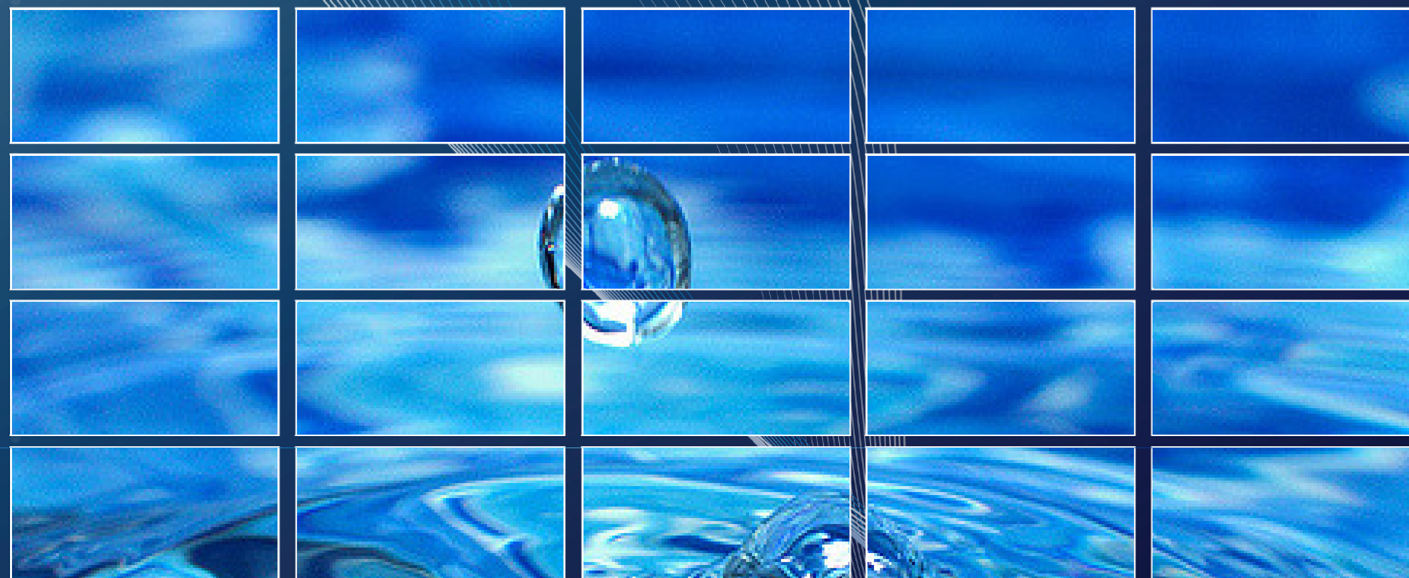
General Hydraulics



SAWEA Workshop 2010

Innovative Water and Wastewater Networks

Presented by Greg Welch, AECOM

Presentation Outline

- Basic Hydraulic Principles
- Open channel flow
- Closed conduit / pressurized flow systems
- Orifices, weirs and flumes
- Pumps and pumping systems
- Water Hammer
- Computer Modeling

Basic Hydraulic Principles

Why Hydraulics?

- Select pipe sizes and fittings for piping systems
- Determine pumping and power requirements
- Choose materials which best suit application

Water – Basic Properties and Assumptions

- Weight and volume
  - 1 m^3 = 1000 kg
  - sg = 1.00
- Viscosity
  - Low viscosity
  - Generally not considered
- Incompressible
- Water Flows Downhill
- Sewage = Water (hydraulically)

Continuity Equation

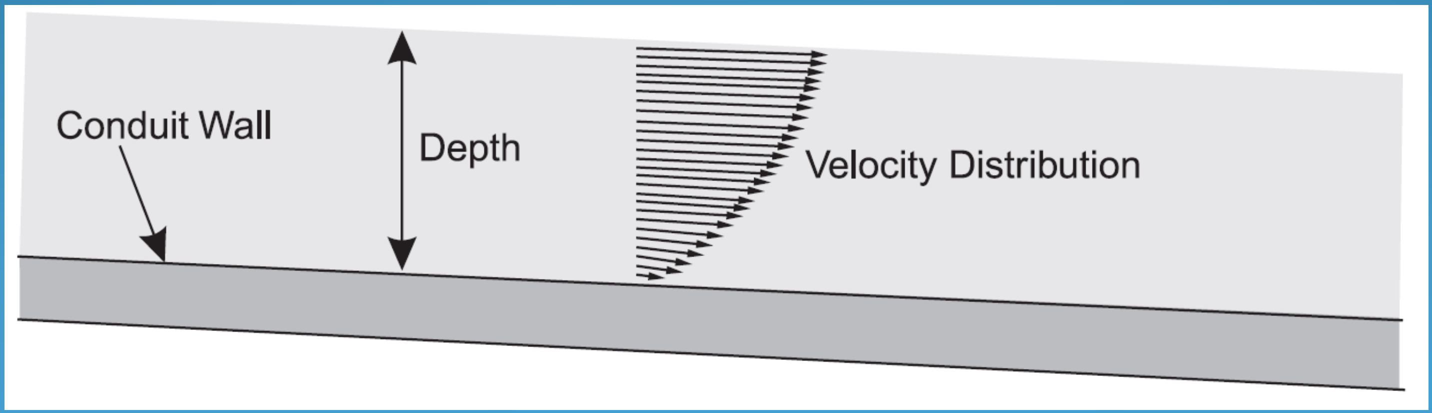
- **Q = VA**

where

Q = flow rate (m/s)

V = average velocity (m/s)

A = cross sectional area (m^2)



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Hydraulic Radius

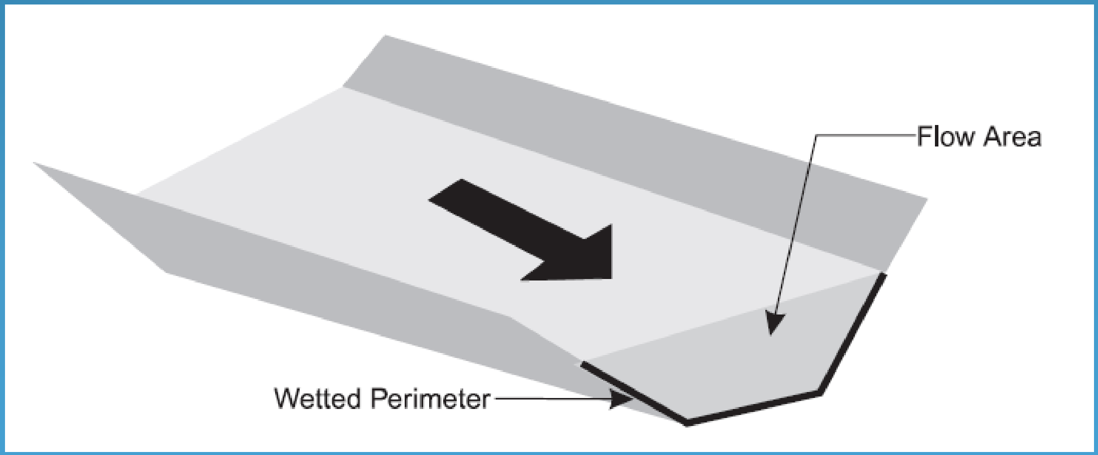
- $R = A / P_w$

where

R = hydraulic radius (m)

P_w = wetted perimeter (m)

A = cross sectional area (m^2)



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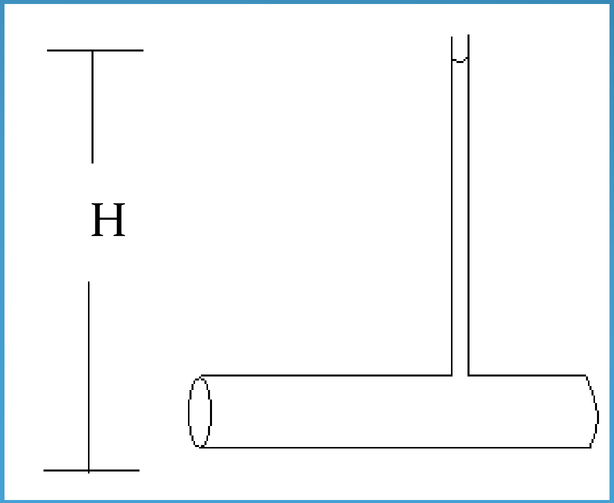
Energy

- Water has energy, namely
  - Potential energy, due to pressure
  - Potential energy, due to elevation
  - Kinetic energy, due to velocity
- Energy typically expressed as head (H)
  - m or ft
  - 1 psi = 2.31 ft
  - 1 kPa = 0.1 m



Energy (Cont)

- **Bernoulli's Equation**

$$H = V^2/2g + p/\gamma + z$$

Where

H = Total energy (m)

V = Velocity (m/s)

g = acceleration gravity (9.81 m/s²)

p = pressure (kPa)

γ = water density (9.81 kN/m³)

z = elevation (m)

Friction Loss

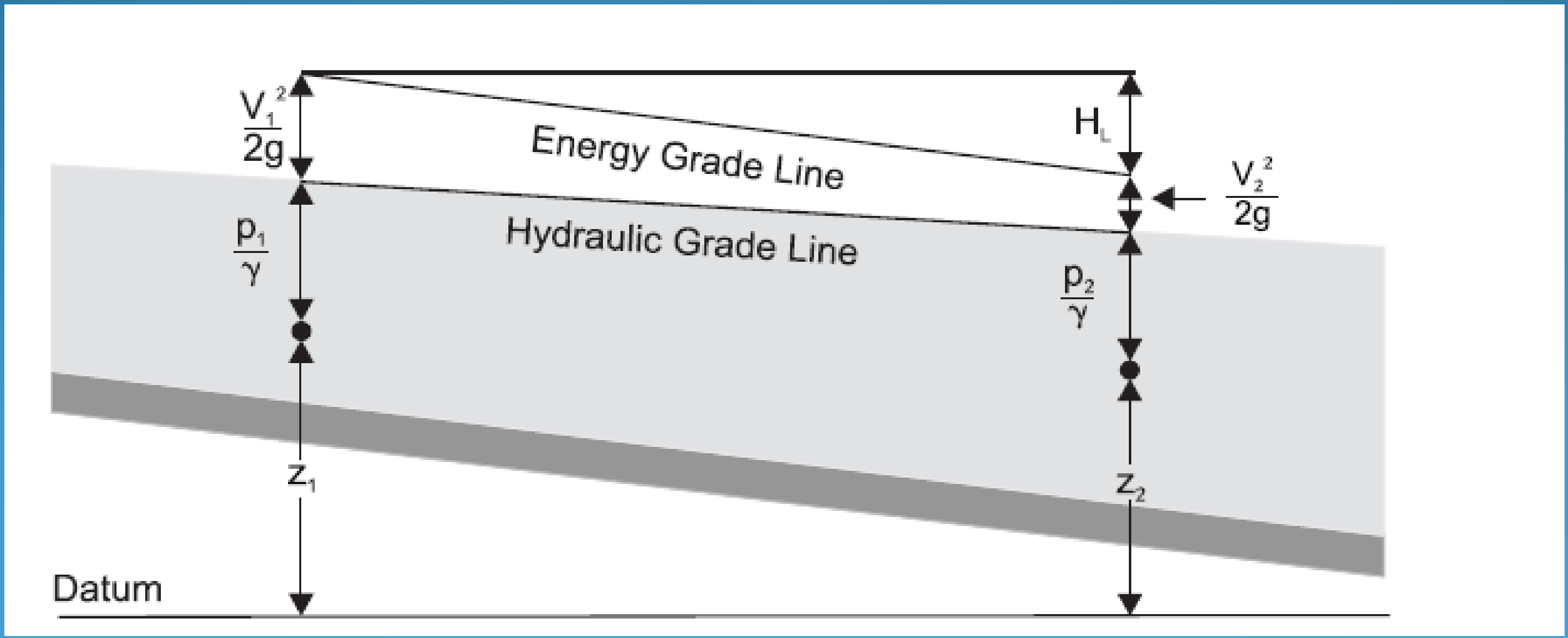
- Energy is lost in piping systems due to friction as water moves through the pipe
- Affected by:
  - Pipe size
  - Pipe length
  - Pipe roughness
  - Flow rate
- Losses also occur in other hydraulic elements:
  - Fittings
  - Valves
  - Entrance/exits
  - Etc.

Energy Equation

$$V_1^2/2g + p_1/\gamma + z_1 = V_2^2/2g + p_2/\gamma + z_2 + H_L$$

H_L = head loss

For Open Channel:



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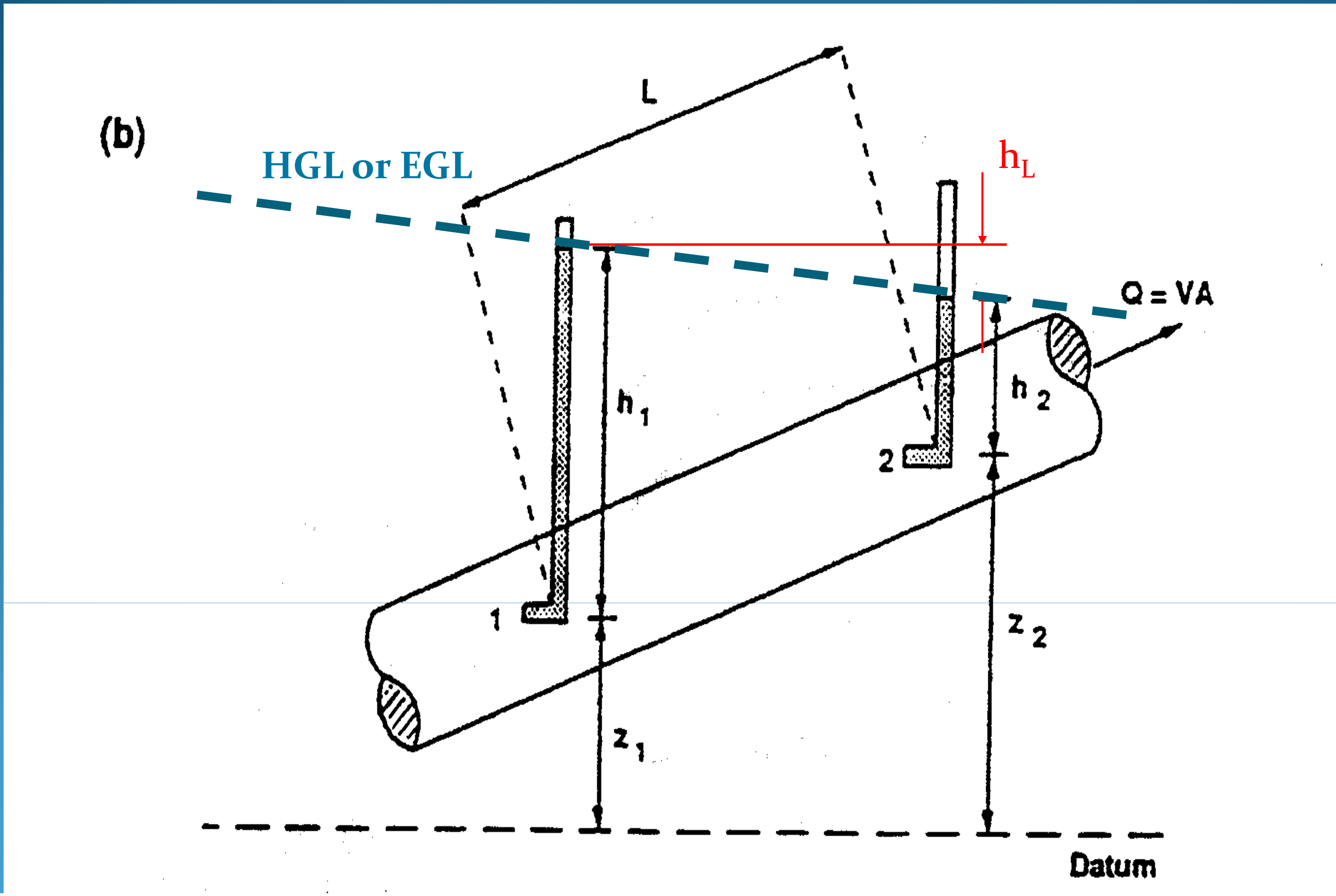
Energy Equation (cont)

and for pressurized pipe systems:



Open Channel Flow

Open Channel Flow

- Typical Design Equations:
  - Manning's
  - Chezy
- Manning's Equation:

$$V = (1/n)\ R^{2/3}\ S^{1/2}$$

where
V = mean velocity (m/s)
n = Manning's roughness value
R = hydraulic radius (m)
S = friction slope (m/m)

Manning’s Value

Typical Values:

Steel	0.010
Cast Iron	0.012
Concrete	0.013
Smooth Earth	0.018
Corrugated Metal Pipe	0.024
Rock	0.040

Pressurized Flow Systems

Pressure Pipe Flow

- **Typical Design Equations:**
  - Hazen-Williams
  - Darcy-Weisbach
- **Hazen Williams Equation:**

$$S = (10.67Q^{1.85})/(C^{1.85}D^{4.87})$$

where
S = head loss (m/m)
Q = Flow (m3/s)
C = Roughness Coefficient
D = pipe inside diameter (m)

Hazen Williams C Values

Typical Values:

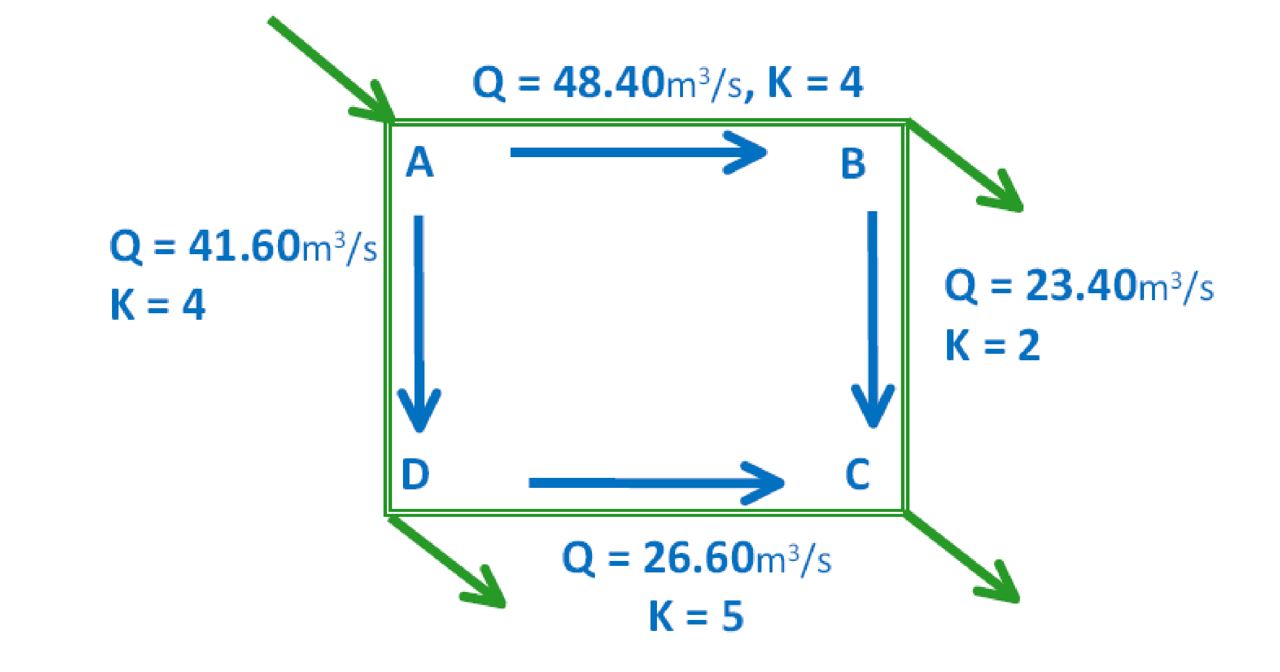
PVC	150
Steel	140
Cast Iron	130
Concrete	120

Hardy Cross Analysis

- Used for analysis of pipe flow and pressure in water networks
- Flowrate in each pipe adjusted iteratively until all equations are balanced
- Basis of many water network analysis programs

Hardy Cross Analysis (Cont)

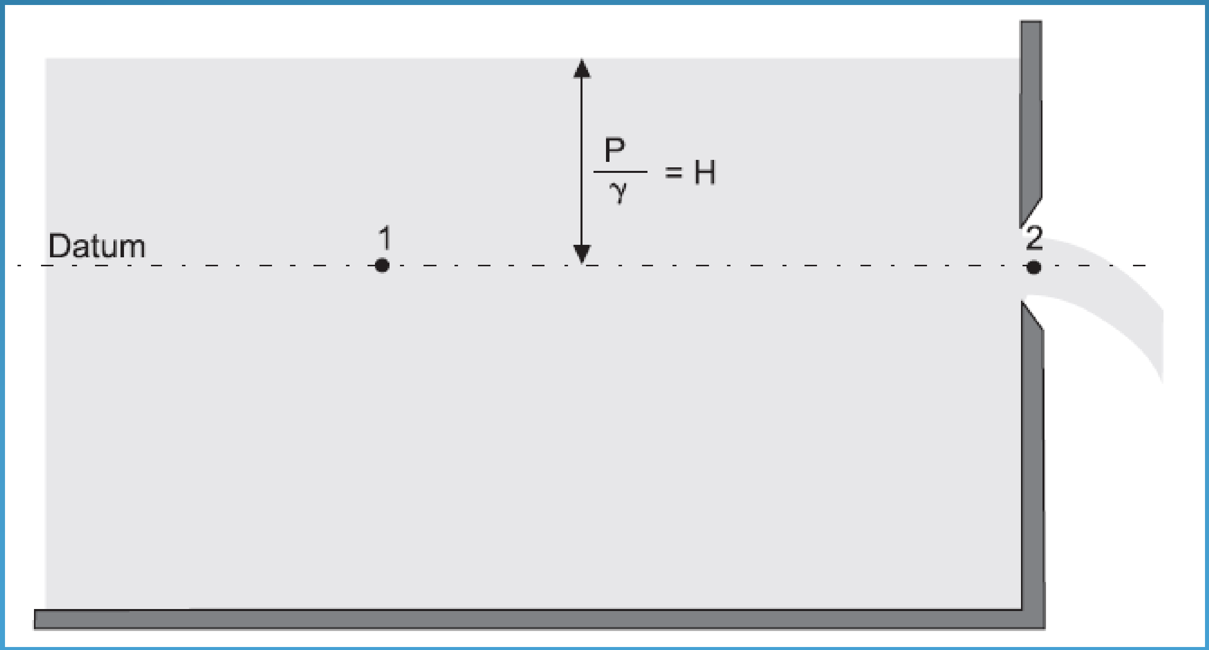
- The method is based on:
  - Continuity Equation:
    - Inflow = Outflow at nodes
    - Example Qa = Qb + Qc
  - Energy Equation:
    - Summation of Head Loss in Closed Loop is zero.
    - ΣHLLoop = Σ(Q+Q)n = 0



Orifices , Weirs and Flumes

Orifices

- $Energy_1 = Energy_2$
- $V_1^2/2g + p_1/\gamma + z_1 = V_2^2/2g + p_2/\gamma + z_2 + H_L$
- $Q = CA\,(2gH)^{1/2}$
- where C = Orifice Coefficient



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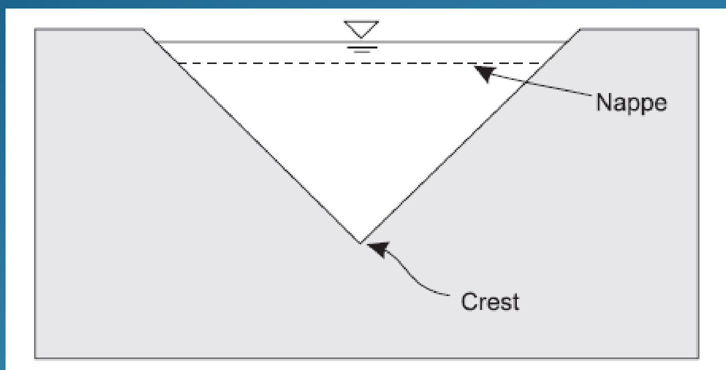
Weirs

Energy$_1$ = Energy$_2$

$$V_1^2/2g + p_1/\gamma + z_1 = V_2^2/2g + p_2/\gamma + z_2 + H_L$$



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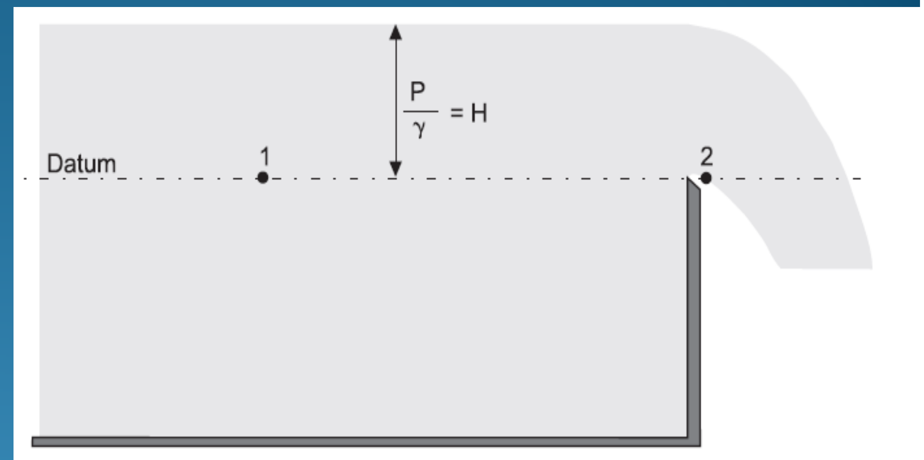


Source: Haestad

Typical V-Notch Weir

	Weir Type	Figure	Equation	Coefficients
Sharp Crested	Rectangular	L, H	Contracted $Q = C(L - 0.1iH)H^{3/2}$ Suppressed $Q = CLH^{3/2}$ i = Number of iterations	Metric C = 1.84 English C = 3.367
	V-Notch	θ, H	$Q = C\left(\frac{8}{15}\right)\sqrt{2g}\tan\theta\left(\frac{H}{2}\right)^{5/2}$	C varies between 0.611 and 0.570 depending on H and Q*
	Cipolletti	L, H, 4:1	Metric $Q = CLH^{3/2}$ English $Q = CLH^{3/2}$	Metric C = 1.86 English C = 3.367
Non-Sharp-Crested	Broad (Side View)	H_r, h_t, L_r	$Q = C_dLH_r^{3/2}$	C_d is a function of H_r, h_t and L_r ranging between 1.25 and 3.1*

Flumes

- Open channel flow measurement
- Flow uniquely related to water depth
- Types:
  - Venturi
  - Parshall
  - Palmer –Bowlus
  - Trapezoidal
  - Custom flumes

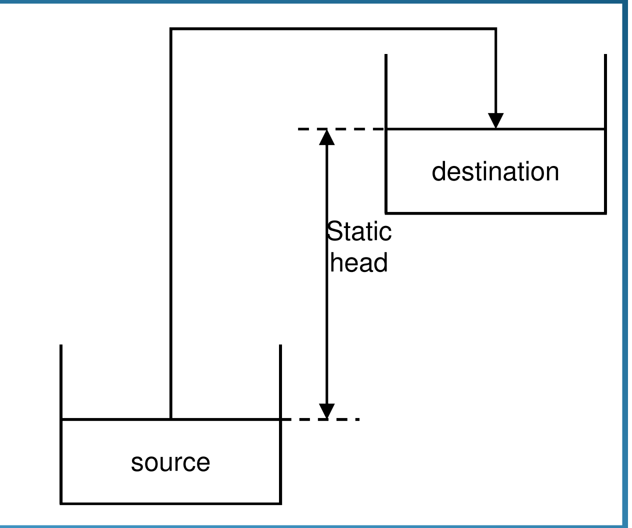
Parshall Flume

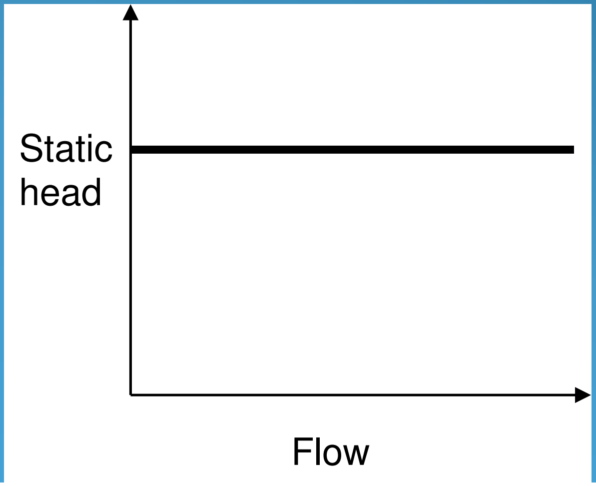
Pumps and Pumping Systems

Pump Basics

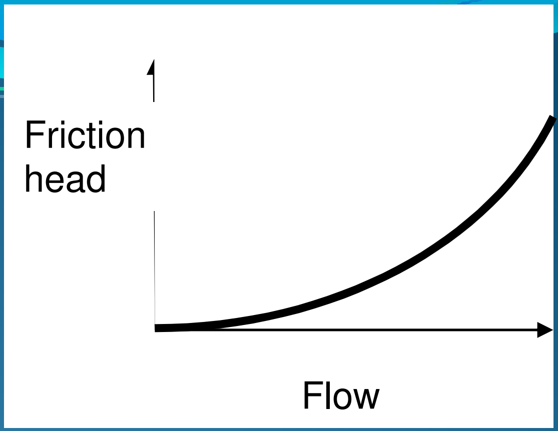
- Head
  - Resistance of the system
  - Two types: static and friction

- Static head
  - Difference in height between source and destination
  - Independent of flow





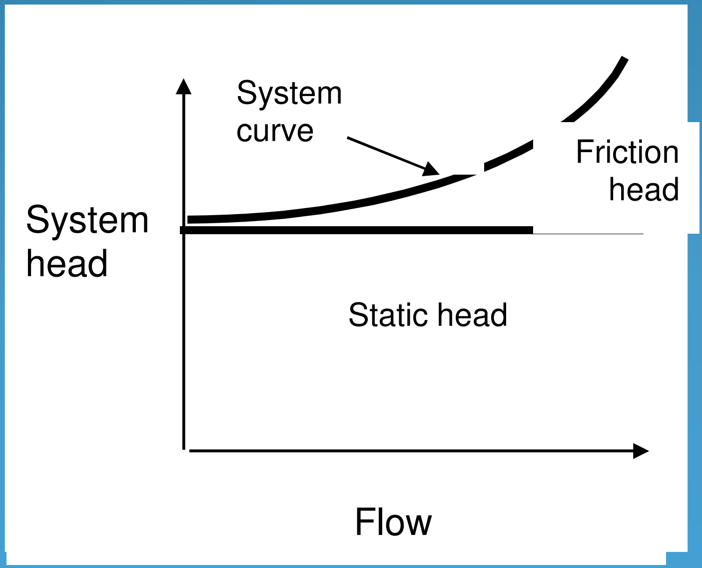
Pump Head

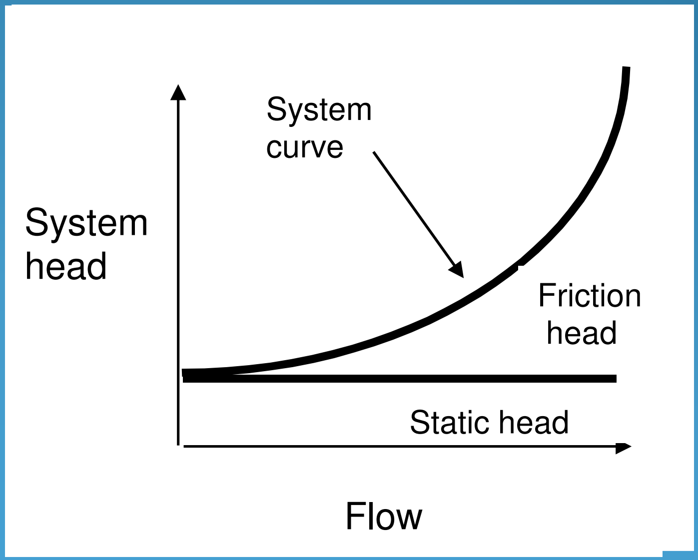


- Static head consists of
  - Static suction head (hS): lifting liquid relative to pump center line
  - Static discharge head (hD) vertical distance between centerline and liquid surface in destination tank
- Friction head
  - Resistance to flow in pipe and fittings
  - Proportional to square of flow rate
  - Depends on size, pipes, pipe fittings, flow rate, nature of liquid
  - Closed loop system only has friction head (no static head)

Pumping System Characteristics

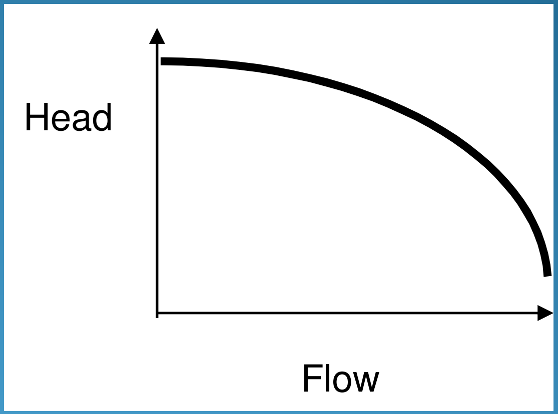
- In most cases:
- Total head = Static head + friction head





Pump Performance Curve

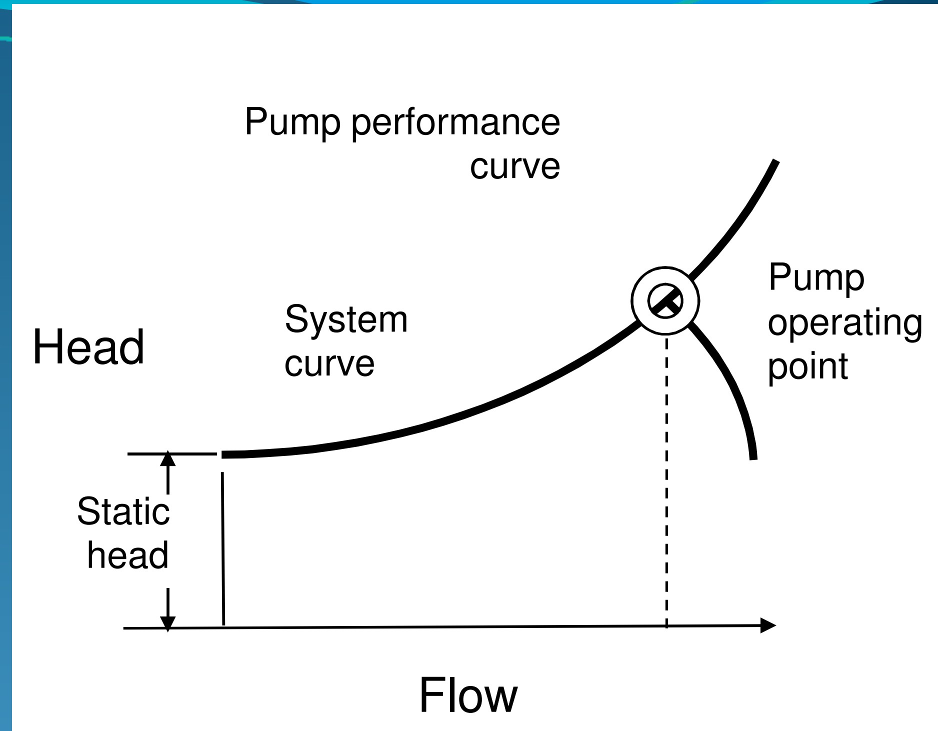
- **Relationship between head and flow**
  - **Flow increase**
  - **System resistance increases**
  - **Head increases**
  - **Flow decreases to zero**
- **Zero flow rate: risk of pump burnout**

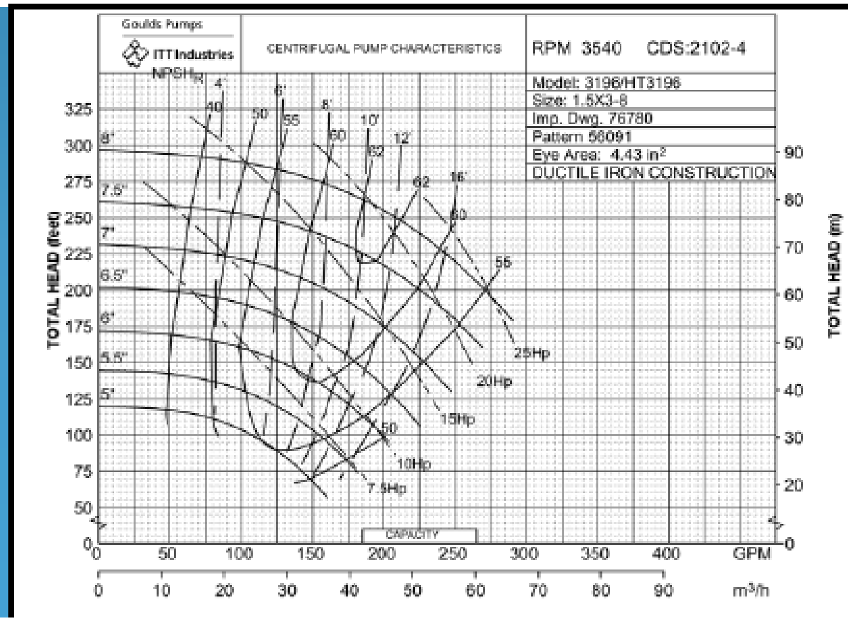


Performance curve for centrifugal pump

Pump Operating Point

- **Duty point: rate of flow at certain head**
- **Pump operating point: intersection of pump curve and system curve**





Pump Suction Performance (NPSH)

- Cavitation or vaporization: bubbles inside pump
- If vapor bubbles collapse
  - Erosion of vane surfaces
  - Increased noise and vibration
  - Choking of impeller passages
- Net Positive Suction Head
  - NPSH Available: how much pump suction exceeds liquid vapor pressure
  - NPSH Required: pump suction needed to avoid cavitation

Hydraulic Surge and Transients

- Commonly known as Water Hammer or Surge
- Causes
  - Pump start-up or shut down
  - Power failure
  - Sudden valve closure
- Impacts on system
  - Reduces life of pipelines
  - Noise
  - Mechanical damage
  - Catastrophic system failure

Basic Equation

ΔP = rcΔv/g

where r = fluid density

c = wave speed

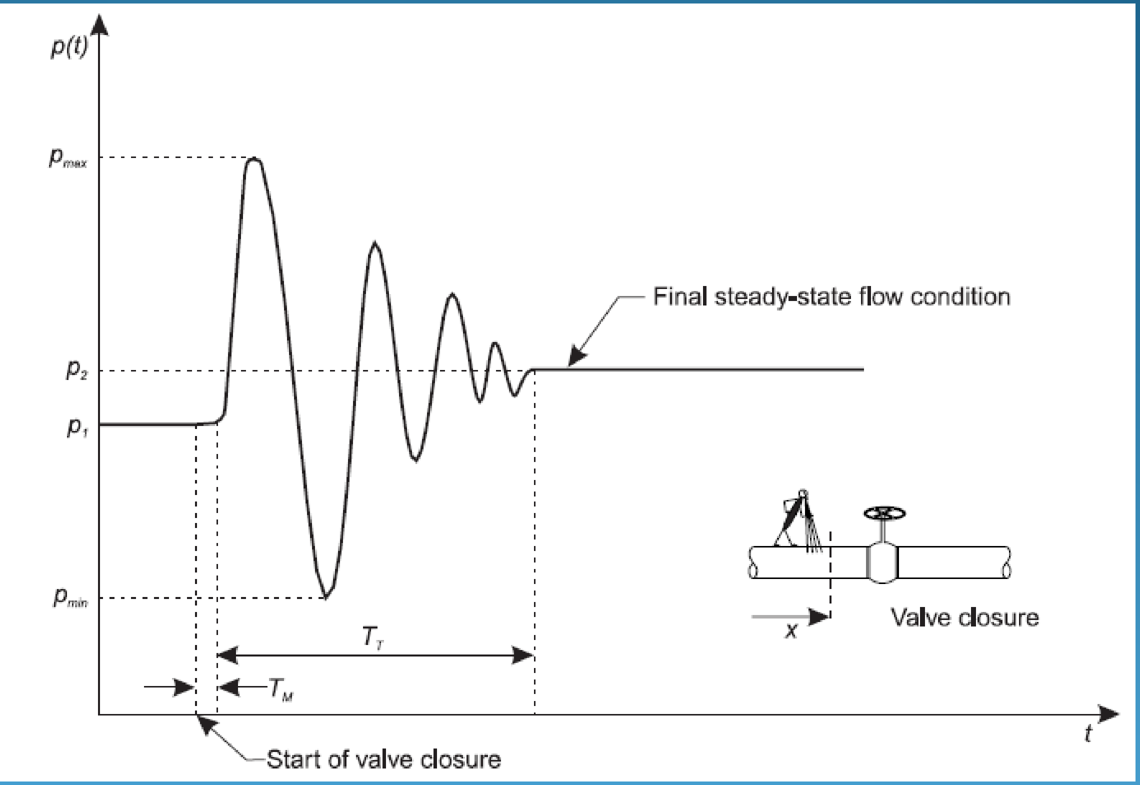
v = change in velocity of fluid

g = gravitational constant

- c is influenced by pipe material
- P directly proportional to Δv

Example – Sudden Valve Closure

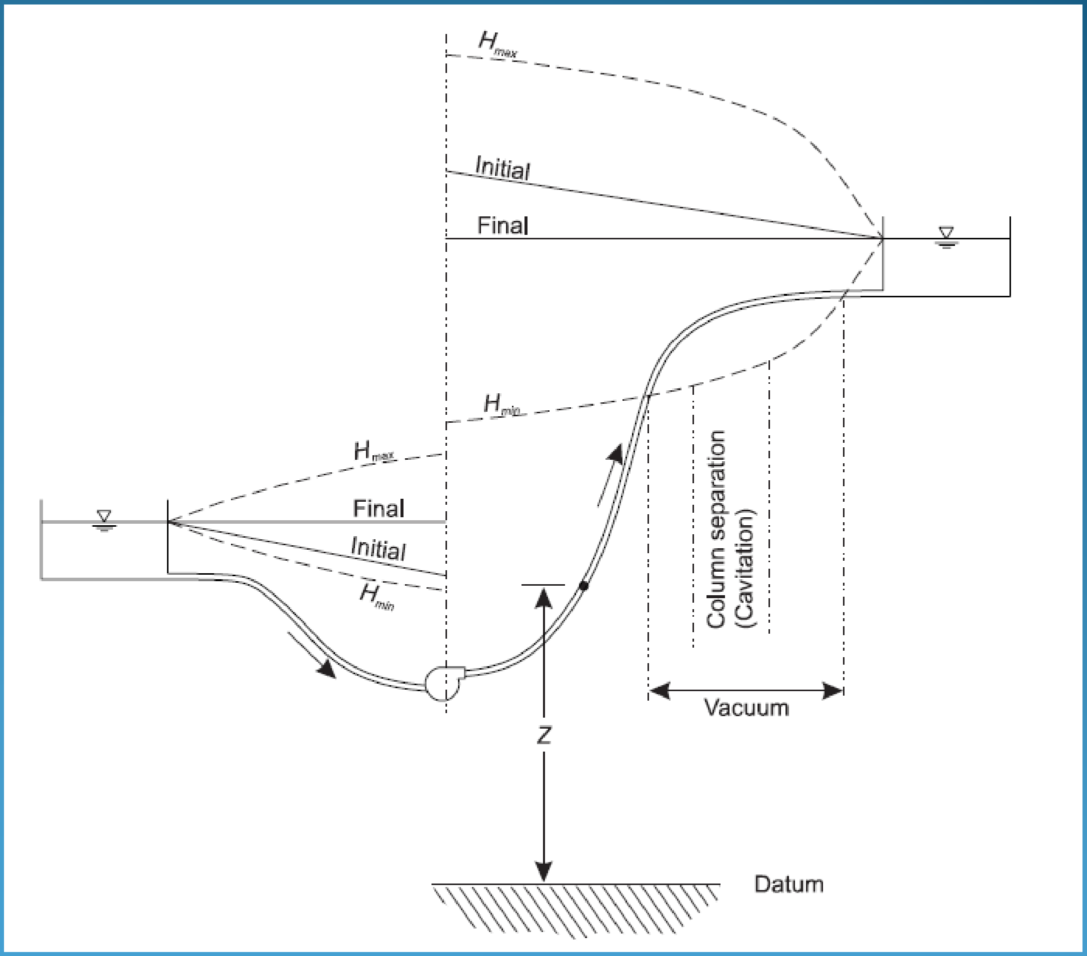
- Results in surge wave propagating and reflecting in system



Source: Haestad

Example – Sudden Pump Failure

- H fluctuates at any given point after pump failure
- Can cause column separation



Source: Haestad

Surge Mitigation

- At pump
  - Pump control valves
  - Surge anticipator valves
  - Surge tanks
  - Pump flywheels
- In Pipeline
  - Vacuum breaker valves
  - Air release valves
  - Combo vacuum/air release valves
  - Select “elastic” pipe materials (ie, PVC)
- Hydraulic modeling always recommended during design of new sewage force mains and water transmission mains.

Computer Modeling

Computer Modeling

- Why computer model?
  - Reduces time
  - More accurate
  - Allows integration with other software (SCADA, GIS)
- Currently there is considerable software for modeling available
  - Water distribution networks
  - Sanitary sewer networks
  - Storm Sewer Networks
  - Surge/transient analysis
  - WWTP Hydraulics
  - Water Quality
- Some considerations
  - For the modeler, understanding of hydraulics just as important as understanding software
  - Garbage in = garbage out
  - Calibration is essential

Advances in Water Distribution System Modeling

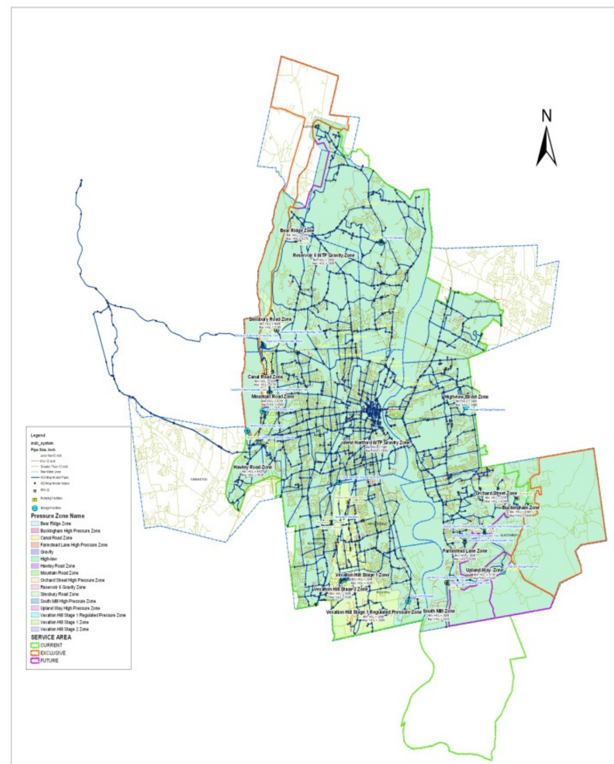
- Developing databases of system assets from multiple, complex sources
- Complex demand management
- Operations management with extended period modeling
- Maintaining disinfectant residual levels while minimizing disinfection by-product formation
- Understanding flow patterns and fate of water quality in storage facilities
- Assessing hydraulic transients in networks

Data Combined from Multiple, Complex Sources into Models

- Data Sources
  - Geographic information systems
  - CAD Drawings
  - Paper maps – Scanned and digitized
  - Demands – Billing databases, operating logs, production records
  - SCADA
- Data Management
  - GIS spatial tools
  - Model software tools
  - Custom programming

Metropolitan District Commission
Hartford, CT

- Population Served:
  - 400,000
- Pipe Segments in Model:
  - 4, 700 (91,000+ in GIS)
- Length of Pipes:
  - 600 miles in model
  - (1550 miles total)
- Water Sources:
  - Surface Water
- Average Day Demand:
  - 55.5 mgd
- Type of Model:
  - EPS
- Software:
  - H2OMap



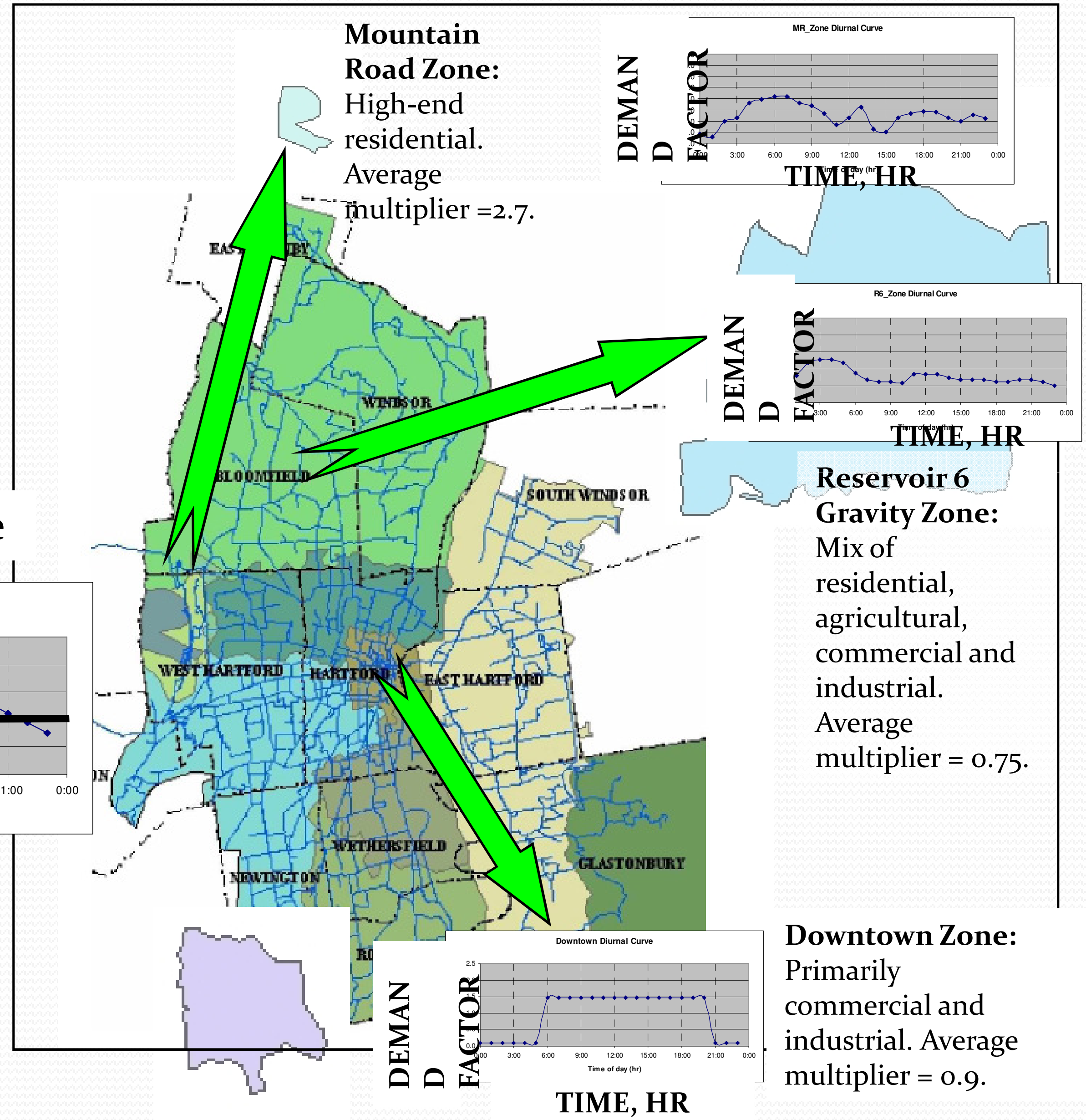
MDC

M&E Metcalf & Eddy

Computer Model of Metropolitan District's
Water Supply, Treatment and Distribution Systems
RFP#161

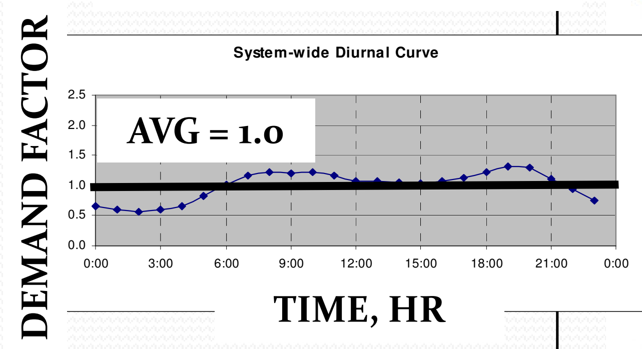
Hartford Connecticut (MDC) Example

MAP OF MDC DEMAND ZONES



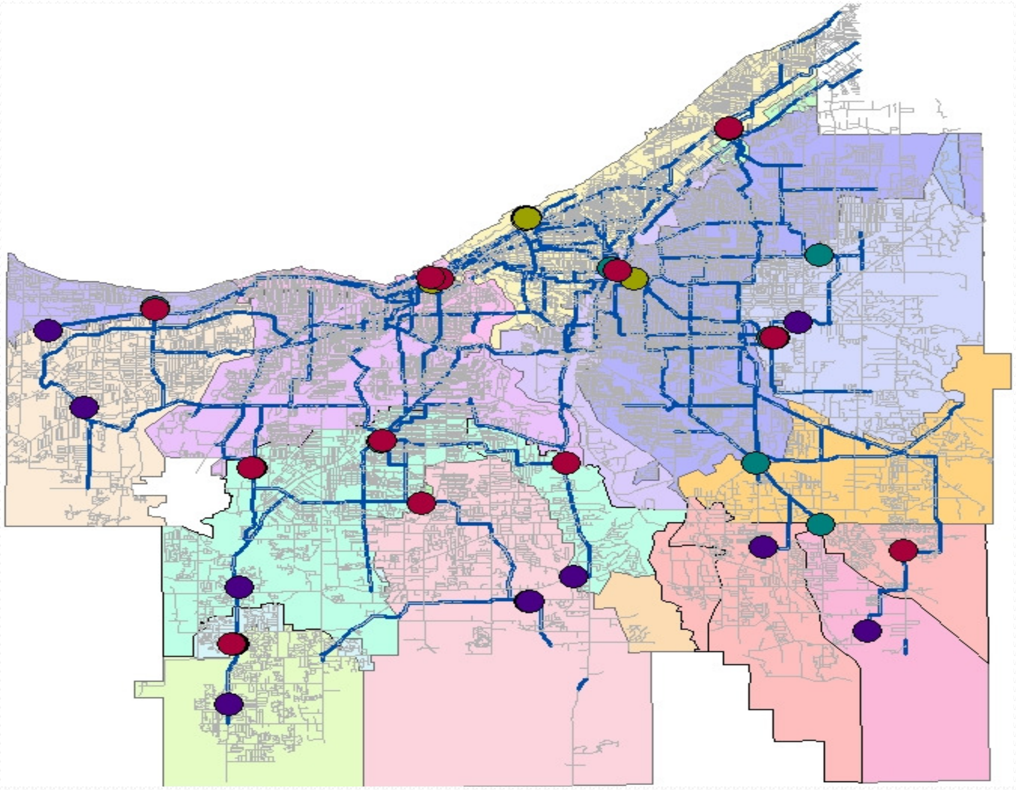
Managing several different demand patterns and multipliers

System-Wide Curve



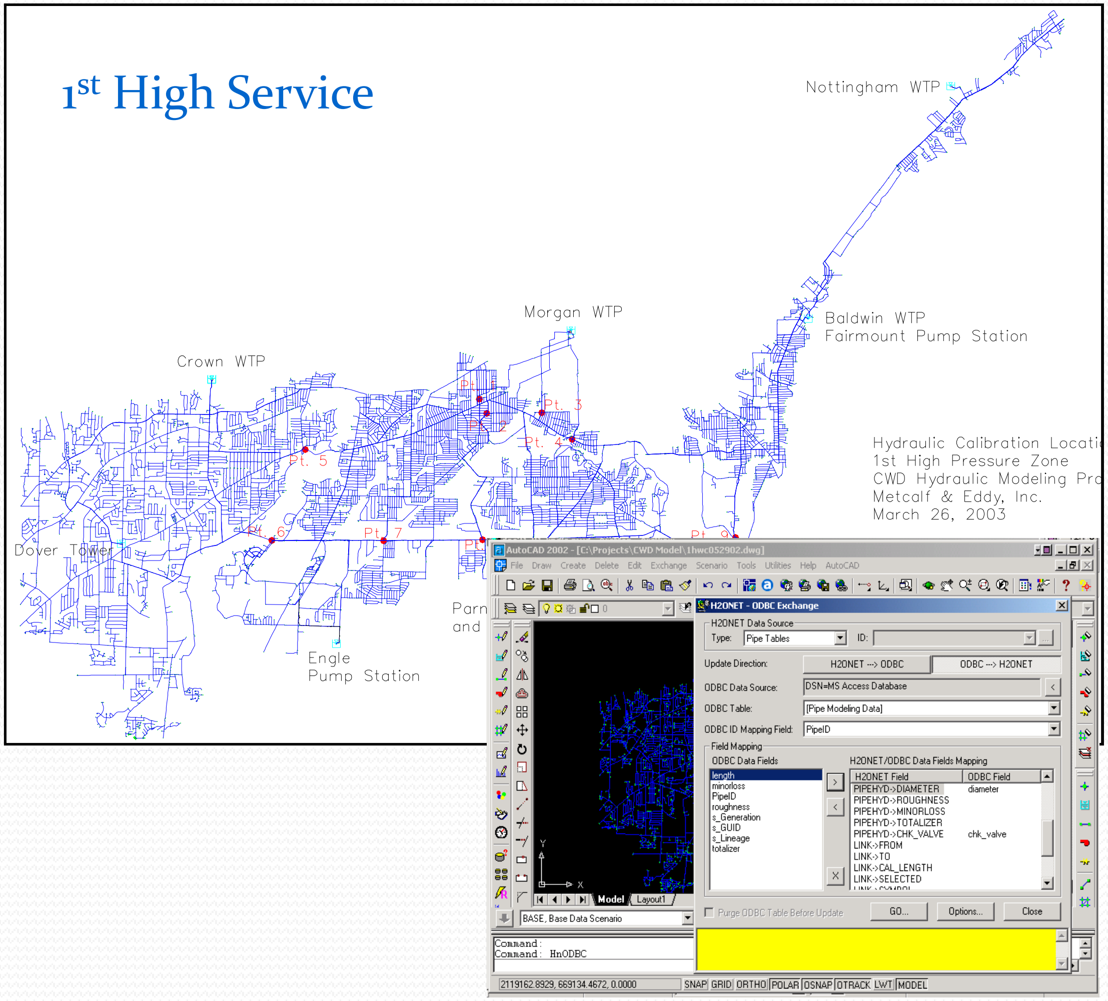
Cleveland (OH) Division of Water

- Population Served:
  - 1.5 million
- Pipe Segments in Model:
  - 57,000
- Length of Pipes:
  - 5,350 miles
- Water Sources:
  - Lake Erie (4 WTPs)
- Average Day Demand:
  - 265 mgd
- Type of Model:
  - EPS and WQ
- Software:
  - H2ONet and SURGE

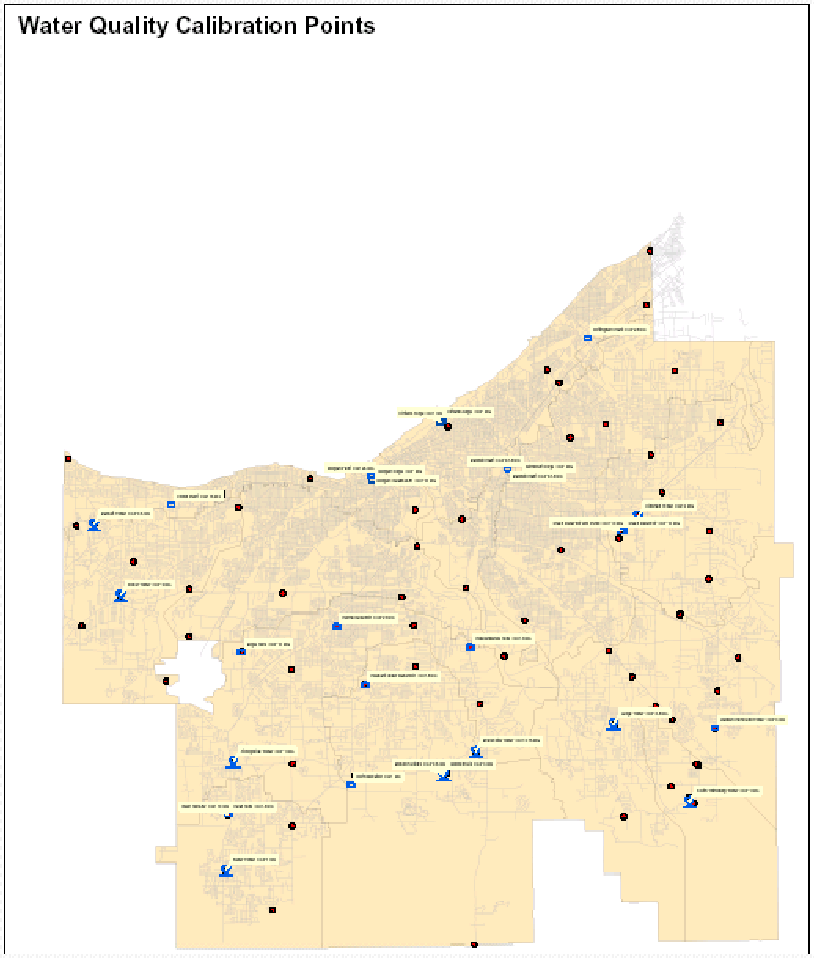


Main Uses of CWD's Hydraulic Model

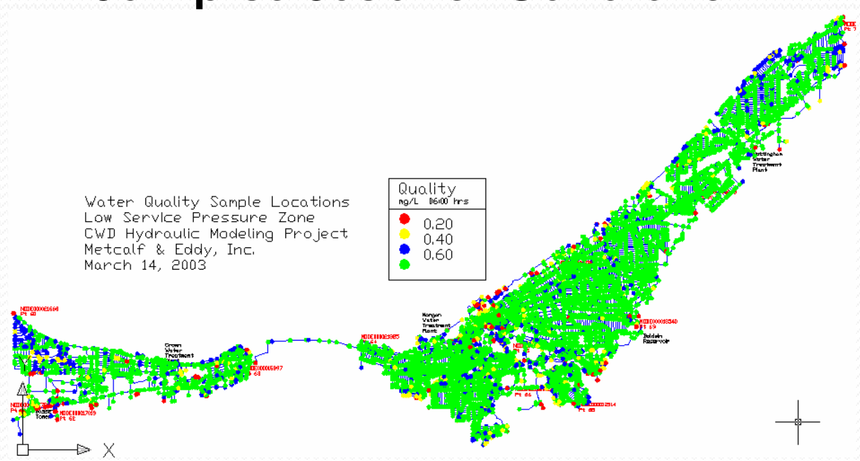
- *Assess System Flows and Pressures*
- *Evaluate Impact of System Growth*
- *Facilitate Maintenance Activities*
- *Manage Operations more Efficiently*
- *Monitor Water Quality*



Field Sampling Used to Develop Water Quality Model

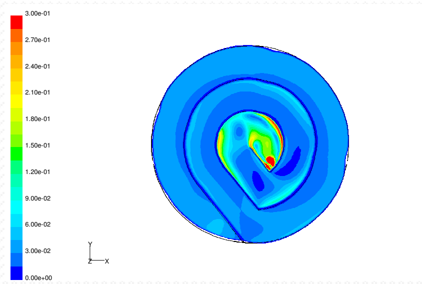


- Coordinated Sampling Program Conducted by CWD
    - Three Sessions
    - Approx. 25 Collection Sites/Session
    - 2-6 Samples/Site Taken Over 48 Hours
- Hydraulic Model Modified to Simulate Chlorine Decay
- Samples Used for Calibration

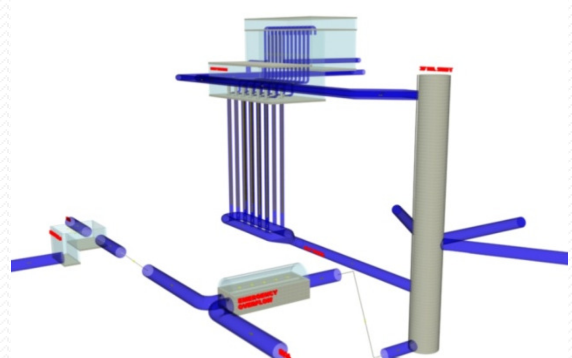


CFD Modeling Provides Insight on Water Quality and Flow Patterns

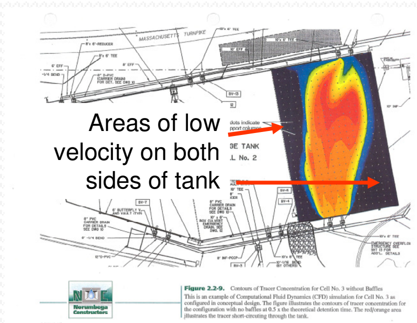
- Assess Flow Patterns
- Design Baffles
- Assess Thermal Stratification

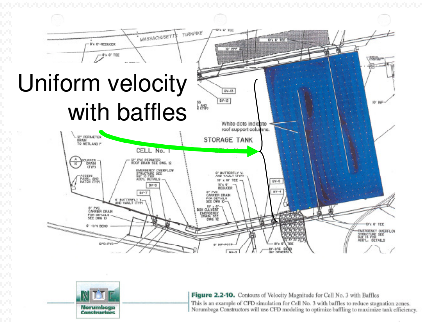


2D Velocity

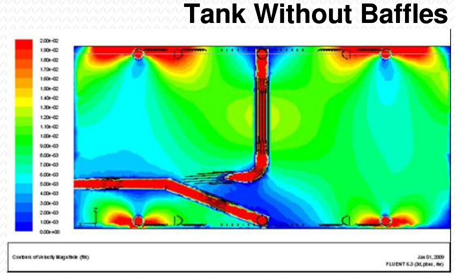


Pump Station Intakes

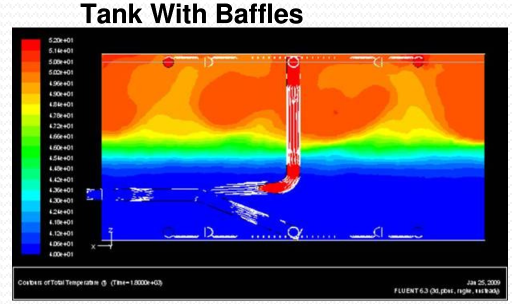




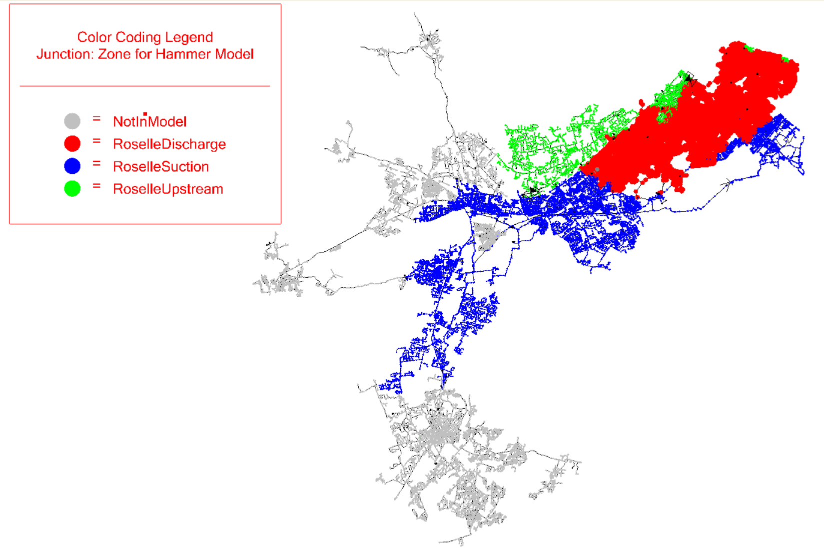
Tank Without Baffles

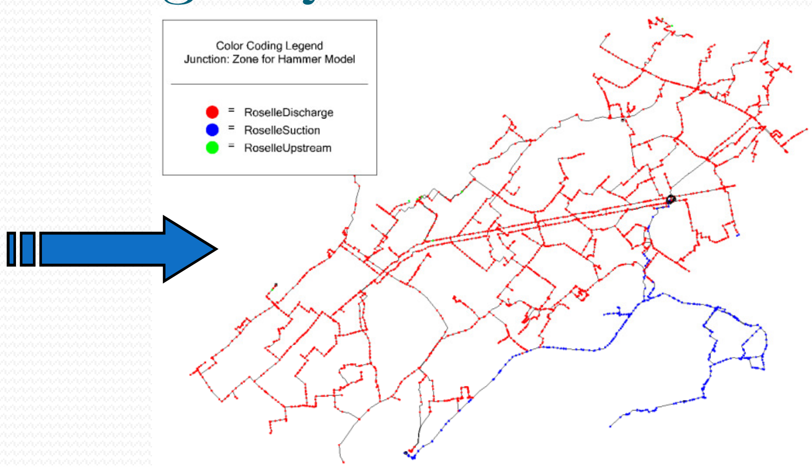


Tank With Baffles



Surge Models Created from Large System Models





<u>Base Model</u>

<u>Skeleton Model</u>

Impact of System Upgrades Assessed with Water Hammer Models

- Model Statistics
  - Pipes = 3,709 pipes (6” – 48” Dia.)
  - Nodes = 3,568 (198 Junctions & 3,370 Consumption)
  - Pumps = 3
  - Tanks = 3 Simple Surge Tanks
  - Reservoirs = 7 Fixed Head Sources
  - Valves = 3 check/control valves, 1 surge relief valve
  - Air Valves not included as conservative measure
  - Base Demand ~ 72 mgd (Maximum day)

Keeping Distribution Systems in Top Working Order with Limited Funds

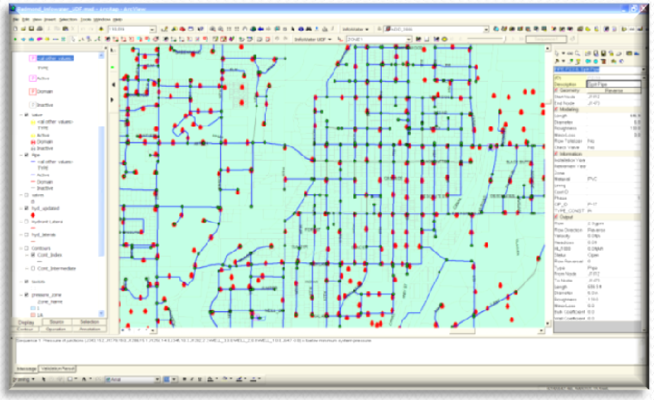
- Flushing Programs
- Optimize Energy
- Unifying maintenance activities with databases
- Planning for pipe replacement
  - Condition assessments
  - Remaining useful life analyses

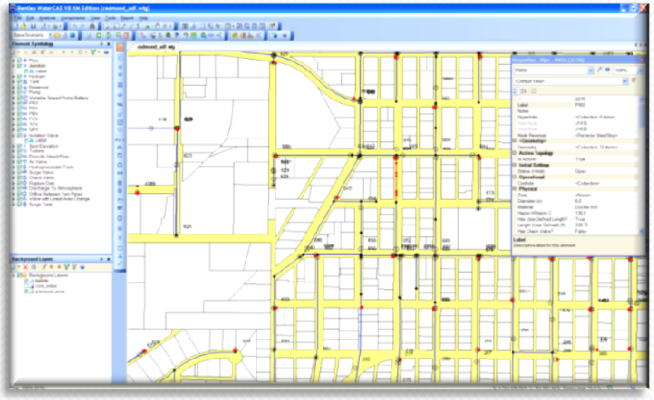
Automated Tools Used to Develop Flushing Programs

- MWH Soft & Bentley Systems

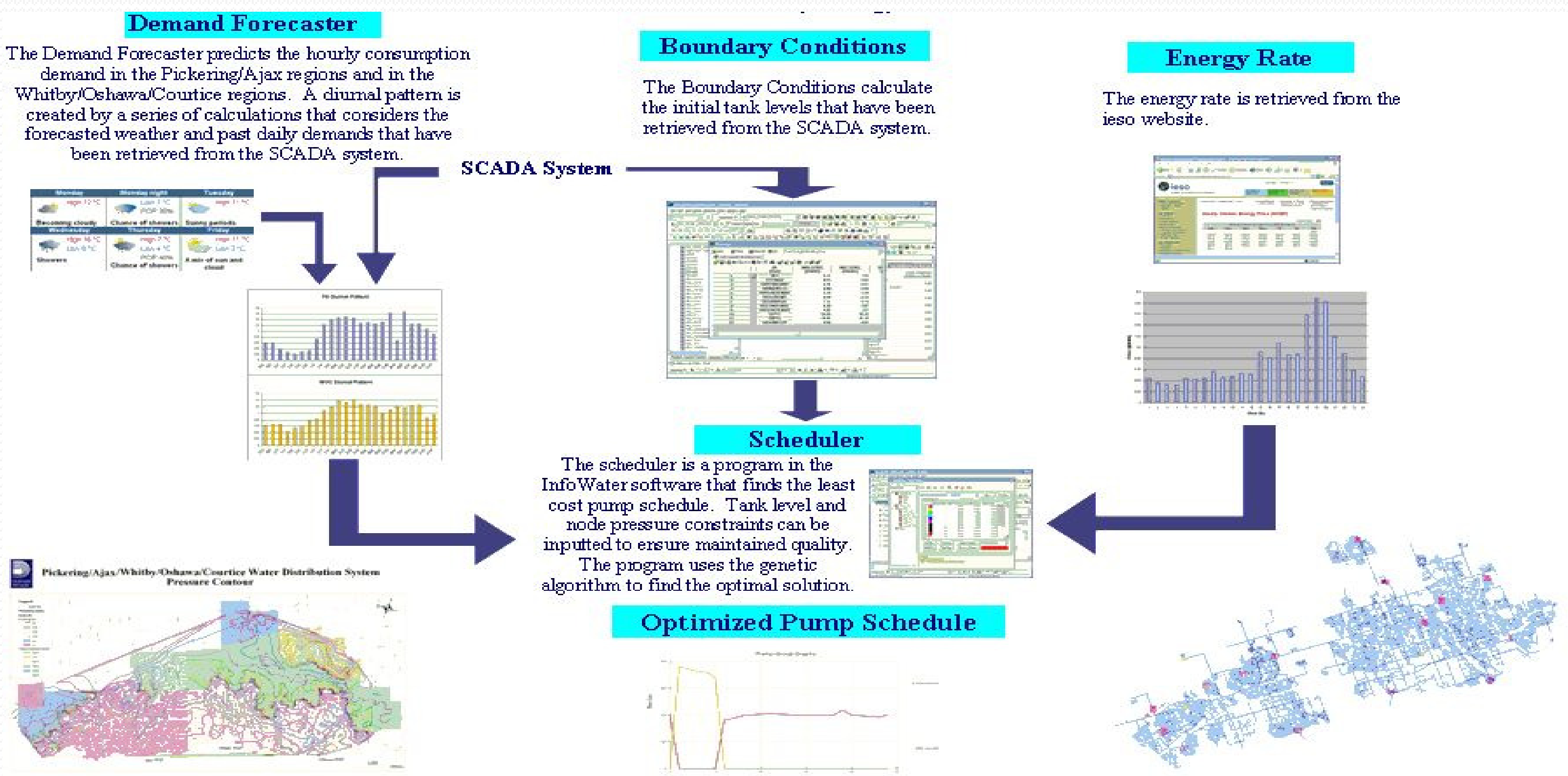
- MWH Soft
  - UDF - separate module
  - Requires InfoWater (ArcGIS) license

- Bentley
  - Includes UDF with all platforms (stand alone, CAD, ArcGIS)





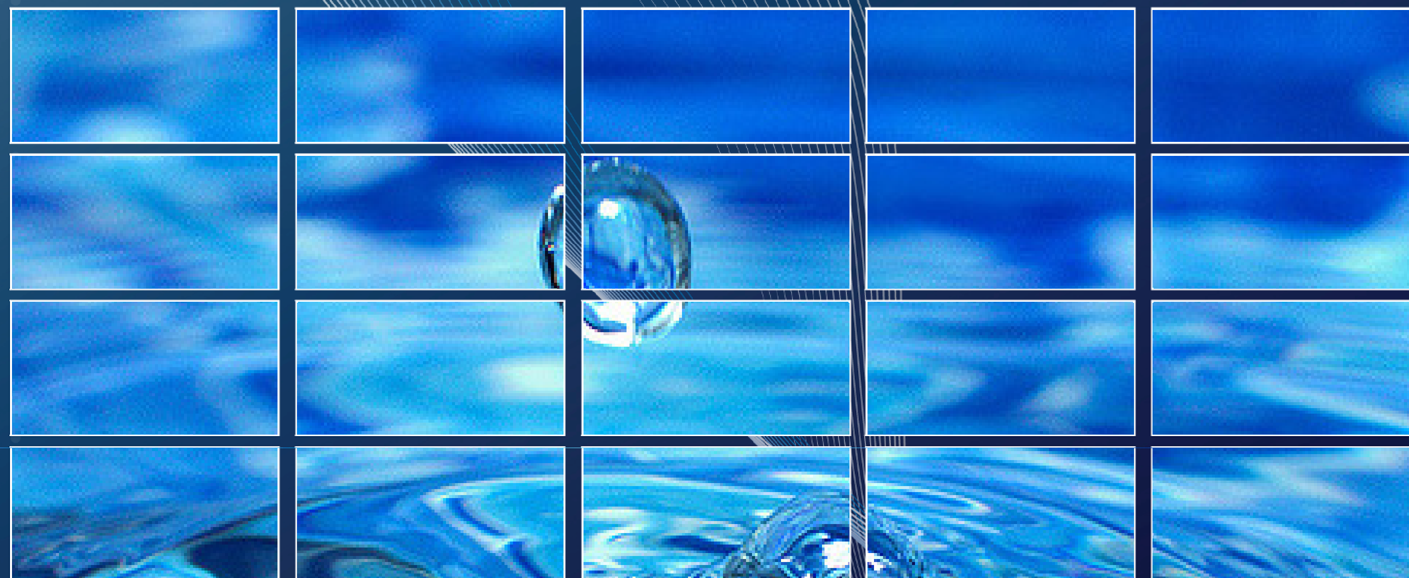
Energy Use Optimized for Durham Region Water System



Work Planning Integration

- Objective:
  - Provide the tools needed to support risk-based planning and decision making for water distribution assets
  - Streamline the collection, management, and use of water system data in risk assessment and work prioritization

Thank You



AECOM