Sanitary Sewer Design and Modeling Workshop

Featuring Bentley Systems SewerGEMS

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Bentley Systems

Scope

- Steady hydraulics
- Model building
- Unsteady hydraulics
- Hydrology
- Dry weather loading
- Sanitary sewers
- Combined Sewers
- Designing new systems
- Pumps and force mains
- Pressure sewers
- Transient analysis
- Monitoring/rehab
- Geospatial data
- Load building
- Water quality

Sanitary Sewer System Overview

- Convey wastewater to treatment
- In some cases stormwater is also conveyed
- Primary components are:
  - gravity pipes
  - connecting manholes or access chambers
  - pump stations and pressure mains
- Most systems designed for gravity flow

Types of Conveyance

- Gravity flow
- Surcharged gravity flow
- Inverted siphons
- Pressure flow in force mains
- Pressure sewers
- Vacuum sewers

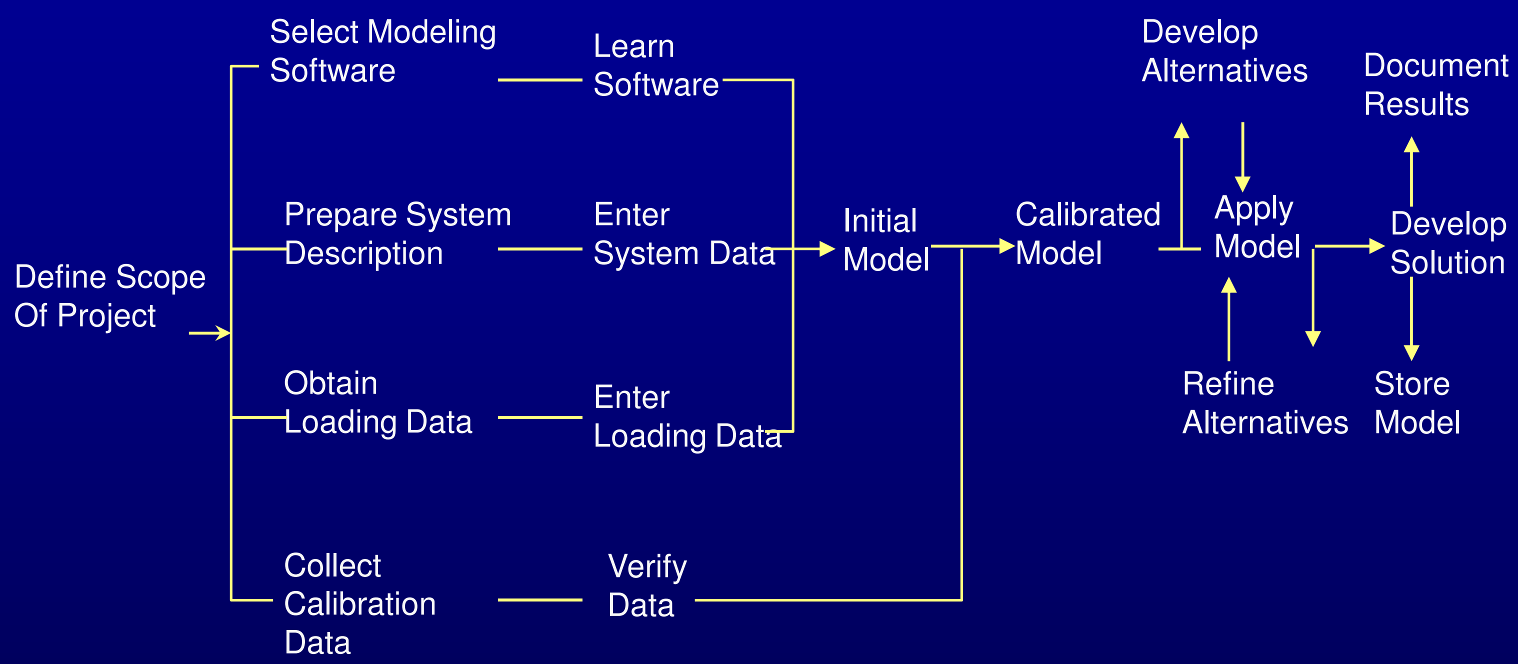
Applications of Collection System Models

- Design
- Long-range master planning
- Rehabilitation studies
- Operational problems
- Regulatory compliance
- “What if?” scenarios

Temporal Considerations

- Steady State
  - Used for design work
  - Typically concerned with extreme conditions
  - Snap shots of the system in time
- Unsteady (extended period)
  - Used when pumps cycling or storage in system are significant
  - Routing hydrographs through system

The Modeling Process



Types of Flow

- Open Channel Flow
  - Flow with free surface exposed to atmosphere
- Pressure or Pipe Flow
  - Flow in closed conduit under pressure

Wastewater

- Incompressible
- Turbulent
- Newtonian Fluid
- Obeys Newton’s Law of Viscosity
- In typical wastewater, solids don’t significantly affect viscosity
- Waste activated sludge still Newtonian
- Thickened sludge not Newtonian

FLOW

- Volume/time
- m^3/s – cubic metres/second (SI)
- L/s – litres/second
- m^3/hr – cubic metres/hour
- ft^3/s – cubic feet/second (FPS)
- gpm – gallons/minute
- MGD – million gallons/day
- ac-ft/day – acre-feet/day
- cufr/frtnt - cubic furlongs/fortnight

PRESSURE

- Force/Area
- Newton/square metre - Pascal (SI)
- kPa – kiloPascal
- bar – 100 kPa
- psf – pound/square foot (FPS)
- psi – pound/square inch (US typical)
- atm – atmosphere (14.7 psi)
- pound?
- Gage vs. absolute

Flow Classification Scheme

	Uniform	Nonuninform
Steady	Normal depth Long channel	Manholes Backwater
Unsteady		Pump cycling Wet weather

Conservation Equations

- Conservation Principles
  - Mass
  - Energy
- Conservation of Mass requires that
  - Inflow - Outflow = Rate of change in storage
  - If Inflow = Outflow, no storage occurs
  - If Inflow > Outflow, excess is stored
  - If Inflow < Outflow, water level drops

Velocity and Flow

- Velocities vary across flow giving a velocity profile.
- In practical applications, average velocity can be used:

$$V = \frac{Q}{A}$$

V = average fluid velocity
Q = pipeline flow rate
A = cross-sectional area of flow

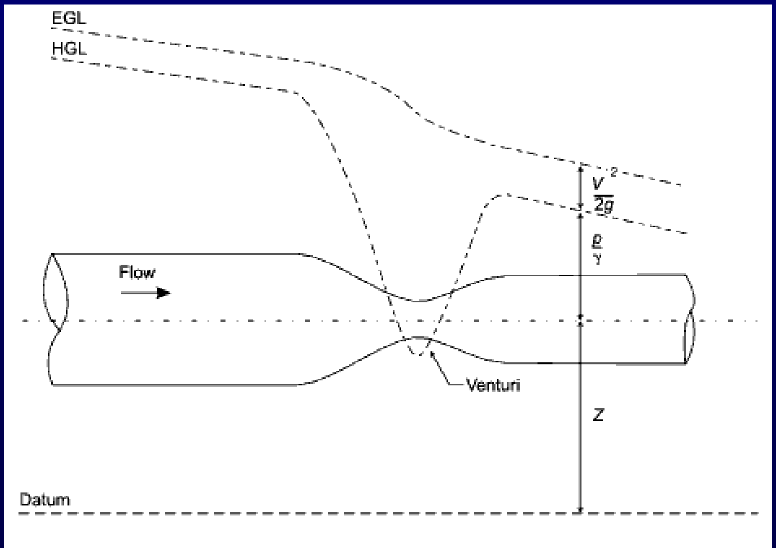
- Substituting the cross-sectional area of a full circular pipe the equation becomes:

$$V = \frac{4Q}{\pi D^2}$$

D = diameter

Conservation of Energy

- Water flows from a region of higher energy to a region of lower energy
- Energy terms are typically expressed as head
- Consider the energy terms for pressurized pipe flow



Conservation of Energy

For steady, incompressible full pipe flow steady

$$\frac{P_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{P_2}{\gamma} + z_2 + \frac{v_2^2}{2g} + h_f$$

p = fluid pressure
γ = specific weight of fluid
Z = elevation above an arbitrary datum plane
V = fluid velocity, averaged over a cross-section
g = acceleration of gravity
h_f = headloss due to friction

Conservation of Energy

- For open channel flow, pressure head is expressed in terms of depth of flow (y)
- The energy equation for open channel flow is:

$$y_1 + z_1 + \frac{v_1^2}{2g} = y_2 + z_2 + \frac{v_2^2}{2g} + h_f$$

Energy Grade Lines

Total energy at-a-point in the fluid system

$$\text{Pipe flow: } EGL = \frac{P}{\gamma} + z + \frac{v^2}{2g}$$

$$\text{Open channel flow: } EGL = y + z + \frac{v^2}{2g}$$

Hydraulic Grade Lines

Sum of the pressure and elevation head terms at-a-point

$$Pipe\ \ flow:\ \ HGL = \frac{P}{\gamma} + z$$

$$Open\ channel:\ \ HGL = y + z$$

Friction Head Loss Equations

- Energy is used to overcome friction and/turbulence
- Several equations are available to calculate head loss:
  - Manning
  - Darcy-Weisbach
  - Kutter/Chezy
  - Hazen-Williams
- Most head losses is wall friction
- Minor losses often small in comparison

Manning's Equation

Most commonly used in US

$$Q = \frac{k}{n} A R_h^{2/3} S^{1/2}$$

k = 1.49 for U.S. customary units and 1.0 for SI units
A = cross sectional area of flow
R_h = Hydraulic radius
S = slope of the energy line = S_o for uniform flow
n = Manning's roughness coefficient

Manning's Equation

Manning's n-value is viewed as a roughness coefficient, but it is actually influenced by many factors:

- Wall roughness
- Viscosity
- Diameter
- Velocity
- Depth of flow
- Obstructions
- Stage and Discharge
- Silting and Scouring

Darcy-Weisbach Equation

Widely used – theoretically correct

$$h_f = f \frac{L}{D} \frac{v^2}{2g}$$

h_f = headloss

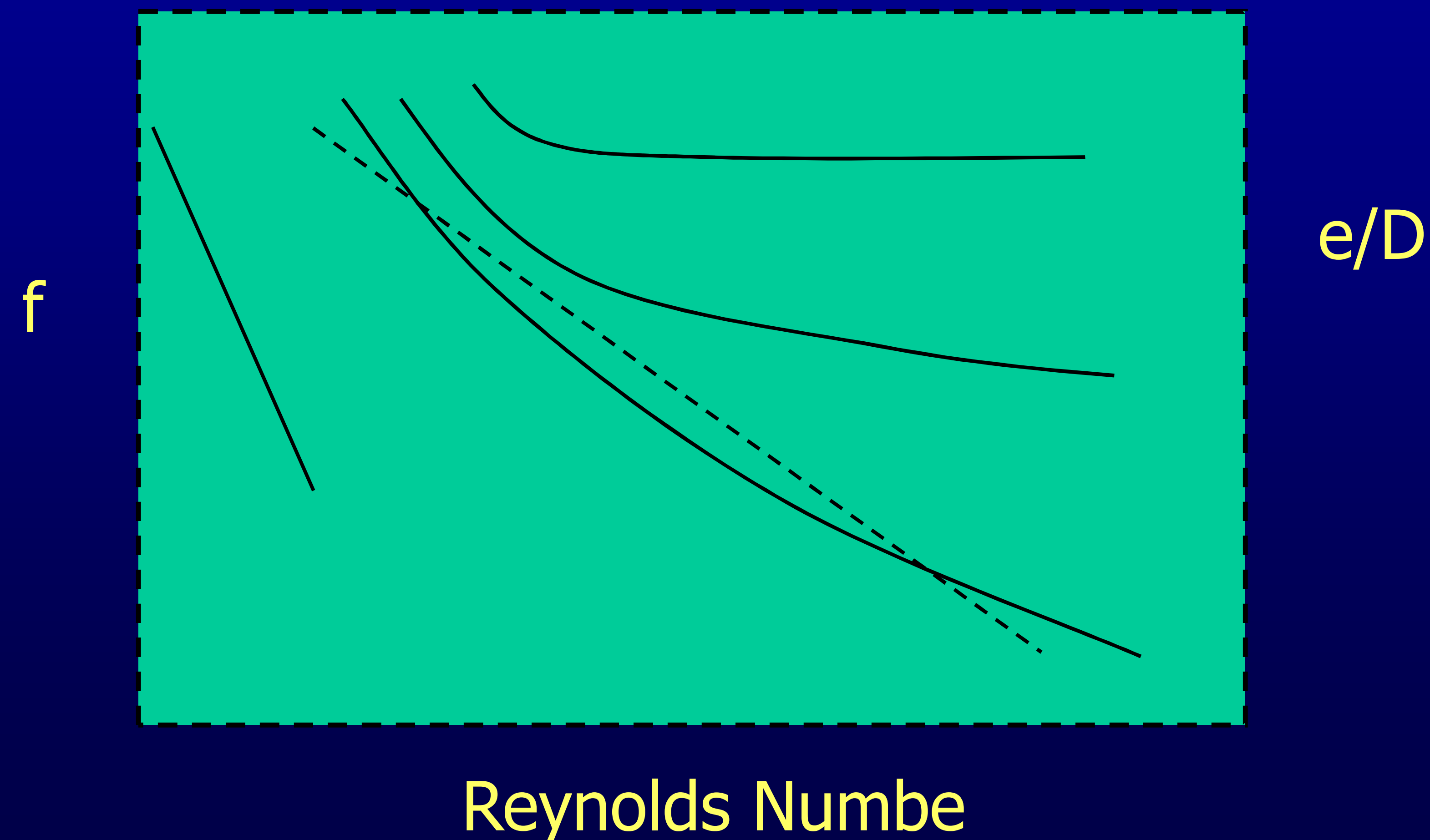
f = Darcy-Weisbach friction factor

L = pipe length

V = average pipe velocity

g = gravitational constant

Moody Diagram



Kutter/Chezy Equation

Sometimes used in various parts of the world

$$V = C\sqrt{R_h S}$$

V = Mean velocity (ft/s, m/s)
C = Roughness coefficient
R = Hydraulic radius (ft, m)
S = Friction slope (ft/ft, m/m)

Hazen-Williams Equation

Frequently used in North America for pressure

$$h_L = \frac{C_f L}{C^{1.852} D^{4.87}} Q^{1.852}$$

h_L = pipe friction head loss
L = pipe length
C = Hazen-Williams C factor
D = diameter
Q = flow rate
C_f = unit conversion factor

Minor Losses

Any feature that causes the flow to accelerate, decelerate, change direction, or change cross-sectional area results in loss of energy. Minor losses typically occur in sewer systems at manholes

$$h_M = K_M \frac{v^2}{2g}$$

h_m = the minor head loss
K_m = a minor loss coefficient

Minor Losses

- Minor losses occur at manholes, where there are entrance and exit losses and changes in flow direction
- Values of K_m for manholes range from 0.5 to 1.0
- Methods for calculating junction losses in SewerCAD
  - Absolute
  - Standard
  - Generic
  - HEC-22 Energy
  - AASHTO

Specific Energy

- Specific Energy (E) - total energy at-a-point (cross-section) in open channel flow with respect to channel bed:

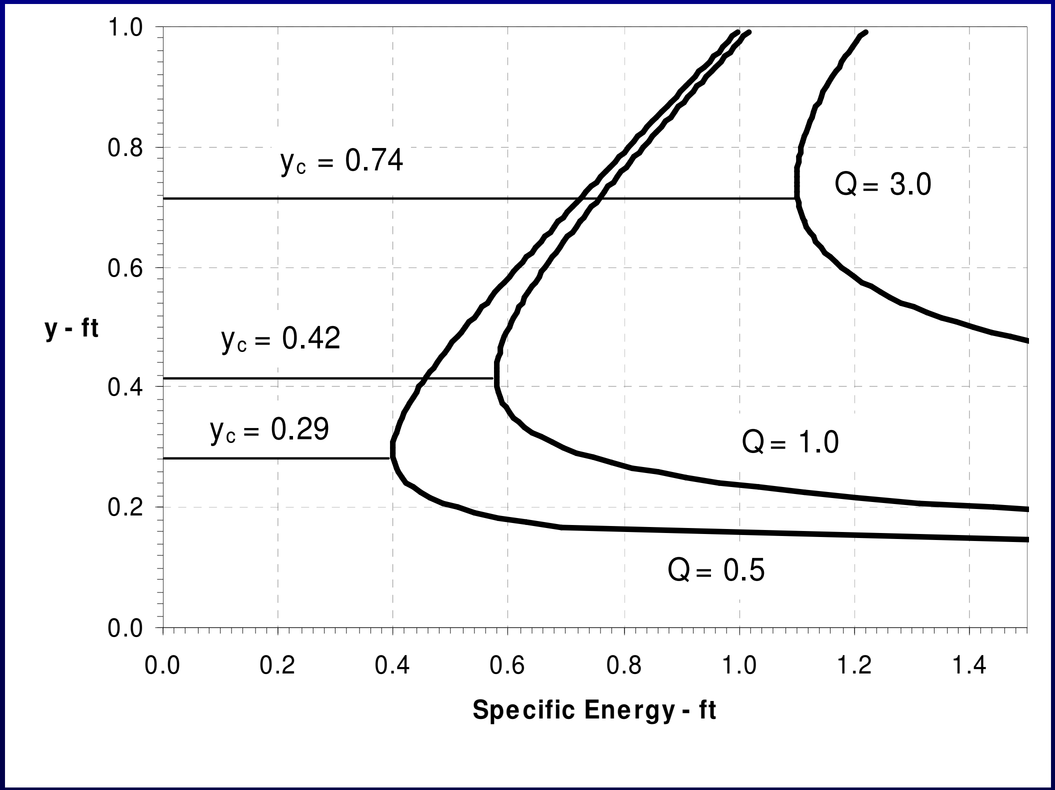
$$E = y + \frac{v^2}{2g}$$

- For a given discharge Q = V*A

$$E = y + \frac{Q^2}{2g\ A^2}$$

Specific Energy

Plot of the depth of flow vs. specific energy for a 12 inch pipe (y_c is the critical depth)



Froude Number

- Dimensionless parameter to classify open channel flow
- The Froude Number is equal to 1 at critical depth

$$\mathbf{F} = \frac{V}{\sqrt{gD_h}}$$

- Classification of flow:
  - Depth of flow is higher than y_c , $F < 1$, flow is subcritical
  - Depth of flow is equal to y_c , $F = 1$, flow is critical
  - Depth of flow is lower than y_c, $F > 1$, flow is supercritical

Non-Uniform Flow

Most channels are non-prismatic

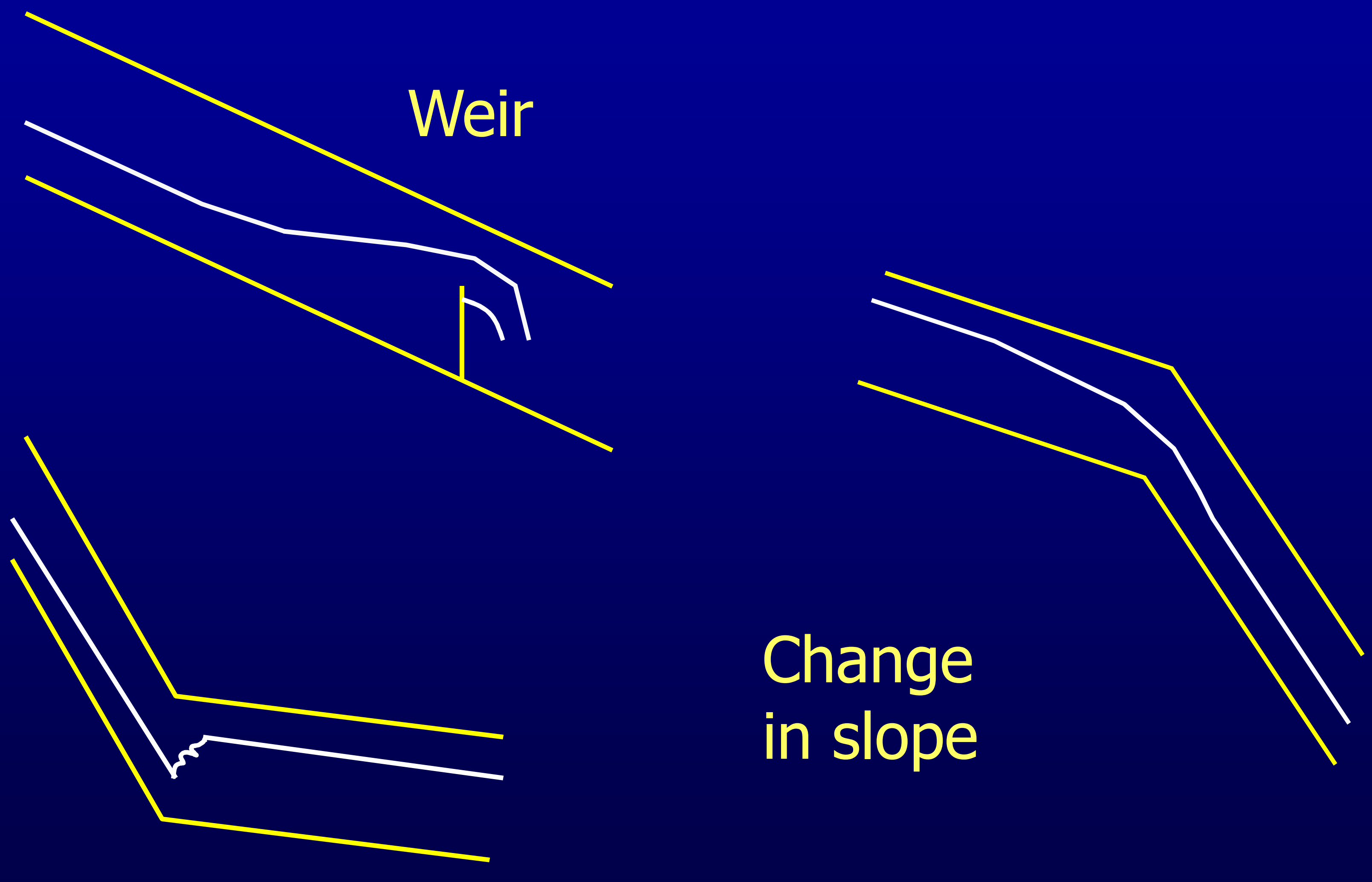
- Sanitary sewers are non-prismatic due to
  - Presence of manholes
  - Changes in pipe diameter, slope and direction

- Flow may be non-uniform in a prismatic channel due to the influence of a control
  - Backwater created by a high tailwater depth
  - Drawdown at a free outfall

Control

- A channel feature (structural) with a unique (1:1) relationship between depth and discharge
  - Free overfall at the end of a mild channel
  - Weirs and Flumes (critical controls)
  - Long prismatic channel (control reach)
- Regulates (controls) the state of flow
  - *Subcritical flow* is controlled by downstream conditions
  - *Supercritical flow* is controlled by upstream conditions

Nonuniform flow controls



Channel Classification

- Channel bed slopes are classified hydraulically as *mild*, *steep*, *critical*, *horizontal* or *adverse*
- For a given flow rate, the bed slope is called:
  - Mild if $y_n > y_c$
  - Steep if $y_c > y_n$
  - Critical if $y_n = y_c$

Assembling the Model

Data Requirements

- Network layout (system data)
- Hydraulic properties
- Sanitary flows (dry weather)
- Inflow and infiltration (wet weather)
- Operation data
- Calibration data

Network Data- System Layout

Data

- coordinates of each pipe segment and manhole
- locations of wet wells, pumps, appurtenances
- pipe connectivity, lengths
- pipe diameters, materials
- pipe invert levels and manhole elevations

Data Sources

- maps – paper/CAD
- construction/as-built drawings
- corporate GIS system
- asset-management systems
- work orders
- field survey

Hydraulic Properties

Data

- pipe roughness
- pump curves

Data Sources

- manufacturers' specifications
- contractor submittals
- literature values
- field tests

Sanitary Flows- Dry Weather

Data

- location of each source
- min, max, mean daily flows
- diurnal patterns
- projections

Data Sources

- metering
- maps, aerial photos
- census data

Inflow and Infiltration- Wet Weather

Data

- infiltration rate for each pipe segment or sub-basin
- locations of inflows
- quantities of inflow

Data Sources

- field inspection
- measurements
- analysis of treatment plant flows
- hydrologic analysis
- literature values

Operation Data

Data

- settings for pump operation
- settings of flow-control structures
- control strategies
- outlet controls

Data Sources

- interviews with operations personnel
- operations records and manuals
- field inspection

Calibration Data

Data

- recorded depth, rate of flow
- frequency/locations of overflows
- Precipitation data

Data Sources

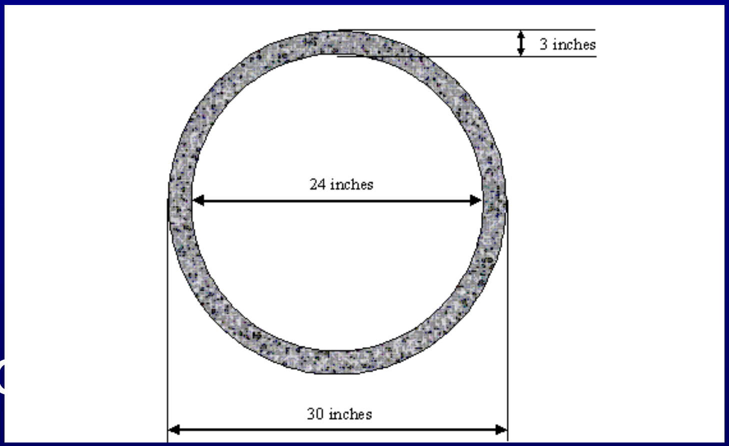
- field inspection and measurements
- operations records
- weather records
- flow-monitoring program

Types of Simulations

	Steady	EPS
Dry	Sizing, Good system	Design Check
Wet	Sizing, I/I system	Overflows, troubleshooting

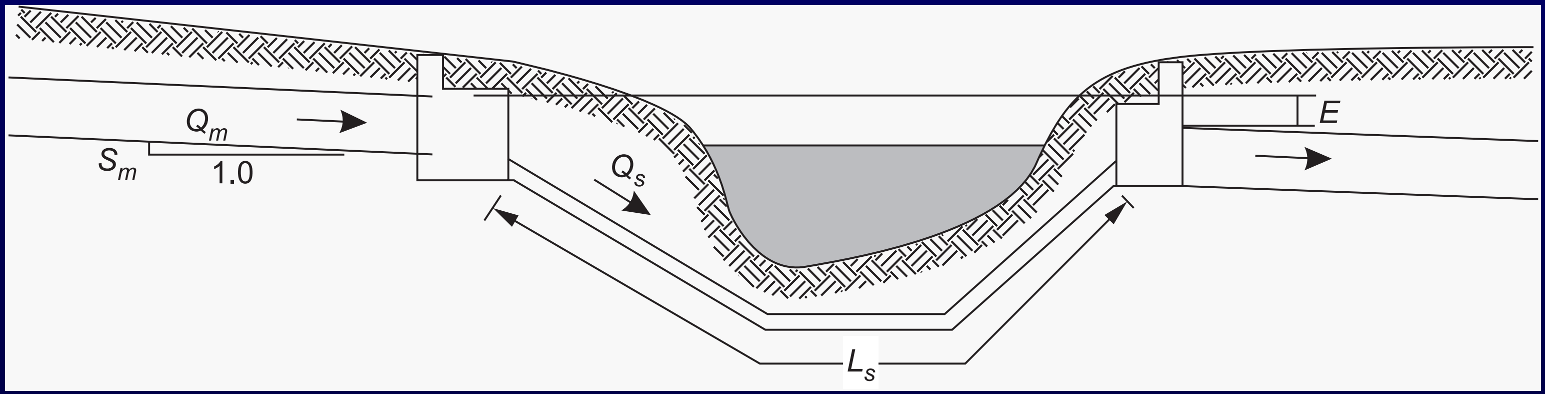
Defining Gravity Pipes

- Internal diameter
- Length (schematic or scaled)
- Material
- Roughness as Manning's n
- Shape
- Invert elevations (set to upstream/d
pipe)
- Number of sections



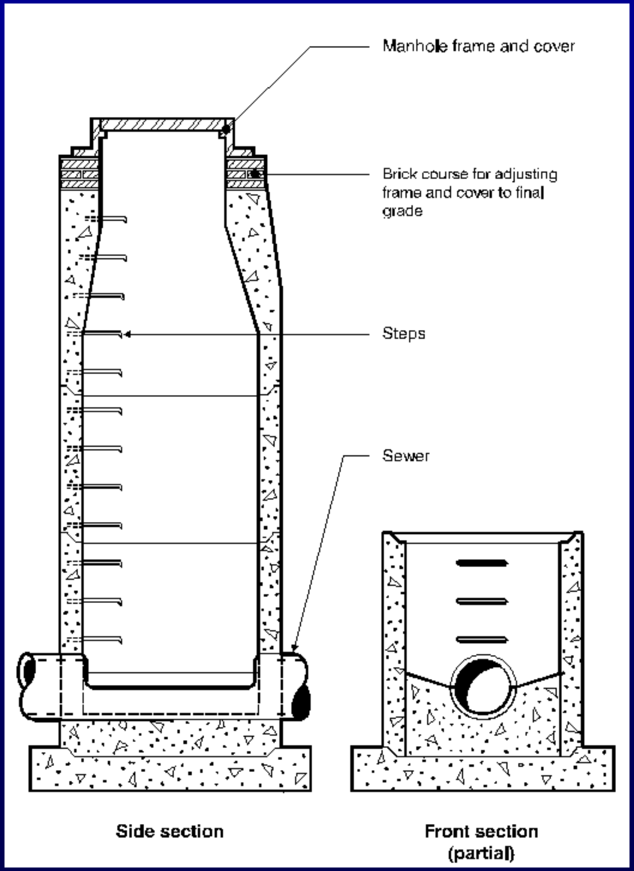
Siphons (Depressed sewers)

- Designed dip in a gravity sewer
- Occurs when sewer must pass under structures
- Sewer line is below the HGL, full, and under pressure
- Designed with smaller pipes to maintain self-cleaning velocities



Defining Manholes

- Invert elevation- bottom of pipe entering manhole
- Rim elevation
- Structure size- common diameter in US is 4 ft
- Drop manhole- incoming sewage transported down vertical shaft



Junction Chamber

- Model special underground structures
- No loading
- Input parameters necessary to physically define a junction chamber are:
  - Coordinates
  - Ground Elevation
  - Structure Diameter
  - Top Elevation
  - Bottom Elevation

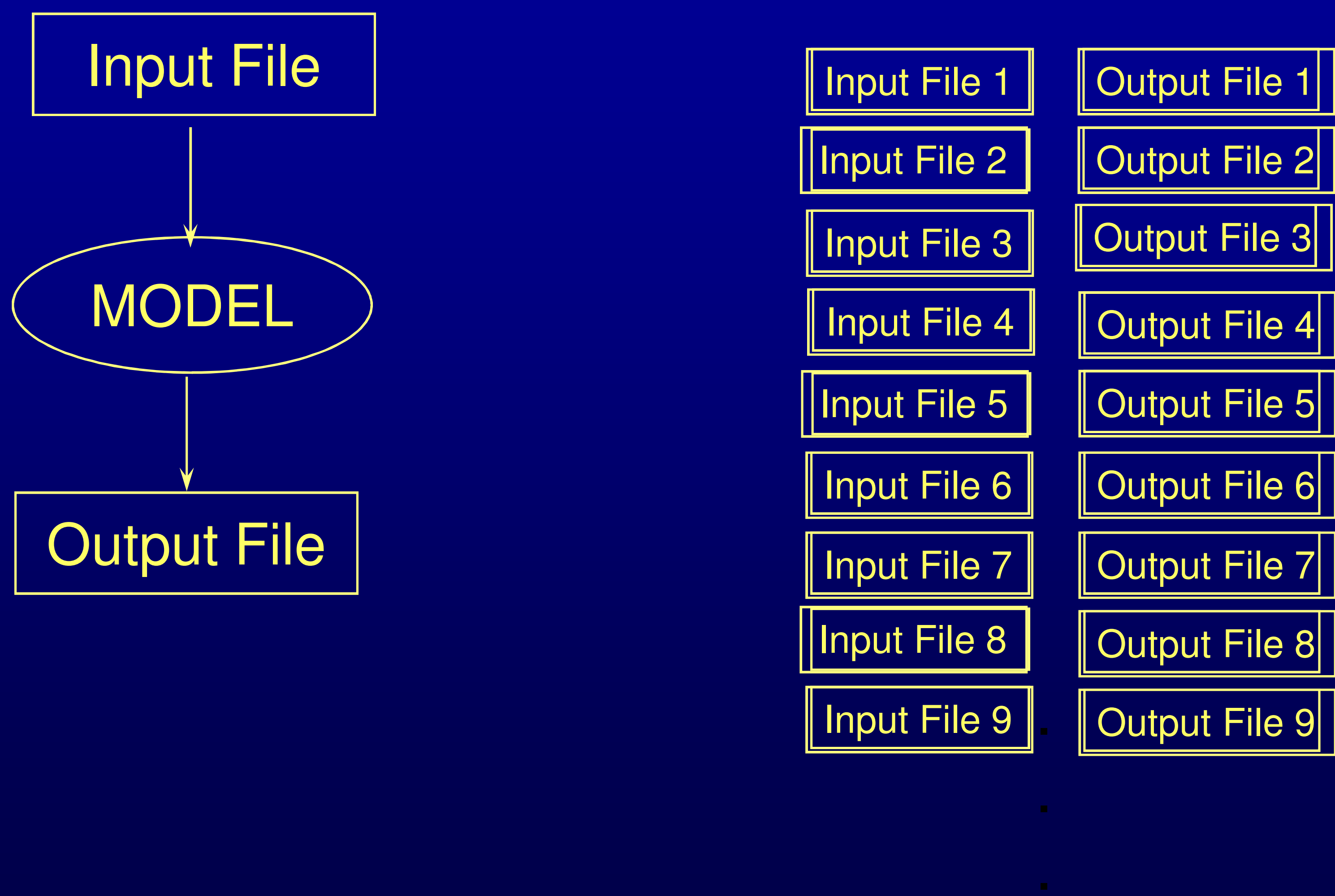
Defining Outlets

- Represents treatment plant, pump station, CSO, SSO or end of study area
- Specify tailwater depth
  - Known tailwater
  - Full pipe
  - Critical depth
- Critical depth appropriate when pipe freely discharges

MODELING PRACTICE

- Data Entry
  - Frequent checking
  - Trial runs and GUI can show major data entry errors
- Using Model
  - Plan runs before you make them
  - Try different scenarios and alternatives
  - Keep track of runs and backup files
- Ongoing Practices
  - Large initial investment in modeling and training
  - Keep good records
  - "Hit by a truck" principle - so train others

TRADITIONAL METHOD OF MANAGING RUNS

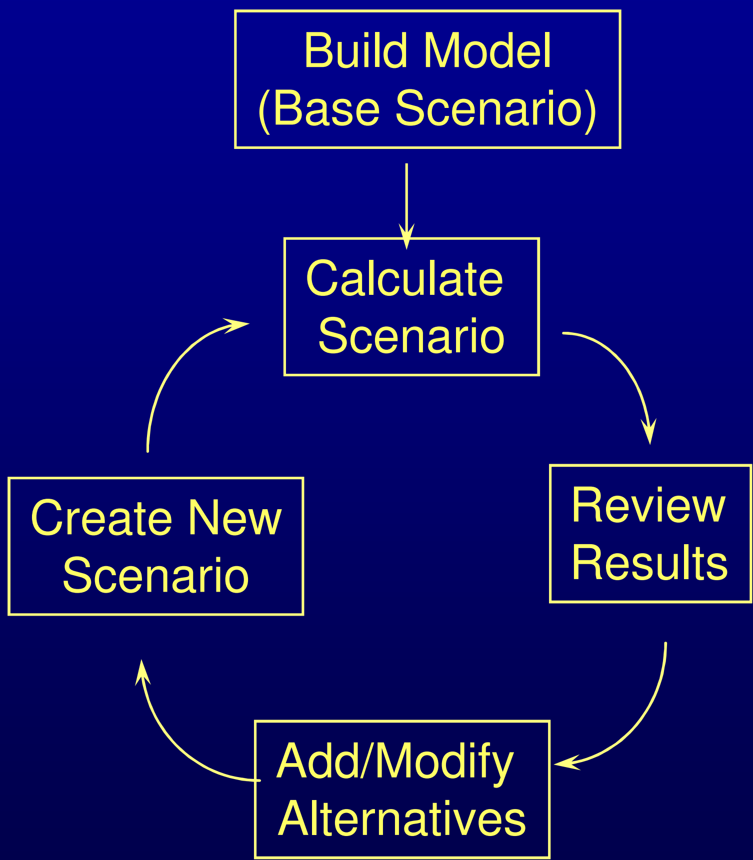


SCENARIO MANAGER TERMINOLOGY

- Scenario = single run of model
  - contains type of run
  - pointers to alternative data
- Alternatives = data set
  - building block of scenarios
- Inheritance = building alternatives and scenarios from previous

SCENARIO MANAGER

Scenario Cycle



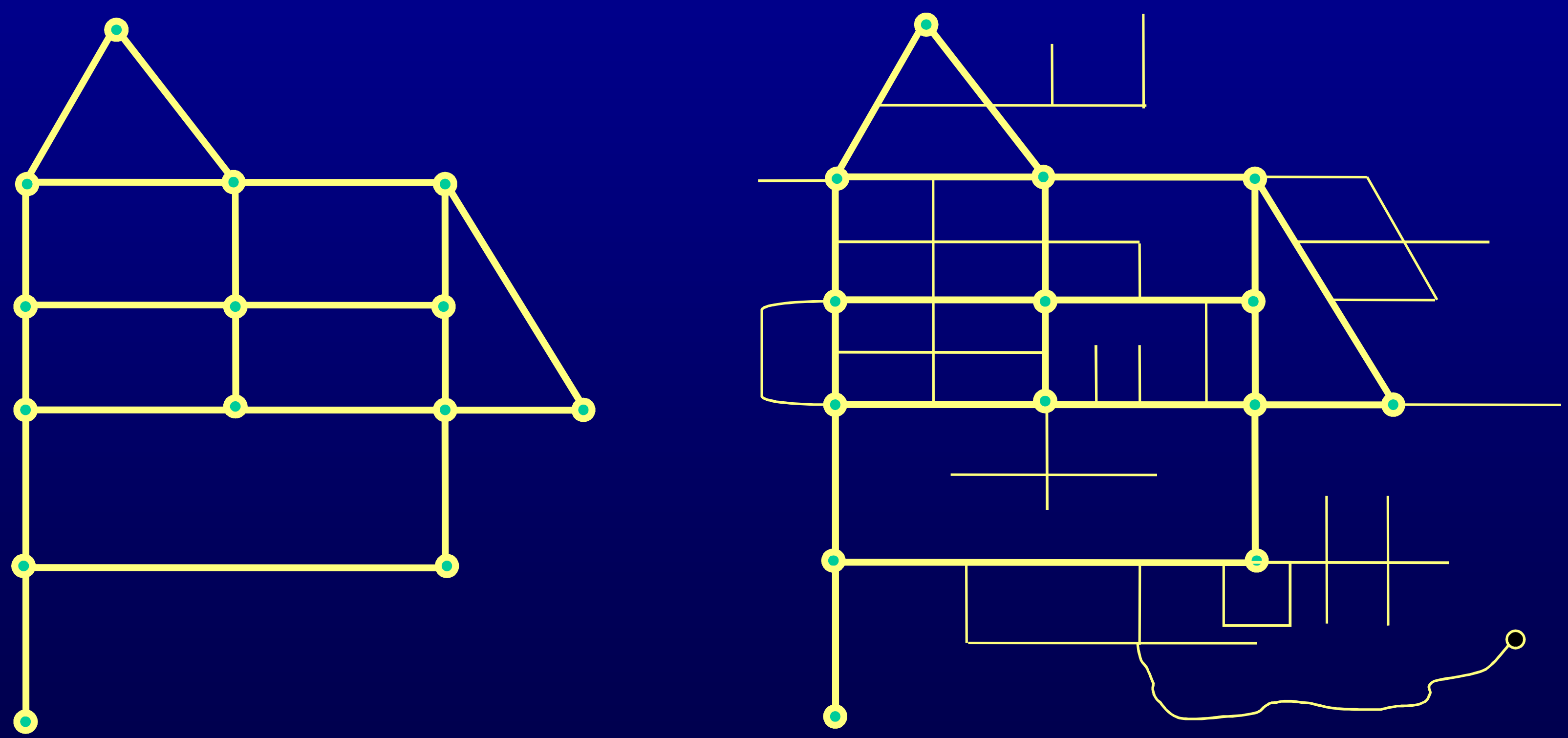
Alternatives

-Topology
-Physical
-Boundary Conditions
-Initial Conditions
-Hydrology
-Output
-Rainfall – runoff
-Water quality
-User data extensions

TOPOLOGICAL ALTERNATIVES

Make individual elements active or inactive

Great for “future” scenarios



Getting at Results

- Property grid
- Flex tables
- Graphing
- Color coding
- Annotation
- Profiling

Managers

- Scenario
- Alternatives
- Calc Options
- Graphs
- Profiles
- Symbology
- Animation

- Selection sets
- Queries
- Drawing navigator
- Backgrounds
- Prototypes
- Flex Tables

Unsteady Flow Hydraulics

What does SewerGEMS do?

Given:
System map
Physical properties
Loading data
(Water Quality)

Determines:
Flow, velocity, depth
in each conduit
Level in
each manhole,
pond, tank
(water Quality)

Evolution of Models

	Sanitary	Stormwater
Steady State	SewerCAD	StormCAD
Simple Routing	SewerCAD EPS	Pond Pack StormCAD
Fully Dynamic (St. Venant)	SewerGEMS	Civil Storm

Elements

- Point
  - Manhole
  - Pressure junction
  - Cross section
  - Junction chamber
  - Catch basin
  - Pump
  - Wet well
  - Pond outlet
  - Outfall
- Line
  - Conduit
  - Channel
  - Pressure pipe
  - Gutter
- Polygon
  - Catchment
  - Pond

Basic Principles

Conservation of Mass

$$S(t+\Delta t) = S(t) + I(t)\Delta t - Q(t)\Delta t$$

Conservation of Energy

$$y_1 + z_1 + \frac{v_1^2}{2g} = y_2 + z_2 + \frac{v_2^2}{2g} + h_f$$

Manning's

$$Q = \frac{k}{n} A R_h^{2/3} S^{1/2}$$

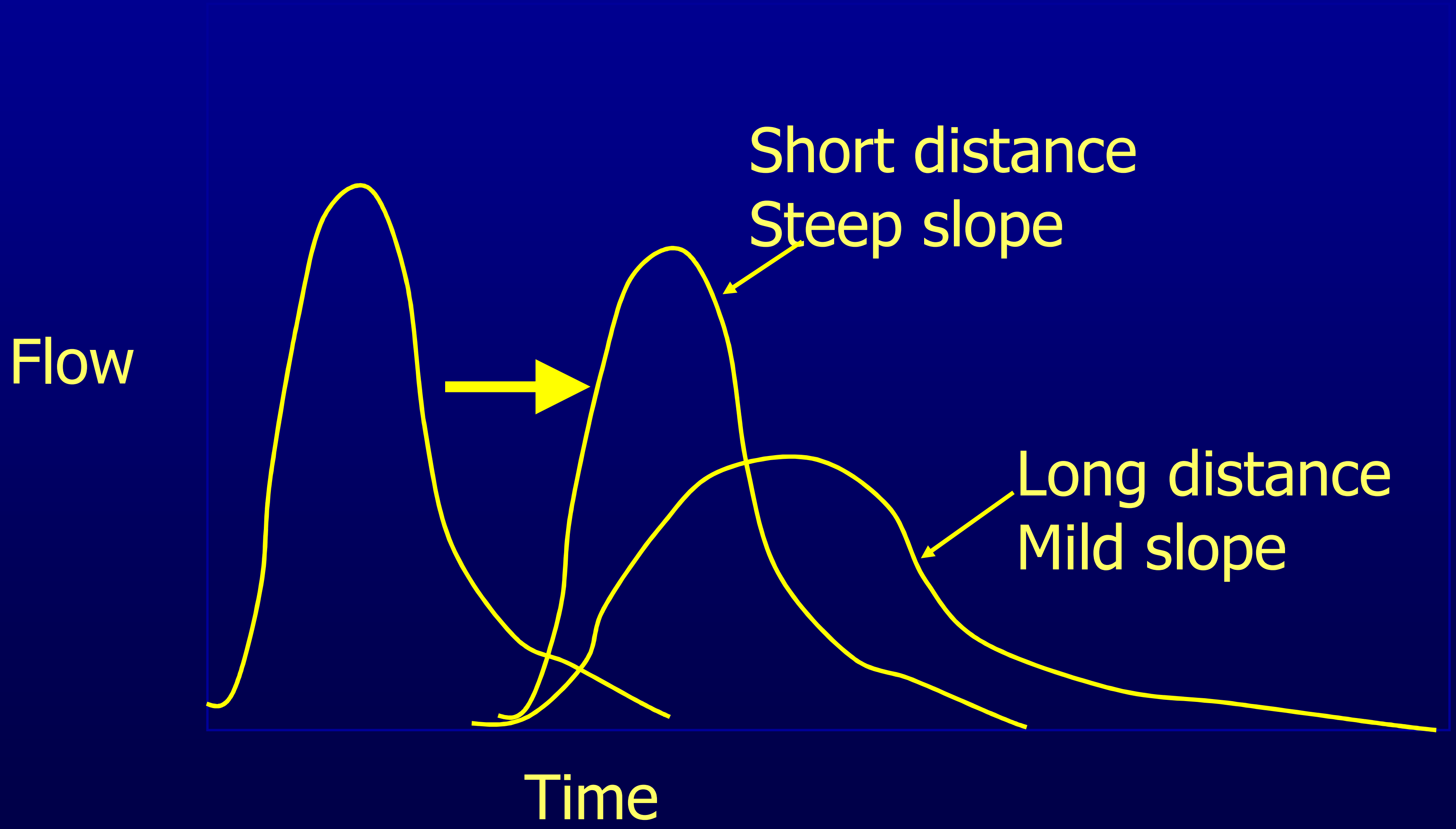
What Causes Unsteady Flow?

- Pumps cycling
- Wet weather I/I
- Batch processes
- Normal diurnal water use variation
- Occurs in sanitary, combined and stormwater systems

Unsteady Flow

- Can’t just slide hydrograph downstream
- Increase in flow shows up as
  - Increase outflow
  - Increase depth (horizontal storage)
- Depends on nature of system

Hydrograph Routing



Routing Methods

- Hydrologic
  - Mukingum
  - Puls
  - Kinematic wave
  - Convex
- Hydraulic
  - St. Venant equations

Fully dynamic model?

Solves full St. Venant equations
for 1-D flow in open channels

Continuity

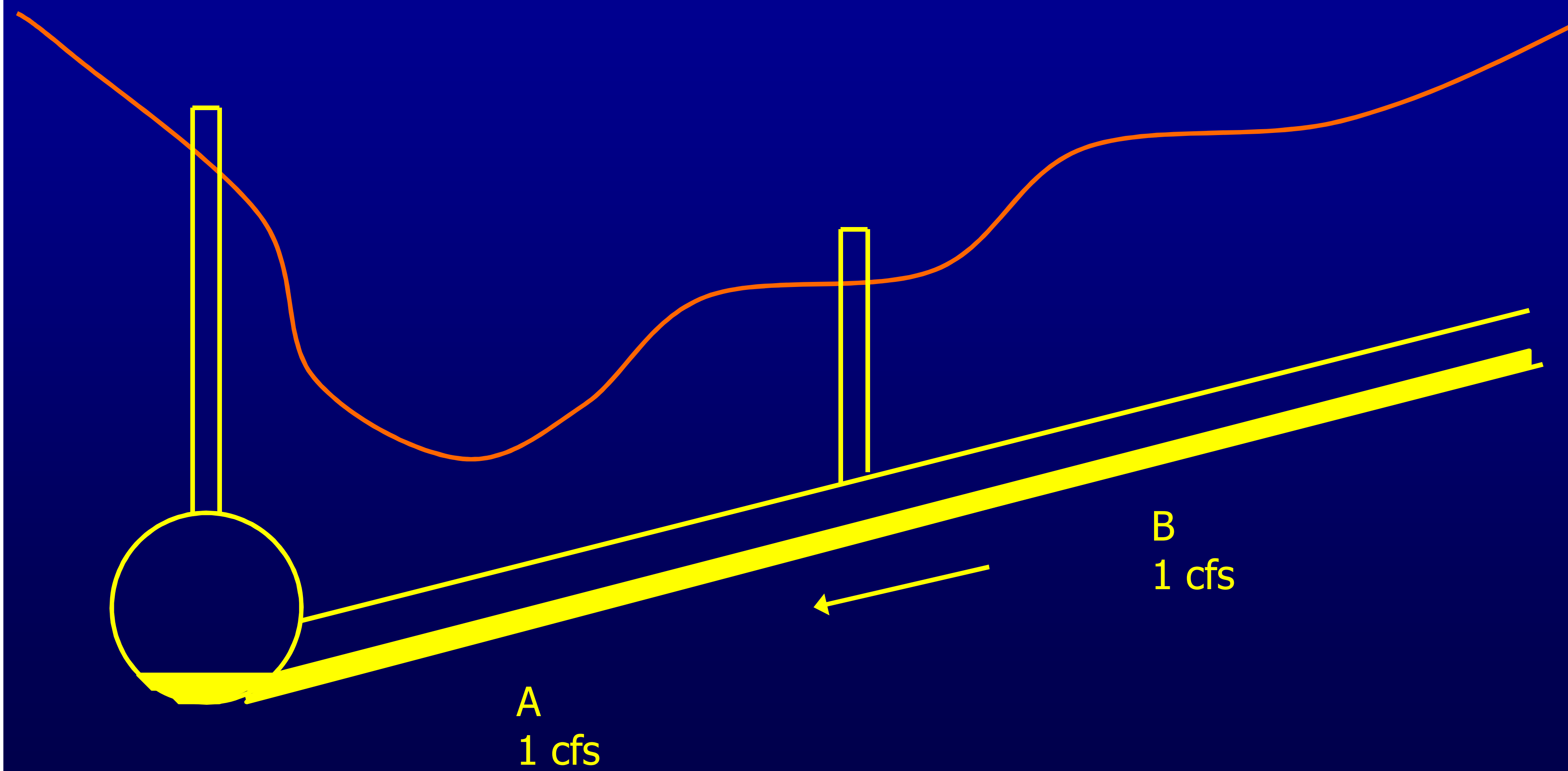
$$\frac{\partial y}{\partial t} + y\frac{\partial u}{\partial x} + u\frac{\partial y}{\partial x} = 0$$

)

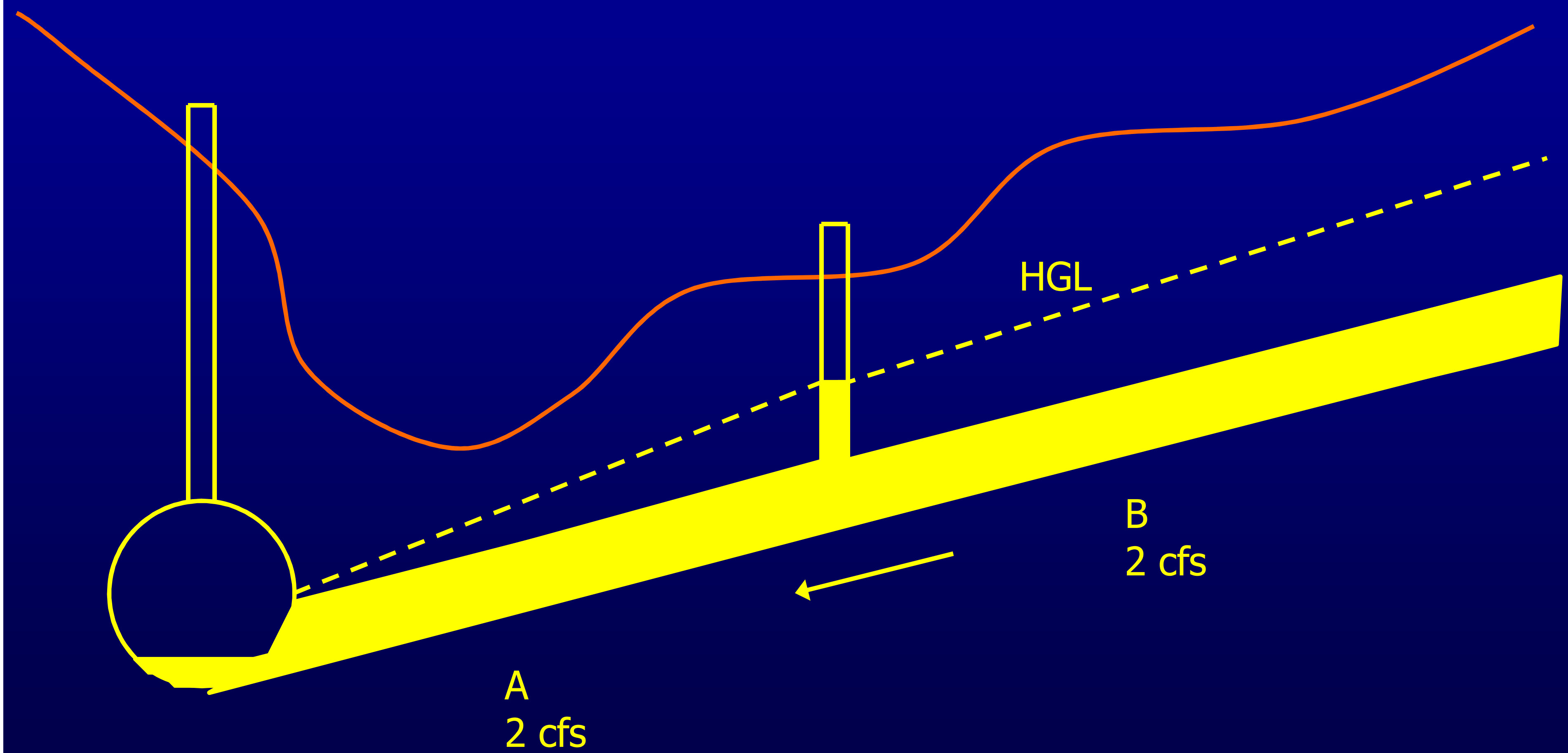
Momentum

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial y}{\partial x} - g(S_x - S_f) = 0$$

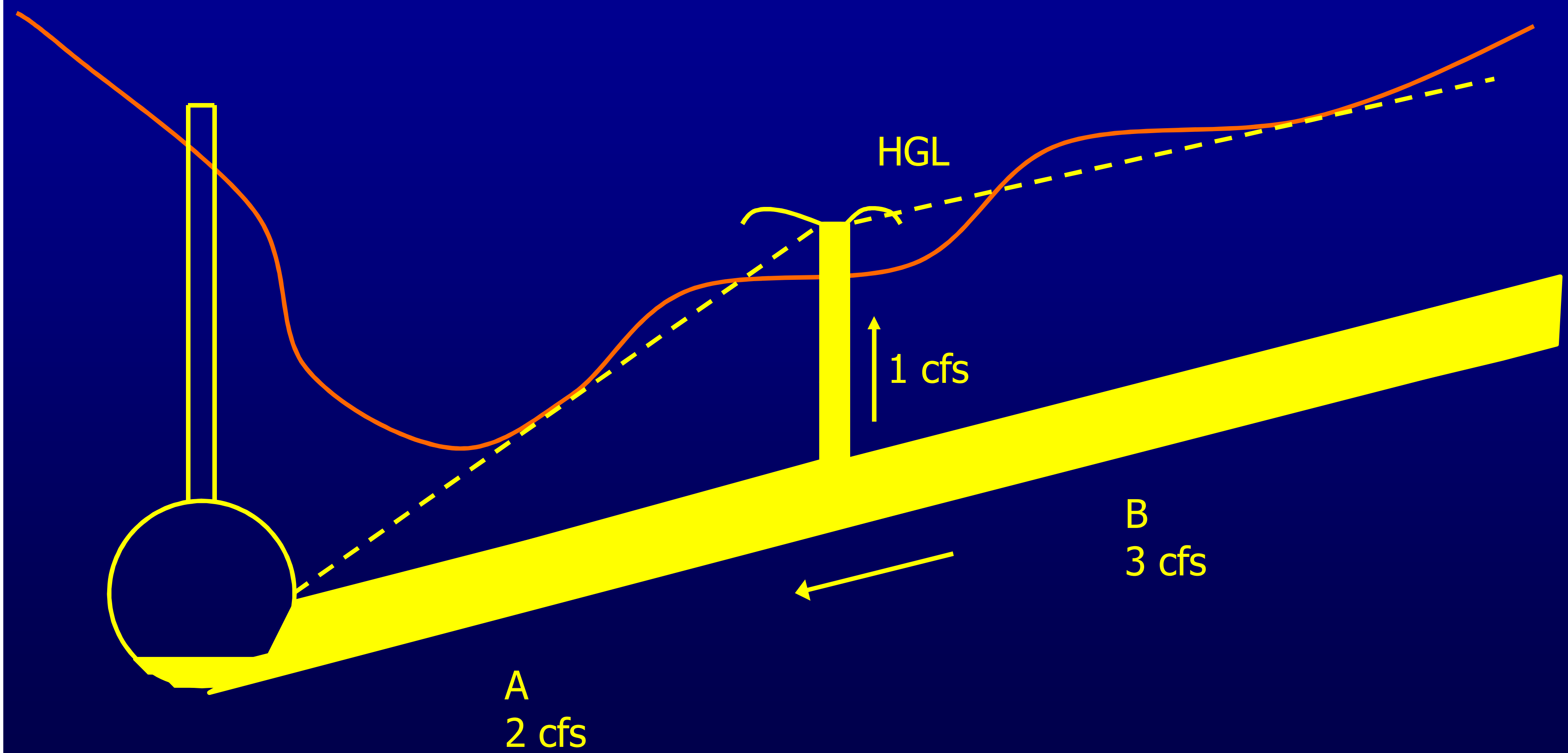
Normal Depth



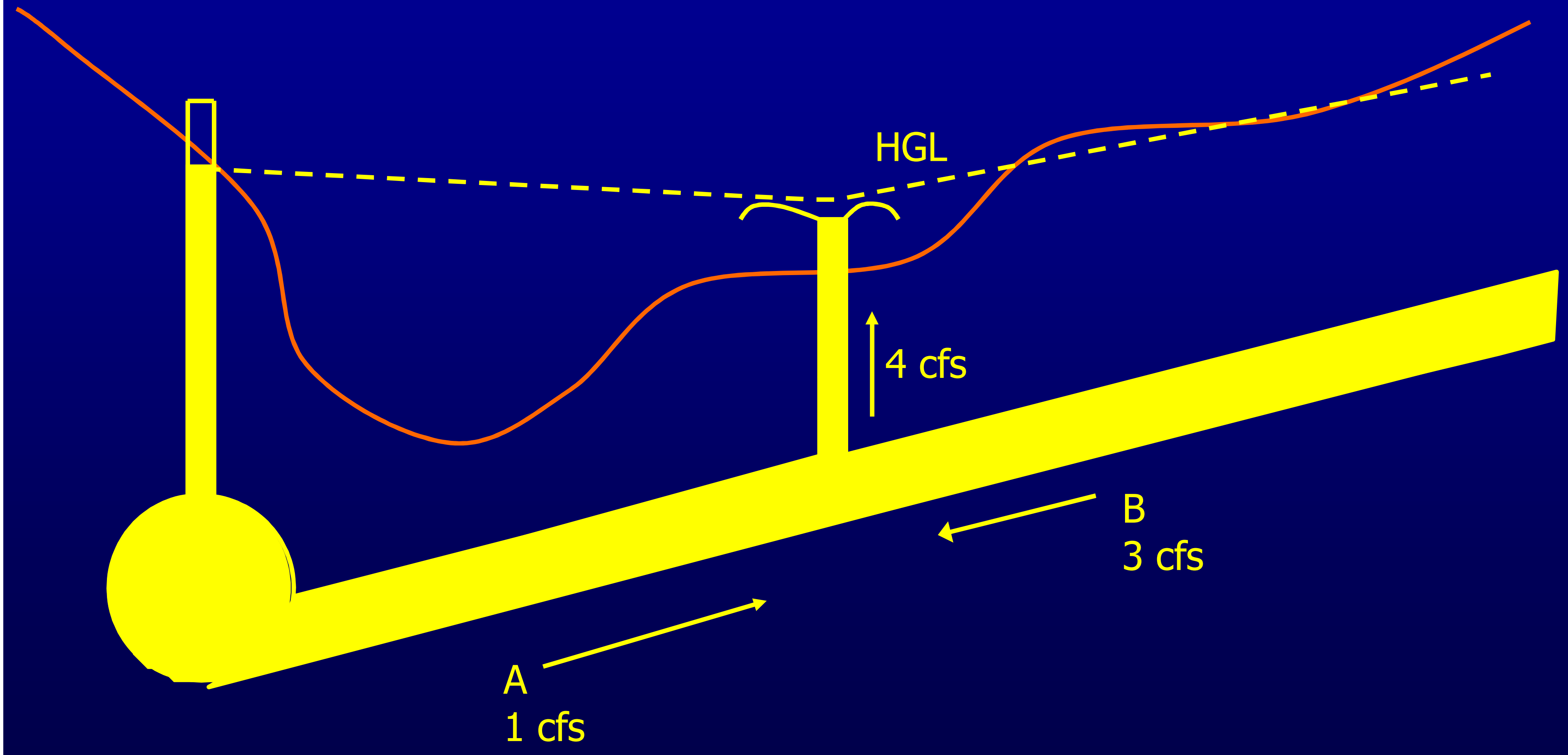
Gradually varied surcharged flow



Overflow



Backup



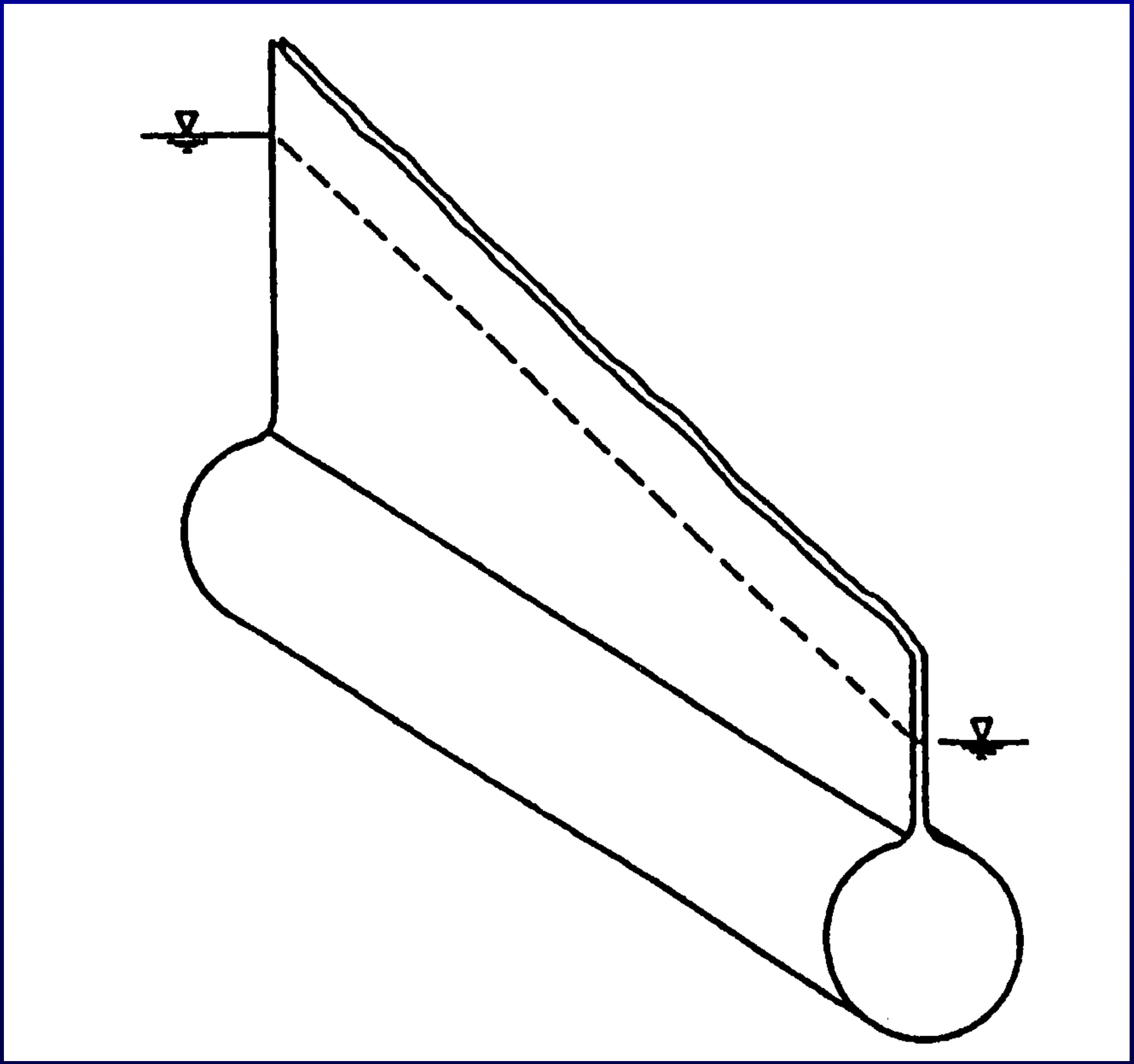
Bentley Dynamic Models

- Solve full St. Venant equations
- Use stable implicit finite difference solution
- Based on FLDWAV
- Routes hydrographs
- Handles surcharging, overflows, backups
- Handles pipes, channels, ponds, pumps
- Used in CSD, SewerGEMS

Special Situations

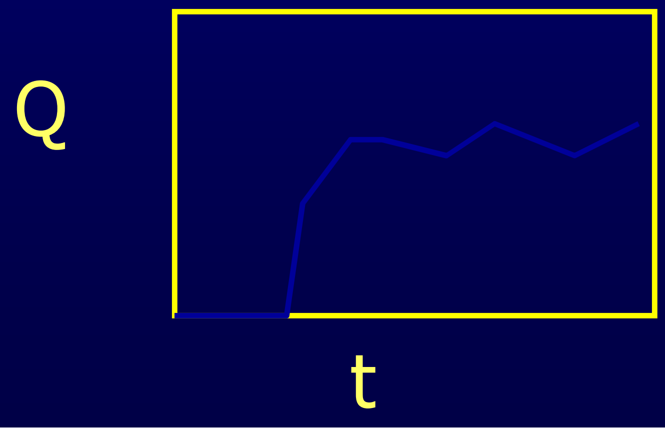
- Surcharging
- Dry pipes
- Drop structures
- Pump cycling

Handling Pressure Flow



Start Type

- Can start with dry pipe
- Can “warm-up” model up to time 0
- Warm up time depends on system
- Experiment to find best warm up



Convergence Tips

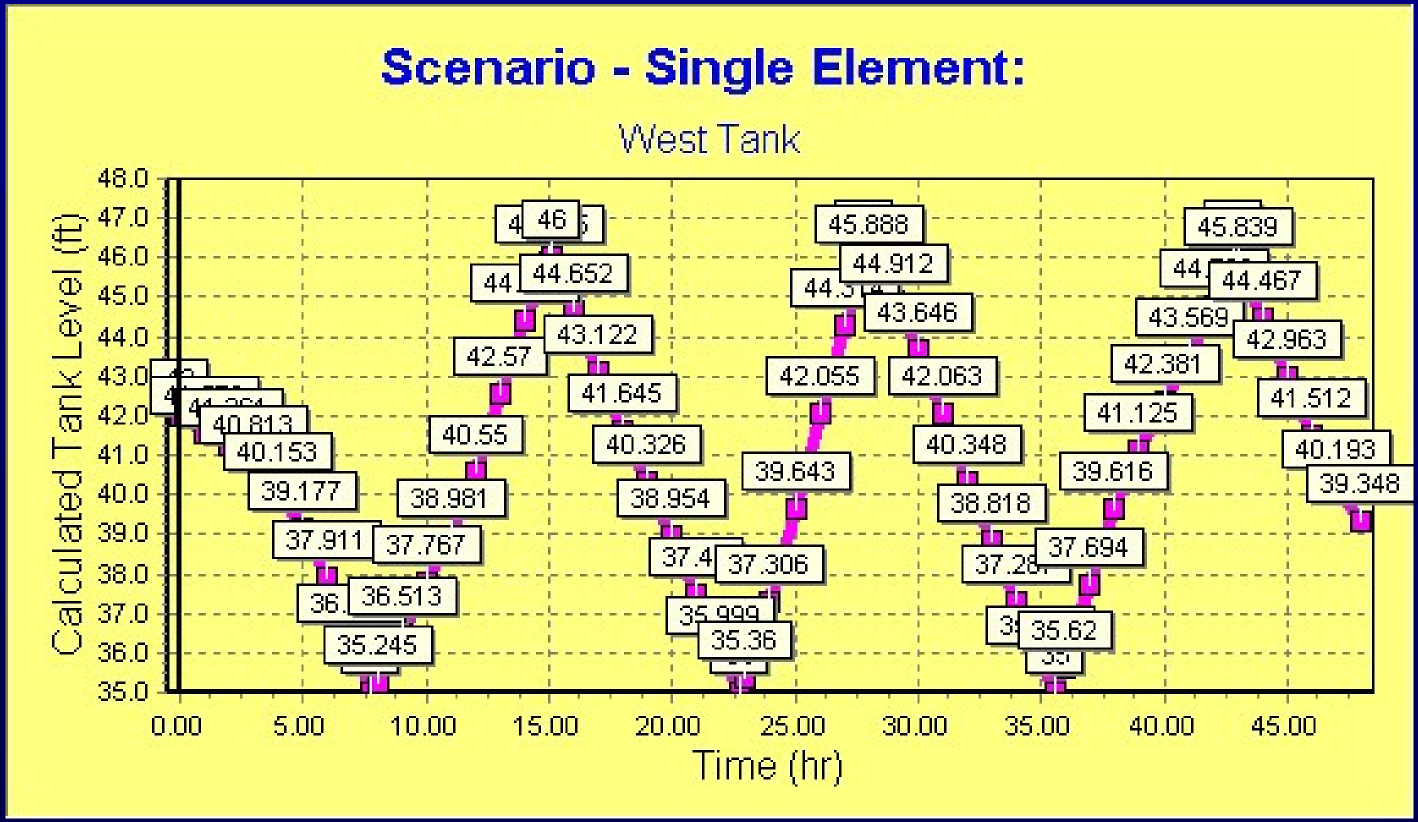
- Avoid very short pipes
- Make computation time step shorter
- Move N-R weighting coefficient closer to one
- Decrease computation distance
- Test with no weir flow

Graphing

A Picture is Worth 10^3 Words

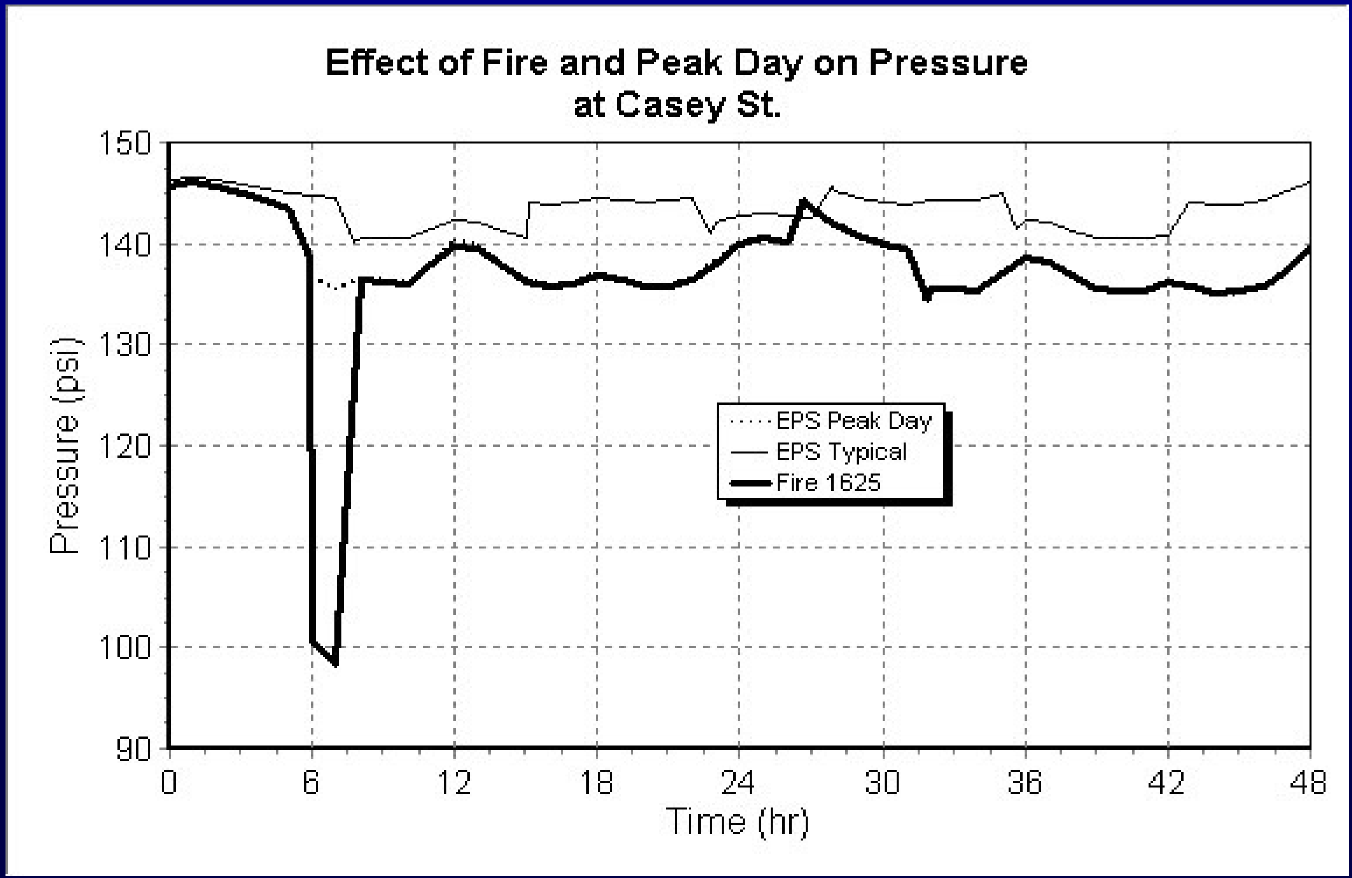
Single Element Over Time

- Shows one attribute for one element over time



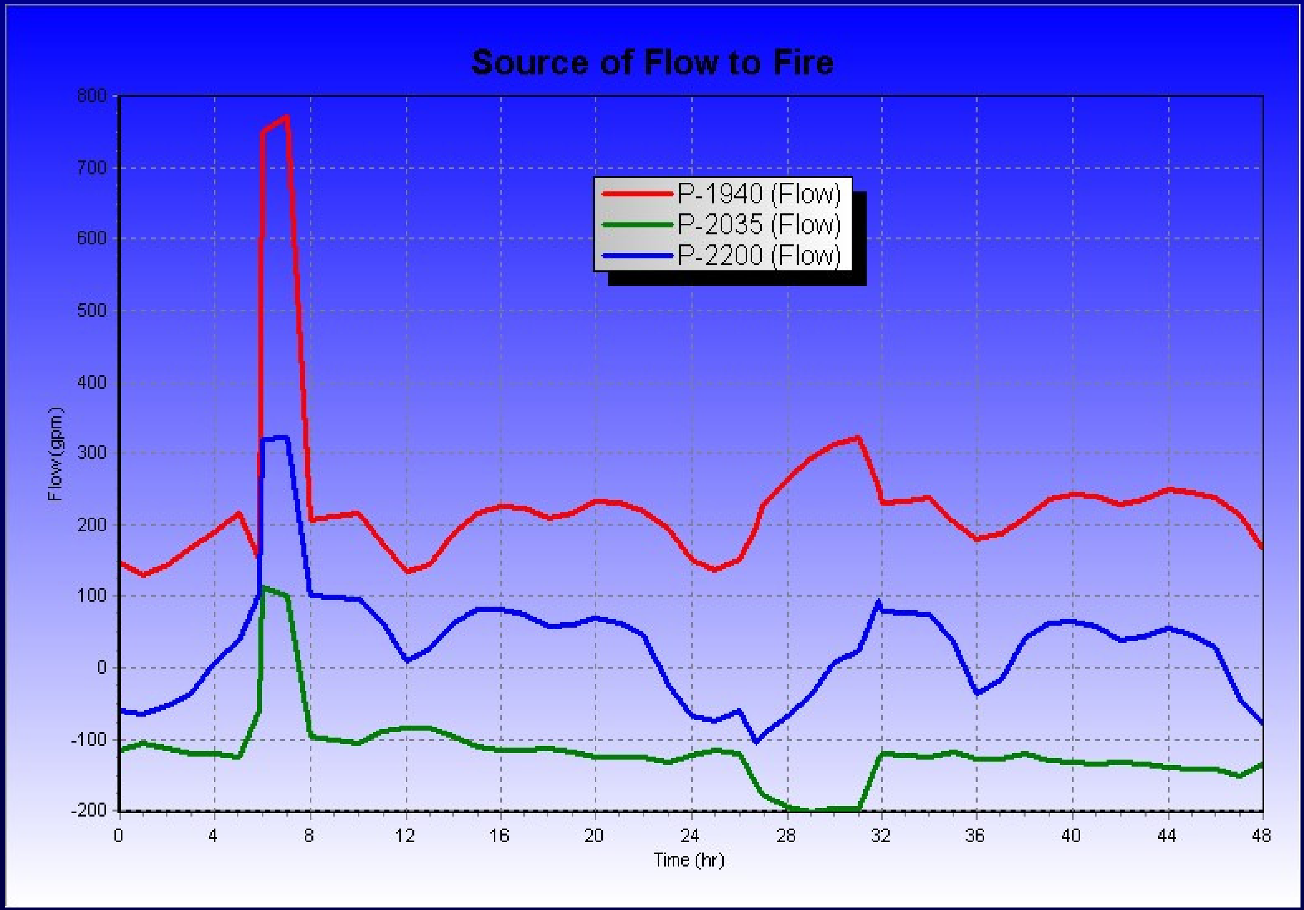
Scenario Comparison over Time

- Used to compare single attribute over time between scenarios



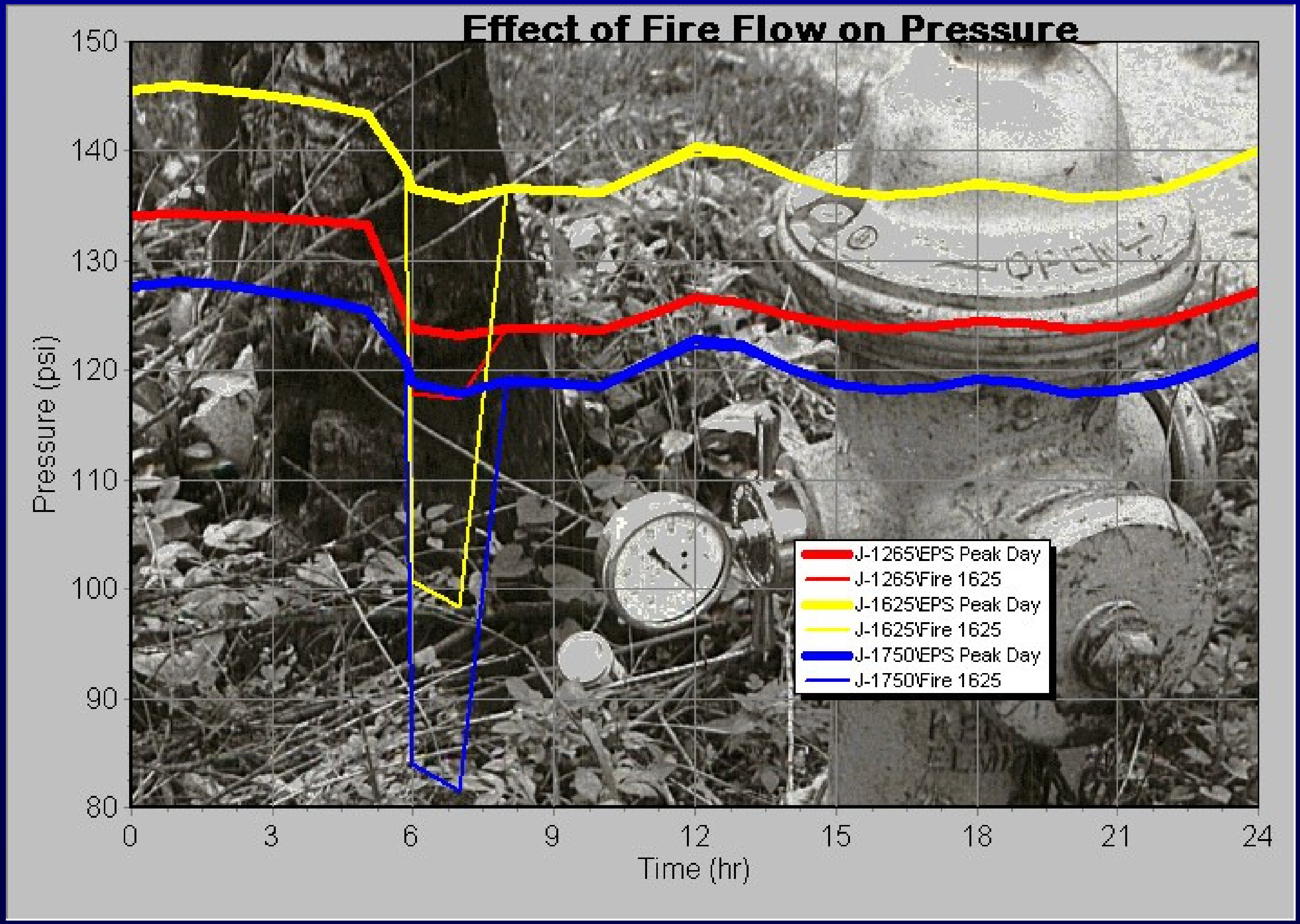
Element Comparison over Time

- Compare attribute for an element over time for single scenario



Element Scenario over Time

- Can include different elements and scenarios for a single attribute over time



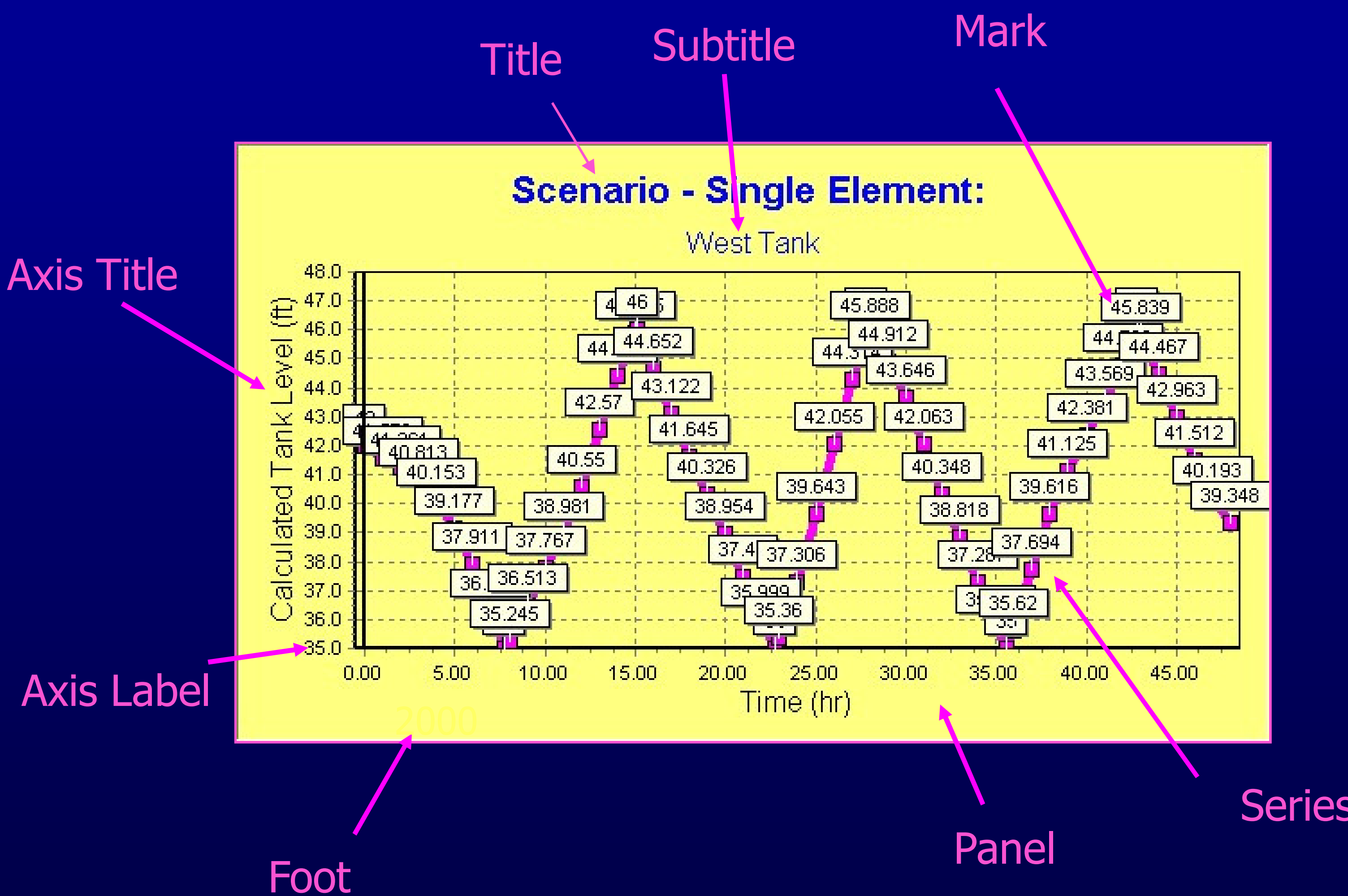
Graphing Controls

- Graph Series Option (SewerGEMS choices)
  - Attribute (fields)
  - Element
  - Scenario
- Chart Options (Graphics choices)
  - Chart tab
    - Axis, title, legend
    - Click on individual series properties
  - Series tab
    - Format, marks

Graphing Tips

- Checking/unchecking “visible” turns things on/off
- Default for legend is outside; use “custom” to move inside
- Set display number of digits in “data” tab or in options
- Background under “panel” tab
- “Marks” refers to placing actual value on graph
- There is no “Undo”; Save work frequently

Terminology



Dynamic Wave Routing

Because life is dynamic

Sanitary Systems

Sanitary Sewer Systems

- Designed for sanitary loads
- Should be minimal wet weather I/I
  - Inflow / Infiltration
  - Problems usually caused by I/I
  - Must understand dry weather flow
- I/I enters through defects
  - Manholes
  - Joints
  - Illegal connections

Sanitary Sewer Modeling

- System design
- System capacity analysis
- Steady, gradually varied flow analysis
- Overflows
- Compliance with Capacity management operation and maintenance (CMOM)

Sanitary Sewer Design

- Dendritic layout
- Controlled by
  - Loading
  - Min and max slopes
  - Right of way and conflicts
- Min pipe size usually 8 in.

Sanitary Sewer Overflows (SSO)

- SSO not permitted
- Understand cause
  - Maintenance (roots, grease)
  - Lack of capacity (growth)
  - RDII (wet weather only)
- Model can help identify cause, remedial action
- Combine modeling and monitoring

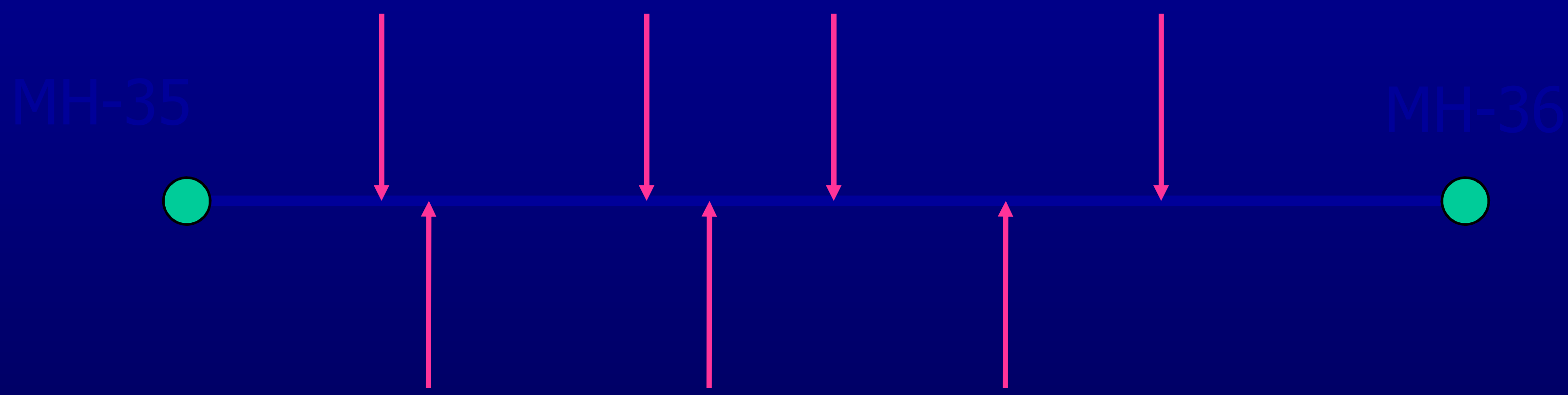
Solving Overflows

- Compare model with monitoring
- Find flow and hydraulic properties that match monitoring
- Propose solutions
  - I/I control
  - Increase capacity
  - Storage
- Model proposed solutions

Dry Weather Loads

- Referred to as:
  - Usage
  - Demand
  - Loading
- Loads are assigned to nodes
- Must add in wet weather loads
- Wide variety of data sources

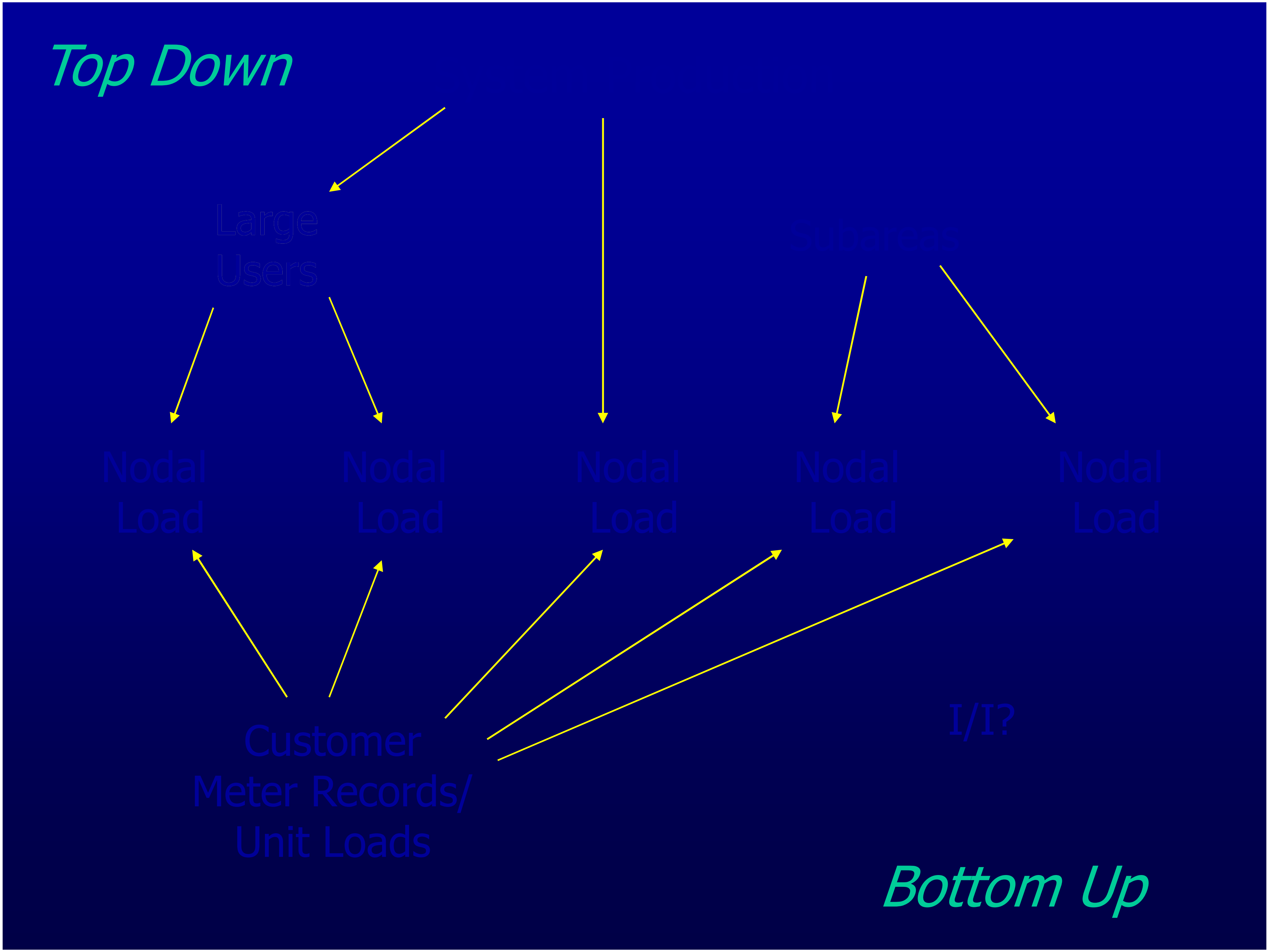
PLACING LOADS AT NODES



Q(load) << Q(in)

Steps in Loading Model

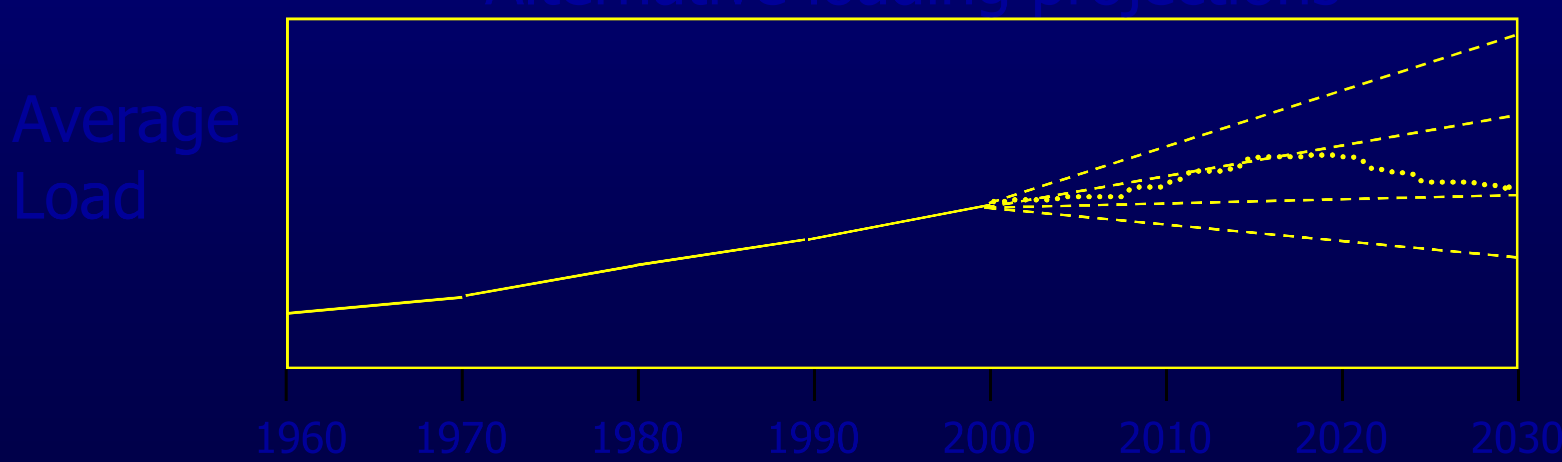
- Current year average day
- Peaking and temporal variations
- Wet weather flows
- Projections

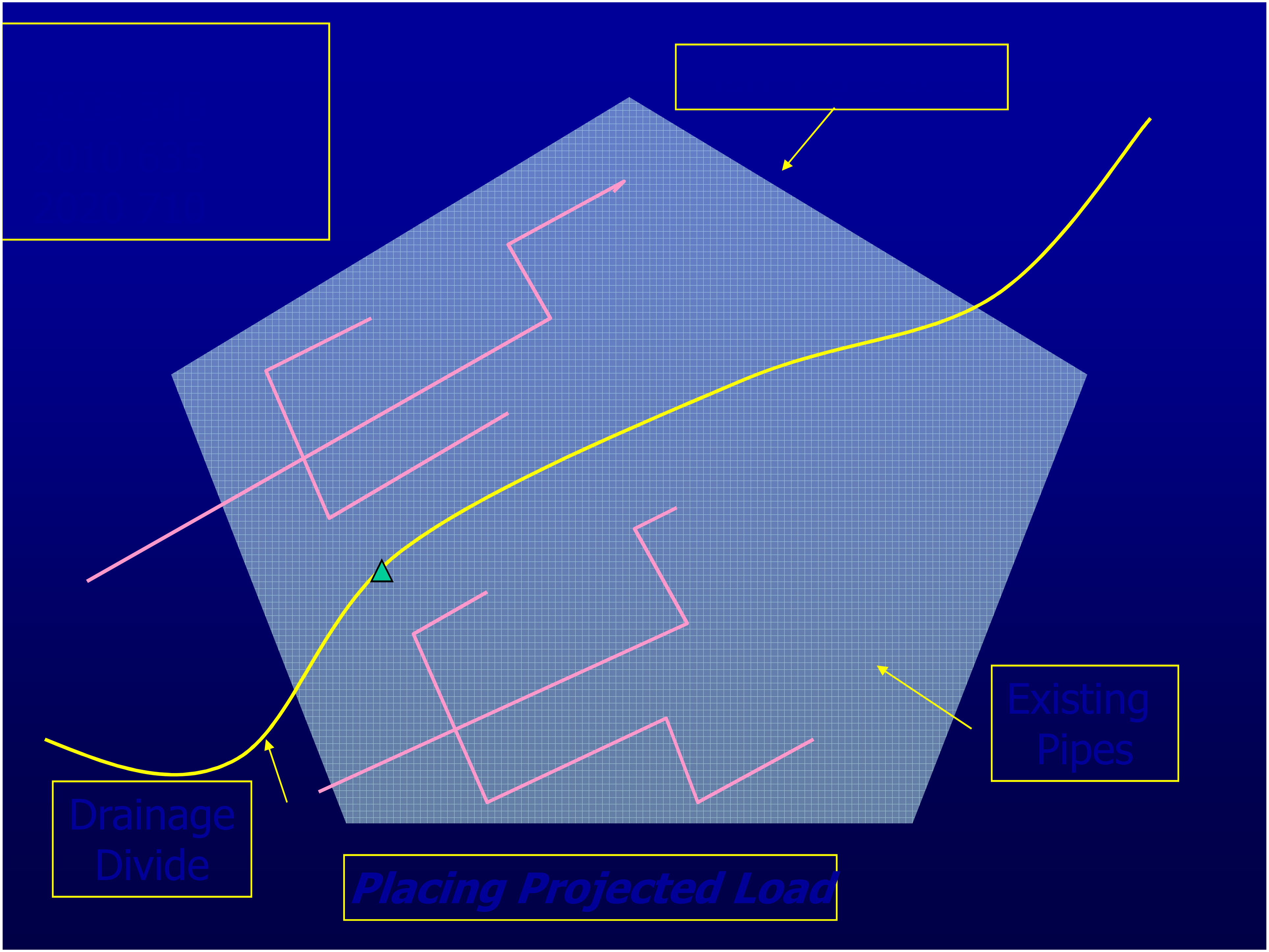

Top Down
Large Users
Subareas
Nodal Load
Nodal Load
Nodal Load
Nodal Load
Nodal Load
I/I?
Customer Meter Records/ Unit Loads
Bottom Up

Loading Projections

- Usually provided by city or regional planners
- Get others to “sign off” on population projections
- Where will high growth be? Where will large water users be?
- Future water conservation and per capita usage rates

Alternative loading projections

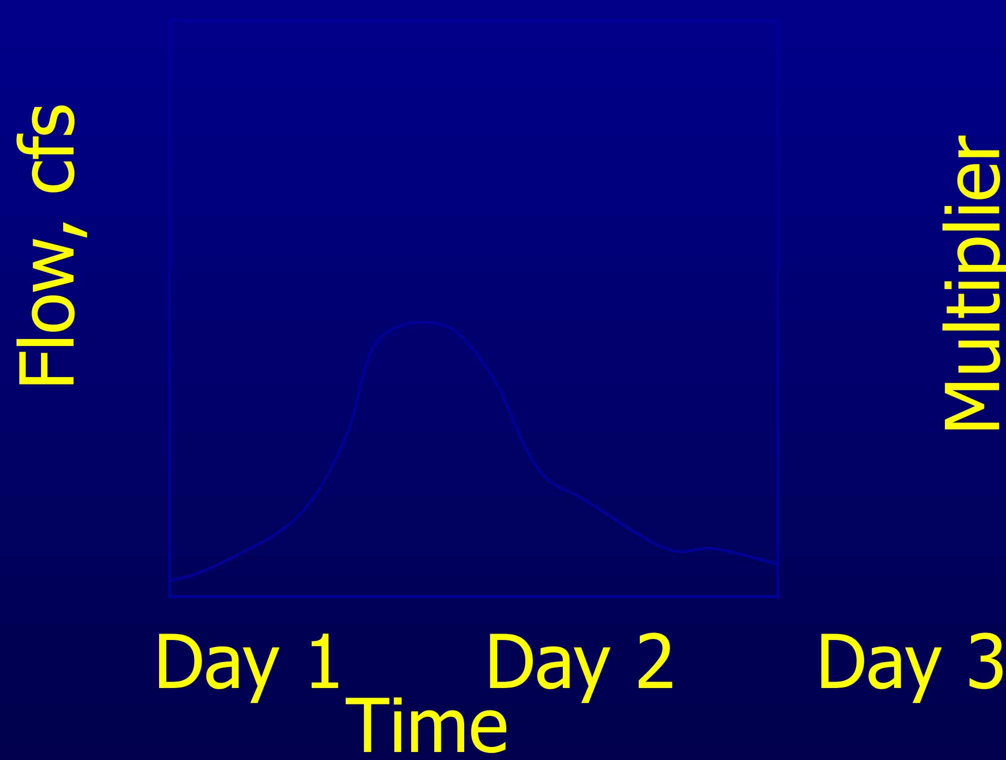



Existing Pipes
Drainage Divide
Placing Projected Load

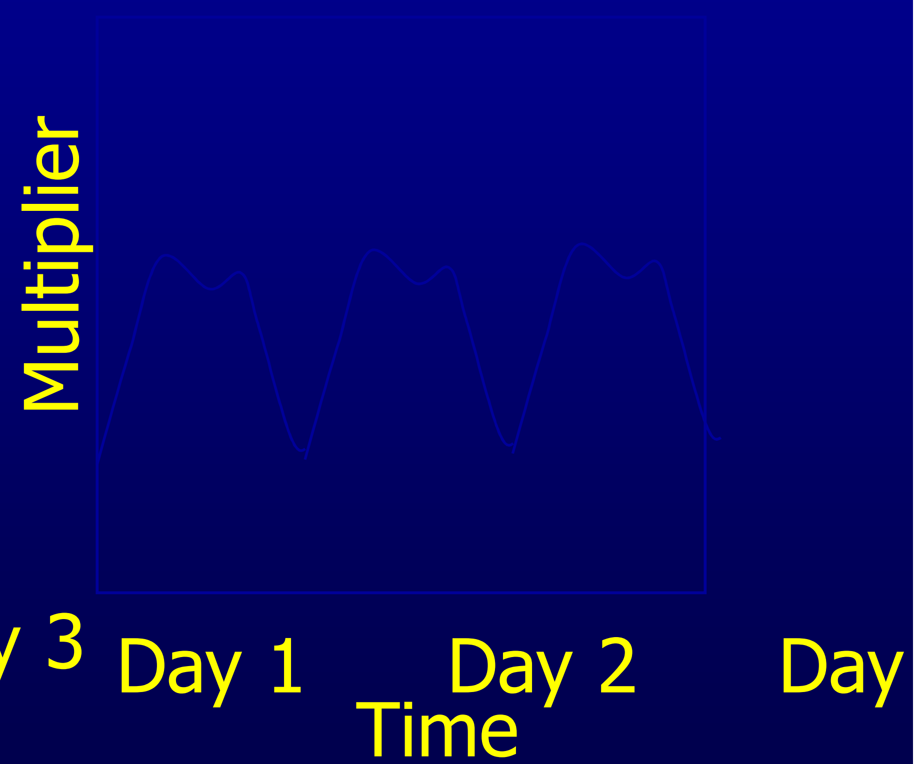
Loading Methods in SewerGEMS

- Sanitary loading
  - Hydrograph
  - Unit load x count (with pattern)
  - Base flow x pattern
- Inflow
  - Fixed inflow
  - Hydrograph
  - Base flow x pattern
- Catchment runoff
- Pipe infiltration

Hydrograph



Pattern

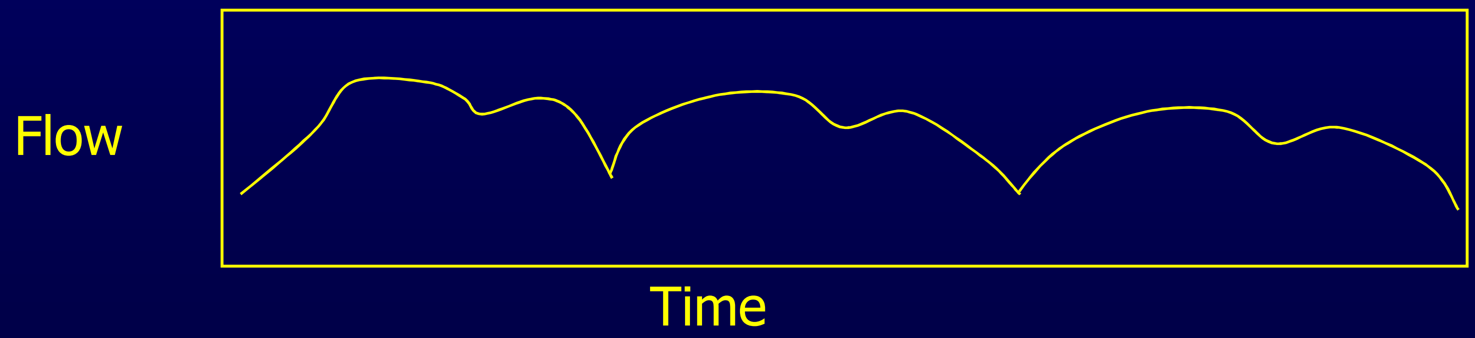


Unit Loading

- Unit load
  - Home
  - Restaurant per customer
  - Office per employee
- Default values available
- User provides count (population)
- Pattern setup assigns pattern to load type

Patterns

- Multiplier x base flow
- Base on flow metering for dry day
- Assign patterns to nodes
  - Few patterns, many nodes
- Repeat each period (24 hrs)



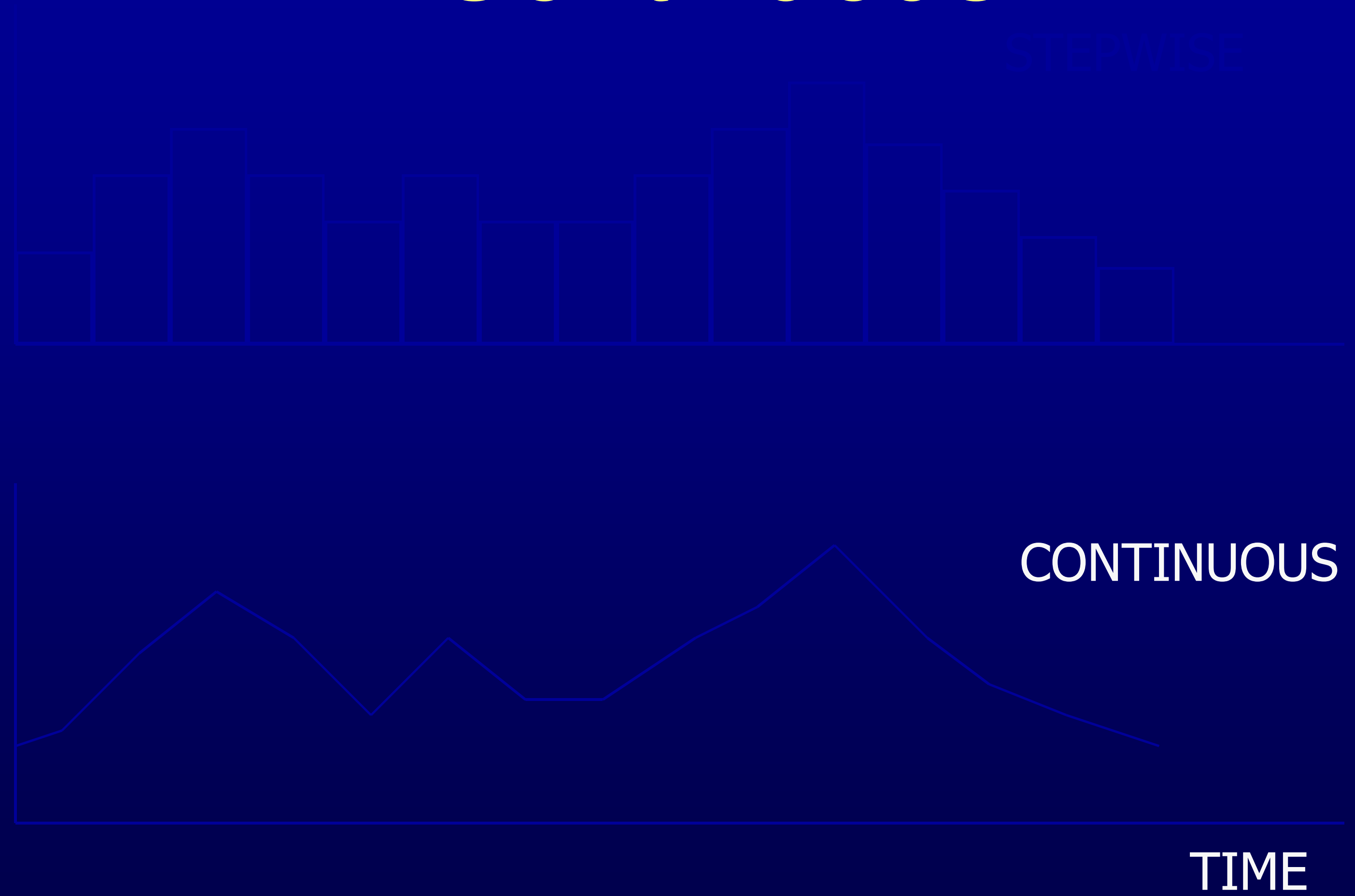
Dry Weather Loading Patterns

Define patterns by demand types:

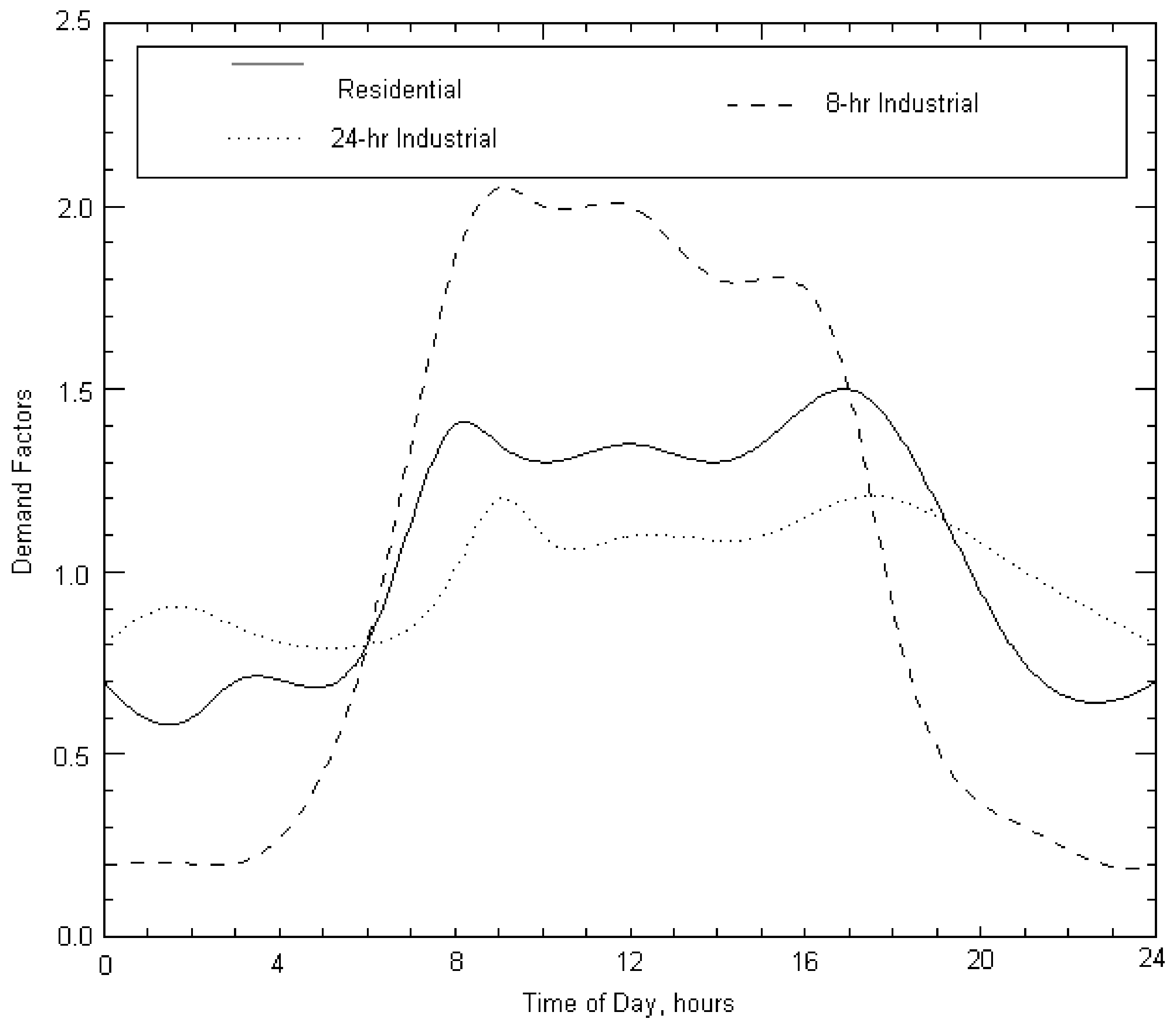
e.g. residential - industrial - commercial

- For large water users, use actual water use patterns
- Data logging
- Literature values can provide first guess – very system specific
- Patterns can vary by season/day of week

Patterns: Stepwise or Continuous



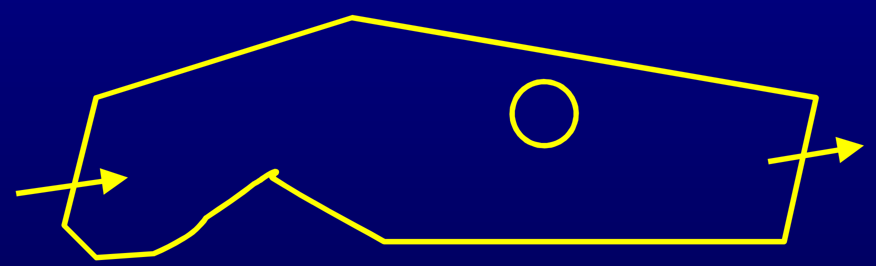
Typical Loading Patterns



Flow Balance

For given time period
Load = V(in) – V(out) +/- □Storage

Define area where all flows and levels are known



Flow = Usage/Time

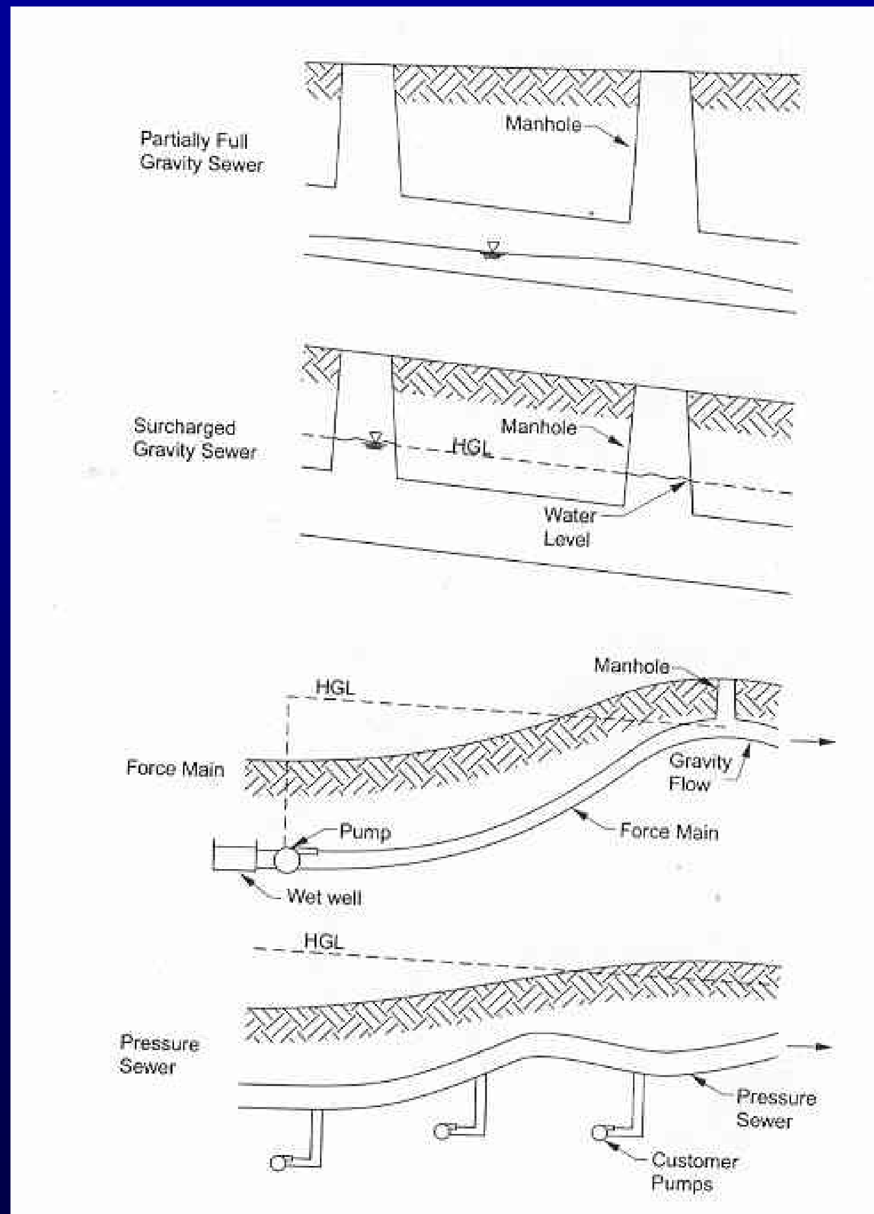
Multiplier = Flow/(Average Flow)

Combined Sewers

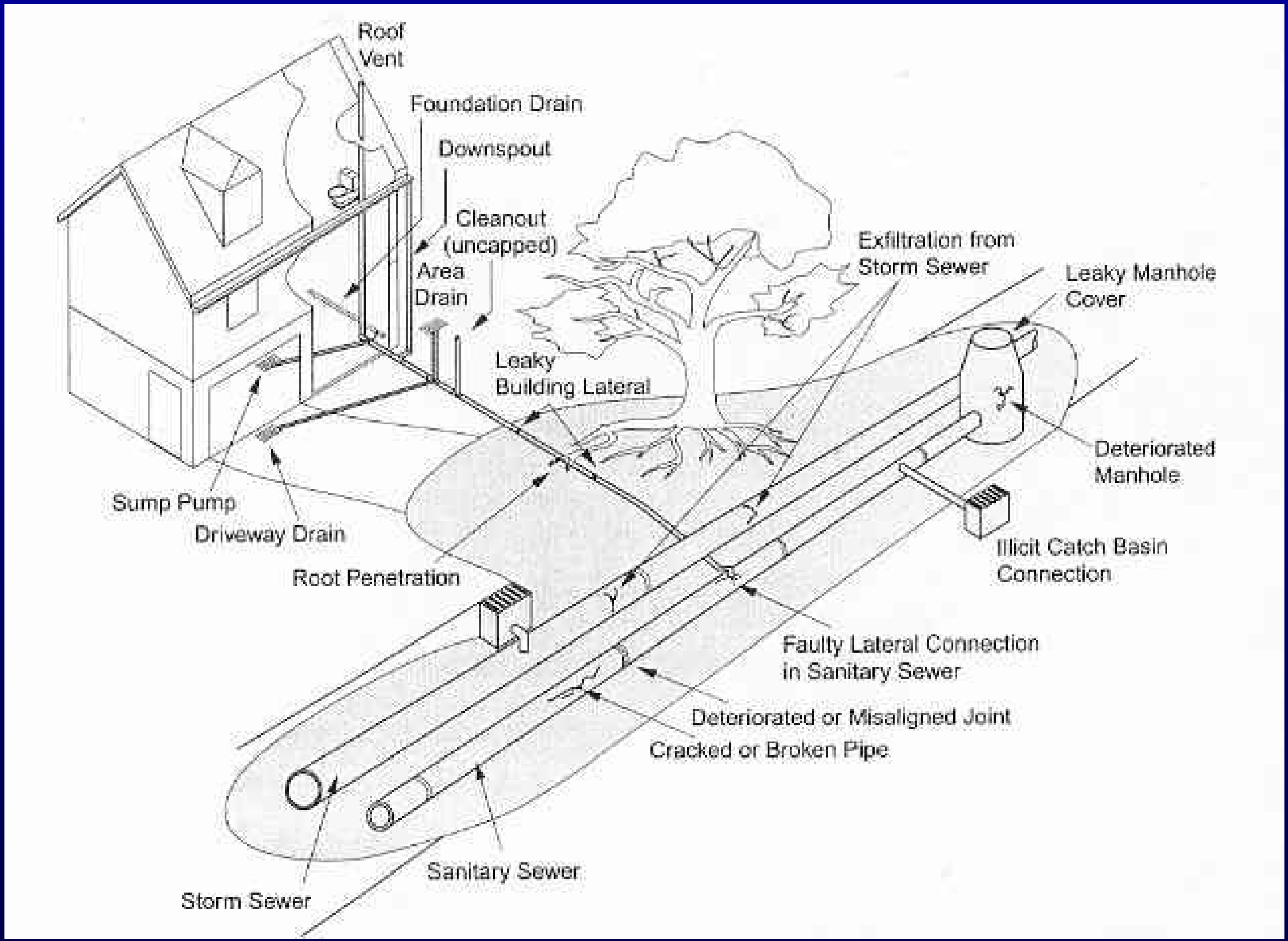
- Carry wastewater and stormwater
- Overflows permitted in wet weather
- No dry weather overflows
- Nine minimum controls

Key Terminology

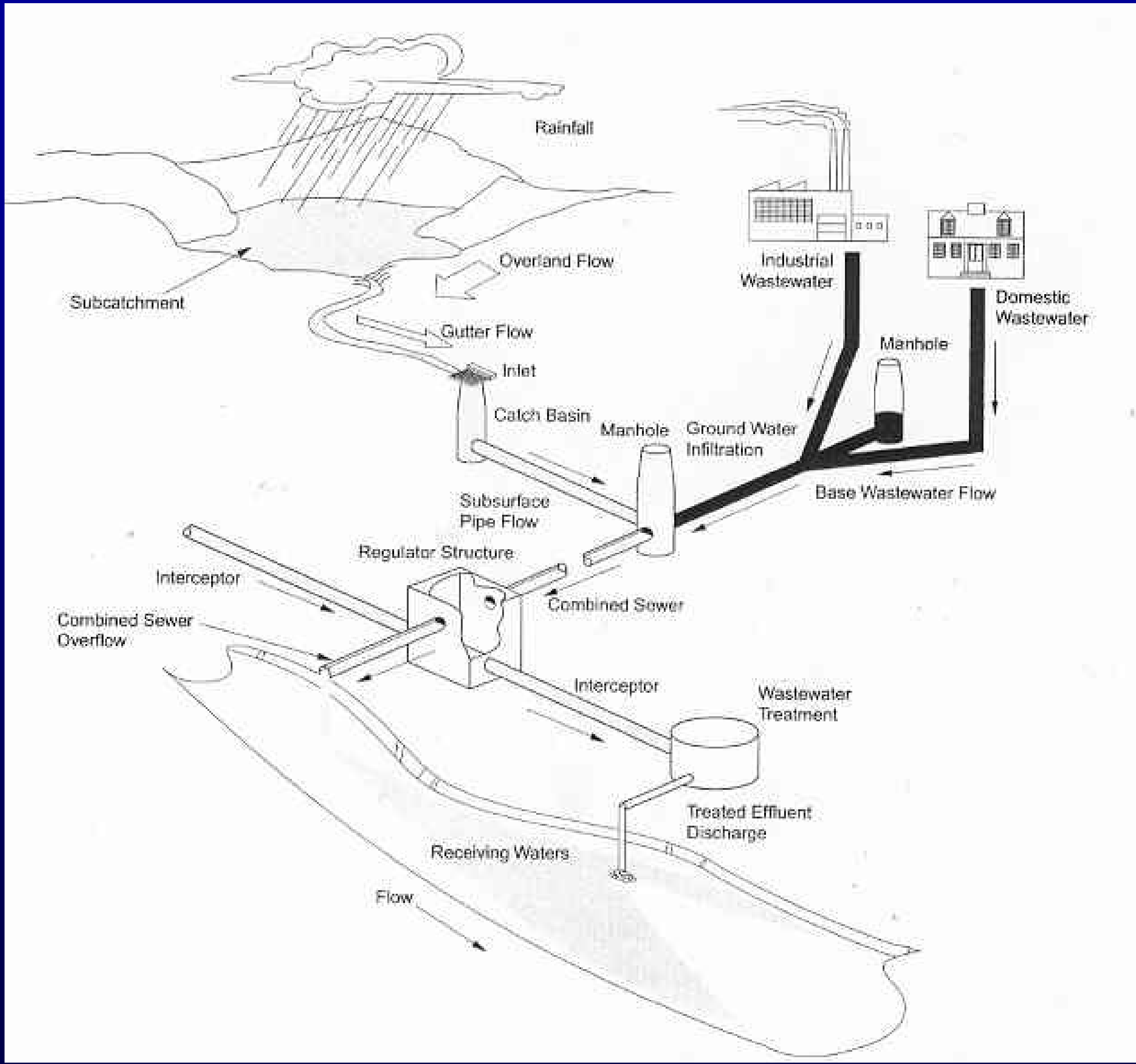
Types of Sewer Flow



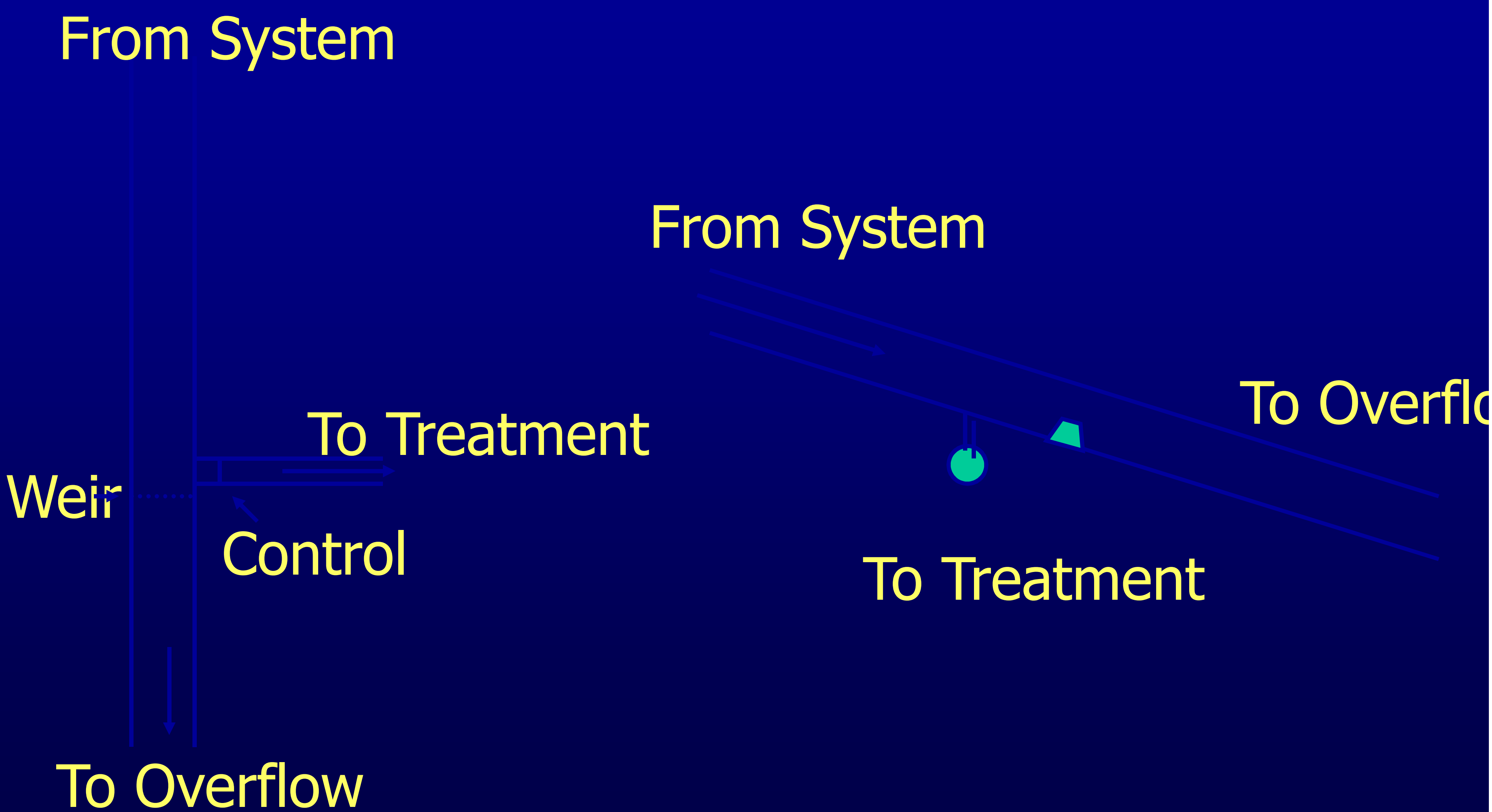
Separate Sanitary Sewers



Combined Sewers



Typical CSO


From System
To Treatment
Weir
Control
To Overflow
From System
To Overflo
To Treatment

Nine Minimum Controls

- Proper O&M
- Maximize use of storage
- Modify pretreatment requirements
- Maximize flow to POTW
- Eliminate dry weather CSOs
- Control solids and floatables
- Pollution prevention
- Public notification of impacts
- Monitor impacts and controls

Modeling Diversions

- Dynamic waver calculates flow split
- Control structures (pipe property)
  - Weir
  - Orifice
  - Functions $Q = a(H\text{-}weir)^b$
  - Depth vs. flow curve
- Stability issues – small time steps
- Hydrologic routine – rating table

Combined System Loading

- Uses both Inflow and Sanitary
- Sanitary - dry weather flow
- Inflow/Infiltration - wet weather flow

Modeling CSOs

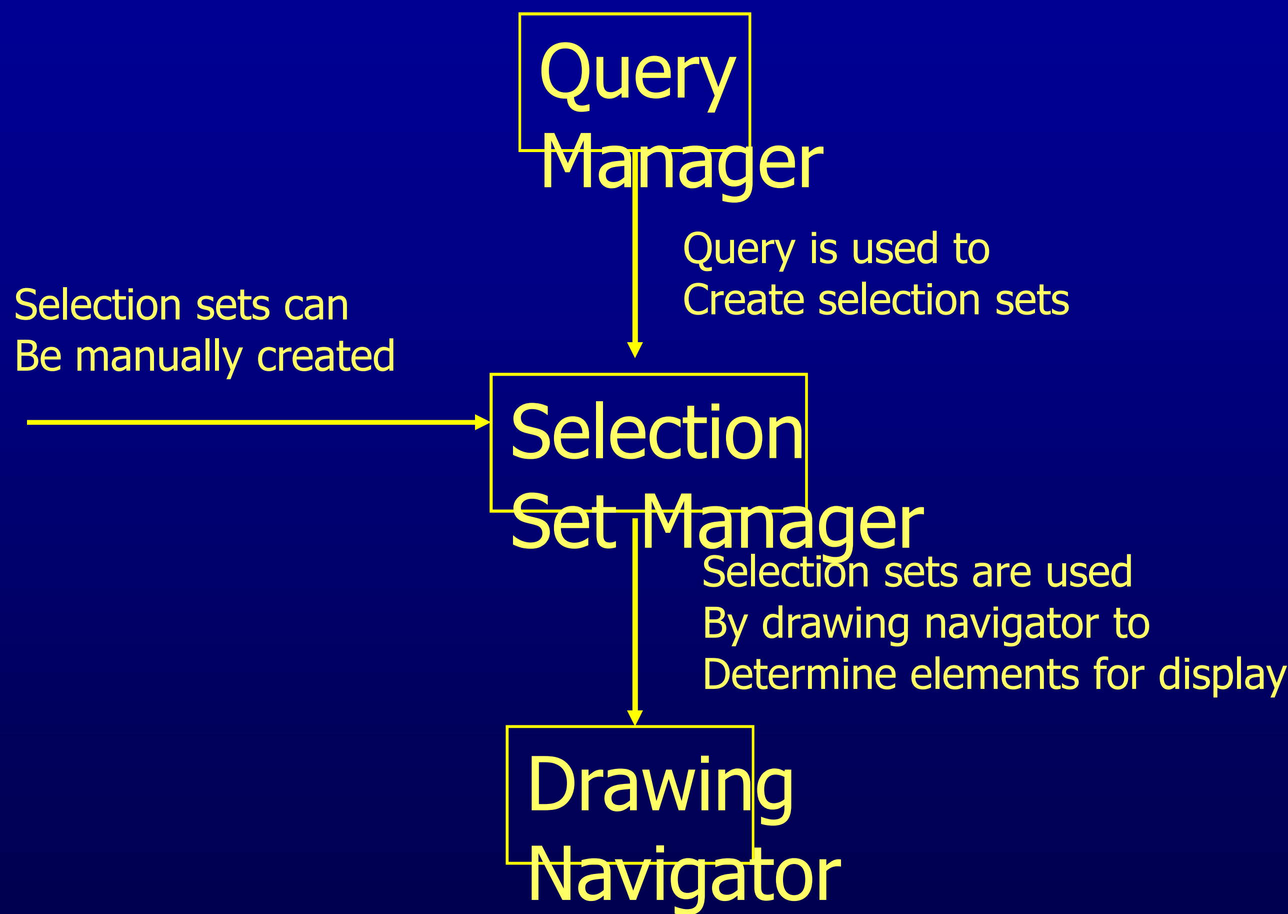
- Determine magnitude of event that causes overflow
- Determine volume of overflow vs. event
- From event frequency, can identify overflow volume
- Long term simulation

CSO Solutions

- Sewer separation
- Storage of wet weather flow
- No new combined systems in EMEA
- Combined sewers common elsewhere
- Modeling important

Selection Sets

- Can define groups of elements for graphics or tables
- Useful for finding things in large models
- Can use queries to create sets
- View with Drawing Navigator


Query Manager
Query is used to
Create selection sets
Selection sets can
Be manually created
Selection Set Manager
Selection sets are used
By drawing navigator to
Determine elements for display
Drawing Navigator

Questions and Answers

Thank you