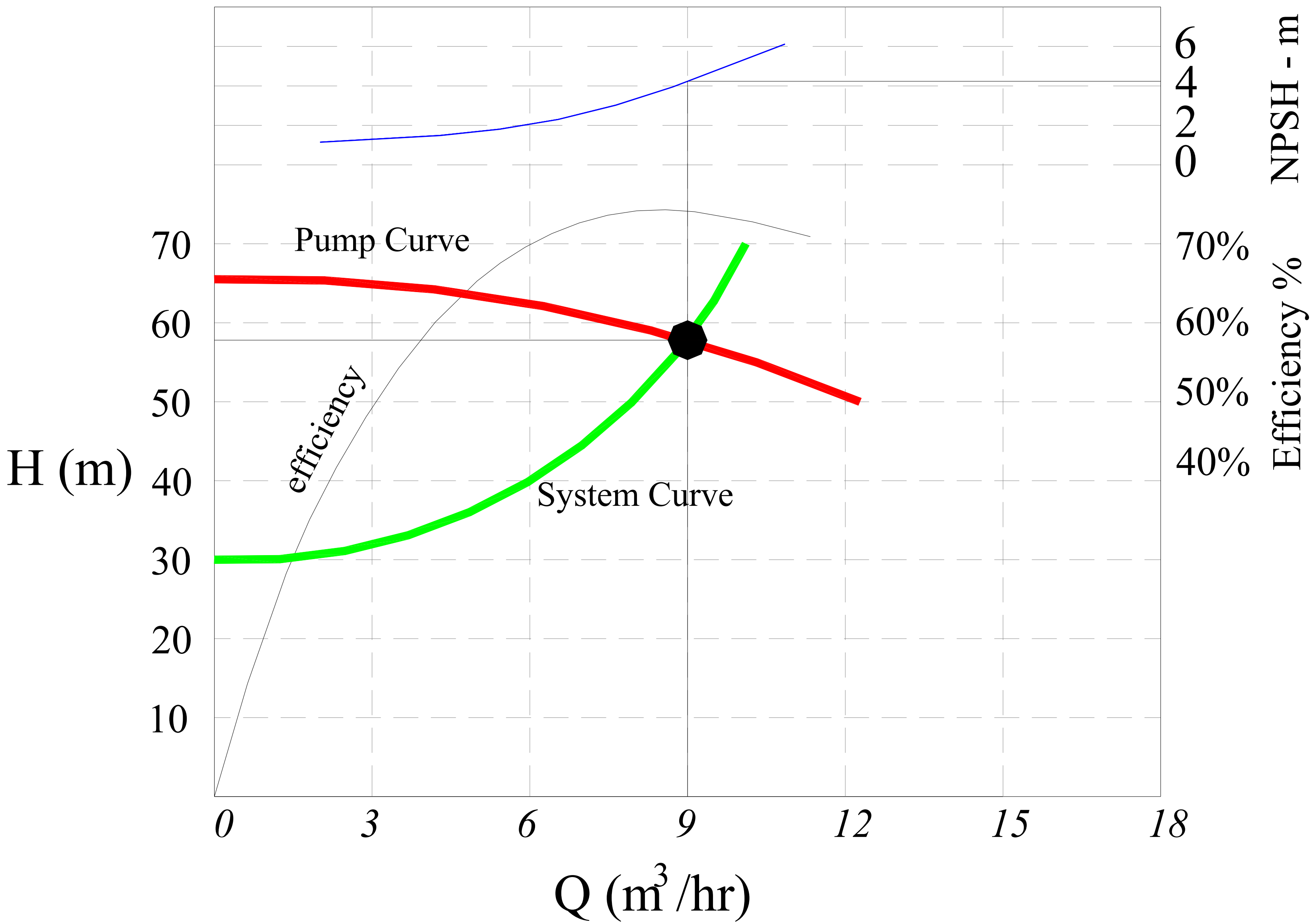
Pump Curves

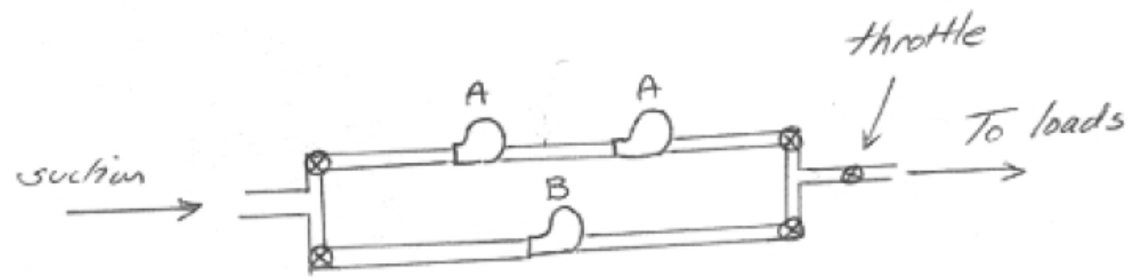


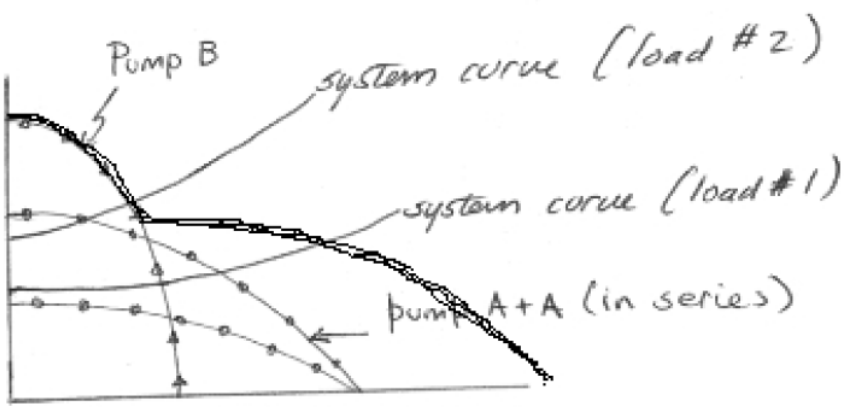
- Pump A cannot meet the needs of the system at any flow rate
- Pump B supplies enough head over part of the system curve
- The shaded area is the area where the pump supplies excess head


6
4
2
0
NPSH - m
Pump Curve
70
60
50
40
30
20
10
H (m)
70%
60%
50%
40%
Efficiency %
efficiency
System Curve
0
3
6
9
12
15
18
Q (m3 /hr)

Multiple Pumps

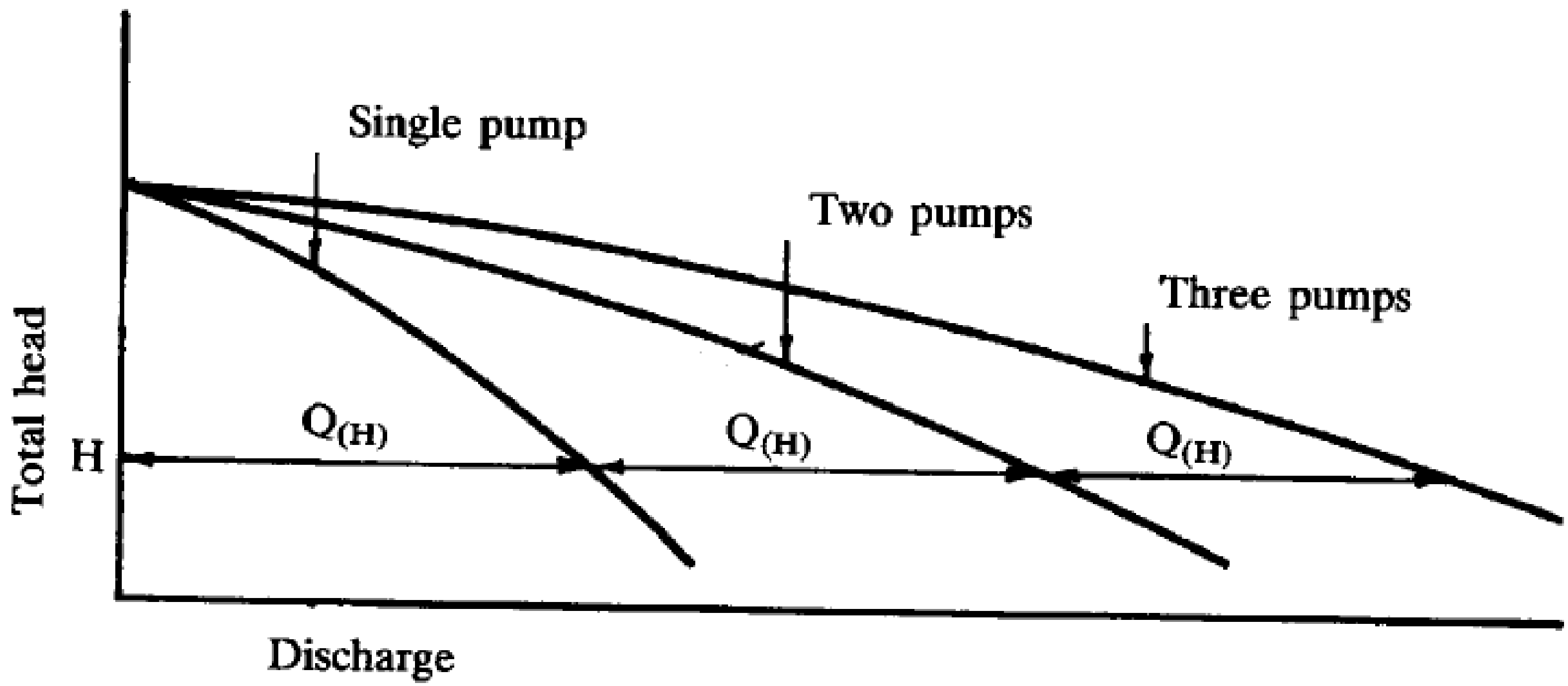
- Series and parallel combinations can be used to adjust "pump curves" to fit system requirements.

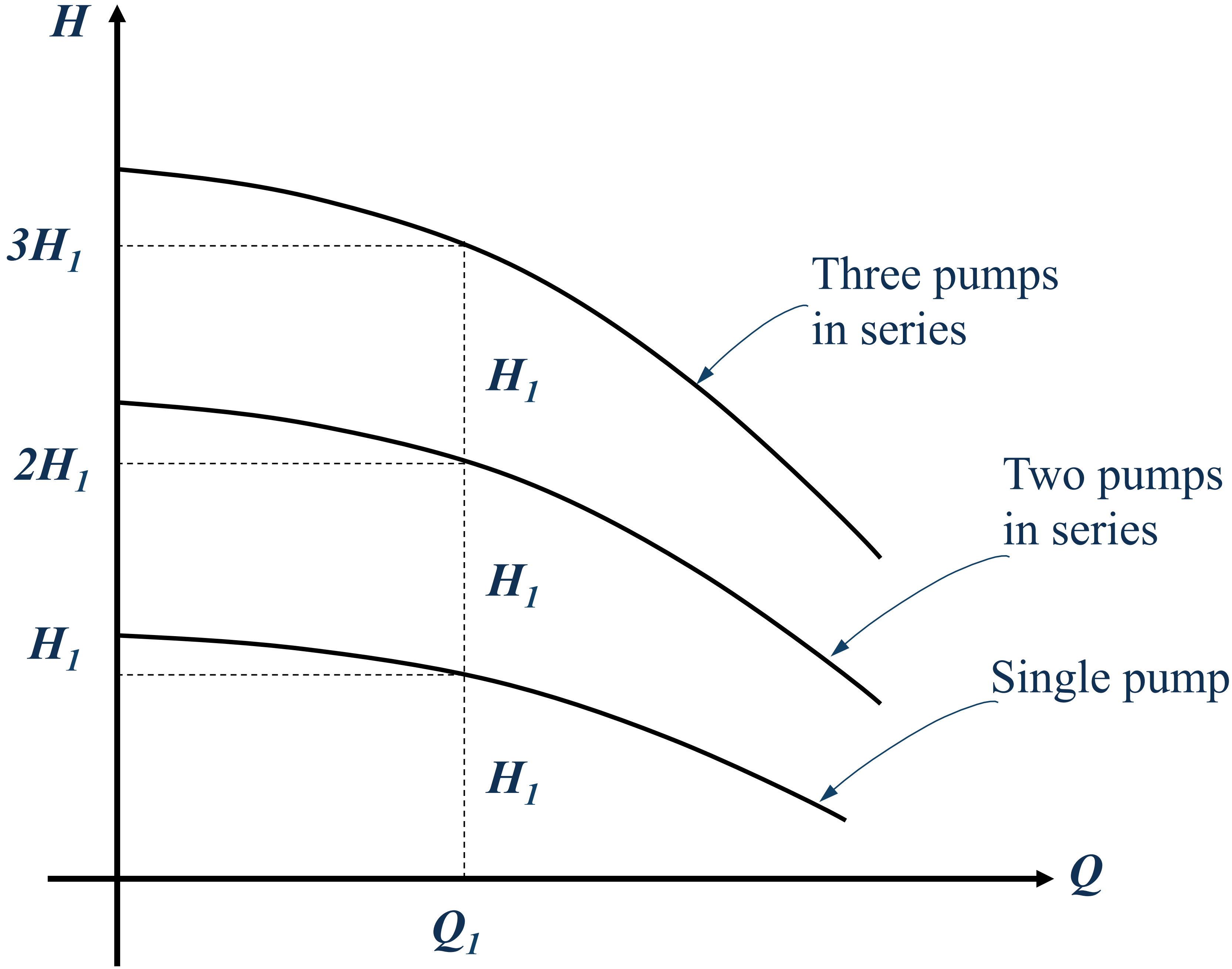




Parallel pumps add flow for given head

Series pumps add head for given flow


Single pump
Two pumps
Three pumps
Total head
H
Q(H)
Q(H)
Q(H)
Discharge


H
3H1
2H1
H1
H1
H1
H1
Three pumps in series
Two pumps in series
Single pump
Q
Q1

Lift Stations!

Lift Stations

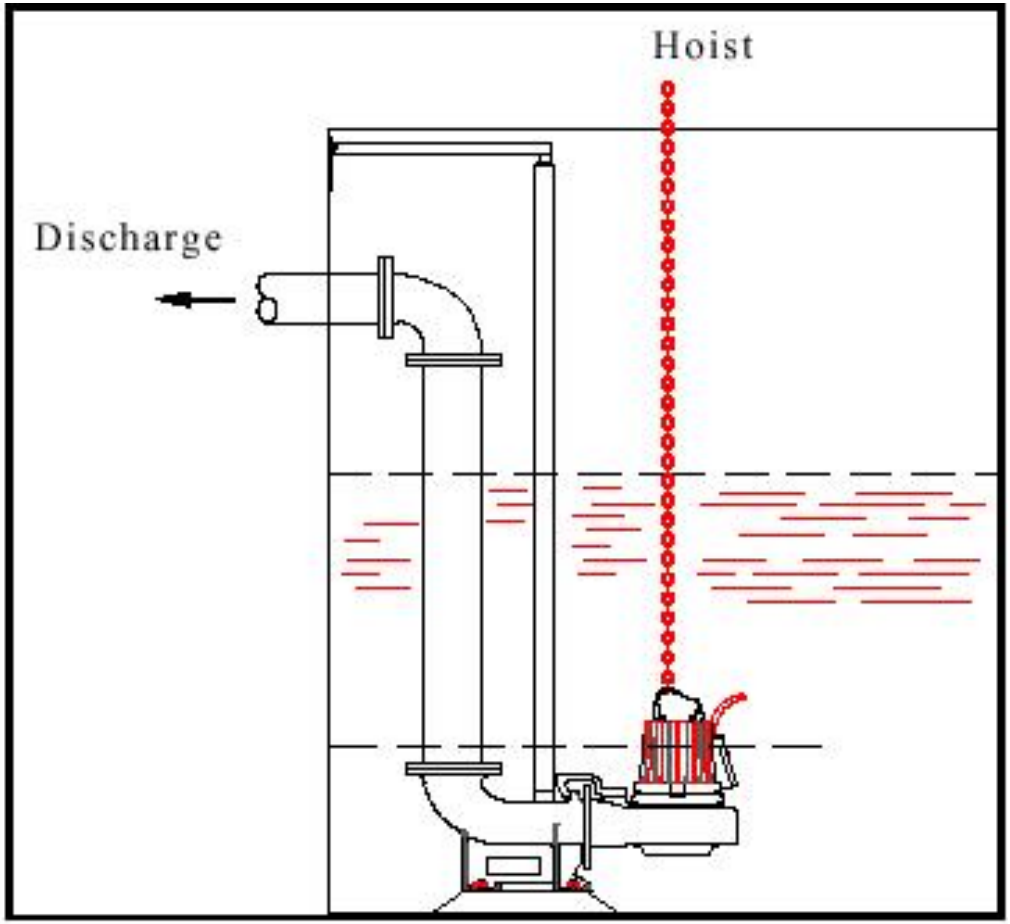
- Lift wastewater/stormwater to higher elevations when:
  - discharge of local collection system lies below regional conveyance
  - terrain or man-made obstacles do not permit gravity flow to discharge point.

Pond and Pump Station

Types of Lift Stations

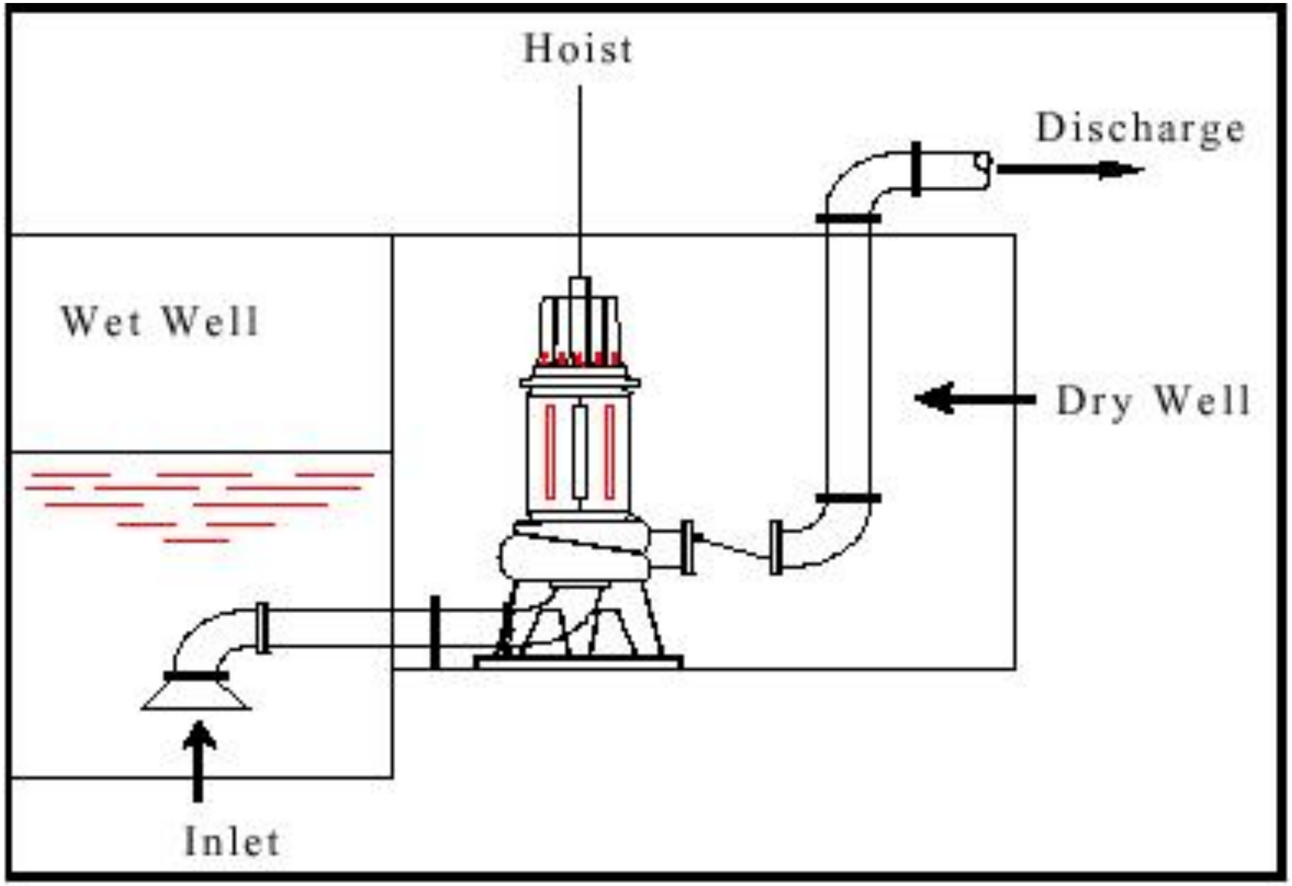
- Submersible
  - Lower initial cost
  - Lower capacity
  - Smaller footprint
- Wet-well / dry-well
  - Higher initial cost
  - Easier inspection/ maintenance

Submersible lift station



Source: Qasim, 1994.

Wet-well / dry-well lift station



Source: Qasim, 1994.

Design criteria

- Size the pumps and the wet-well (sump) storage capacity to accommodate inflow variability and detention time limits.
- Match the pumps to the flow and head requirements.
- Provide ‘near-absolute’ reliability
  - Automated controls
  - Redundant systems
  - Alarms
  - Regularly scheduled, preventive maintenance
- Assess and mitigate environmental factors
  - Flood risk, noise pollution, visibility

Site plan and facilities

- Protected and accessible during a major flood
- Redundant power supplies
- Intruder-resistant with controlled access

Readings (on server)

Pump Specification

Pump Selection Walker, R. 1973. Pump Selection. Ann Arbor Science pp. 3-9

Suction and Discharge Conditions Walker, R. 1973. Pump Selection. Ann Arbor Science pp. 11-31

Lift Station Design Highway Stormwater Pump Station Design. FHWA-NHI-01-007

Lift Station Design City of Houston, Lift Station Design Guidelines

NPSH Exlaination Hauser, B. A., 1991. Practical Hydraulics Handbook. Lewis Publishers, Michigan. pp 296-299