# *Basics of Pump and Pipeline Design*

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# Objective

To provide the participants with basic knowledge of pump and pipeline design and selection.

This knowledge is essential to designing an economical and efficient irrigation or watering and conveyance system as well as verifying third party designs.

Not Covered:

- Detail analysis of transient flow and surge
- Pipeline network design & economic pipe sizing
- Design of laterals and manifolds or multi-outlet pipes
- Specialty pumps  and much more…

# Outline

Part I – Pipeline Design

- Technical Resources & Hydraulics ..... Farahani
- Design Considerations ..... Prestwich

Part II – Pump Design

- Technical Resources, Types, & Components ..... Prestwich
- TDH, Pump Curve, Energy ..... Farahani
- Pump Station Layout & VFD ..... Prestwich

# Wooden Pipe (Los Angeles - late 1800s)

# Pipeline Technical Resources

- Conservation Practice Standard – 430 Irrigation Pipeline
- Conservation Practice Standard – 516 Livestock Pipeline
- NEH Part 636, Chapter 52, Structural Design of Flexible Conduits

  Plastic, steel, aluminum, corrugated metal, & ductile iron pipe
- ASABE – Design, Installation and Performance of Underground Thermoplastic Irrigation Pipelines; Standard S376.1
- ASCE - Pipeline for Water Conveyance and Drainage
- Irrigation and hydraulics design textbooks
  - Irrigation System Design – R.H. Cuenca
  - Design & Operation of Farm Irrigation Systems – ASABE
- Manufactures' literature – Hunter, JM Eagle
- Pipeline Installation – Ambster Howard
- PPI Handbook of Polyethylene Pipe (2nd ed.) – http://www.plasticpipe.org/
- NRCS AgPipe - Design of Irrigation and Livestock Pipe Systems (Win7?)
- NRCS EFT - Pipeline Tool (under construction?)
- State irrigation, pipeline, watering facility design spreadsheets (Numerous!)

# National Payment Schedule

- **Typical Pipes in National Scenarios:**
  - 430 Irrigation Pipeline – Typical practice sizes 2 – 24”
    - PVC (IPS & PIP) <= 8” & >= 10”
    - HDPE (IPS-tubing) <= 8” & >= 10”; Surface HDPE (IPS-tubing)
    - Steel (IPS) <= 8” & >= 10”; Surface Steel (IPS); Steel (CSP)
    - Surface Aluminum

  - 516 Livestock Pipeline – Typical practice sizes 1/2 – 4”
    - PVC (IPS)
    - HDPE (IPS-tubing); Surface HDPE (IPS-tubing)
    - Steel (IPS); Surface Steel (IPS)

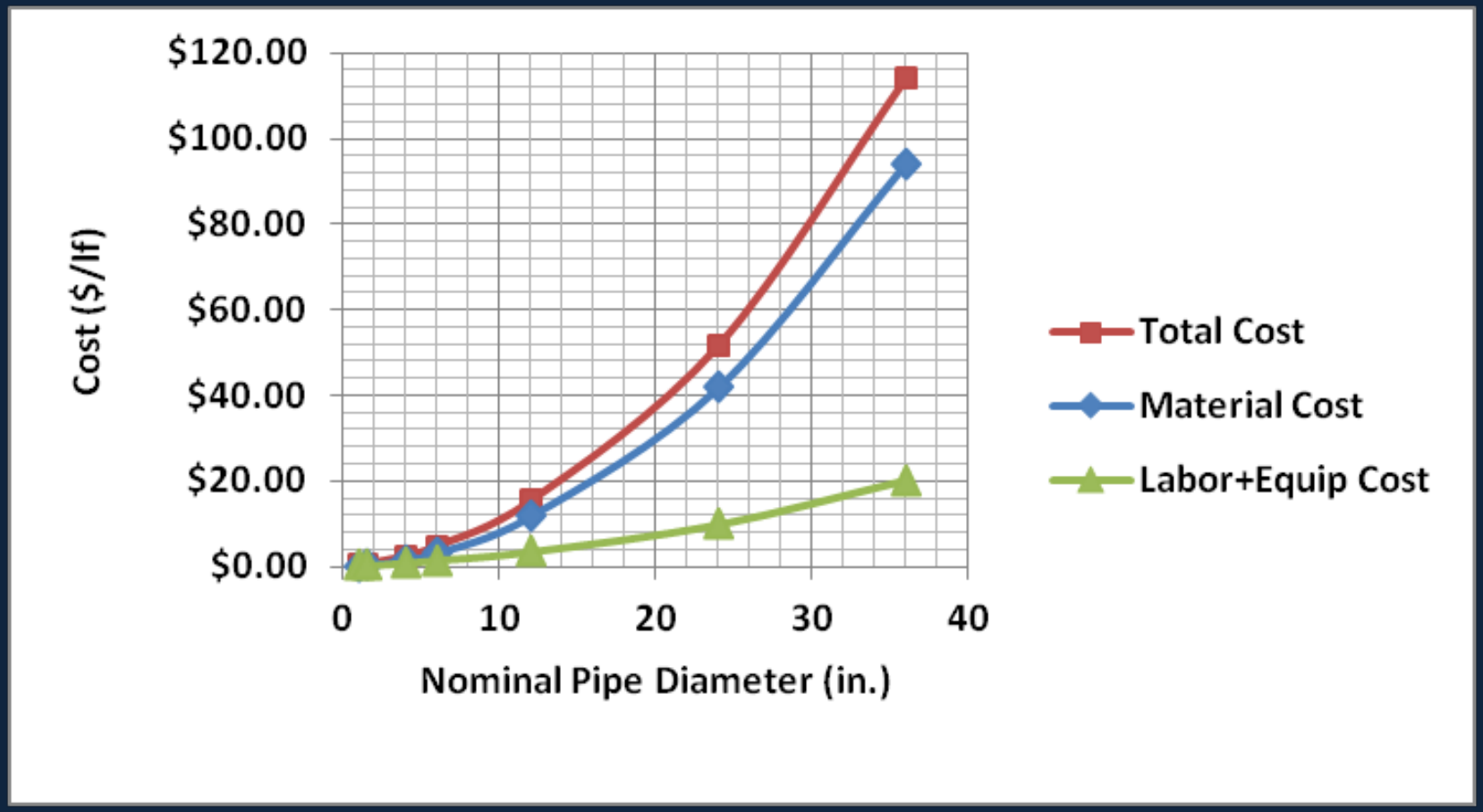
- **Regional Scenarios – Units are “lb” and/or “ft”**
  Mostly bracketed by type & diameter, & by ease and depth of installation

- **NRCS Pipe Weight Calculator Tool (Peter Robinson, WNTSC)**
  Helps field employees determine weight of pipe used in NRCS contracts.
  https://ems-team.usda.gov/sites/NRCS_ST/wntsc/coreteam/engineering/WME/PWC/SitePages/Home.aspx
  (inspired by the first calculator designed by Joe Lange, NRCS WA)

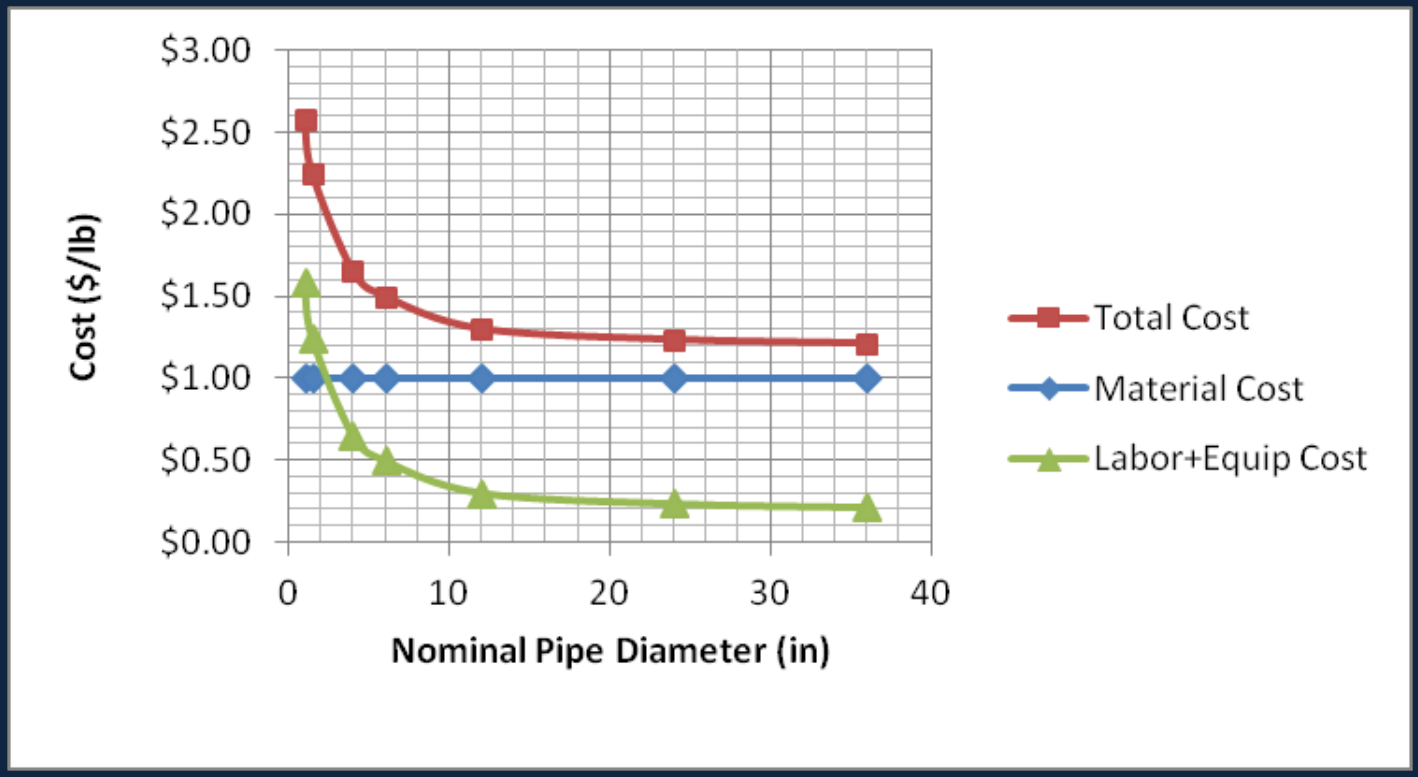
# Pipe Weight Calculator

| | |
|---|---|
| **Pipe Material:** | PVC (Polyvinyl Chloride) |
| **Pipe Rating:** | SDR-26.0, PVC 2120, 160 psi |
| **Nominal Diameter (inches):** | 2½ |
| **Length of Pipe (feet):** | 5,280 |
| **Unit Weight (pounds/foot) =** | 0.605 |
| **Total Weight (pounds) =** | 3,194 |

# PVC Pipeline by Length ($/Linear Foot)



# PVC Pipeline by Weight ($/Pound)




Total cost = A decay function

# Importance of Proper Pipeline Design & Installation

Performance of a pumping plant and its associated pipelines are interrelated, so shall be their design.

- Pipelines are costly investments, yet extensively used on-farm.

- Poor pipeline design and installation can lead to:
    - high initial cost (i.e., via over design)
    - excessive friction losses and increased pumping costs
    - costly repairs and safety issues caused by surge, air entrapment, freezing, improper joints & placement, and corrosion/abrasion.

Pipeline explosion

# Pipeline Implosion

Leaks

# Pipeline Definition

Pipelines are enclosed conduits that convey water from a source to an outlet.

Water flows in the pipeline because of gravity pressure (elevation changes), pumping pressure, or a combination thereof.

# Pipeline Design

Design to provide adequate pressure and flow at each turnout of the pipeline.

Two Factors are important: Friction and Surge
(both influenced by the relationship between flow velocity and pipe size)

- Friction losses result from surface roughness.
- Water hammer/surge results from transient flow (i.e., sudden change in velocity) in the pipe.

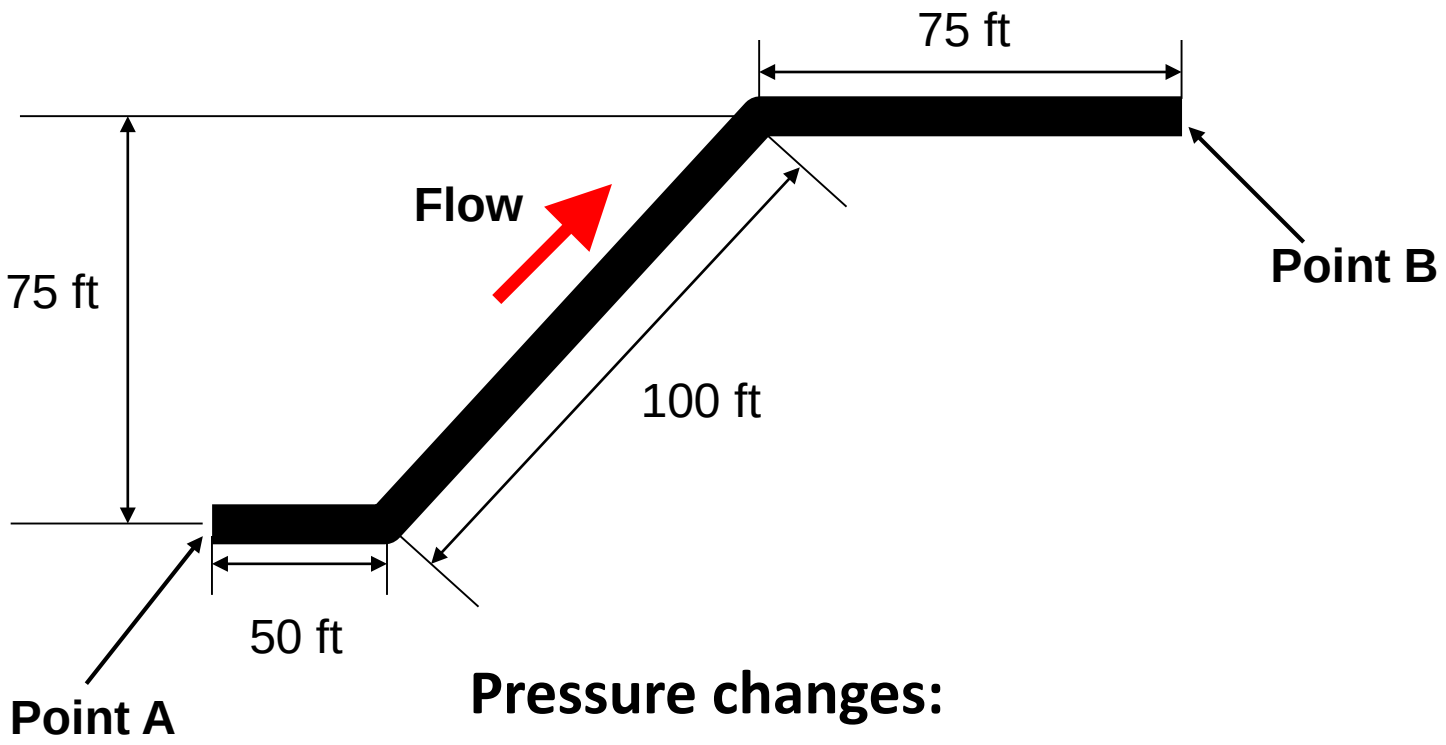
# Pipeline Sizing

The best size is not always the one with the lowest initial cost, but the size which minimizes the capital, pumping, maintenance and energy costs during the life of the system.

Use of larger diameters should be considered when significant long-term energy savings can be made in the operation of the overall system.

Economics generally dictate that the minimum velocity should be at least 3.0 ft/s.

# Pressure Changes in Flowing Pipeline




**Pressure changes:**

- Elevation change - uphill 75 feet - STATIC
- Friction losses in 225 ft pipe
- Minor losses (bends, entrances, fittings)

## What Causes Pressure Changes in Pipeline?

- Pressure loss (or gain) due to elevation
- Pressure losses due to friction
- Pressure losses (minor losses) due to valves, meters, and fittings, and entrances

# Friction Loss Calculation

## Hazen-Williams Equation

$$\text{Friction Loss} = \frac{10.536}{D^{4.866}} \left[ \frac{Q}{C} \right]^{1.852} \text{x L}$$

Friction Loss in ft (Note: 1 ft of head = 0.433 psi)

Q = flow in gpm

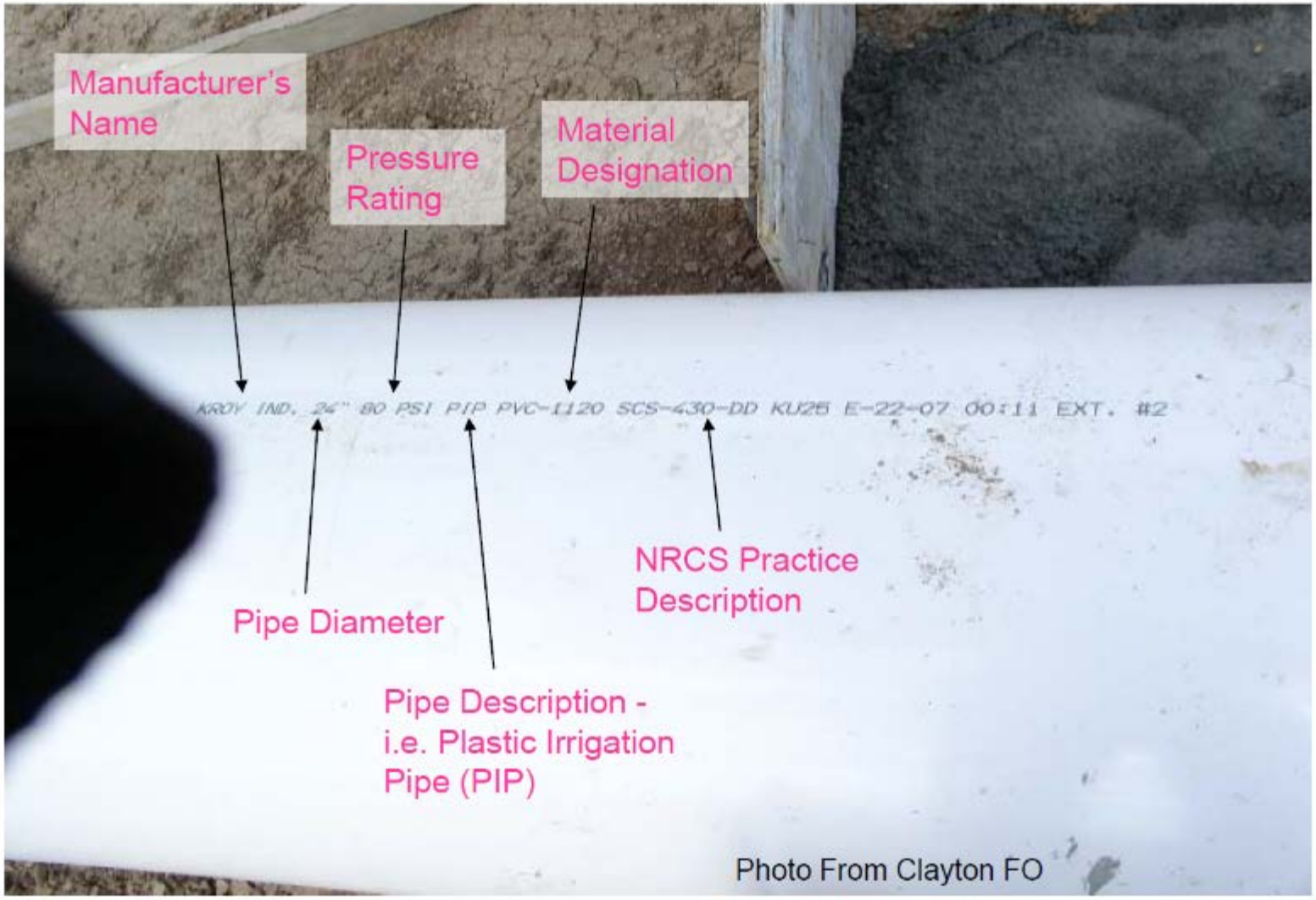
C = roughness coefficient

D = inside diameter of pipe in inches

L = length of pipe in feet

LET'S EXAMINE THIS EQUATION…

# Plastic Irrigation Pipe Markings
## Example



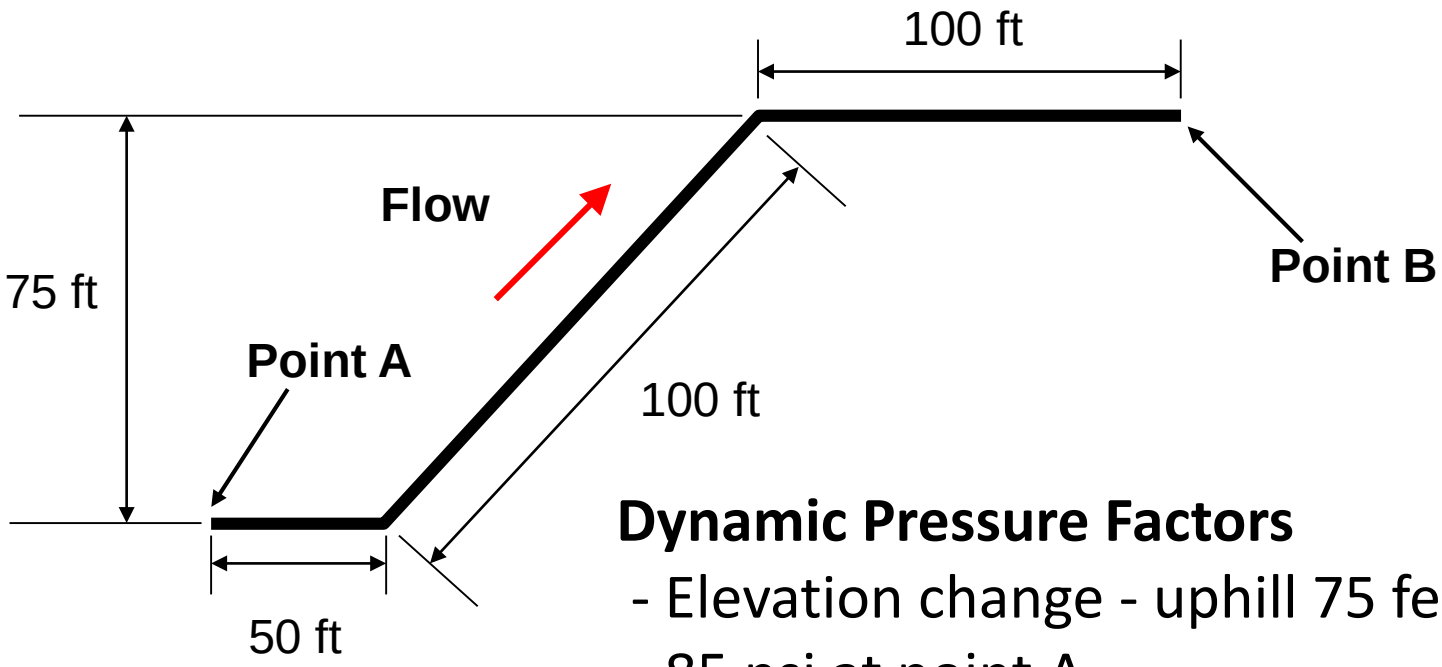
# Friction Loss Characteristics
## Class 200 IPS PVC Plastic Pipe
## (1120, 1220) SDR 21 C=150 3/4" through 5"
## Pressure Loss per 100 feet

| **Nominal Size** | **3/4"** | | **1"** | | **1-1/4"** | |
|---|---|---|---|---|---|---|
| **Pipe ID** | 0.93 | | 1.189 | | 1.502 | |
| **Pipe OD** | 1.050 | | 1.315 | | 1.660 | |
| **Wall Thickness** | 0.060 | | 0.063 | | 0.079 | |
| **Flow GPM** | **Velocity FPS** | **PSI LOSS** | **Velocity FPS** | **PSI LOSS** | **Velocity FPS** | **PSI LOSS** |
| **1** | 0.47 | 0.05 | 0.29 | 0.02 | 0.08 | 0.01 |
| **2** | 0.94 | 0.22 | 0.58 | 0.07 | 0.06 | 0.02 |
| **3** | 1.42 | 0.46 | 0.87 | 0.14 | 0.54 | 0.04 |
| **4** | 1.89 | 0.79 | 1.15 | 0.24 | 0.72 | 0.08 |
| **5** | 2.36 | 1.19 | 1.44 | 0.36 | 0.90 | 0.12 |
| **6** | 2.83 | 1.67 | 1.73 | 0.51 | 1.09 | 0.16 |
| **7** | 3.30 | 2.23 | 2.02 | 0.67 | 1.27 | 0.22 |
| **8** | 3.77 | 2.85 | 2.31 | 0.86 | 1.45 | 0.28 |
| **9** | 4.25 | 3.55 | 2.60 | 1.07 | 1.63 | 0.34 |
| **10** | 4.72 | 4.31 | 2.89 | 1.30 | 1.81 | 0.42 |
| **12** | 5.66 | 6.04 | 3.46 | 1.83 | 2.17 | 0.59 |
| **14** | 6.60 | 8.04 | 4.04 | 2.43 | 2.53 | 0.78 |

# C Values for Different Pipe Material

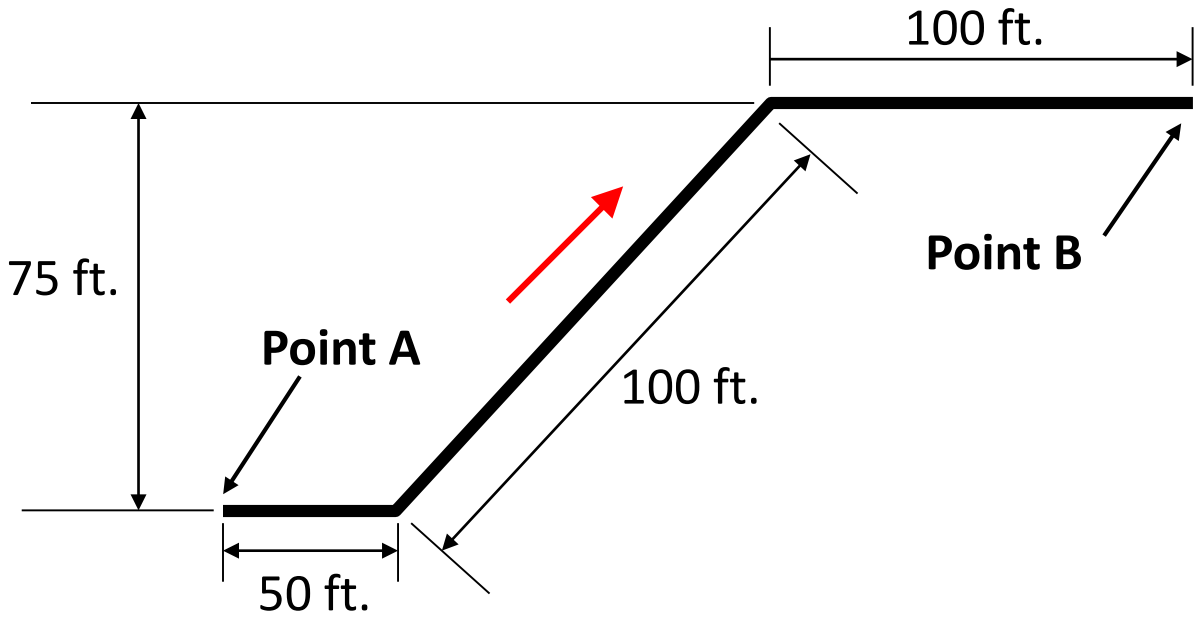
| | |
|---|---|
| PVC | 150 |
| Cement-Asbestos | 140 |
| PE | 140 |
| PE w/emitters | 130 |
| Alum w/couplers | 120 |
| 15-year-old Steel | 100 |
| Concrete | 100 |
| Steel, Corrugated, Helical | 90 |
| Steel, Corrugated, Annular | 60 |

# Exercise - Pressure Change From A to B



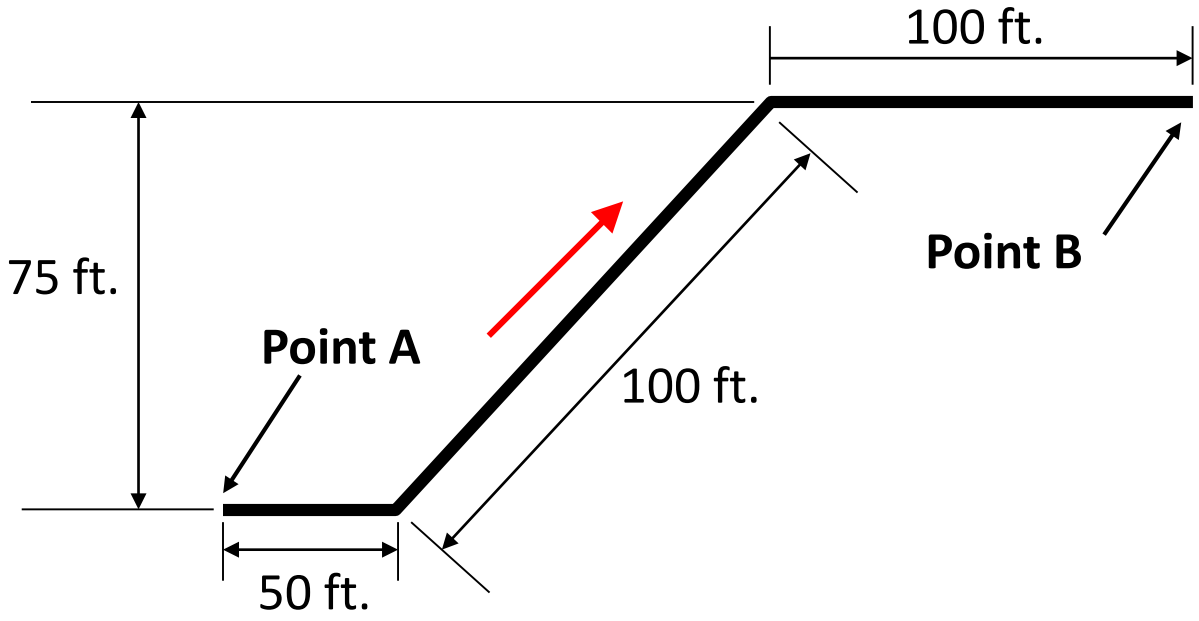

**Dynamic Pressure Factors**

- Elevation change - uphill 75 feet
- 85 psi at point A
- Pipe is 250 feet of 2-1/2 in. SDR 21 IPS PVC
- 100 gpm from point A to B




## Pressure Loss due to Elevation

75 ft x 0.433 psi per ft = 32.48 psi loss

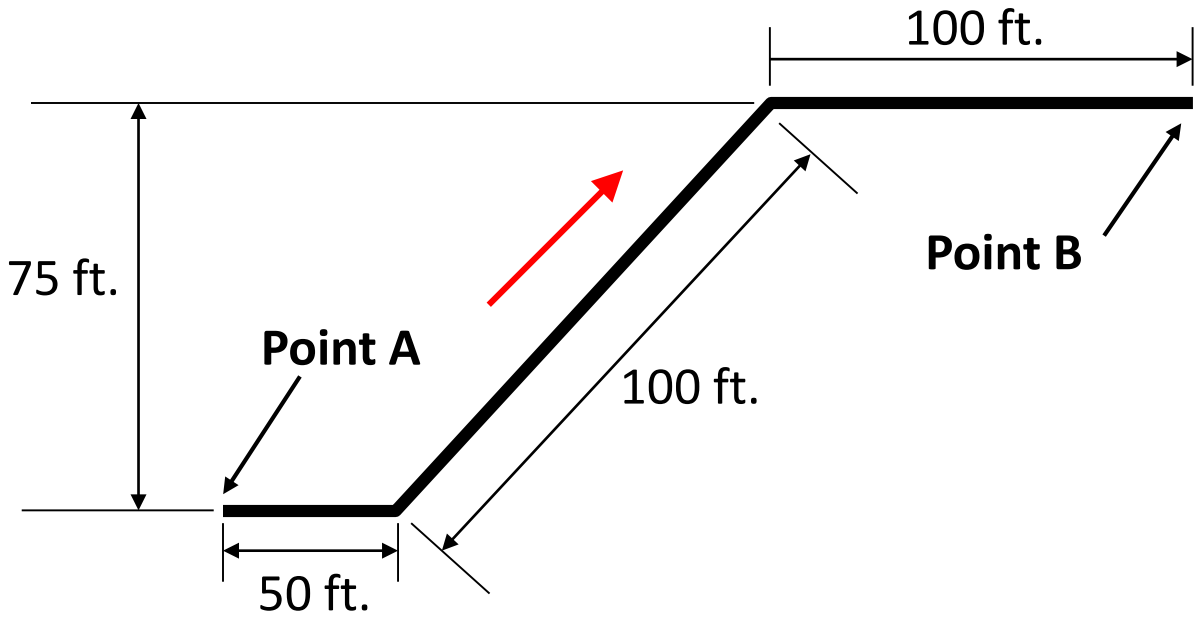



## Friction Loss in Pipe

From published Tables, friction loss = 2.06 psi per 100 ft

$H_f$ = 250 ft x 2.06 psi loss/100 ft = 5.15 psi

# Pressure Change From A to B




| | |
|---|---|
| 85.00 | psi at point A |
| -32.48 | psi loss due to elevation |
| -5.15 | psi friction loss in pipe |
| **47.37** | **psi pressure at point B** |

# Pressure Loss in Fittings

$$H = k\frac{v^2}{2g}$$

H = Head Loss in Feet

K = resistance coefficient

V = average velocity of liquid flow in the pipe in feet per second

g = acceleration of gravity, 32.2 ft. per second

# Head Loss Coefficients for Fittings and Special Conditions where $H = kv^2/2g$

| Nature of Resistance | Recommended k |
|---|---|
| Square edge entry | 0.50 |
| Projecting pipe at entry, or re-entrant pipe | 1.00 |
| $90^o$ large radius bends | 0.25 |
| $90^o$ short radius bends | 0.50 |
| Tees or crosses, straight flow | 0.10 |
| Tees or crosses, angle flow | 1.50 |
| Taper reducer (refer to smaller pipe) | 0.25 |
| Taper increaser (refer to smaller pipe) | 0.15 |
| Sudden contraction (refer to smaller pipe) | 0.35 |
| Sudden enlargement (refer to smaller pipe) | 0.20 |
| Foot valve | 3.00 |
| Globe valve, open | 3.00 to 15.00 |
| Gate valve | 0.10 |
| Angle valve, open | 5.00 |
| Alfalfa valve | 3.00 |
| $45^o$ short radius bends | 0.38 |
| Check valve[1] | 3.00 to 10.00 |

# Summary

- Design for the land owner
- Design with expansion in mind
- Design with long-term energy cost in mind
- Best size not always the lowest cost
- Remember pipeline failures can be very costly
- Verify third-party/owner designs before installed
- Inspect installation

# Outline

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## Part II – Pump Design

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- Pump Station Layout & VFD ..... Prestwich

# Pipe design

# Pressure

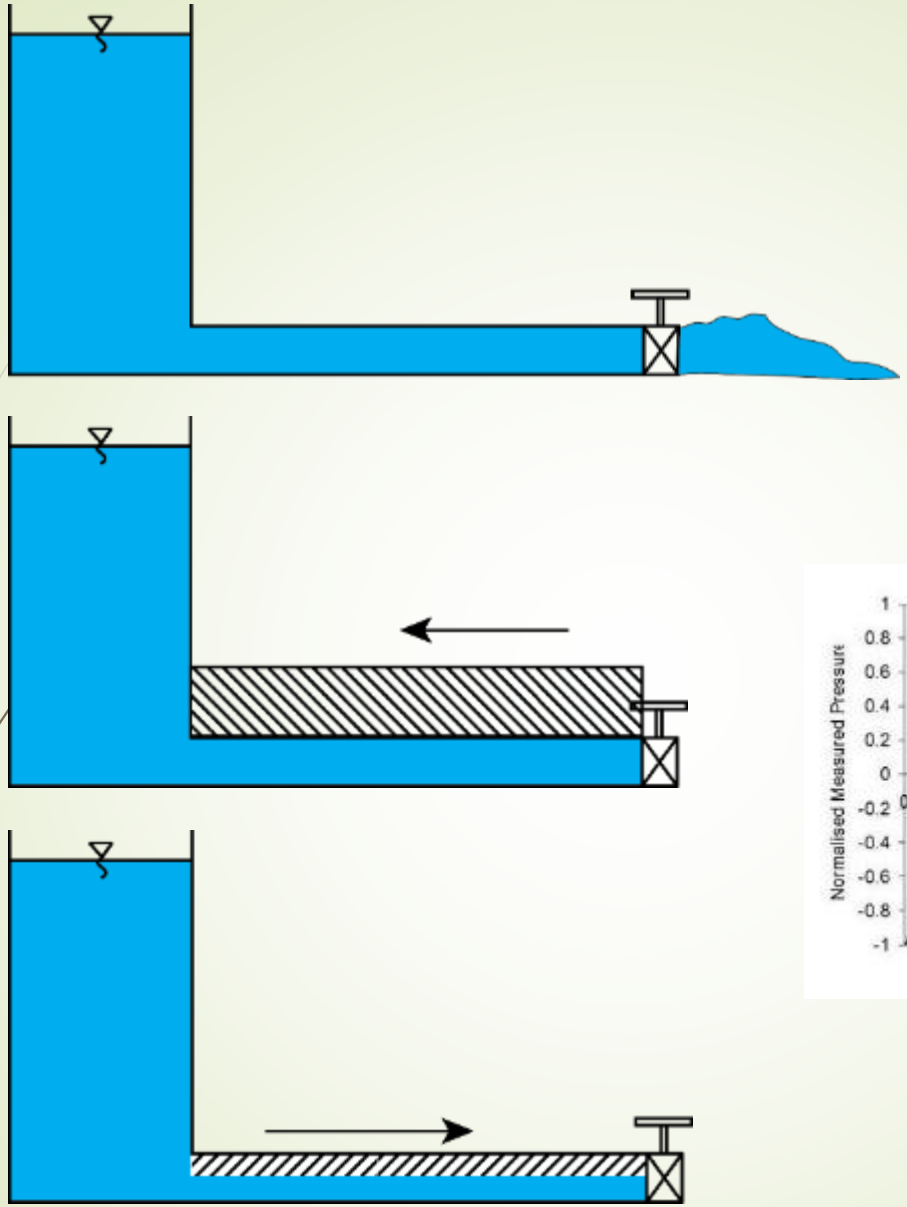
- The loss in pressure caused by friction is the primary consideration in the design of any pipe system.
- Source of pressure.
  - Pumped
  - Gravity
  - Combination pump and gravity

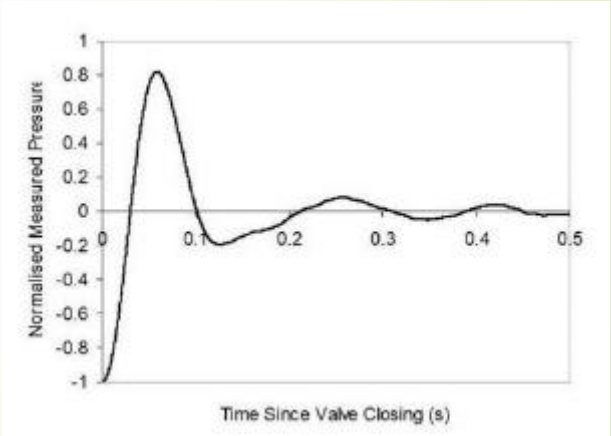
# Design Considerations

- Limit maximum operating velocities to 5 ft/s.
- Limit working pressure to 72 percent of pressure rating of pipe.

# Water hammer

- Transients occur in pipelines due to many actions, such as:
  - Starting and stopping of pumps
  - Changes in valve openings
  - Operation of pressure relief valves
  - Filling and emptying of pipelines
  - Sudden movement of air pockets
  - And others
- Water hammer is usually a concern in supply (conveyance) pipelines and in mainlines, so it should be afforded at least a cursory analysis




1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
0.1
0.2
0.3
0.4
0.5
Time Since Valve Closing (s)

# Air

- Why air vents/valves
  - Remove entrapped air
  - Relieve vacuum
- Type of air valves
  - Air vent
  - Air valve
  - Air/vac valve
  - Combination Air valve

# Where

- Peaks or summits
- Isolating valves
- Inlets
- Dead ends
- Sloped pipes –
- partial flow
- Long runs – flat grade
- Pumps road crossings
- Filter station
- Any place that might cause a disturbance or air can collect

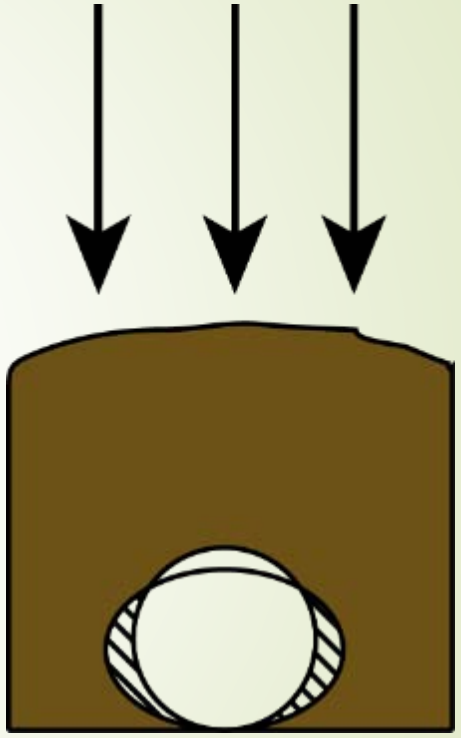
# Installation

- Buried pipe shall be installed at sufficient depth below the ground surface to provide protection from hazards imposed by traffic loads, farming operations, freezing temperatures, or soil cracking, as applicable.
- Pipelines shall have sufficient strength to withstand all external loads on the pipe for the given installation conditions. Appropriate live loads shall be used for the anticipated traffic conditions.
- Freezing, Floating, Deflection/deformation, Sunlight/UV, Traffic, Fire, Corrosion

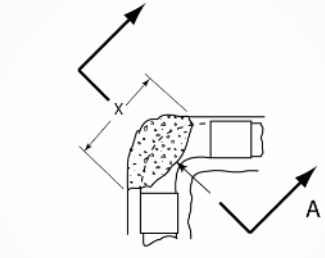
# Deflection

Special procedures are needed for following conditions

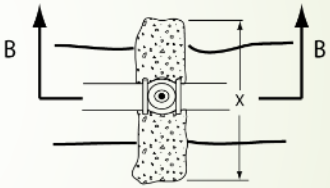
- Over 5 foot of fill
- Pipe diameters greater than 21”
- Water
- Traffic



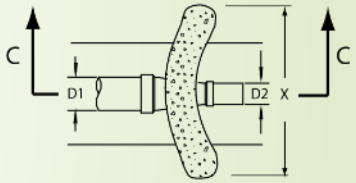
# Thrust Blocks



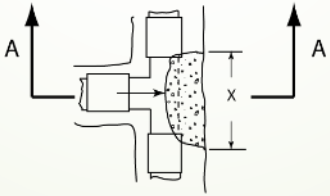
Elbow



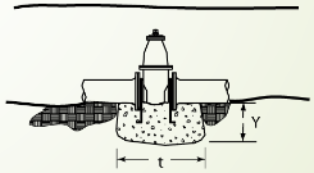
Valve



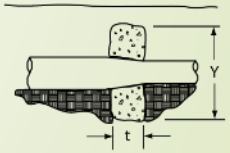
Reducer



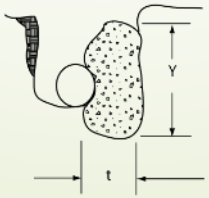
TEE



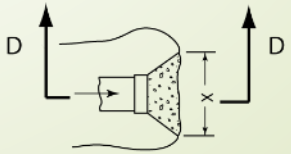
Section BB



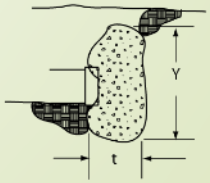
Section CC



Section AA



Dead end



Section DD

# Allowable Soil Bearing Pressure

| Natural Soil Material | Depth of cover to center of thrust block* | | | |
|---|---|---|---|---|
| | 2 ft. | 3 ft. | 4 ft. | 5 ft. |
| | lbs/ft$^2$ | | | |
| Sound Bedrock | 8,000 | 10,000 | 10,000 | 10,000 |
| Dense sand & gravel mixture (assumed $\phi$) | 1,200 | 1,800 | 2,400 | 3,000 |
| Dense fine to coarse sand (assumed $\phi = 35$) | 800 | 1,200 | 1,650 | 2,100 |
| Silt & Clay mixture (assumed $\phi = 25$) | 500 | 700 | 950 | 1,200 |
| Soft clay & organic soils (assumed $\phi = 25$) | 200 | 300 | 400 | 500 |

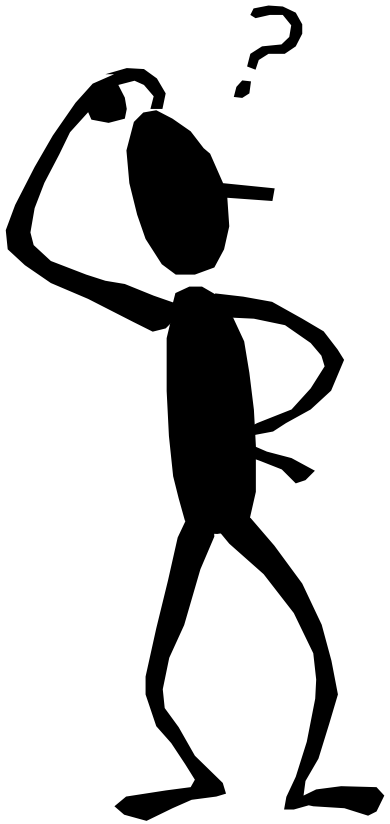
* Center of thrust block should be the same as the center of the pipe.

# Screens

# Gauges and pressure relief

# Flow meters

# Valves



# Questions?

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# Pumps

# Resources

- 533 conservation practice standard
- NEH Section 15, Chapter 8 Irrigation pumping plant
  - NEH Part 623, Chapter 8 Irrigation pumping plant
- Pumping Systems, USDA-ARS, H.Duke
- Hydraulics and Pump Seminar, Cornell Pump Company
- Understanding Pumps, Irrigation Association
- Pump Fundamentals, ITRC, Cal Poly
- Pump-flo.com
- Pump ed 101
- Manufactures literature

United States
Department of
Agriculture

Natural
Resources
Conservation
Service

**Part 623 Irrigation**
**National Engineering Handbook**

# Chapter 8 Irrigation Pumping Plants

Draft

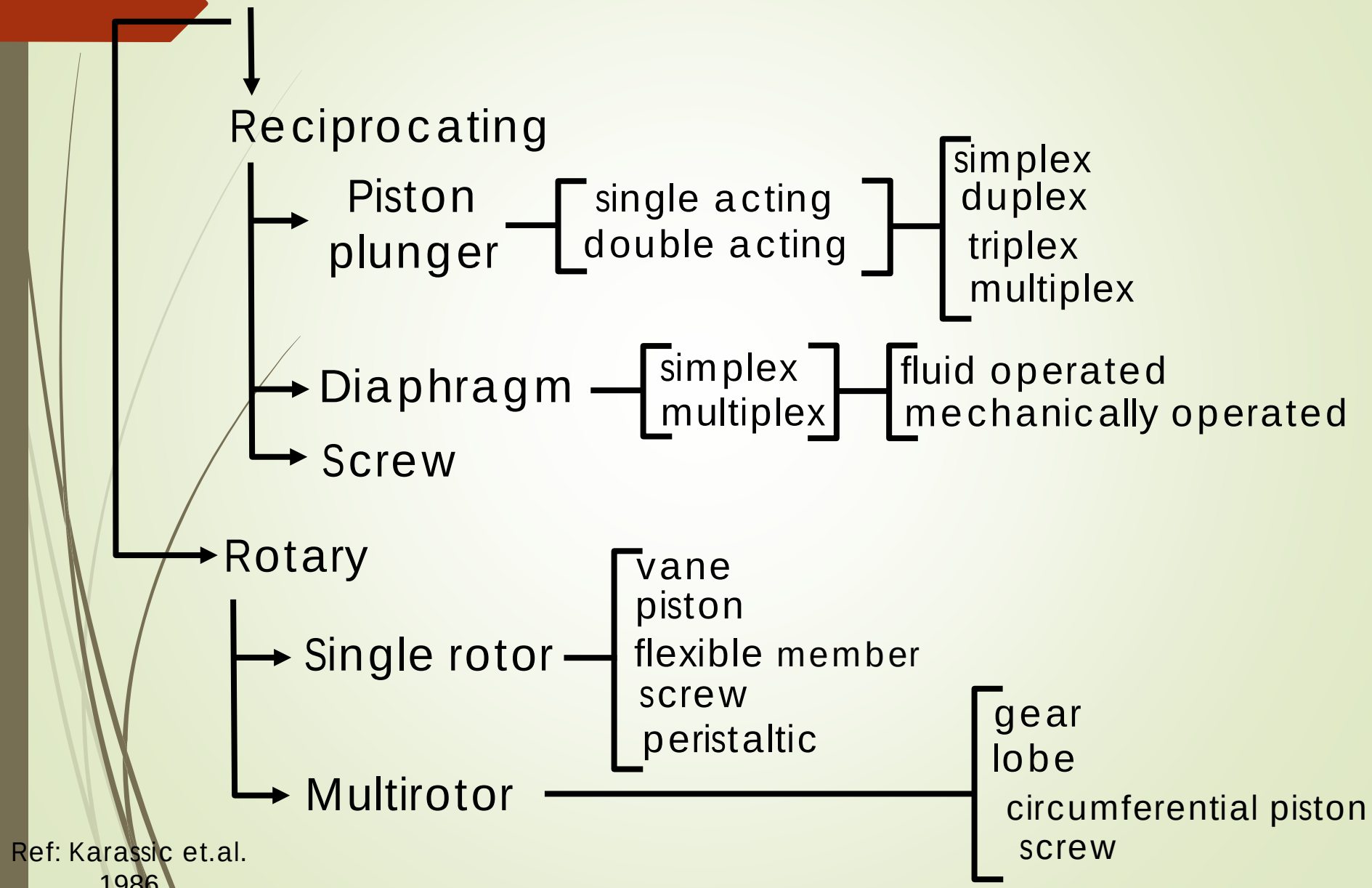
# Dynamic (energy transfer by kinetic principles)

## *Kinetic* (centrifugal)

- Axial flow
  - single stage
  - multistage
    - closed impeller
    - open impeller
      - fixed pitch
      - variable pitch
- Mixed flow
  - single suction
  - double suction
    - self priming
    - nonpriming
    - single stage
    - multistage
      - open impeller
      - semi-open impeller
      - closed impeller
- Radial (peripheral)
  - single stage
  - multistage
    - self-priming
    - nonpriming
- Special
  - jet (eductor)
  - gas lift
  - hydraulic ram
  - electromagnetic

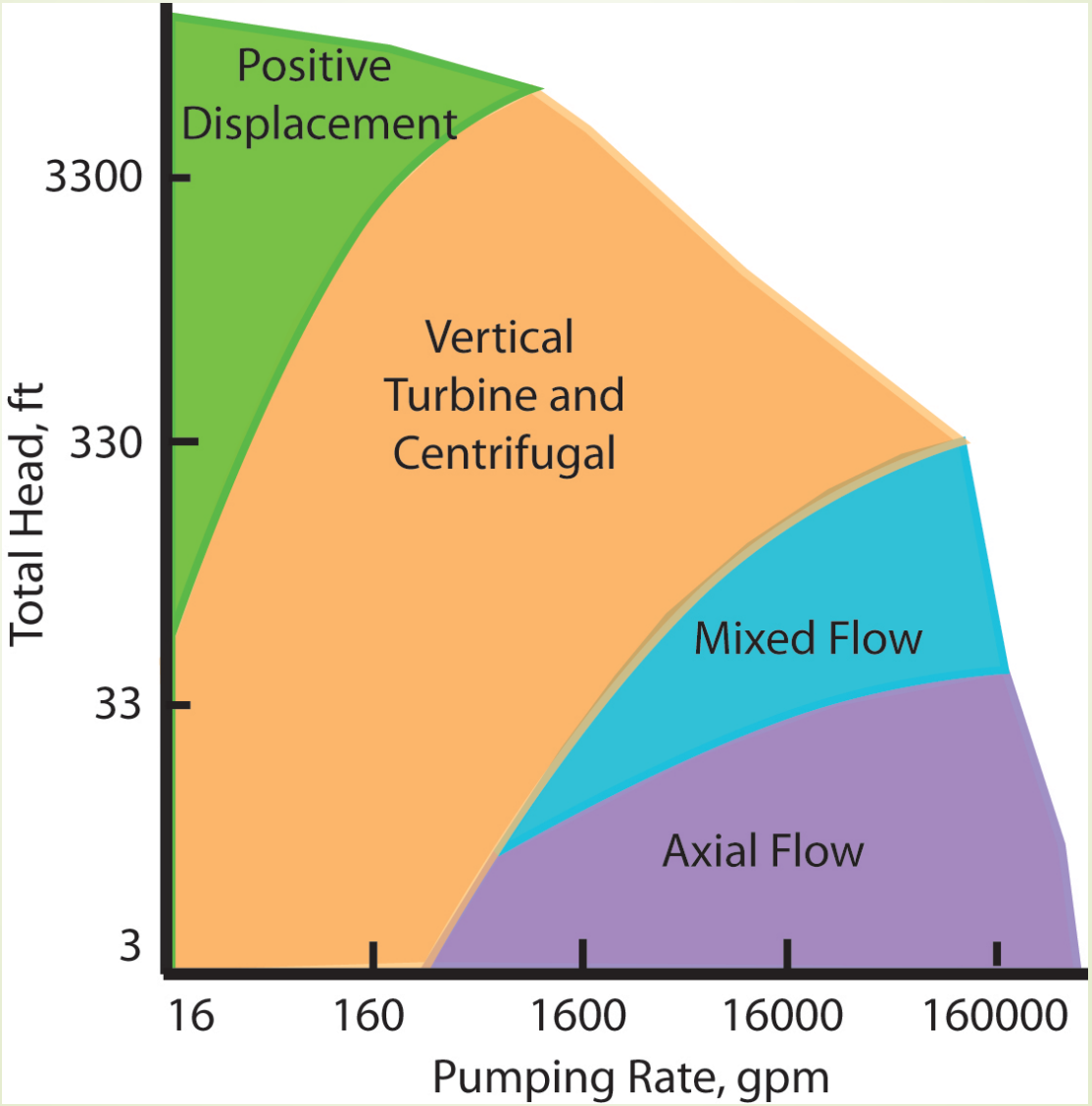
Ref: Karassic et.al. 1986

# Displacement (energy imparted by displacement)



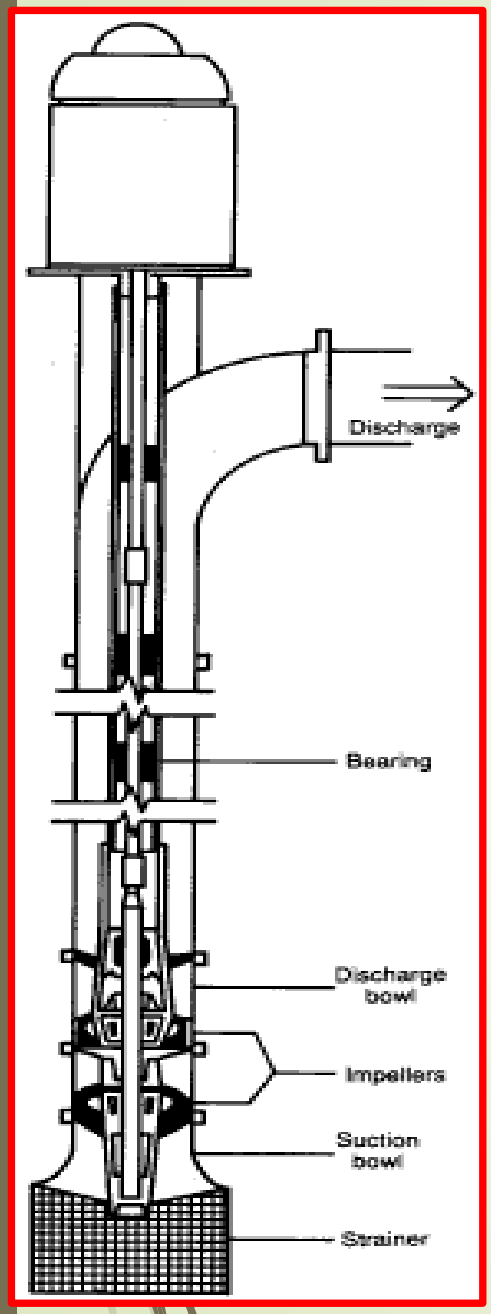

Ref: Karassic et.al. 1986

# Pump Types


Positive Displacement
Vertical Turbine and Centrifugal
Mixed Flow
Axial Flow
Total Head, ft
3300
330
33
3
16
160
1600
16000
160000
Pumping Rate, gpm

# Lift Pump

# Propeller Pumps



- Similar in configuration to a turbine
  - Suction Bowl
  - Impellers
  - Discharge Shaft

Low H – High Q

# Turbine pump

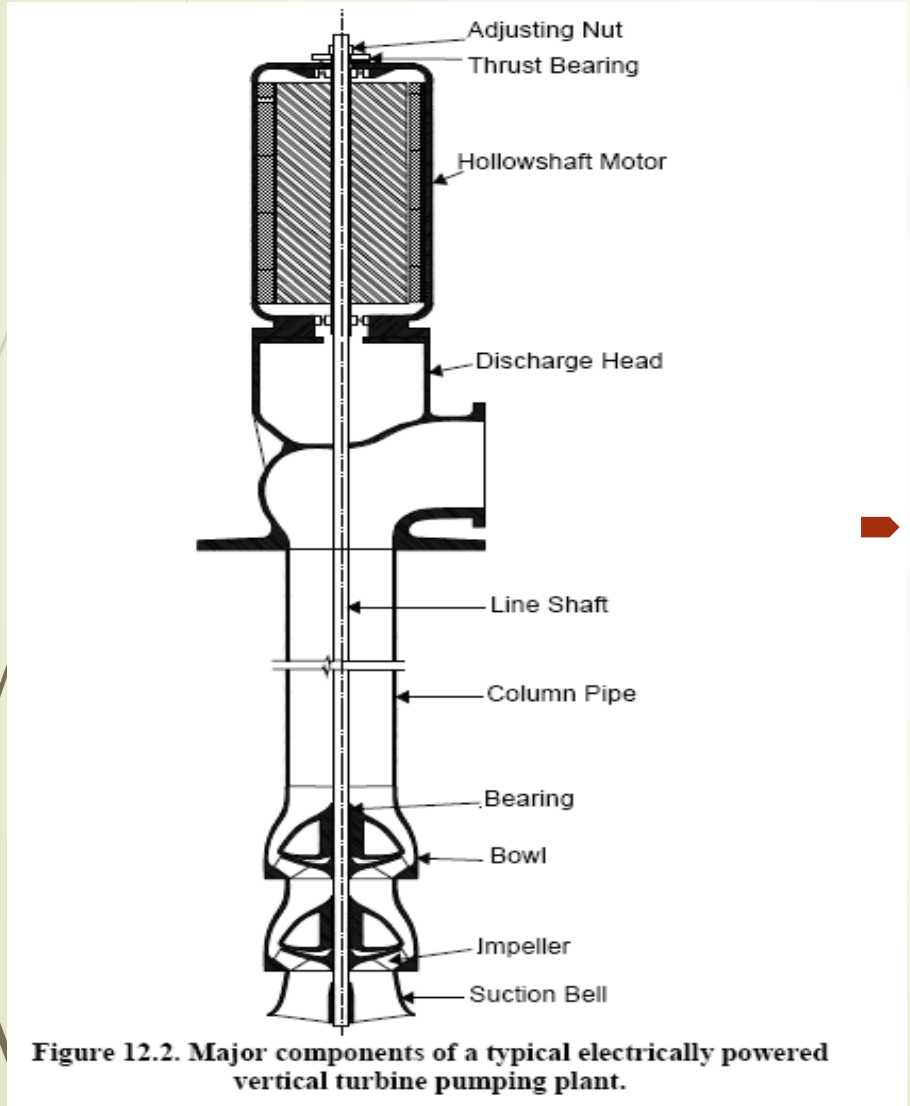



**Figure 12.2. Major components of a typical electrically powered vertical turbine pumping plant.**

- Primary Components
  - Motor (Driver)
  - Discharge Head Assembly
  - Column and Shaft Assembl
  - Bowl Assembly

**High H – High Q**

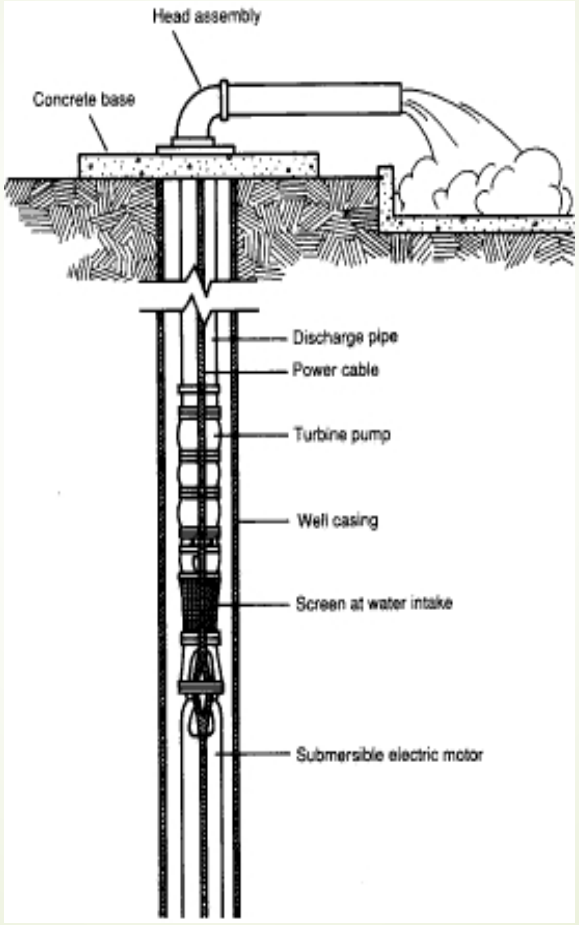
# Centrifugal Pumps

- Advantages
  - High Efficiency
  - Adaptable to range of operating conditions
  - Economical
  - Easy installation

- Disadvantages
  - Suction lift limited (NPSH requirements)
  - Requires priming

# Submersible Pump

- Advantages
  - Very Efficient
  - Minimal motor noise
  - Straight well not required for operation
  - Bowls can be fine tuned to meet user needs




- Disadvantages
  - Major work required to maintain motor and bowls
  - Large motors are very expensive
  - Electricity only practical power source

- Electric
- Propane
- Diesel

# Primers

# Foot Valves

- Used to hold water in suction line

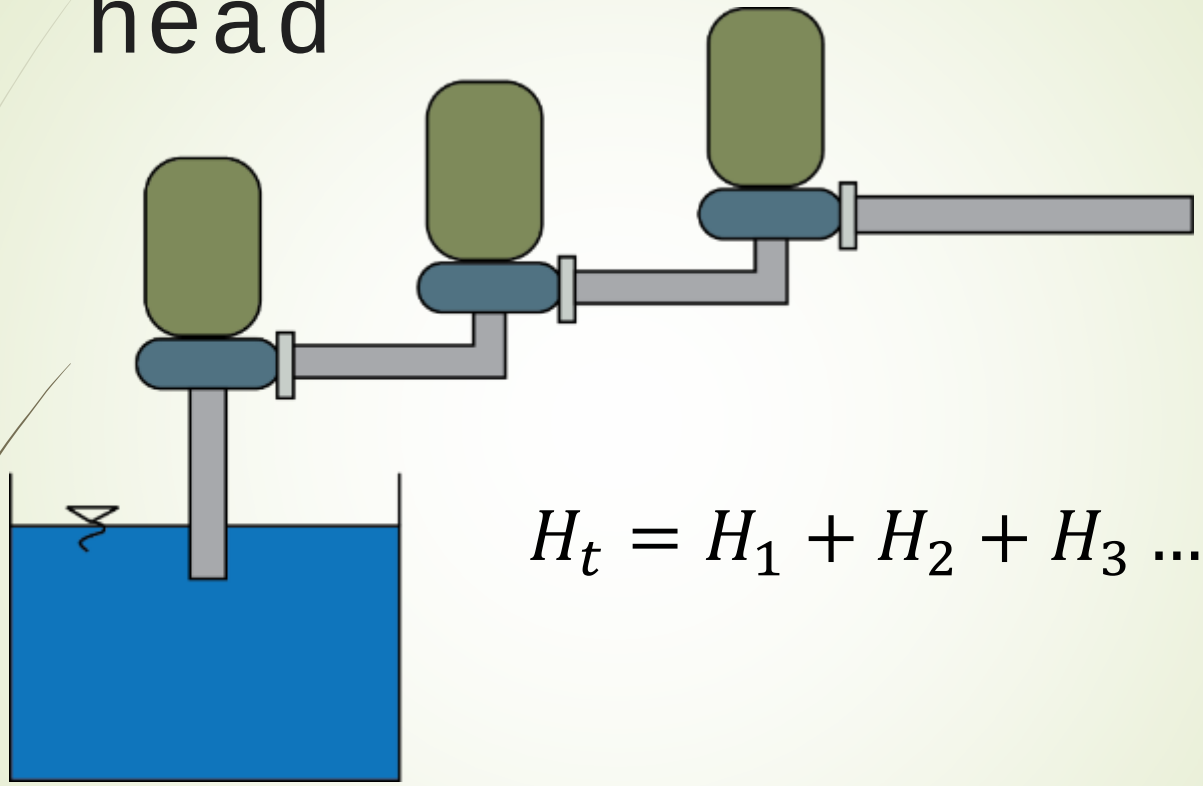
# Valves

# Air valves, PRV's, Pressure gages

# Multiple pumps

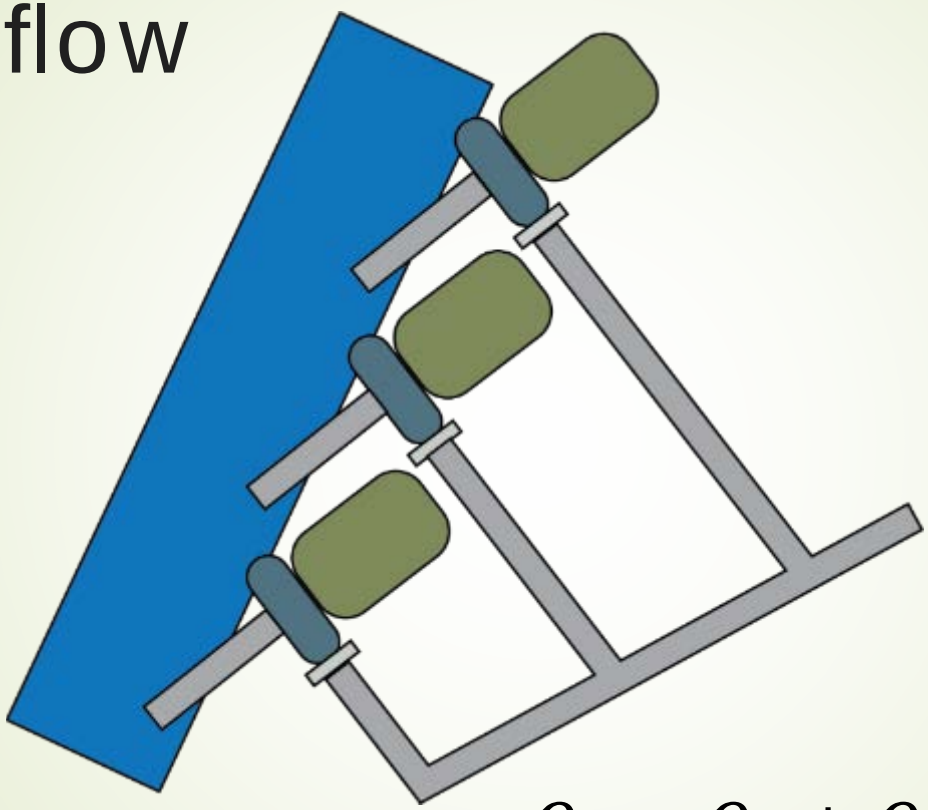
- Pumps in series
- Pumps in parallel
- Combinations

# Pumps in series add the head



$$H_t = H_1 + H_2 + H_3 \ldots$$

# Pumps in parallel add the flow



$$Q_t = Q_1 + Q_2 + Q_3 \ldots$$

# Outline

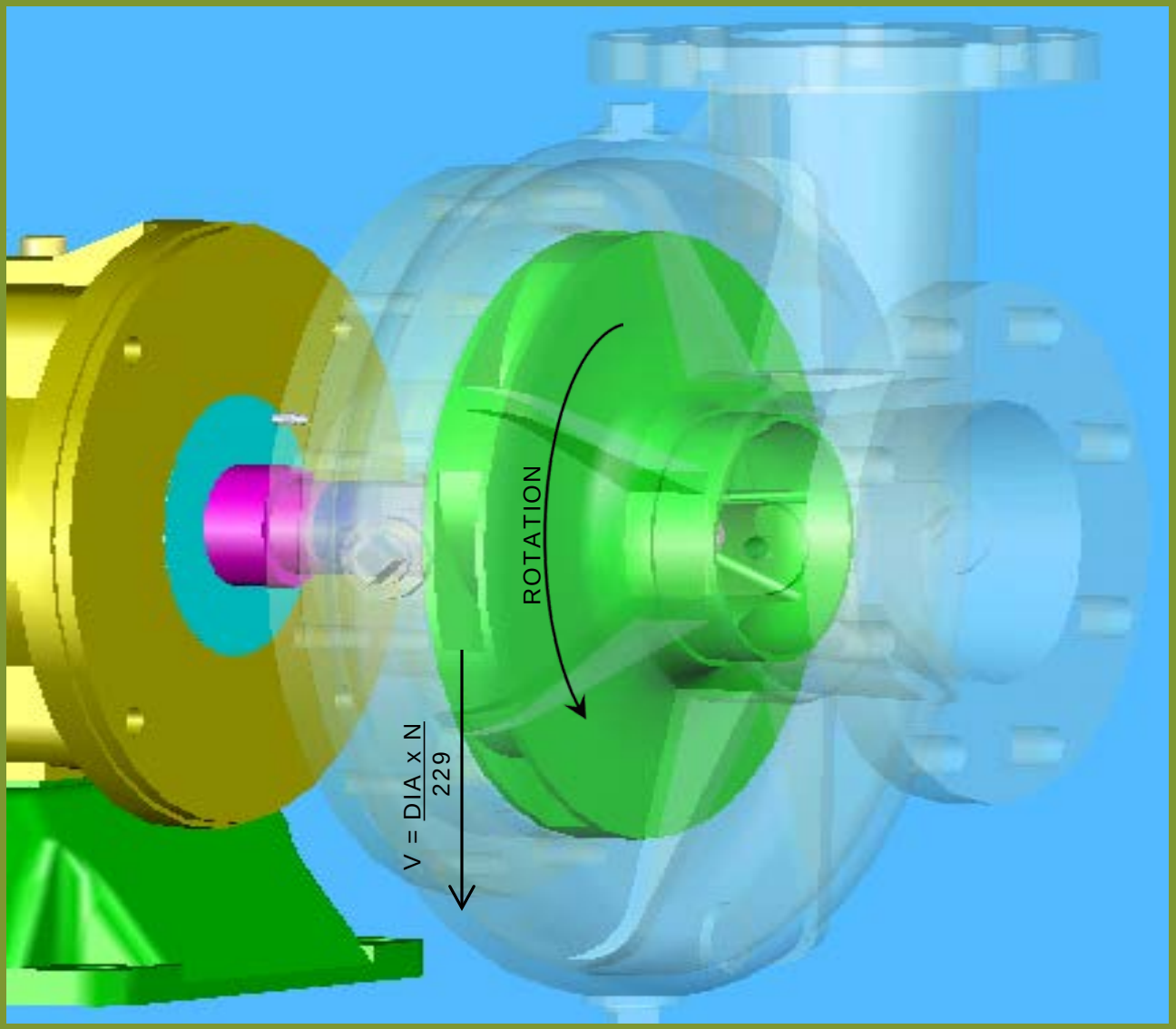
## Part I – Pipeline Design

- Technical Resources & Hydraulics ..... Farahani
- Design Considerations ..... Prestwich

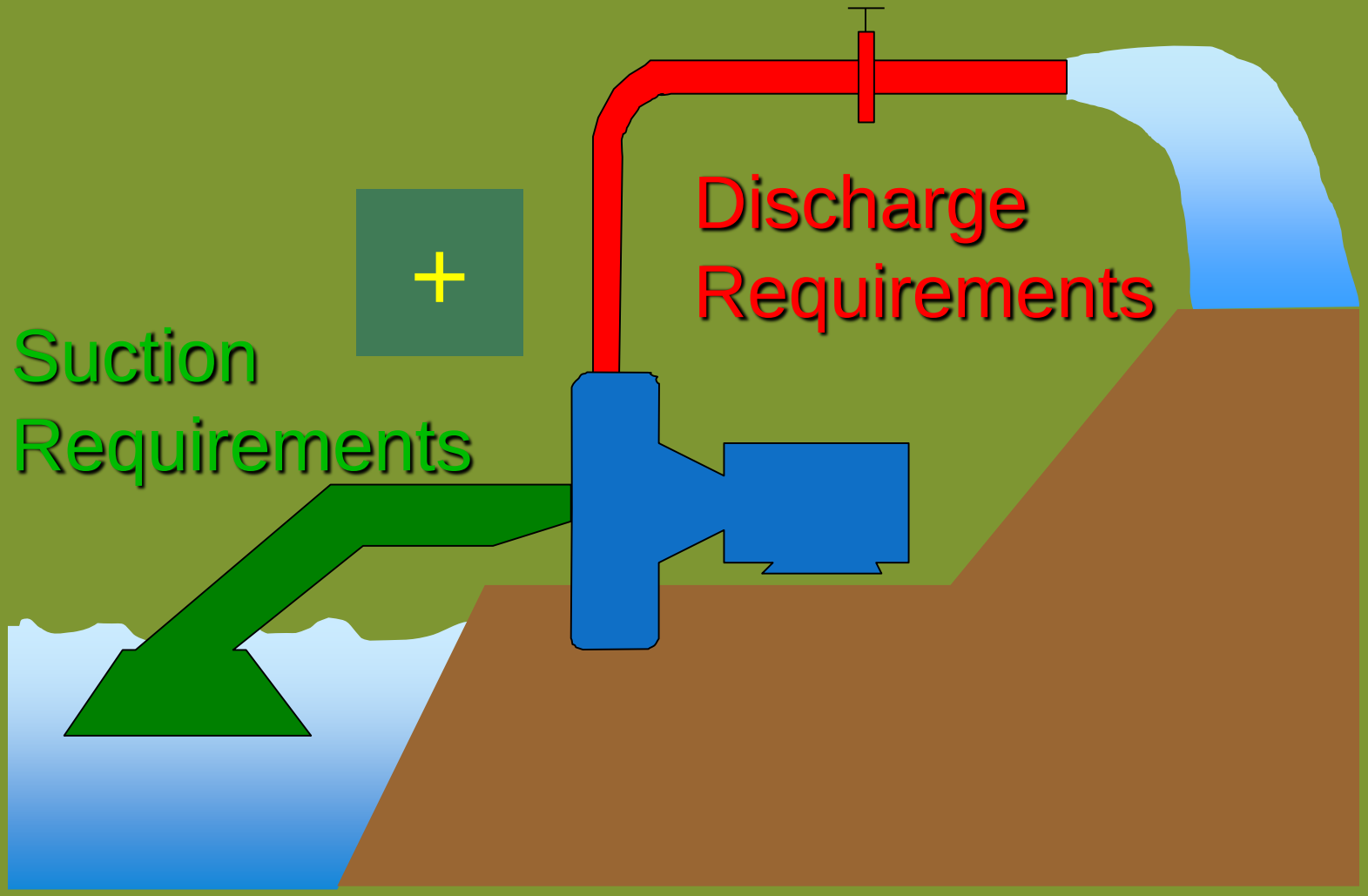
## Part II – Pump Design

- Technical Resources, Types, & Components ..... Prestwich
- TDH, Pump Curve, Energy ..... Farahani
- Pump Station Layout & VFD ..... Prestwich

The vanes in a centrifugal pump do work (spin) to increase the velocity, which then translates to pressure in the casing.



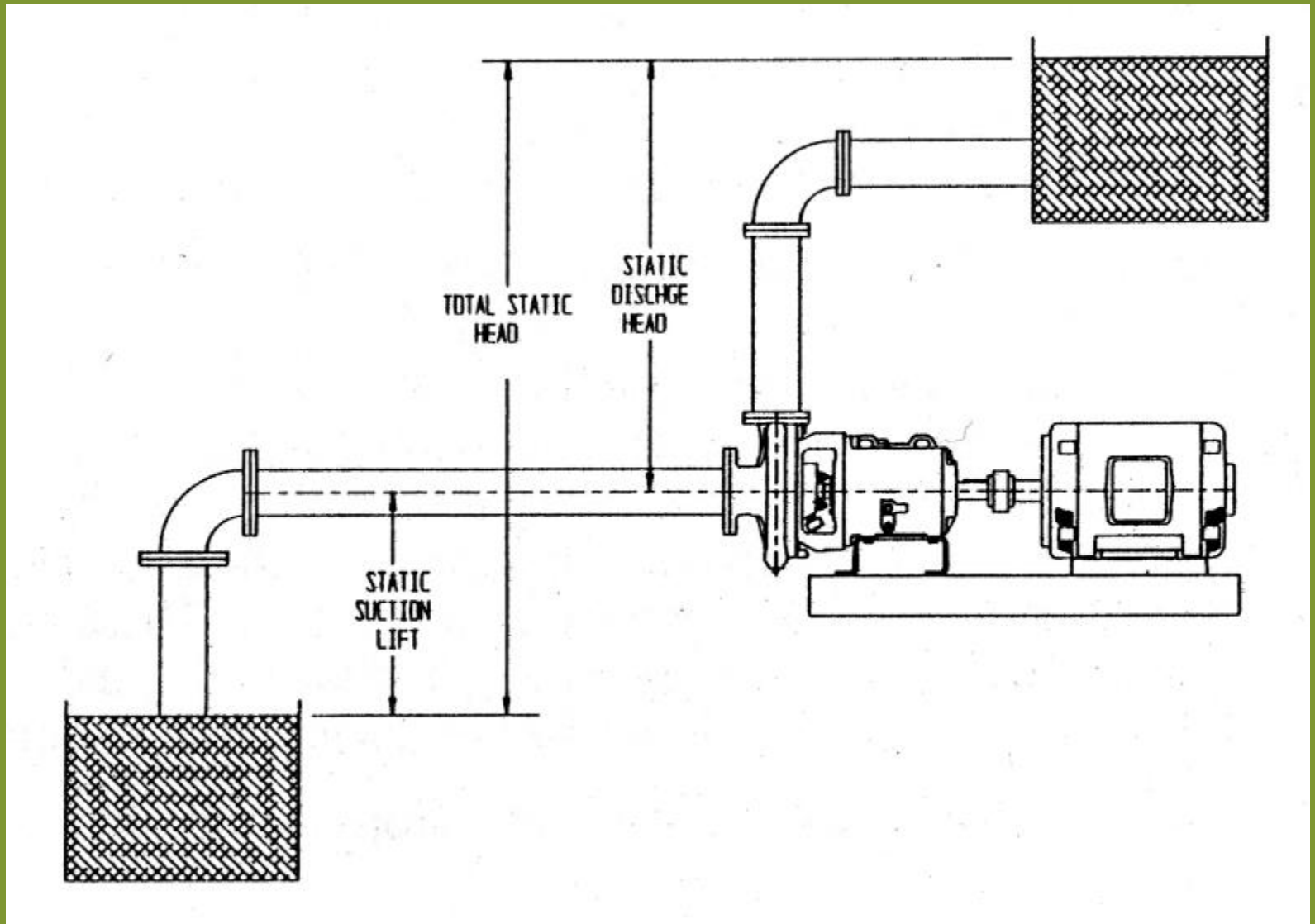
# Total Dynamic Head (TDH)



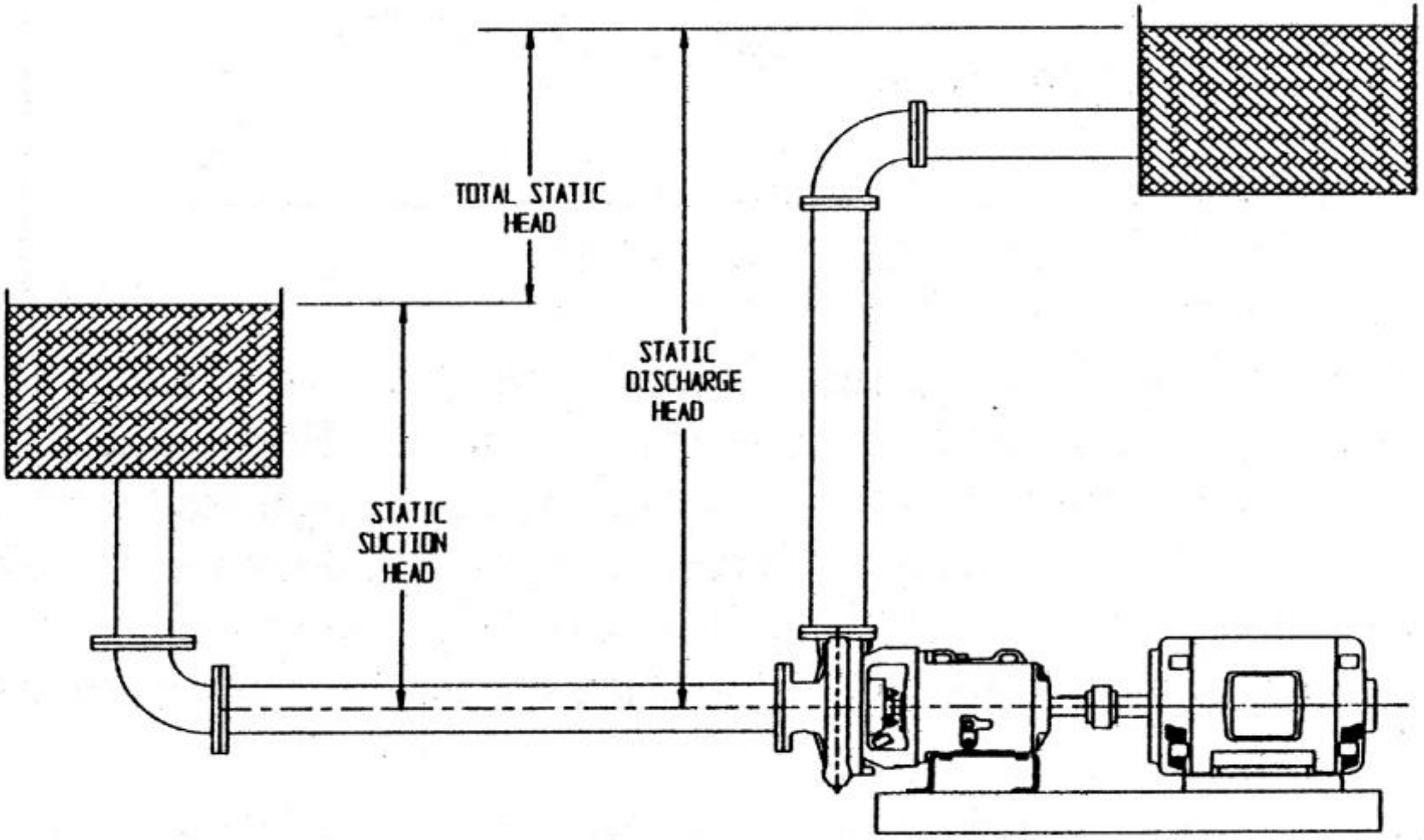
# Total Dynamic Head (TDH)

- The total of all components of the required system head – with fluid in motion
  - Discharge Side
    - System Requirement
    - Elevation
    - Friction Loss
  - Suction Side
    - Can be positive or negative
    - Elevation
    - Friction Loss

# Suction Lift



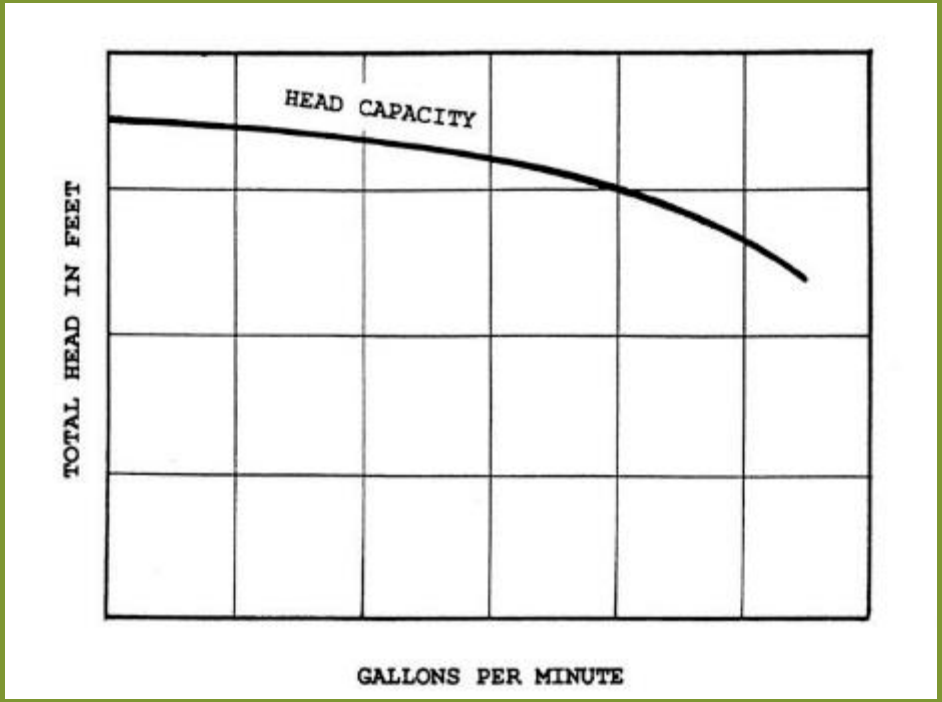
# Positive Suction Head



# Head vs. Capacity Curve

## Pump Curve

**Pump Curve:**
A graphic representation of the relationship between the flow and pressure across a centrifugal pumps' range of operation.




For a particular speed,

For a particular impeller diameter,

And when handling a liquid of negligible viscosity,

**Any centrifugal pump has a rating curve which indicates the relationship between:**

The head (or pressure) developed by the pump,

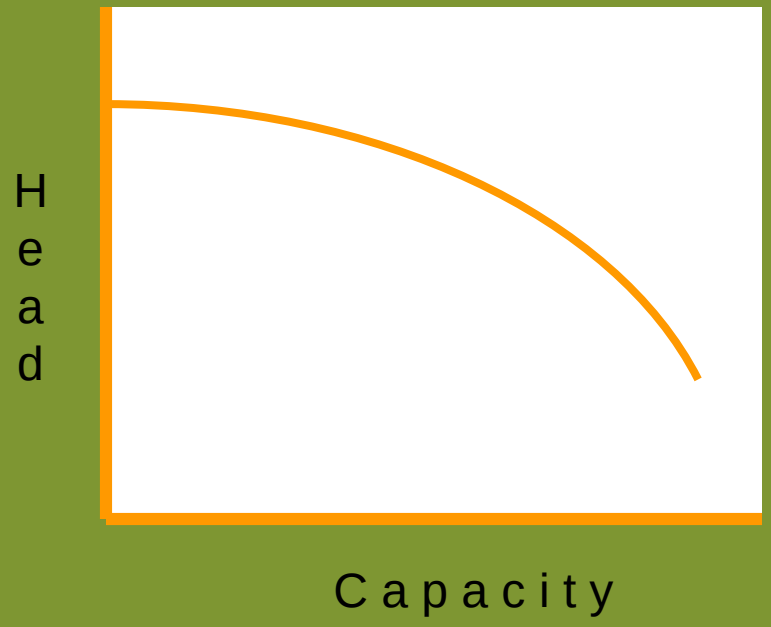
The flow (or capacity) through the pump

# Pump Curves

- Typical Classifications
  - Gradually Rising
  - Drooping
  - Steep
  - Flat

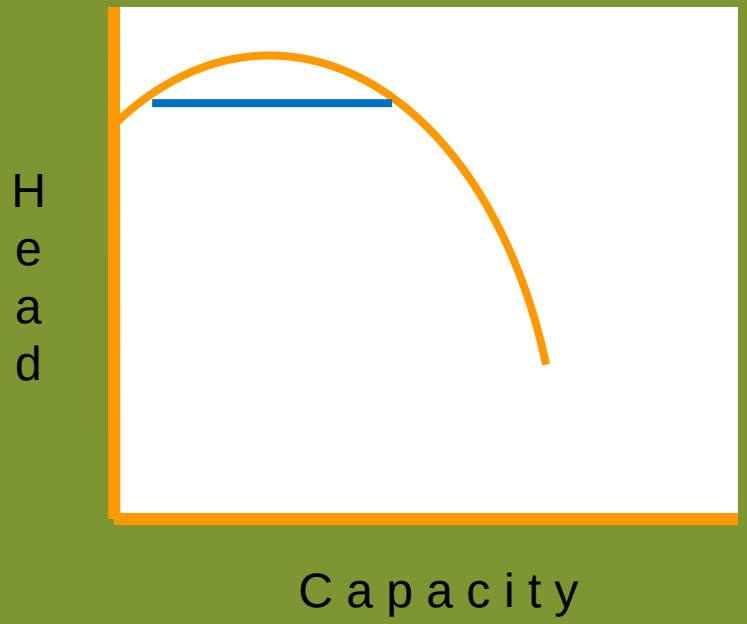
# Gradually Rising Curve

- Head rises continually as Capacity is decreased
- Stability
  - Very good



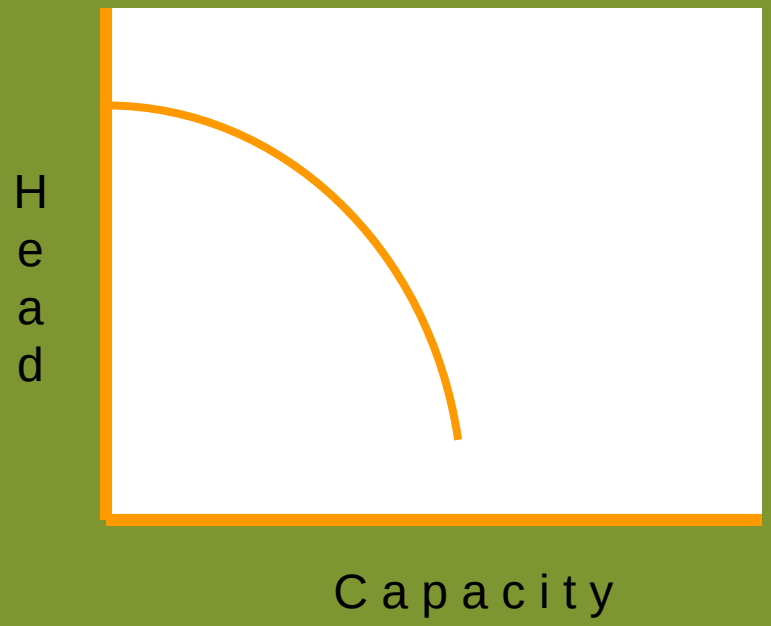
# Drooping Curve

- Good performance with high Capacity but only within a limited range
- Stability
  - Can be stable at two distinct points



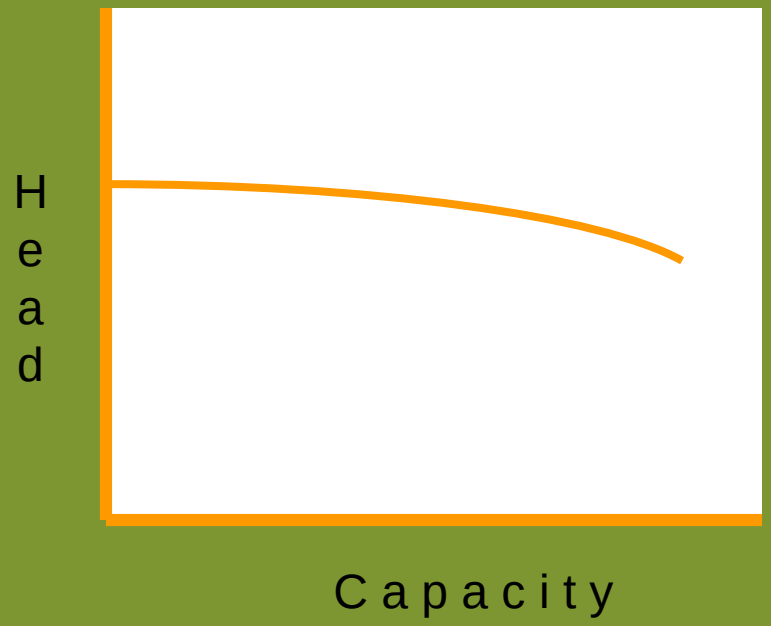
# Steep Curve

- Able to dramatically change Head with little Capacity change
- Stability
  - Excellent



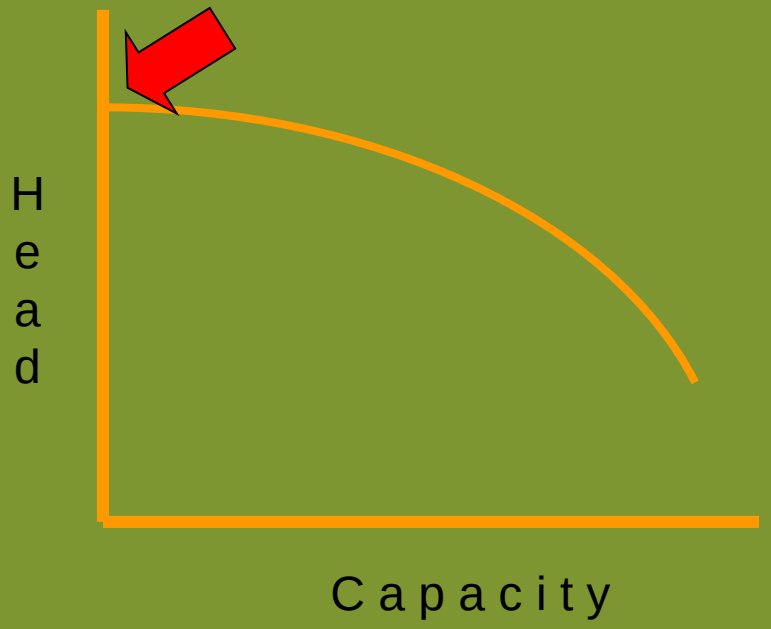
# Flat Curve

- Capable of large Capacity changes with little Head change.
- Stability
  - Good



# Pump Curves

- Shut Off
  - Capacity
    - Zero
  - Head
    - Typically the highest obtainable by the pump
- Caution
  - Recirculation of fluid can cause significant heat
  - Heat can damage a pump



# Pump Power

- **Hydraulic HP**

$$\frac{\text{Q (in gpm) x H (in feet)}}{3960}$$

- **Brake HP**

$$\frac{\text{Q (gpm) x H (in feet)}}{3960 \times \text{pump efficiency}}$$

- **Pump Efficiency**

$$\frac{\text{Hydraulic HP}}{\text{Brake HP}}$$

# BHP vs. Capacity Curve

In order for the pump to deliver the desired performance, it requires a certain horsepower.

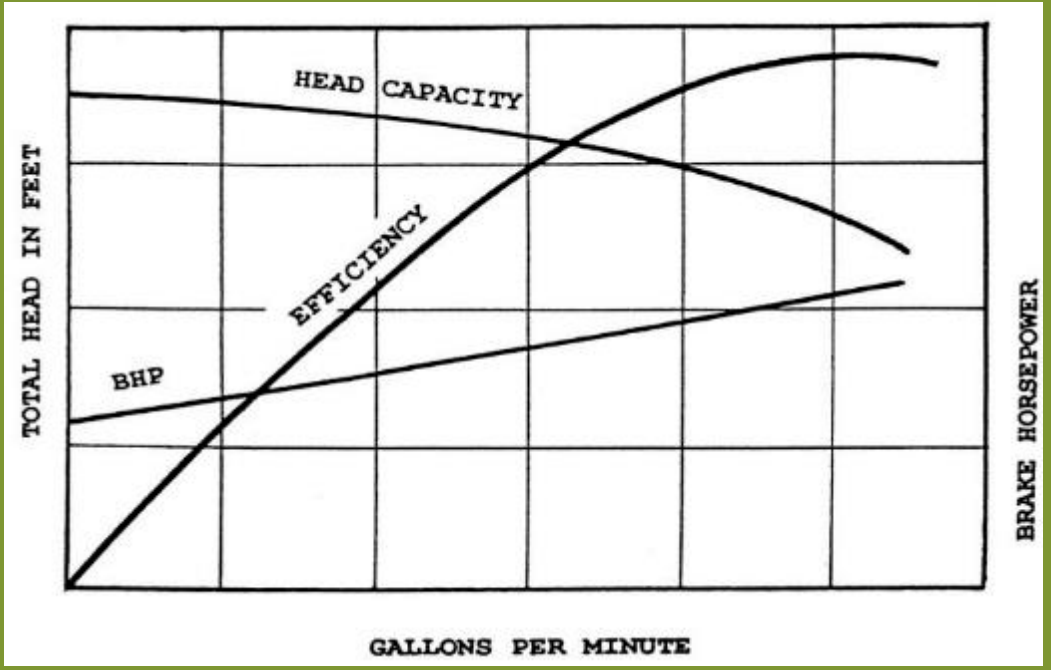
The relationship between capacity and brake horsepower is also a useful plot on the pump curve.

These two characteristics, plotted on the curve, are determined by testing an actual pump.

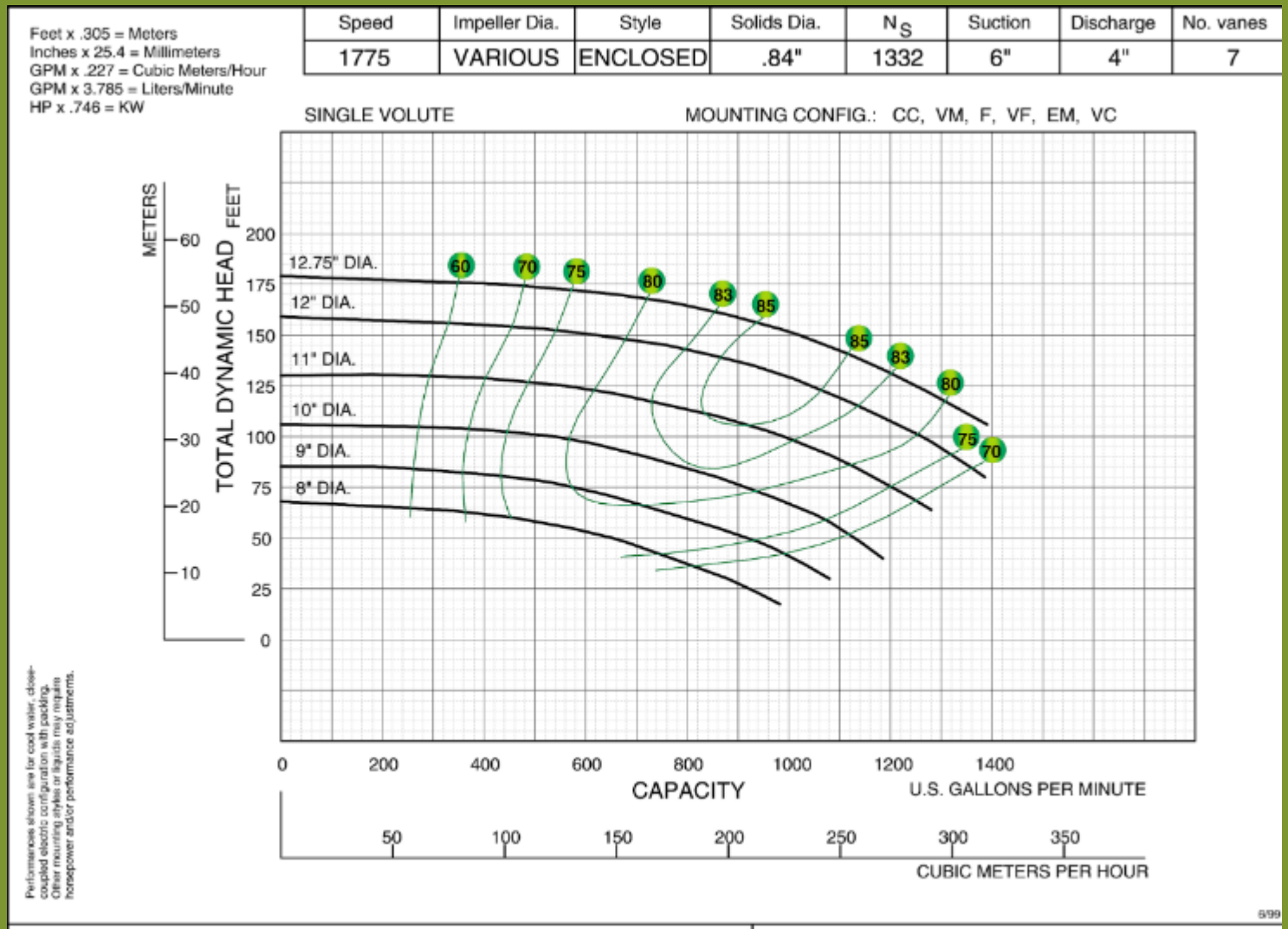
A third characteristic, efficiency, is derived from the previously discussed curves:

Efficiency is calculated:

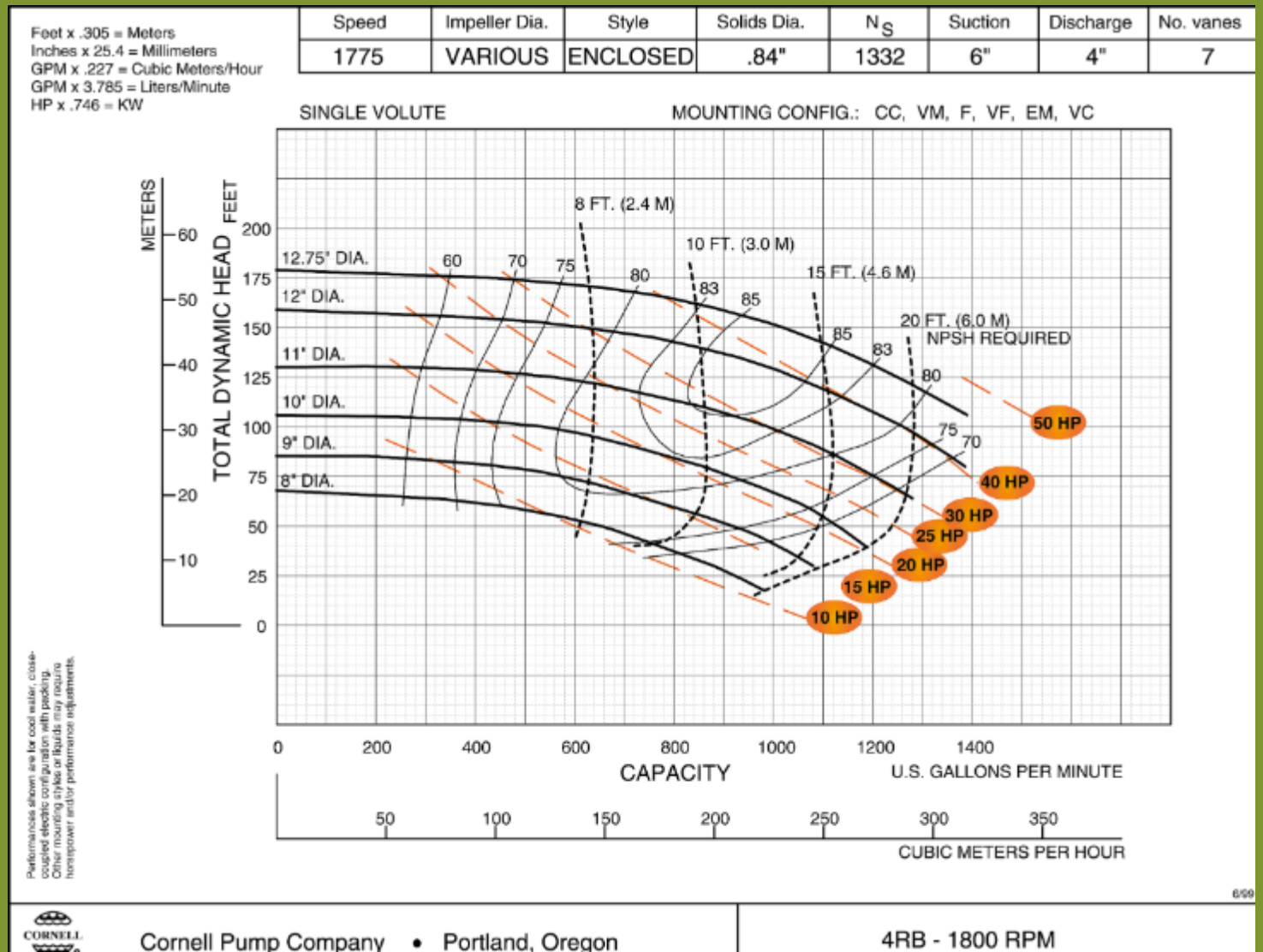
$$\frac{Q \times H}{3960 \times BHP}$$



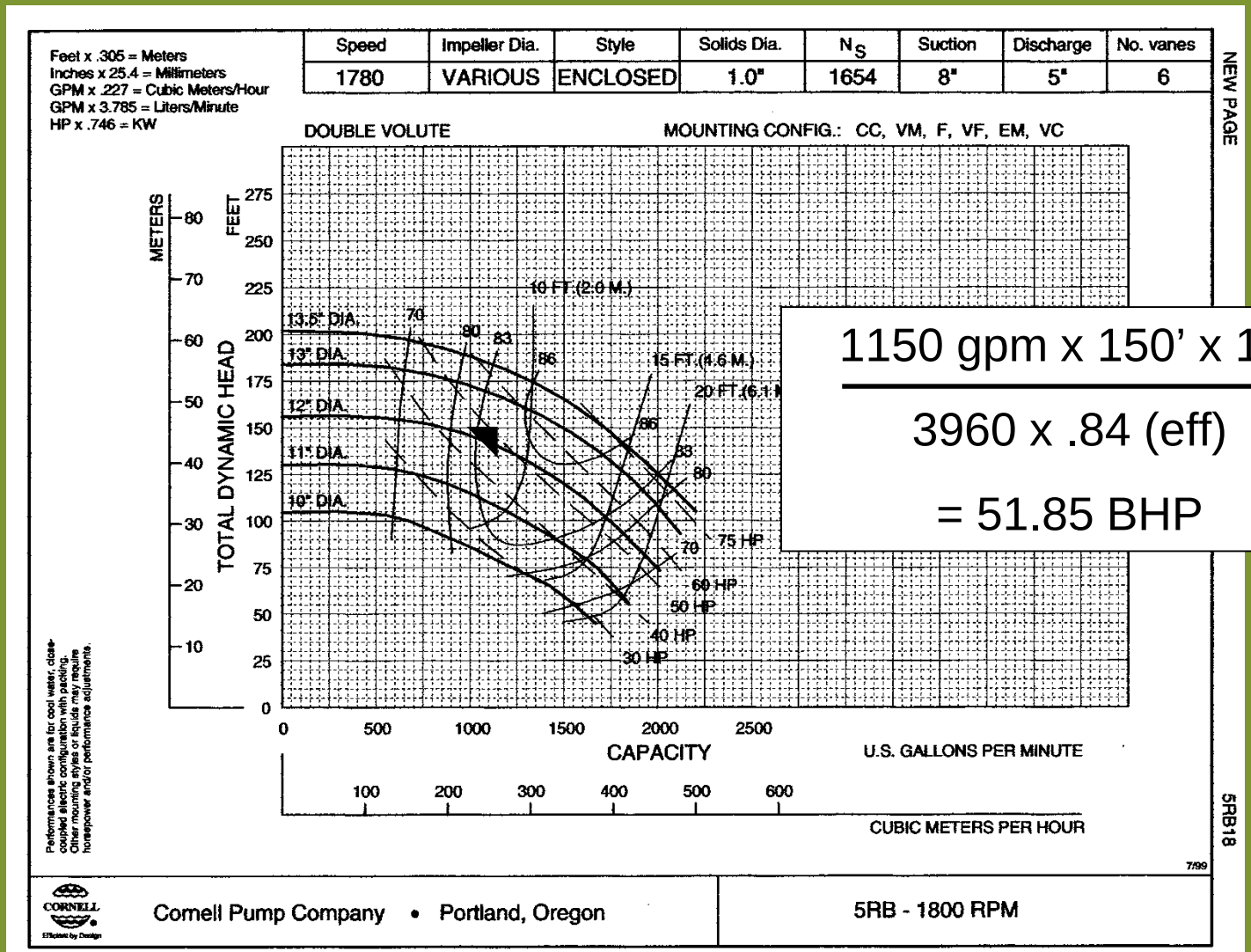
# Pump Curve: Efficiency



# Pump Curve: Horsepower



# Pump Power




$$\frac{1150 \text{ gpm} \times 150' \times 1.0}{3960 \times .84 \text{ (eff)}} = 51.85 \text{ BHP}$$

# Pump Curves

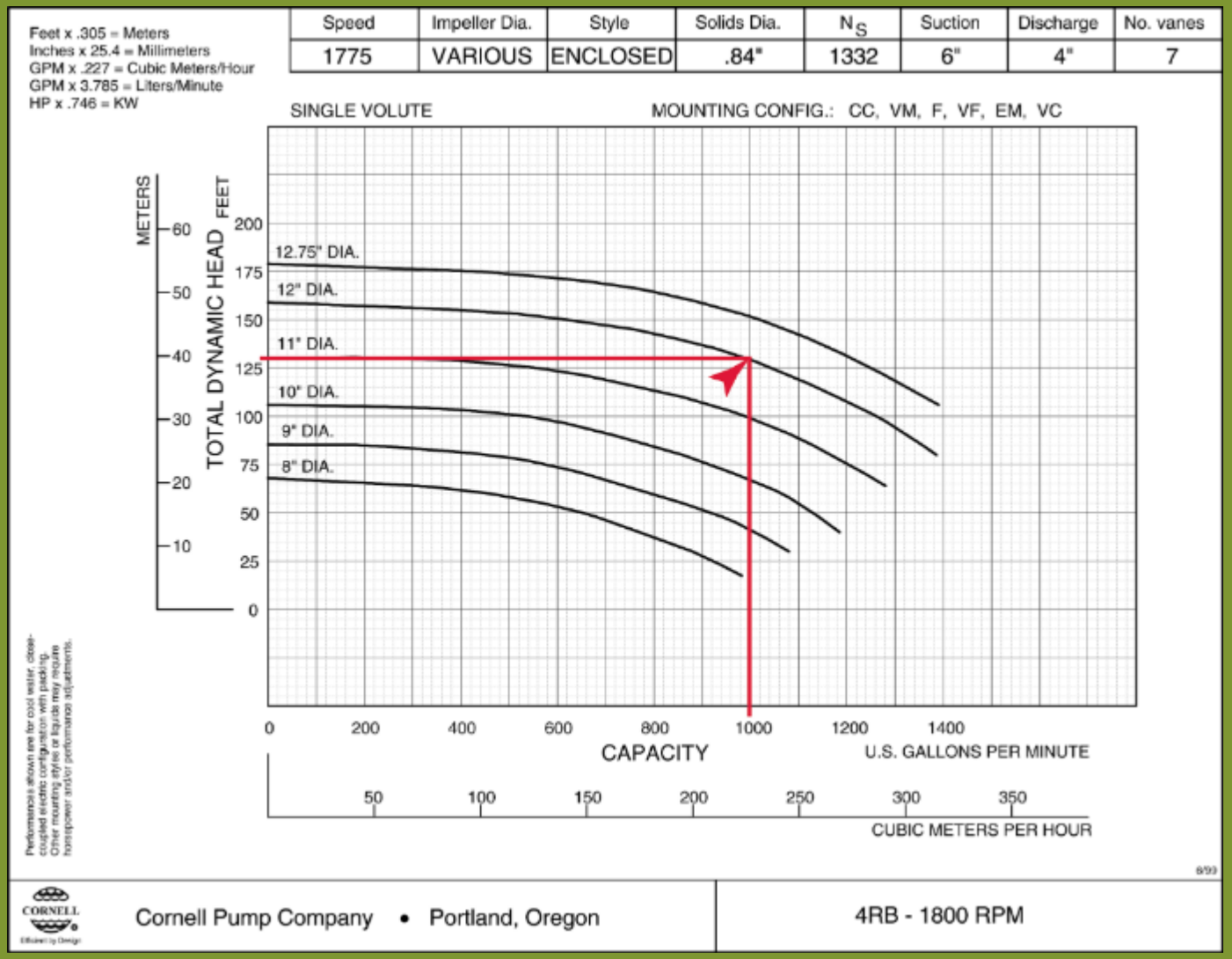
## Bringing it all Together

# Pump Selection

**1000 GPM**

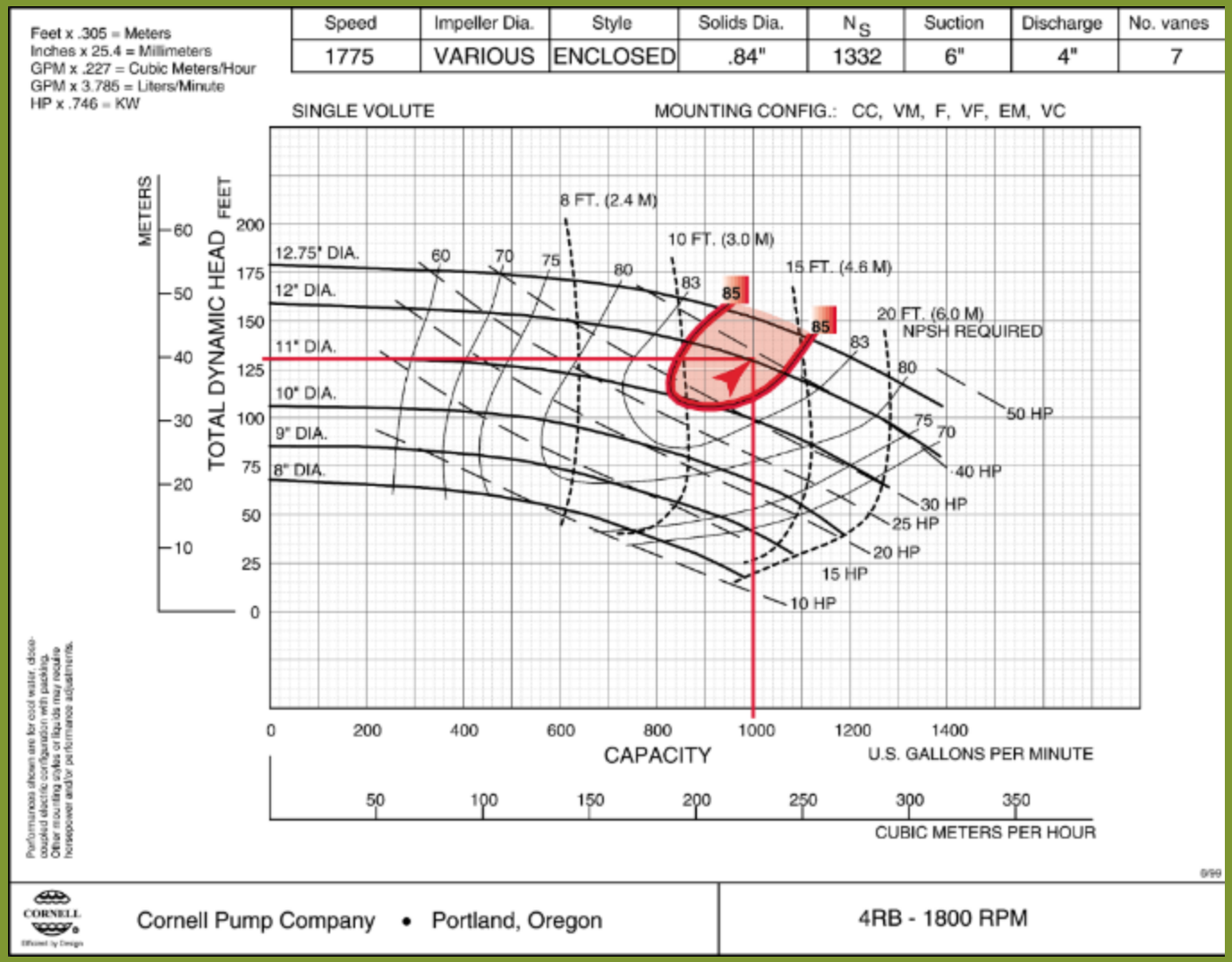
**@**

**130’ TDH**



# Pump Selection

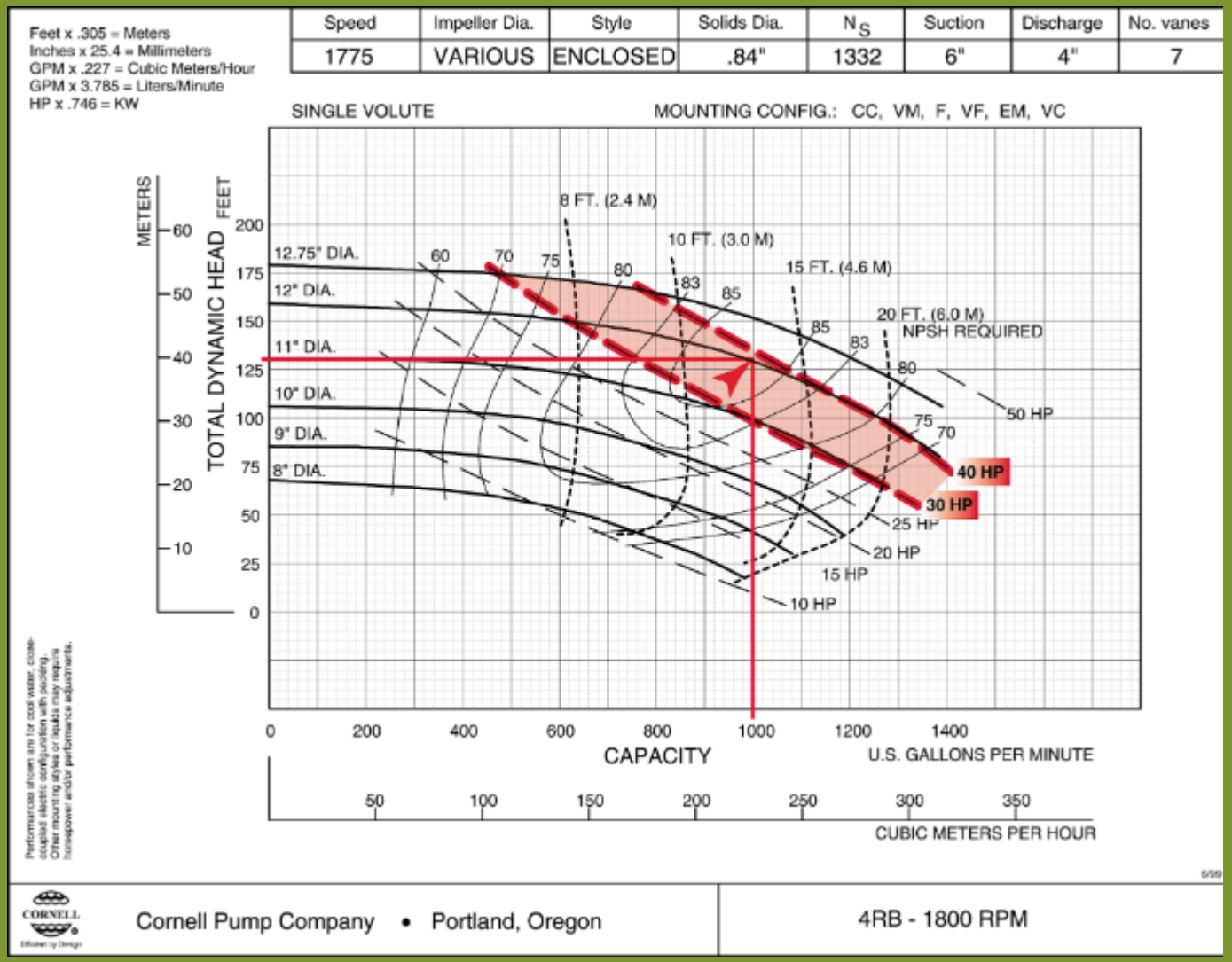
- Efficiency
  - **85%**



# Pump Selection

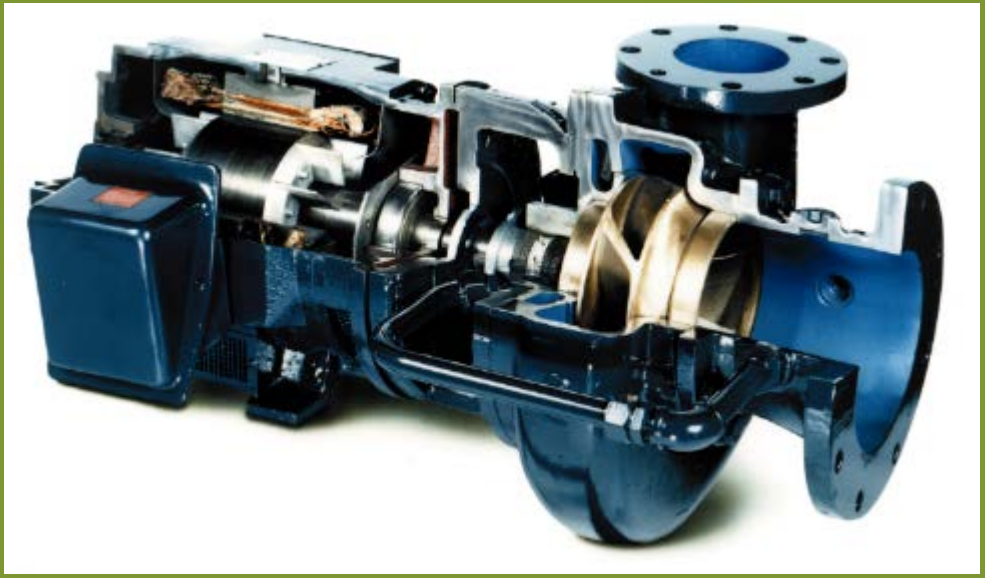
- HP
  - > 30
  - < 40

(38.62)



# Pump Curve Situation

- Cornell 4RB-40-3-4
  - **40 Hp, 3 phase, 4 pole**
  - **6” suction, 4” discharge**
  - **Trim 12.00”**
  - **Efficiency 85%**



# Energy Conservation in Irrigation Systems

See Previous Webinar:

Presented on July 27, 2011 in three parts by
Hamid Farahani, Jerry Walker, and Kip Pheil

Replay at Conservationwebinar.net
http://www.conservationwebinars.net/

# Pathways to Energy Conservation in Irrigation

1. Increase the Efficiency of the Pumping Plant

   Remember: This may increase flow, pressure, or even input HP

2. Reduce Quantity of Water Pumped (reduce flow and/or time)

   Water management (scheduling), change type, deficit irrigation

3. Reduce Irrigation System Pressure

   Renozzle to lower pressure (may need to modify pump)

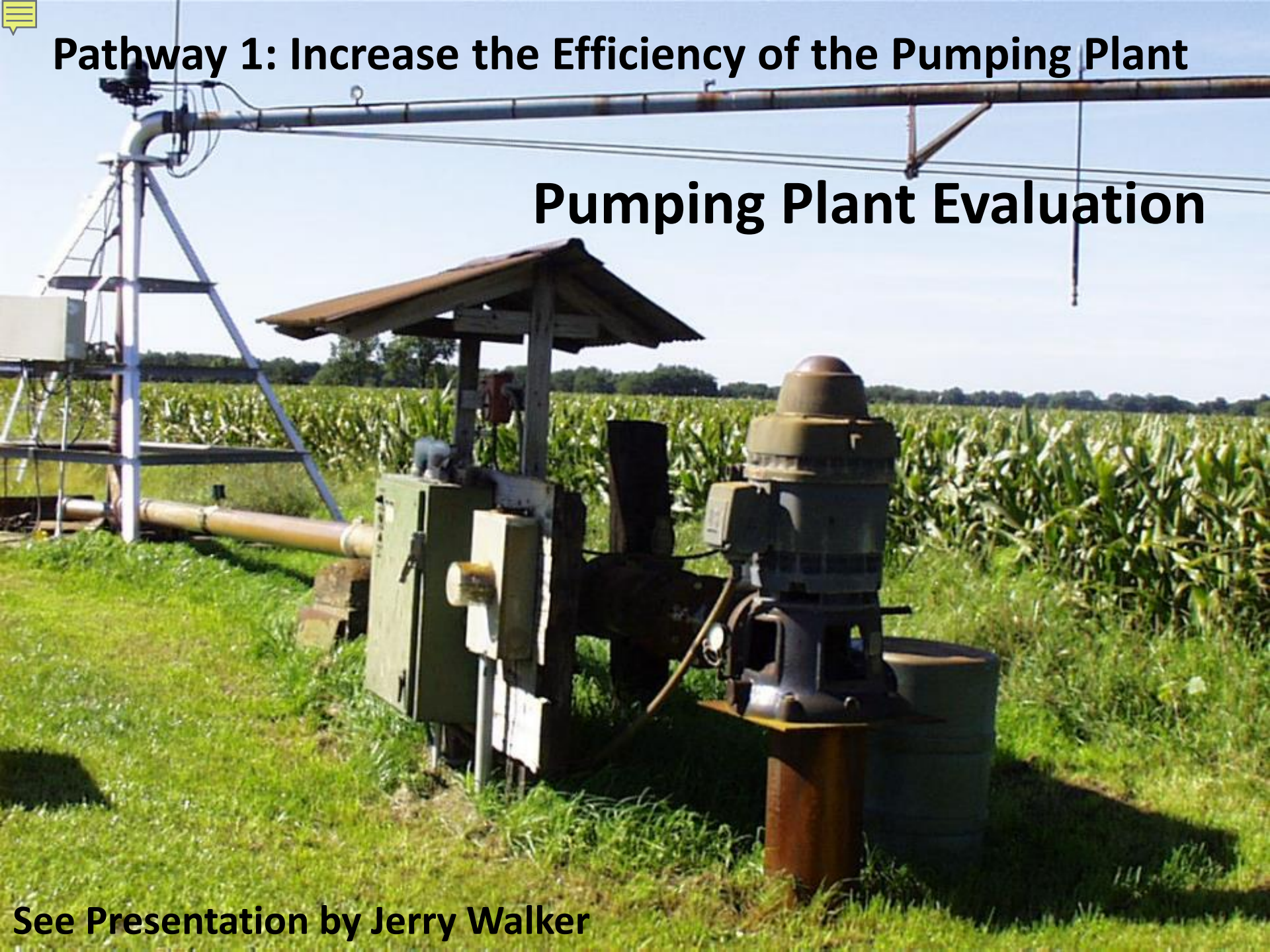
4. Increase System Performance (reduce quantity pumped)

   Correct non-uniformity, leaks, worn/missing nozzles

5. Manage Time of Use (reduce unit cost of energy)

6. Convert to a Different Energy Source (diesel to electric)

# Pathway 1: Increase the Efficiency of the Pumping Plant



## Pumping Plant Evaluation

See Presentation by Jerry Walker

# Outline

## Part I – Pipeline Design

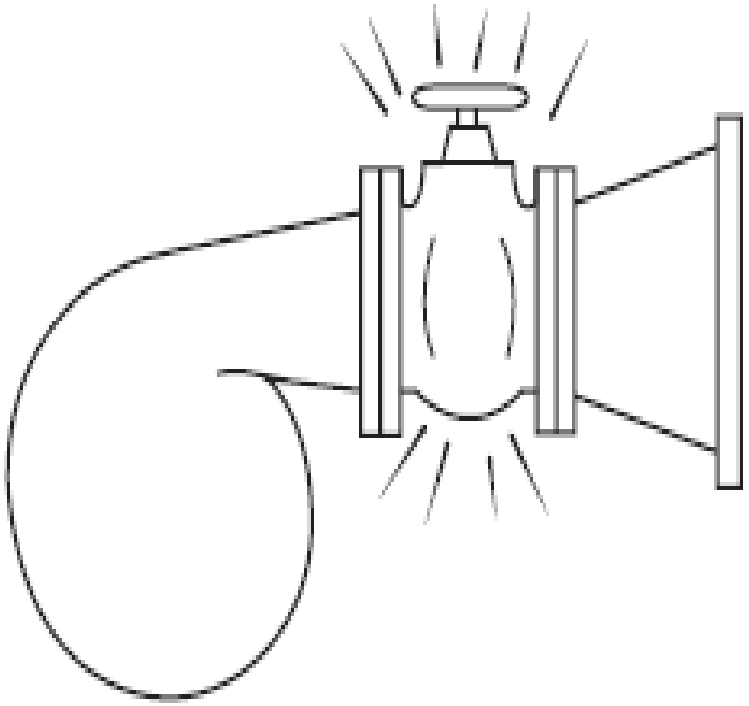
- Technical Resources & Hydraulics ..... Farahani
- Design Considerations ..... Prestwich

## Part II – Pump Design

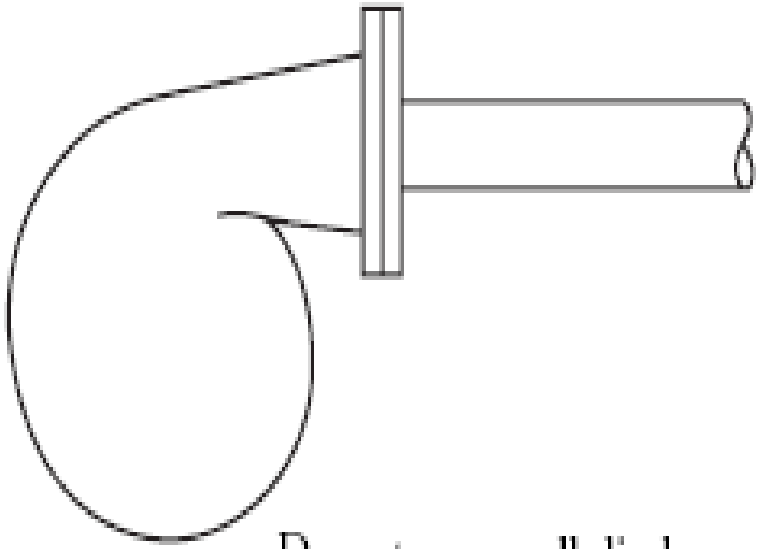
- Technical Resources, Types, & Components ..... Prestwich
- TDH, Pump Curve, Energy ..... Farahani
- Pump Station Layout & VFD ..... Prestwich

# Pump Station Layout,

# Avoid Restrictions

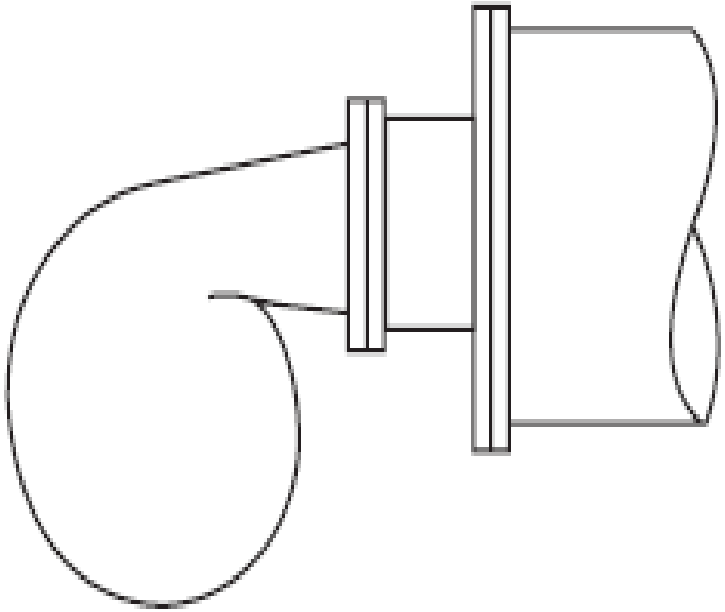


Do not design a system to operate with the discharge valve partly closed.

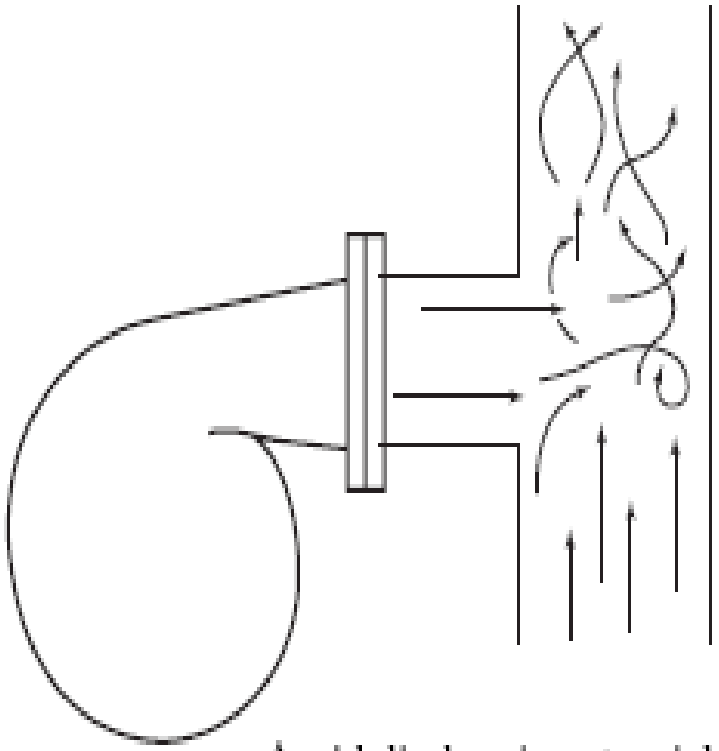


Do not use small discharge valves, piping, and fittings. This adds to friction loss.

# Avoid sudden enlargements

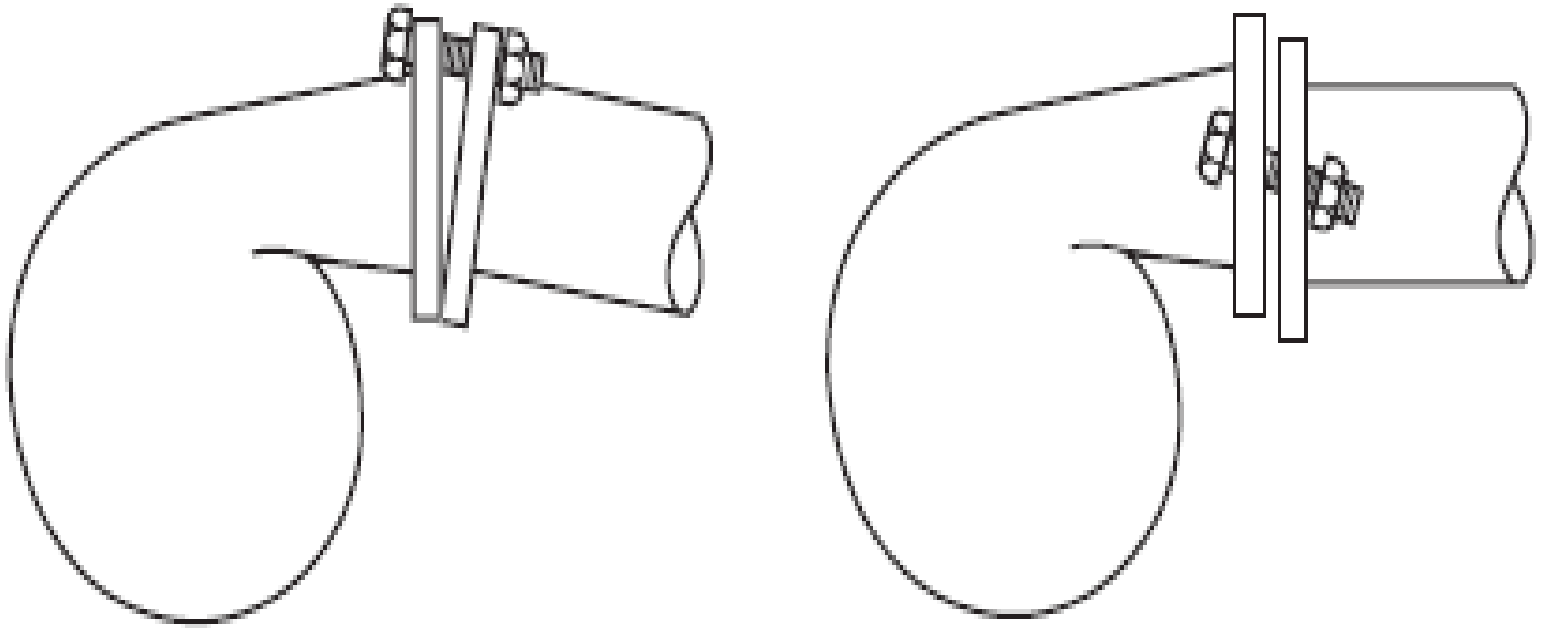


Avoid abrupt changes in pipe diameter.



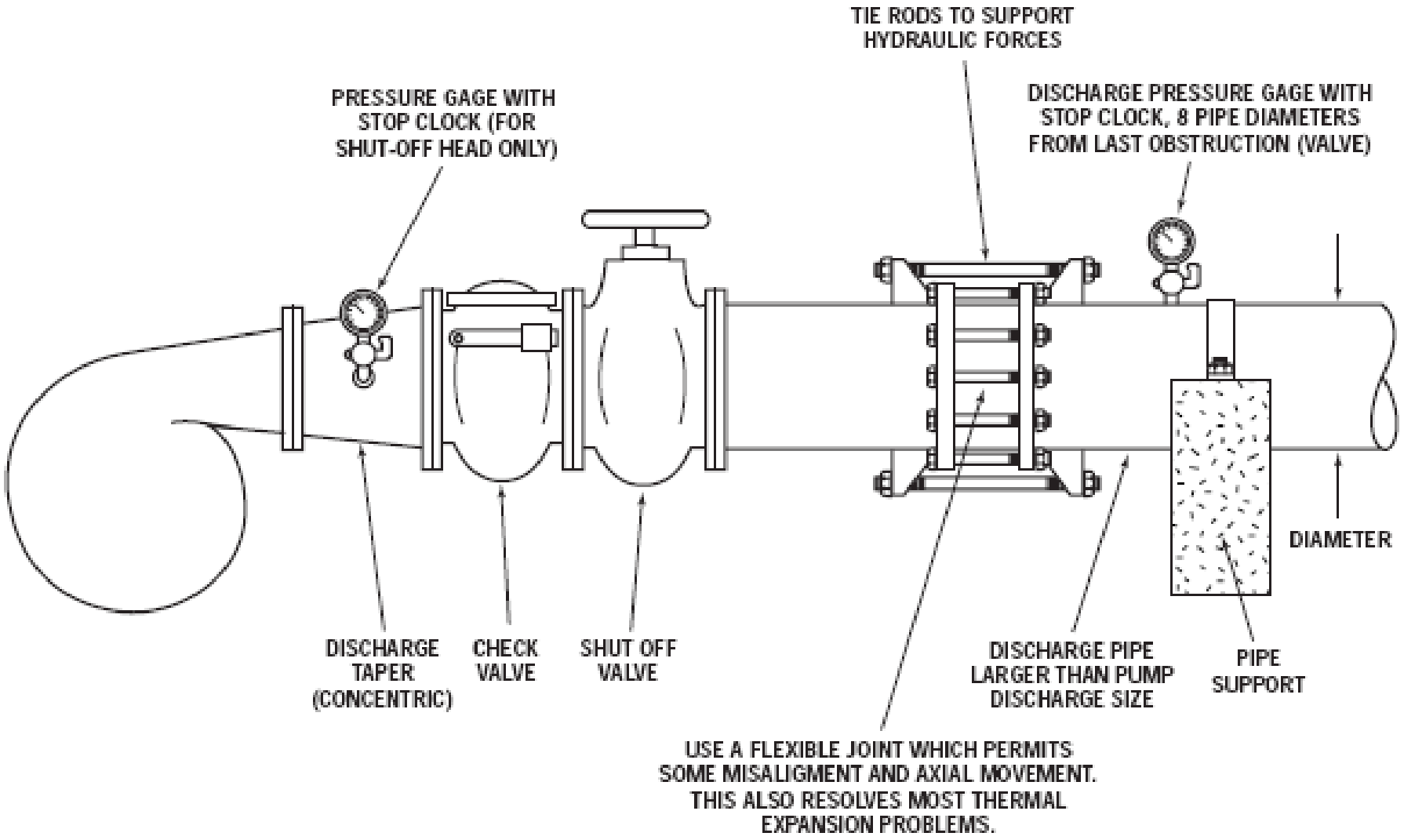
Avoid discharging at a right angle into a manifold flow. A "Y" connection in the direction of flow is preferred.

# Make sure of proper alignment

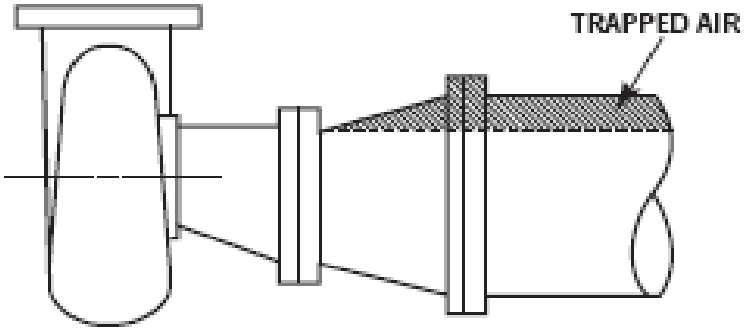


Do not tighten bolts on misaligned flanges. This can damage wear surfaces, bearings, coupling, overload motor, and create other problems.

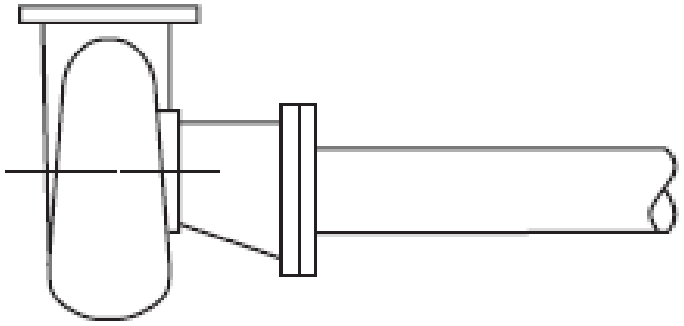
# Proper Installation - Outlet side



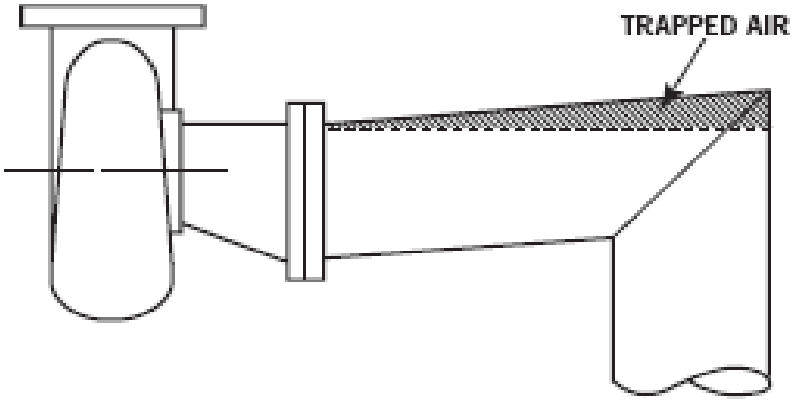
# Suction Piping



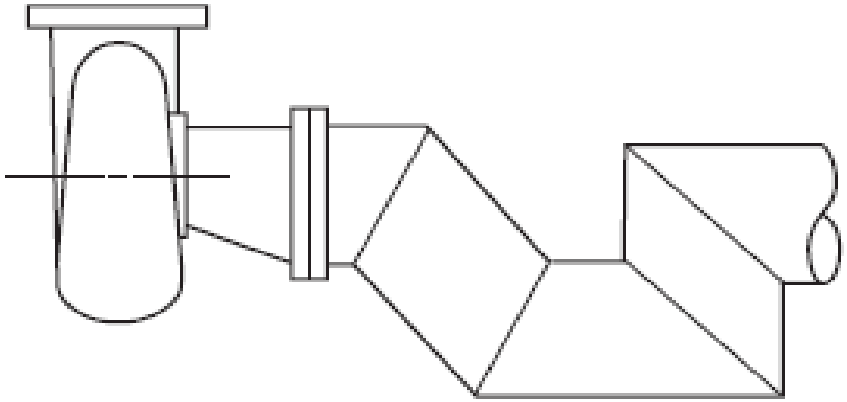

Do not use a concentric reducer. Air remains in pipe, and the pump may lose prime.



Do not restrict the flow. This may cause cavitation, reduce performance, and add friction losses.

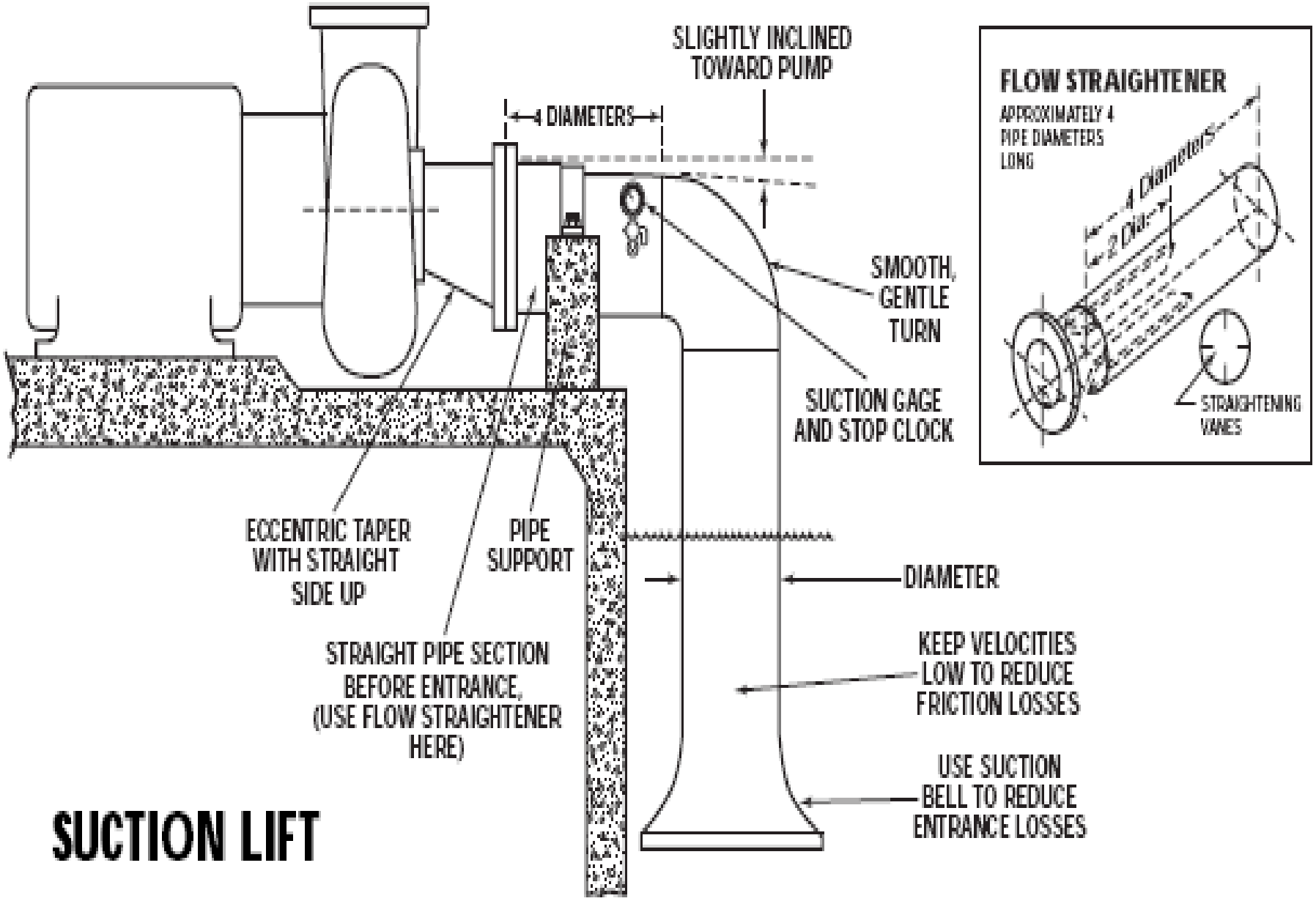



Do not slope piping down toward the pump. Trapped air may cause the pump to lose prime. Avoid the use of 90° miters.



Do not use many fittings. This creates high friction losses and may cause cavitation, trapped air and reduced performance.

# Proper installation – Inlet side

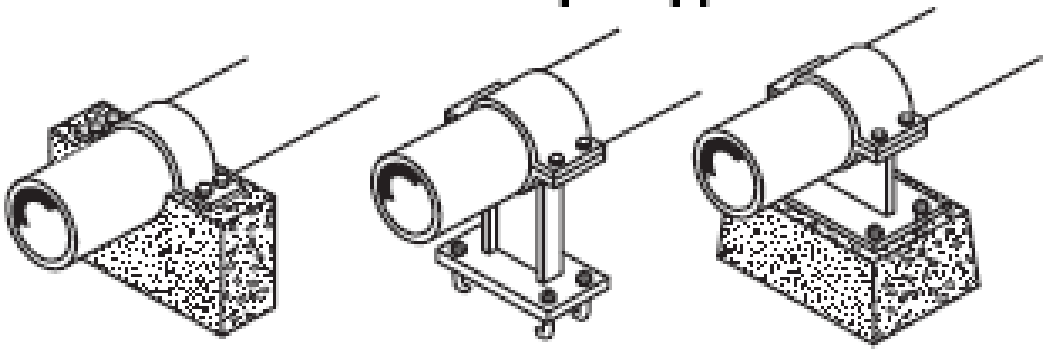


# Bracing and supports

## PIPE SUPPORTS

Pipe supports must handle piping weights as filled with pumpage. If the system is subject to wide temperature ranges, make provisions for thermal expansion. *(See page 4)*

### Permanent Pipe Supports



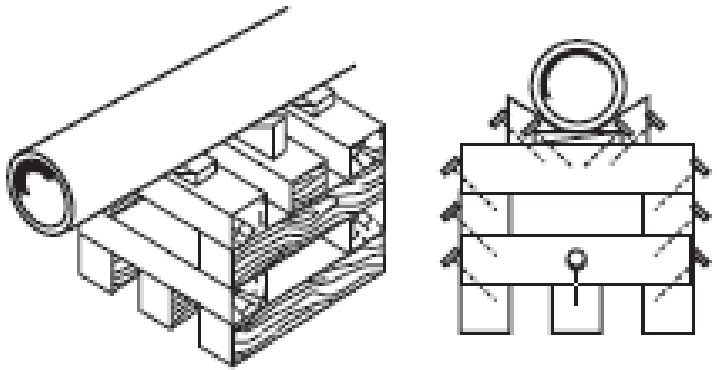
Concrete with metal strap.

"J" bolts or anchor bolts.

Use pads between piping and support.

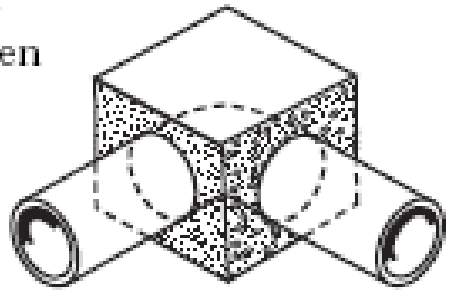
### Temporary Pipe Supports

Nail all parts together.

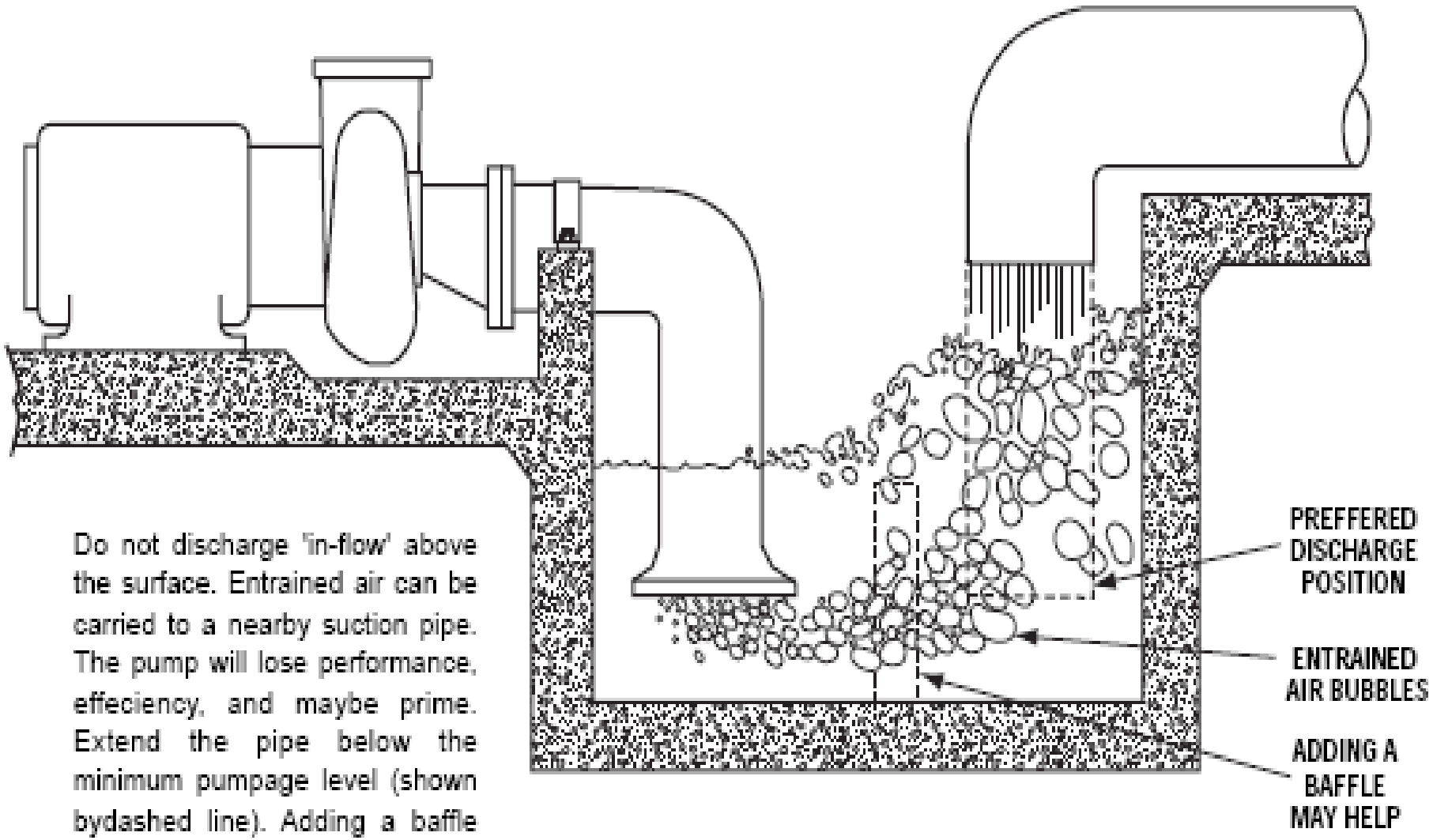


### Corner Thrust Block

Use large corner thrust blocks even on buried pipe.

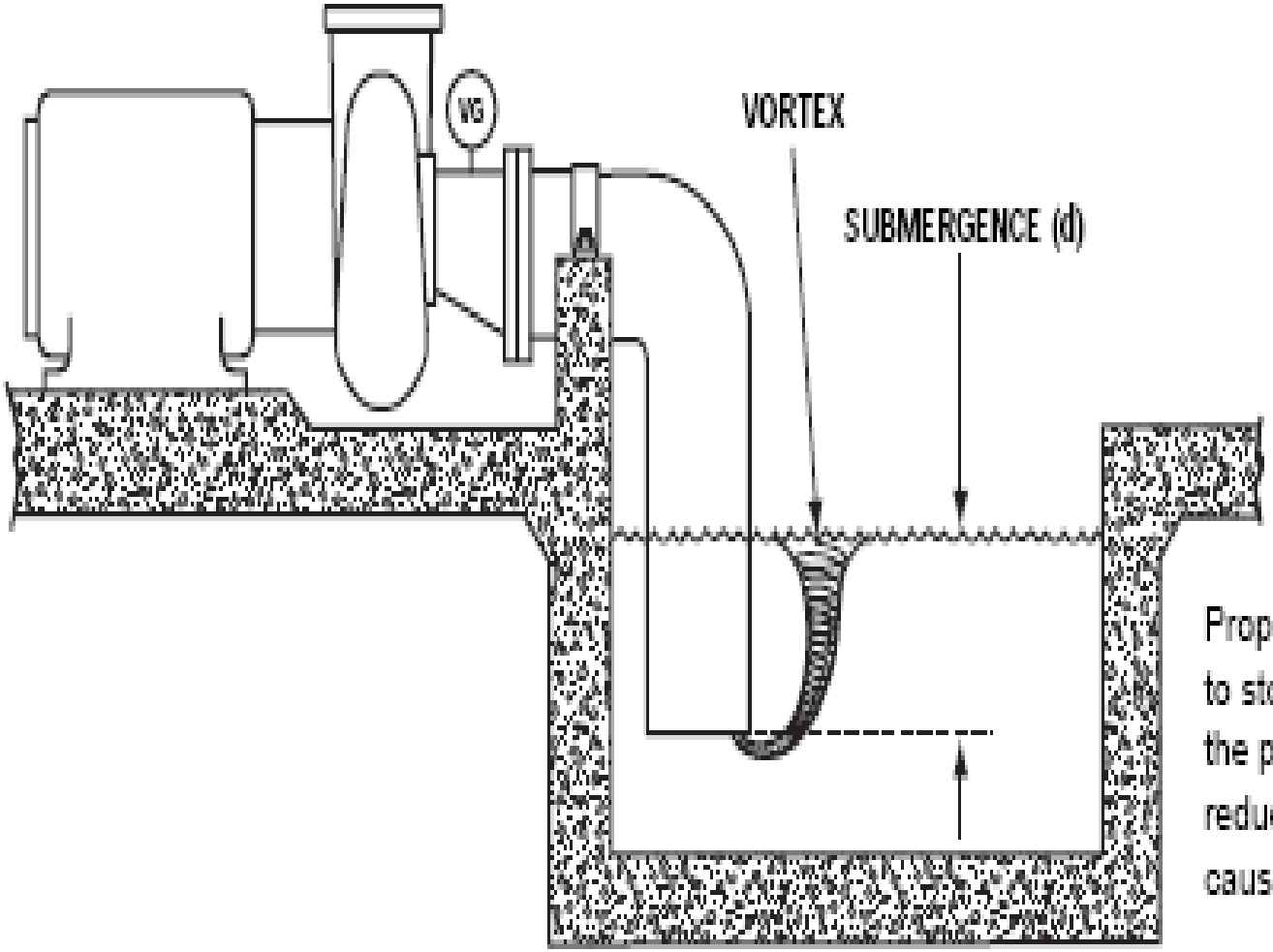


# Sump design



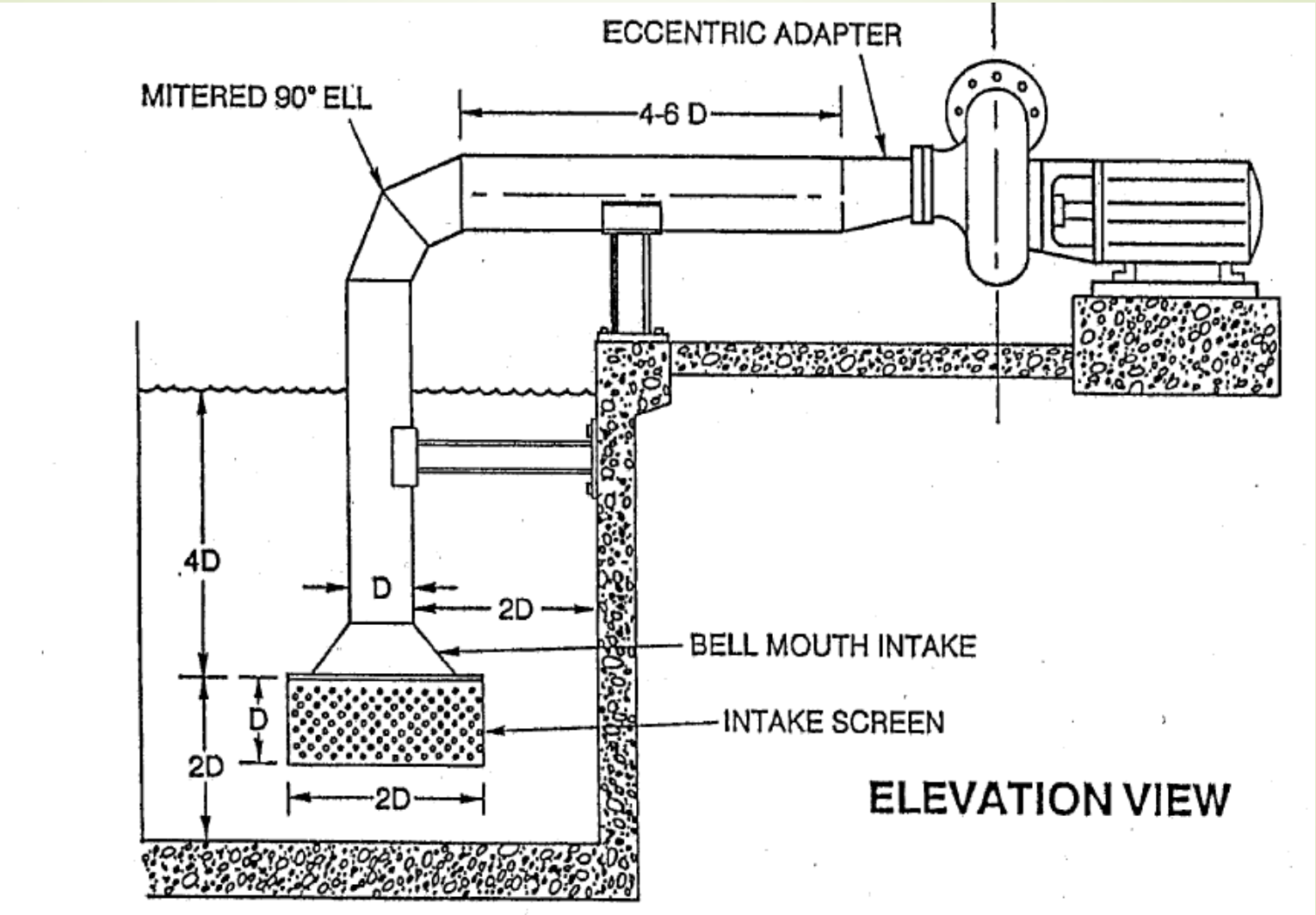

Do not discharge 'in-flow' above the surface. Entrained air can be carried to a nearby suction pipe. The pump will lose performance, effeciency, and maybe prime. Extend the pipe below the minimum pumpage level (shown bydashed line). Adding a baffle may help if the 'in-flow' already contains air bubbles. Do not let the flow cascade over the baffle.

# Submergence




Proper submergence is required to stop vortexing, which can make the pump lose prime, reduce head, reduce flow, lower efficiency and cause noise.

# Approximate Sump Dimensions

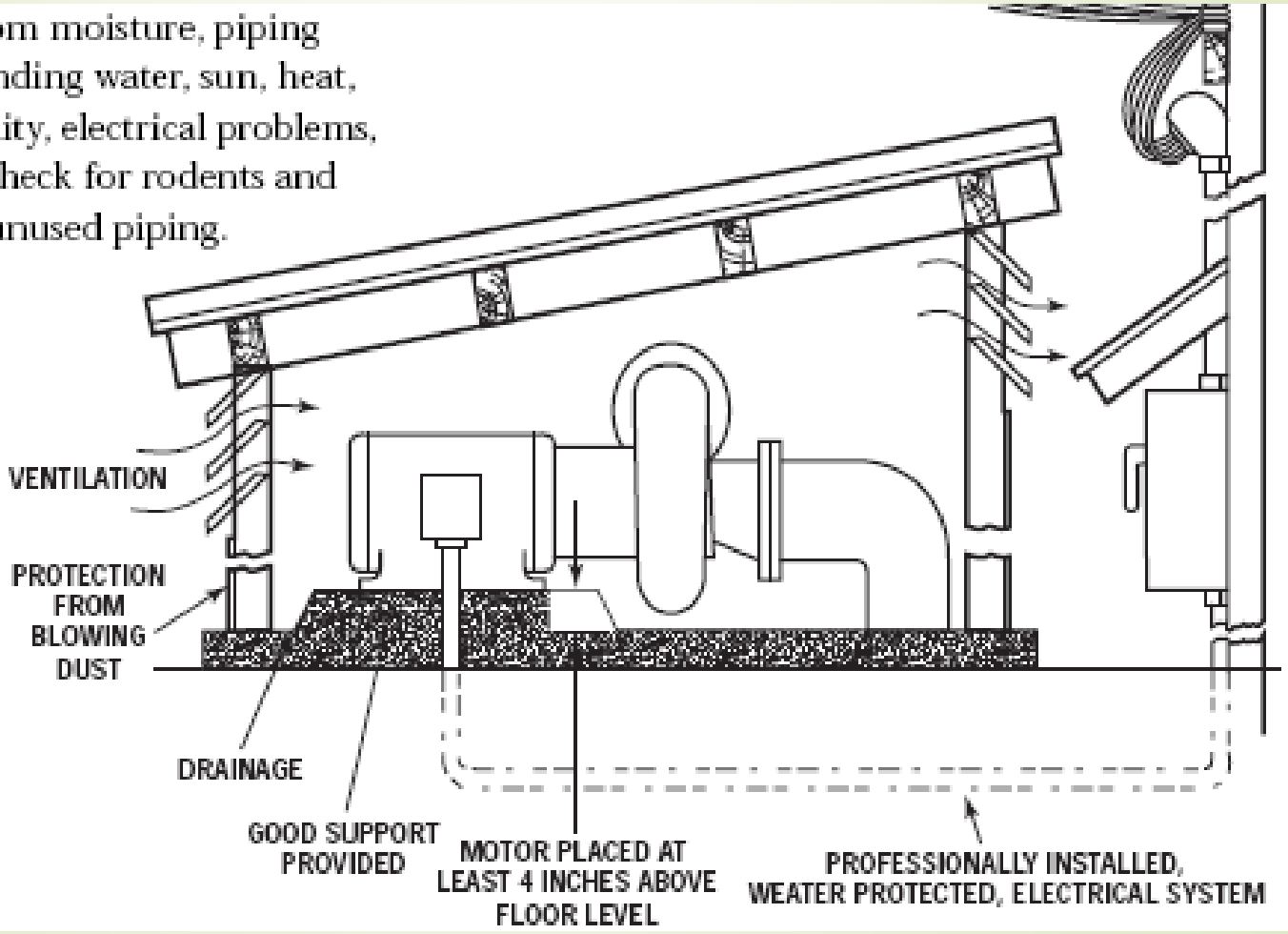


# Pump protection

- Radiation from the sun adds considerable heat and increases the operating temperature of a motor
- For every 18º temperature rise above the safe limit, motor life is reduced by one half. This is also linear with time expected life is reduced 4 hours for every hour of operation above the safe limit.
- 27% of motor failure is from overheating

# Shelters

Protect the pump from moisture, piping movement, dust, standing water, sun, heat, freezing, high humidity, electrical problems, and flooding. Also check for rodents and nest in temporarily unused piping.



# Debris Management - Trash Racks

Open channel intakes shall include a trash rack which shall be kept free of debris. In certain cases, a satisfactory profile bar screen can substitute for a trash rack (ODFW)

Flow through velocity 1-2 ft./sec. (Irrigation Association)

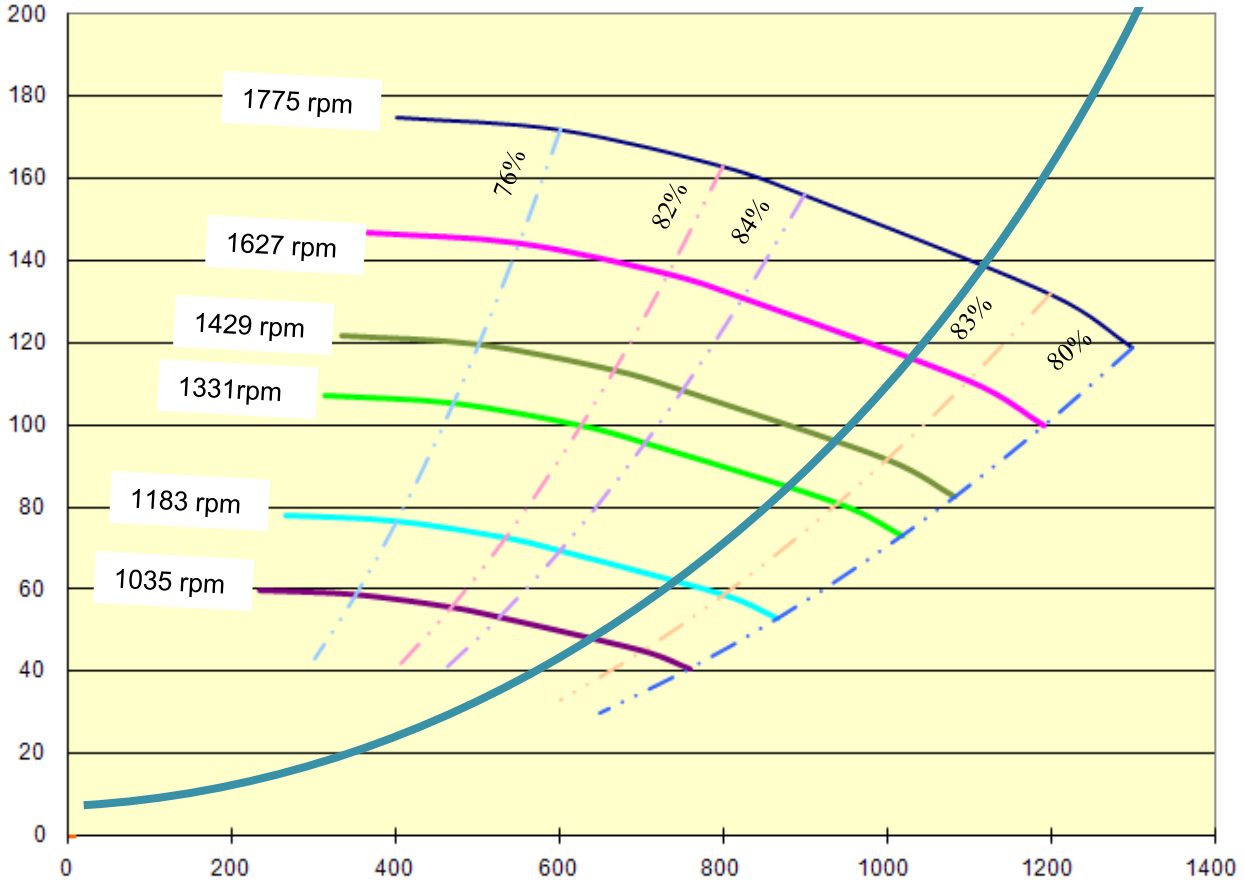
# Variable Speed & Pumps

- When a pump application is required to operate over a range of flow rates and pressures there are several method to control of the pump over the range of operation. One of them is controlling the speed of the pump

# How is variable speed accomplished?

- Mechanical (diesel and gasoline engines)
- Hydraulic (hydraulic coupling)
- Electrical (variable speed motor using variable frequency drive, or VFD – *most common*)
- Variable speed pulley arrangements
- Changeable gearbox
- Magnetic coupling

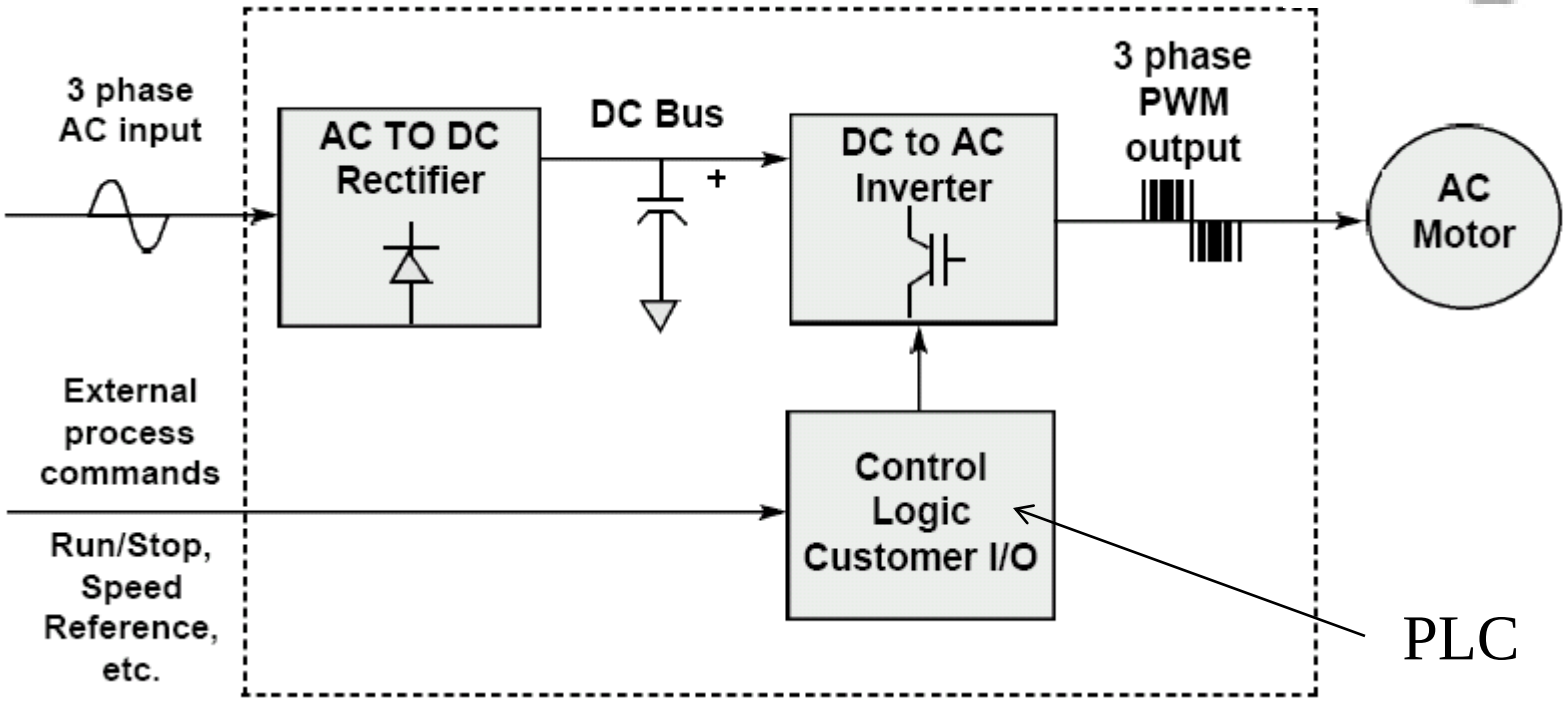
# Speed vs. System curve




**Changing the pump speed, ω, has nearly the same effect as changing the impeller diameter**

# Variable Frequency Drives (VFD's)

- VFDs are electronic systems that convert AC to DC and then simulate AC with a distinct frequency via pulses



# VFD Advantages

- Power savings
- Soft start and stop
- Single phase to three phase conversion
- Unity Power factor
- Application Change
- Open delta balancing
- Automation and system control

# Power savings

- Power savings are realized by allowing the to operate more efficiently over the ranges of flow
- Using just one motor and pump where multiple pumps may have been needed before

# Variable Speed Drive - Economic comparison

| Cooperators name | Location |
|---|---|
| | |
| | |

| Management inputs | | | |
|---|---|---|---|
| Field size (ac) | System flow rate (gpm) | Gross irrigation requirement (in/yr) | Total seasonal Operating Hours |
| | | | |

| Motor assumptions | | Costs | |
|---|---|---|---|
| Motor Efficiency (%) | VFD Efficiency (%) | Average Cost per kWh ($) | Installed Cost VFD ($) |
| | | | |

| Selected or Existing Pump | | | |
|---|---|---|---|
| Manufacturer | Type | Model | Pump RPM |
| | | | |

| Base pump curve (60 Hz) | | | |
|---|---|---|---|
| Point | Flow (gpm) | Head (ft) | Efficiency (%) |
| 1 | 400 | 208 | 60 |
| 2 | 600 | 200 | 74 |
| 3 | 800 | 180 | 81 |
| 4 | 1200 | 113 | 62 |
| 5 | 1400 | 85 | 55 |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |

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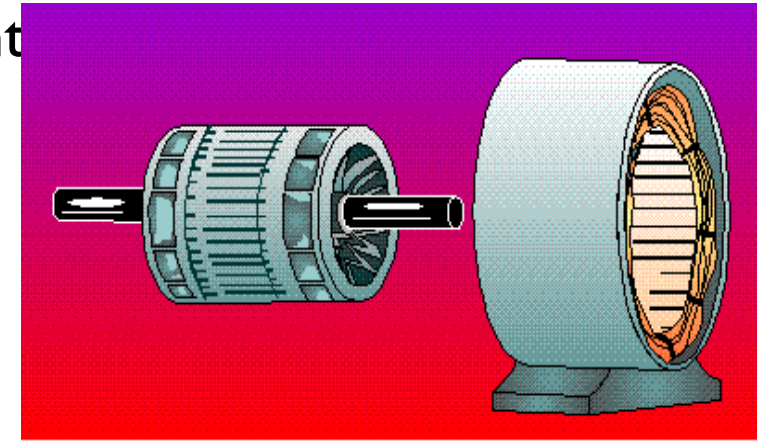
| Operating points/ system curve without VFD | | | | Operating points/System curve with VFD | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | Find | |
| Point | Flow (gpm) | Head (ft) | Pump Efficiency (%) | Flow (gpm) | Head (ft) | VFD freq (Hz) | Pump Efficiency (%) |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |

| Operating points/ system curve without VFD | | | | Operating points/System curve with VFD | | | |
|---|---|---|---|---|---|---|---|
| Point | %Hrs | Input-HP | KWh | VFD freq (Hz) | Input-HP | %Hrs | KWh |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |

# Soft Start & Stop

## Regardless of the Application

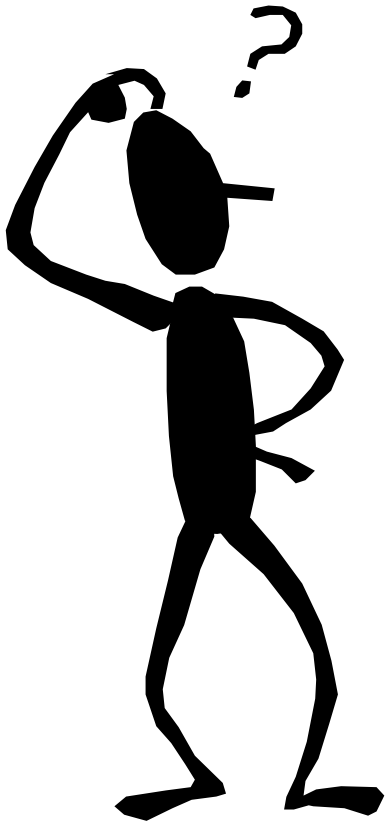
- Lower Locked Rotor Current
- Lower Mechanical Stress
- Lower Hydraulic Stress
- Longer Life



A point on the periphery of a two pole, 11.5" diameter rotor accelerates to 180 fps (123 MPH) in about 1 second.

# Single to Three Phase

- Regardless of input power output power will always be three phase
  - Sizing maybe an issue – rule of thumb double the normal three phase capacity



# Questions?

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