SEWER NETWORK MODELING

Aalto University / 21.3.2019

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- Recap on sewer network model components
  - Point components
  - Line components
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- Task: Modeling a pumping station and pressurized pipes
- Essential results in sewer modeling
- Few last words

SEWER NETWORK MODELING IN GENERAL

SEWER NETWORK MODELING IN GENERAL

- General lecture on modeling already held
- Lecture on WSS modeling already held – most issues apply here also. We'll focus on the differences.
    - Modeling as a project is similar
    - Input data and systems from where they are collected are similar
    - Reporting and visualization have similar general principles – crucial results are different
- Storm water lecture also was just held

- Simulation times are longer than in WSS (significant in larger networks)
    - Can be reduced by varying calculation parameters
    - And often simply by using a smaller model, if the whole system is not under analysis

- Usually less measurements available than in WSS
- Accuracy in general: WSS > SEWER > STORM WATER
- Largest sources of inaccuracy in sewer modeling:
    - Leakage – precise location and amount
    - Clogs
    - Sensitivity to elevations
    - (Errors/assumptions in model)

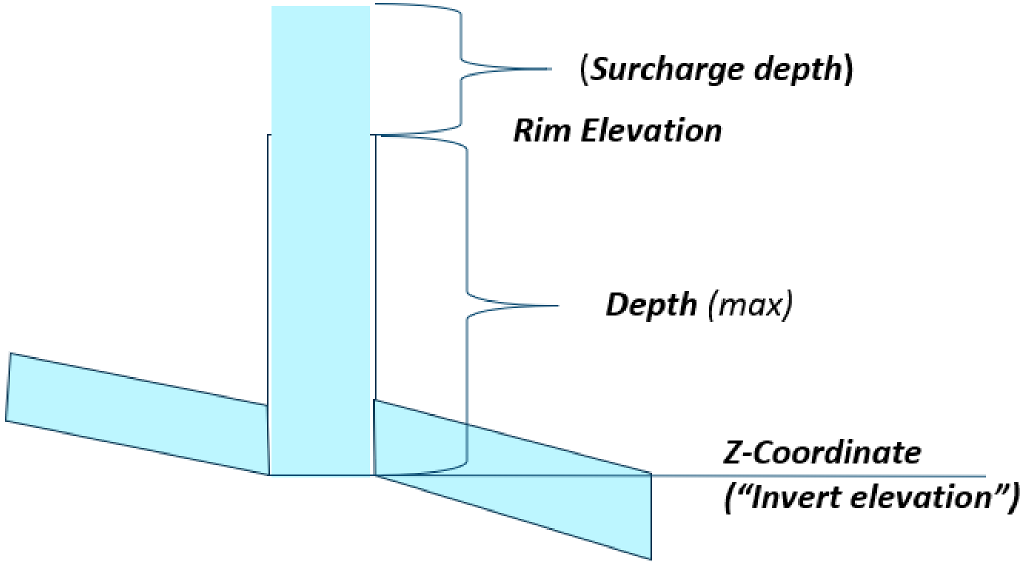
RECAP ON SEWER NETWORK MODEL COMPONENTS

NODE OBJECT: JUNCTION / MANHOLE

Junction-6 - Properties

Properties | Results | Identifiers

General	
Name	Junction-6
Description	
X-Coordinate	25,496,431
Y-Coordinate	6,674,745
Z-Coordinate (Elevation)	1.5
Symbol	No symbol set
Depth	2
Rim Elevation	3.5
Critical Level	�
Tags	
Properties	
Average Demand	0.04
Diameter	0
Initial Level	0
Number of Consumers	1
Ponding Area	0
Surcharge Depth	0
Settings	
Station	[None]
Inflows	
Daily Demand	3.44
Inflows	1
Treatment	
Sewershed Area	0
Unit Hydrograph	[None]
Ignore for Geocoded	☐



Surcharge depth represents nodes ability to hold pressure. Default is 0 - it holds no pressure above its rim - if water level rises above rim elevation, it floods out.

Junctions default area can be defined in Model Properties and used for all manholes. By default it is 1,168 m² - an area produced by diameter of about 1,22 m.

NODE OBJECT: STORAGE UNIT

StorageUnit-1 - Properties

Properties | Results | Identifiers

General	
Name	StorageUnit-1
Description	Pumping station storage unit. It ...
X-Coordinate	25,496,458
Y-Coordinate	6,675,012
Z-Coordinate (Elevation)	8.95
Symbol	Sewage Pumping Station
Depth	3
Rim Elevation	11.95
Critical Level	�
Tags	
Properties	
Initial Level	0
Ponding Area	0
Surcharge Depth	0
Area	7.07
Area Curve	[None]
Area Coefficient	0
Area Exponent	0
Area Constant	7.07
Volume	21.21
Diameter	3
Evaporation Fraction	0
Soil Suction Head	�
Soil Saturated Hydraulic Conductivity	�
Soil Initial Moisture Deficit	�
averageDemand	0.00847
numberOfConsumers	1
Settings	
Station	[None]

Storage unit is a finite tank: flow into or out of the tank changes the head (ie. level and volume)

Volume is calculated with a formula or given in a volume curve

- Formula: Volume = (A*Depth^B + C)*Depth

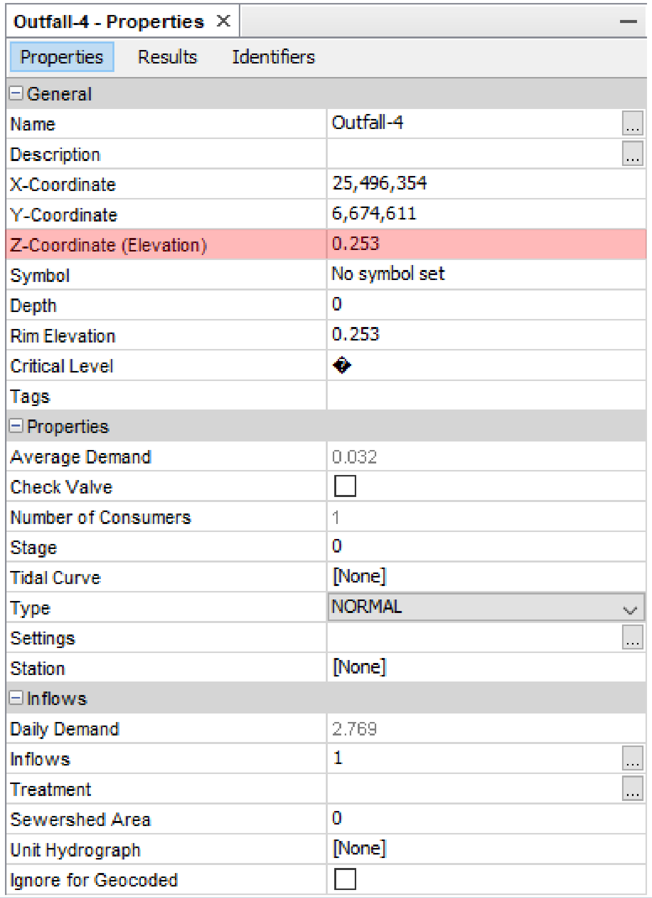
In our exercises we assume that the storage unit is symmetrical along it's vertical axis

- This by far the most common type in reality also
- All the other constants are 0 except **Area Constant**
- Thus volume is C * depth → C is the cross section area of the tank

Essential parameters for storage unit are:

- Elevation of the bottom **(Z-coordinate)**
- Depth of the storage unit **(Depth)**
- Area **(Area Constant)**

NODE OBJECT: OUTFALL



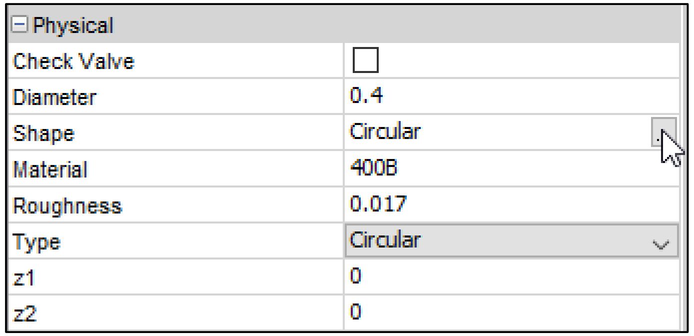
Outfall is an infinite receiving water body: head does not change depending on the flow (doesn't "fill up"). Head CAN be made to change over simulation time (but is usually fixed).

All the water in a model has to have a theoretical possibility to end up in a outfall. In outfall the water is removed from the system.

Outfall usually models WWTP inflow tank or some natural body of water (lake, river, sea).

In our models outfall is Type "**Normal**" and "**Elevation**" is used to model the elevation of the outfall (infinite water surface).

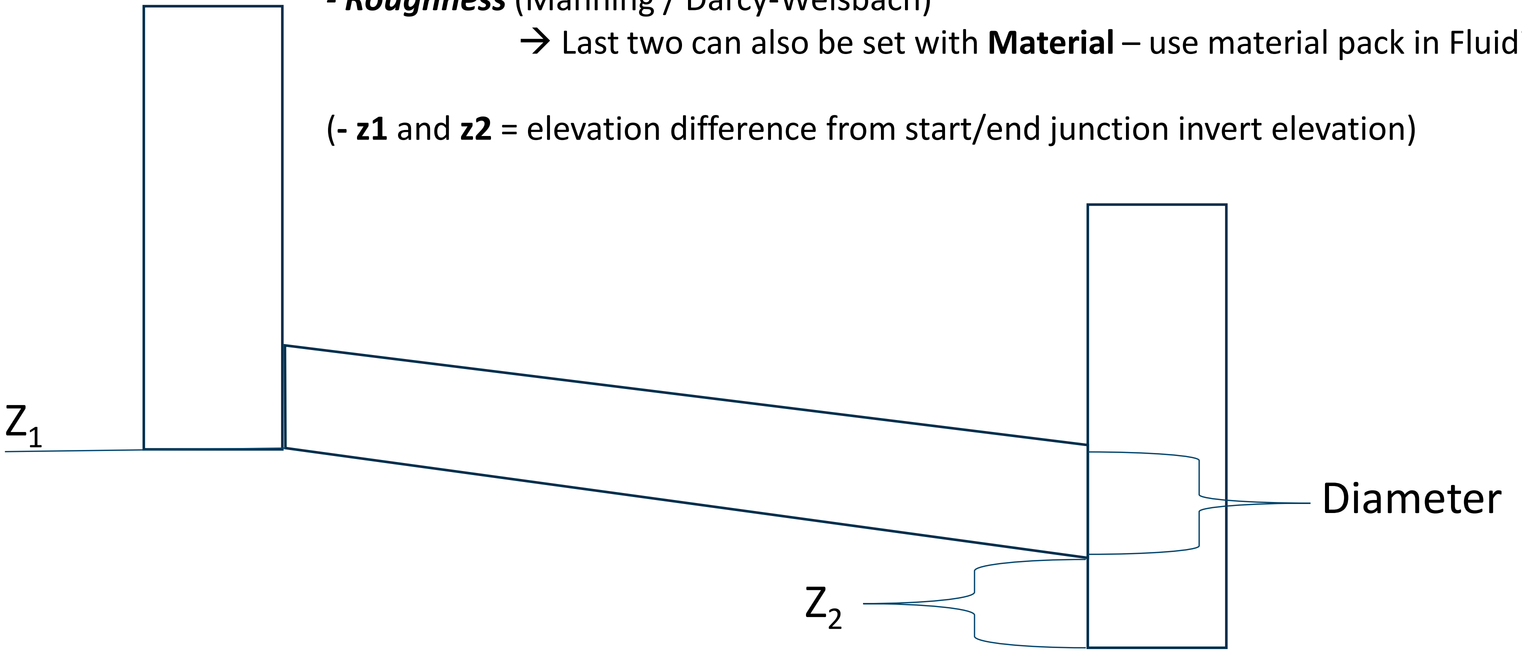
LINE OBJECT: PIPE



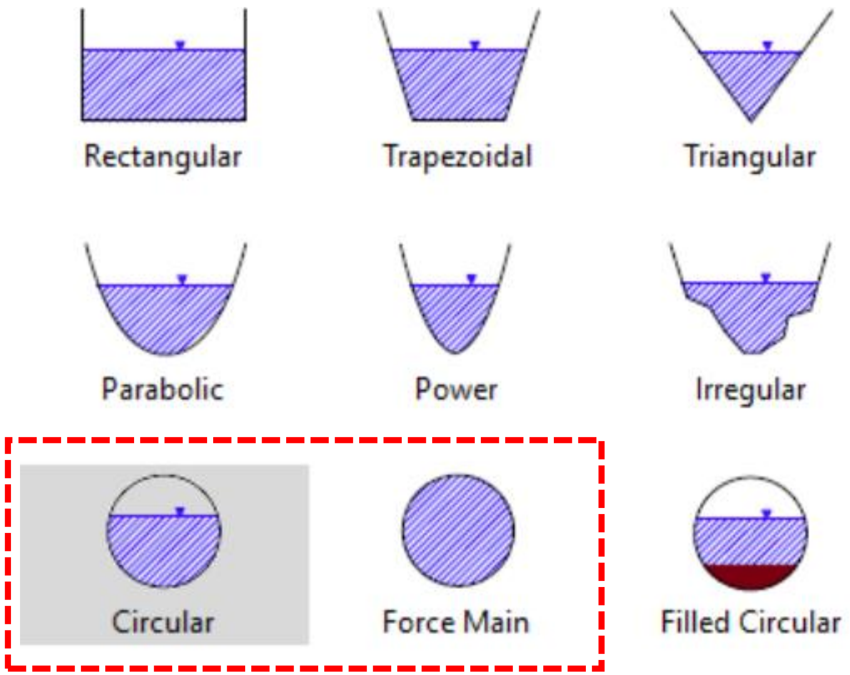
Essential attributes of pipes:
- ***Length*** (automatically calculated, but can also be set manually)
- ***Shape***
- ***Diameter*** *(*inner diameter of the pipe)
- ***Roughness*** (Manning / Darcy-Weisbach)

→ Last two can also be set with **Material** – use material pack in Fluidit Sewer

(**- z1** and **z2** = elevation difference from start/end junction invert elevation)



Different pipe shapes



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LINE OBJECT: PIPE

Most of the sewage network is gravitational, in which the pipe headloss is calculated using Manning's equation on closed conduits.

Mannings equation is not precise on very smooth surfaces.

$$Q = \frac{1}{n} R_n^{2/3} S_f^{1/2}$$

Q , flow [m³/s]
n, manning's factor $[\mathrm{s/m^{1/3}}]$
R_n , Hydraulic radius (Area/Perimeter) [m]
S_f, Slope [m/m]

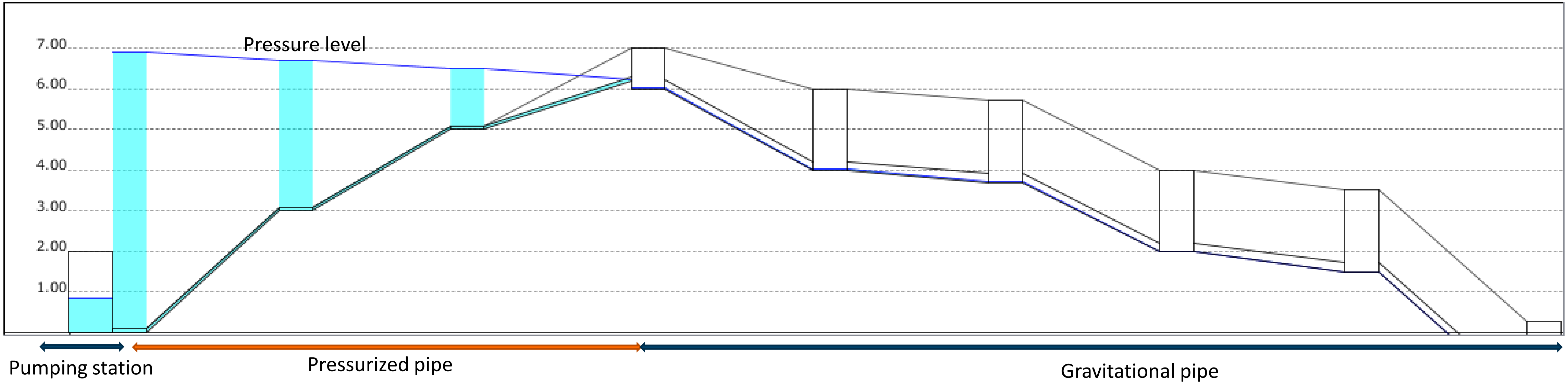
A.7 Manning's n – Closed Conduits

Conduit Material	Manning n
Asbestos-cement pipe	0.011 - 0.015
Brick	0.013 - 0.017
Cast iron pipe - Cement-lined & seal coated	 0.011 - 0.015
Concrete (monolithic) - Smooth forms - Rough forms	 0.012 - 0.014 0.015 - 0.017
Concrete pipe	0.011 - 0.015
Corrugated-metal pipe (1/2-in. x 2-2/3-in. corrugations) - Plain - Paved invert - Spun asphalt lined	 0.022 - 0.026 0.018 - 0.022 0.011 - 0.015
Plastic pipe (smooth)	0.011 - 0.015
Vitrified clay - Pipes - Liner plates	 0.011 - 0.015 0.013 - 0.017

Source: ASCE (1982). *Gravity Sanitary Sewer Design and Construction*, ASCE Manual of Practice No. 60, New York, NY.

Common pipe materials:
Concrete (B/Betoni)
Plastics (PVC)
(+ PEH for pressure)
Iron / Cast iron
Asbestos cement

LINE OBJECT: PRESSURIZED PIPE



When modeling a pressurized pipe in sewer model:

- In reality, there are no manholes (junctions) in the line, but in order to get the pipe profile right, junctions are needed for the elevation of the pipe profile
  - (link components have no elevation, only the elevation of their start and end nodes)
- Junctions in a pressurized line are not allowed to flood, so we need to implement **Surcharge Depth** for these junctions. Good value to use is 100 mwc (~ 10 bar), or if you know the pressure class of the pipe, use it.
- **Depth** for these junctions should be set to 0 – these are not real manholes and have no volume
- All the pipes (conduit) in a pressurized pipeline should to have the shape **Force Main.** Headloss formula is different in pressurized pipes.

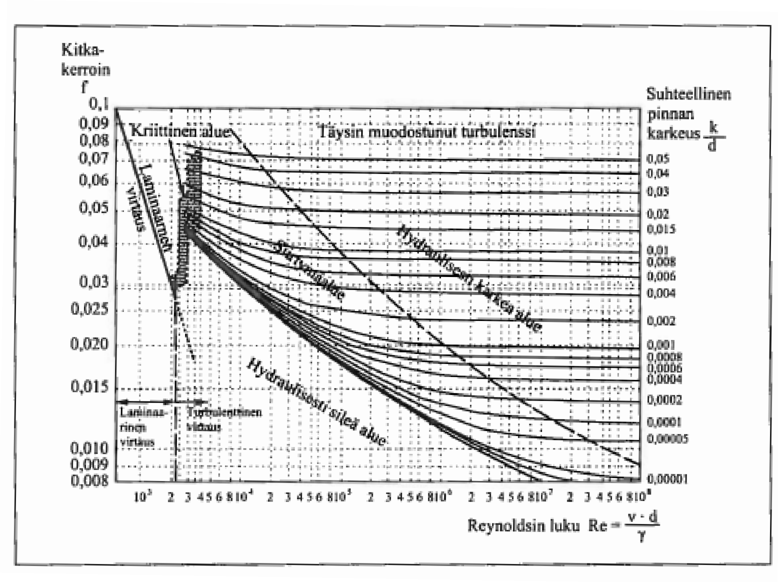
LINE OBJECT: PRESSURIZED PIPE

Headloss formula in pressurized pipe (Darcy-Weisbach) →

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

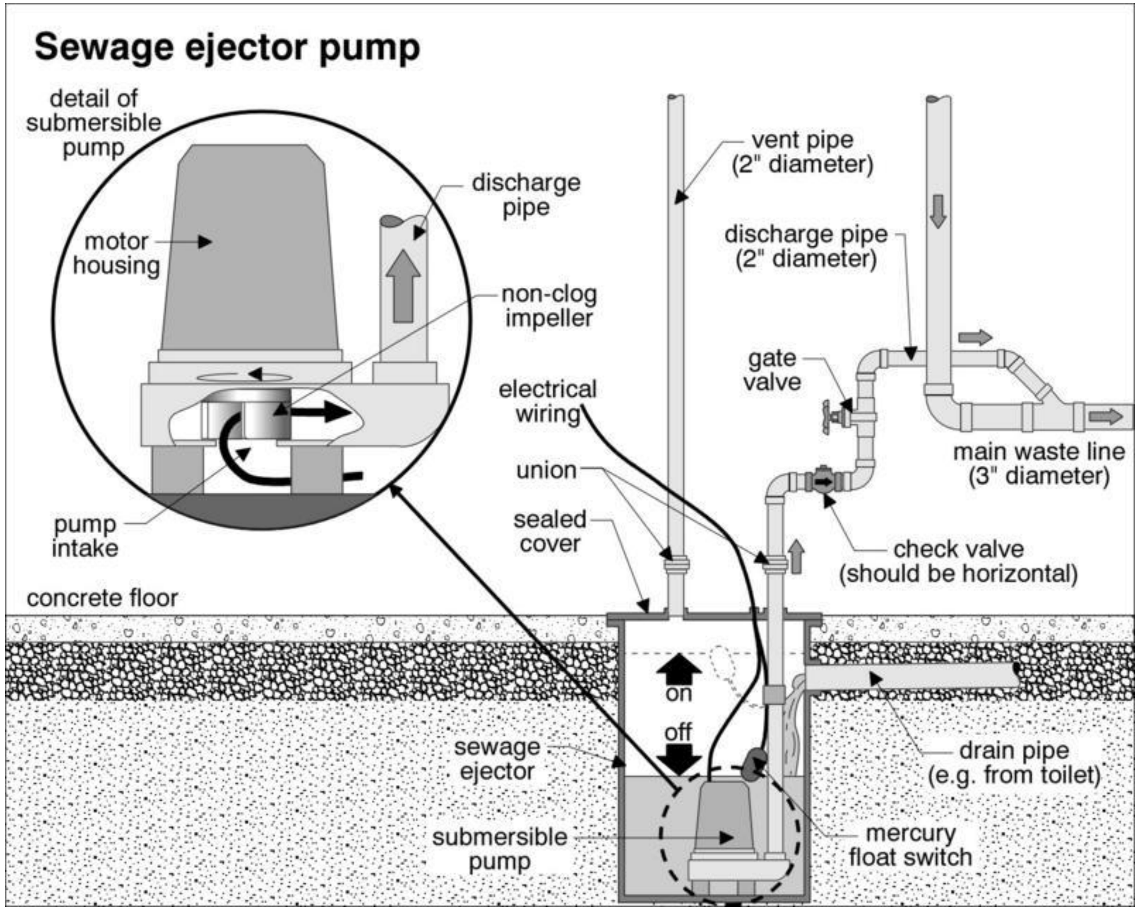
Pipes not marked as *Force Main* can still get pressurized

h_f , friction loss [m]
L, pipe length [m]
d , hydraulic diameter (inner diameter) -> Pipe D_{pipe} [m]
v, average speed of flow in the flow cross-section [$\frac{m}{s}$]
g, gravity constant [$\frac{m}{s^2}$]
f, dimensionless friction coefficient



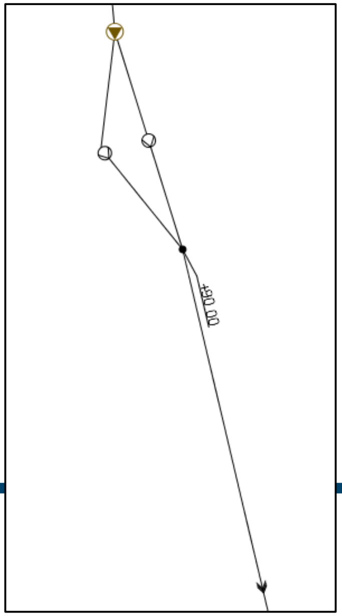
Different materials have different friction coefficients. (eg iron pipe vs plastic pipe)

PUMPING STATION

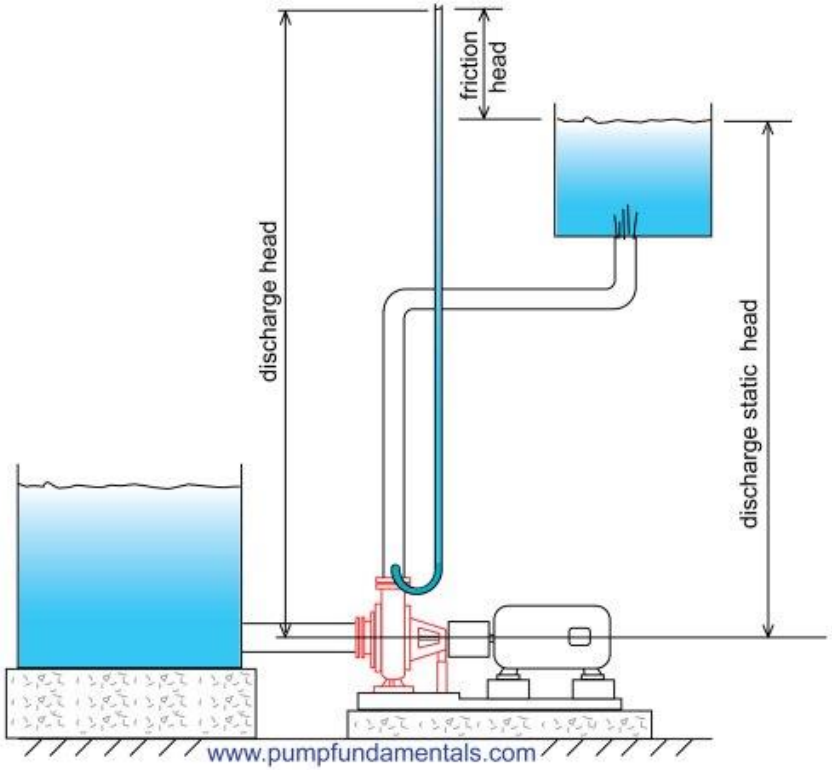


Typical ("package") pumping station have the following components (for modeling purposes):

- Inlet pipe (can be pressurized or gravitational)
  - Often not connected to the bottom of tank, but higher
- A storage unit – tank
- Two pumps
- Outlet pipe, pressurized (*Type: Force main*)



LINE OBJECT: PUMP

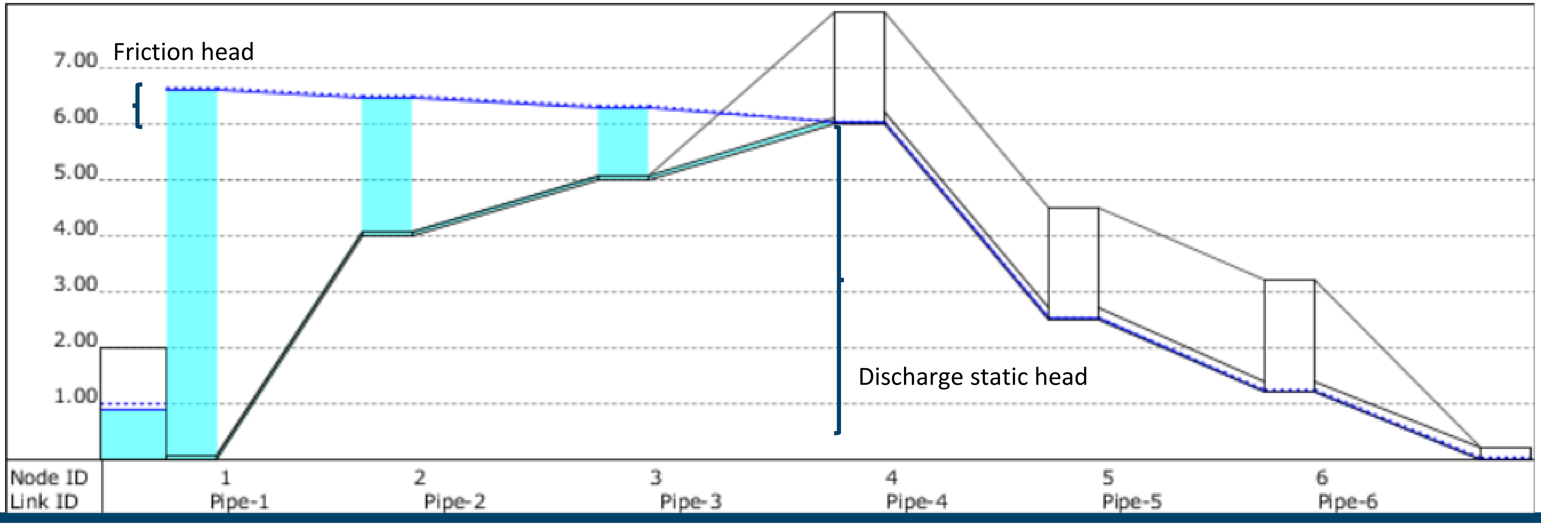


Pumps need to have a pump curve (via pump definition) and startup & shutoff depths.

In sewer systems (usually by far) most pumps are controlled by simple on/off water levels. Complex control systems can also be modeled.

In pump sizing you need to take into account:

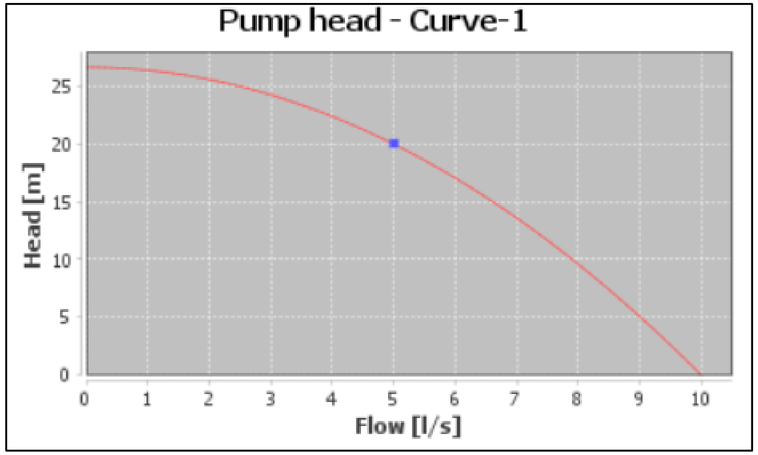
- Discharge static head / “geometric head” (due to elevations)
- Friction head (due to friction loss in pressurized pipe)
- Flow

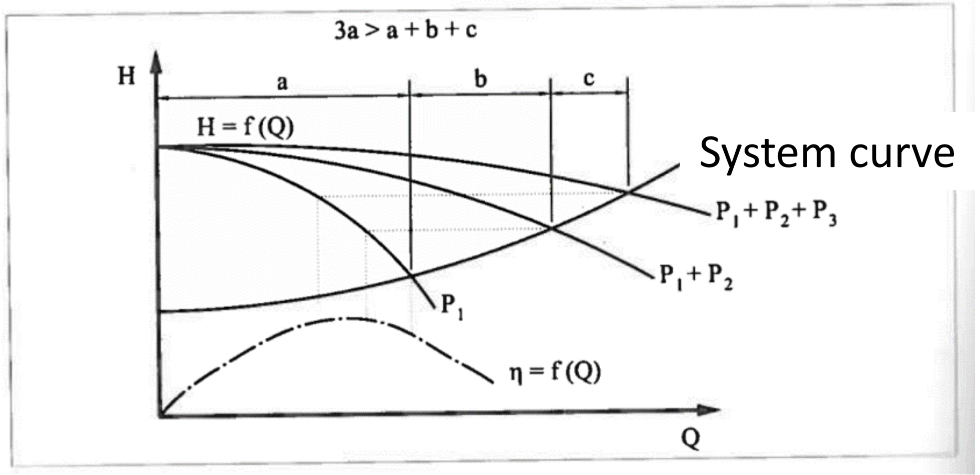


PUMPS IN SEWER SYSTEMS

- Pumps, especially impellers, vary more than in WSS
- Generally have higher penetration, but lower efficiencies
- Higher wearing
  - There can be a big difference in pump head/flow compared to new pumps
- Smaller ones are usually submerged pumps, larger ones either submerged or dry
  - Difference is not that significant for the pump itself, but more for the electric motor (cooling)
- Typical pumping station:
  - Has two pumps, large ones three
  - Simple on/off controls

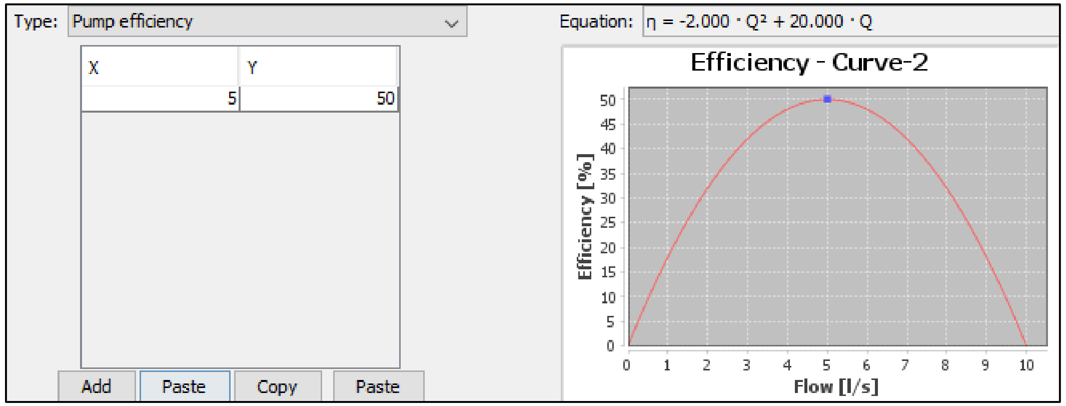
NON-PHYSICAL OBJECT: PUMP CURVE





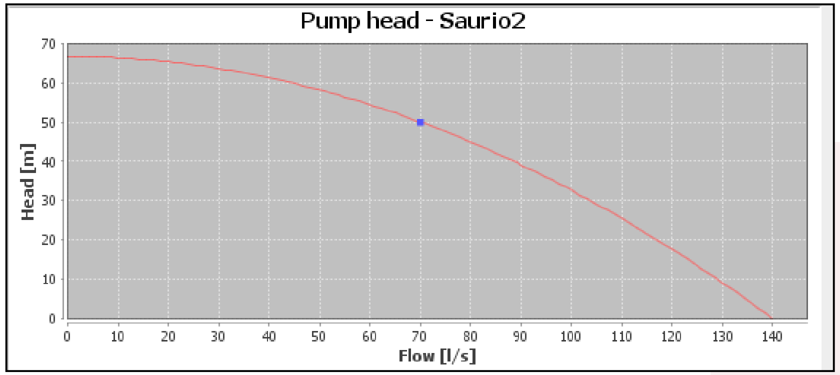
- Pump curve depicts the output of the pump, usually as a Q-H (Flow/Head) –relation
  - This is how real pumps work and QH-curves are provided by the manufacturer
- In Fluidit Sewer curves are defined in **Model → Curves,** and they are composed into pumps in **Model → Pump Definitions.** Pump components in the model are then given a pump definition.
- With only one point given, program will fit a "general" pump curve around this (nominal duty) point
  - Assuming: max flow = 2 * nominal flow and max head = 1,33 * nominal head
- In reality, wastewater pumps, especially small ones, can have very different curves from this assumption
  - Curves can be given with more than just one point (three is next where a curve is fitted, or in a tabular form with as many points as needed)

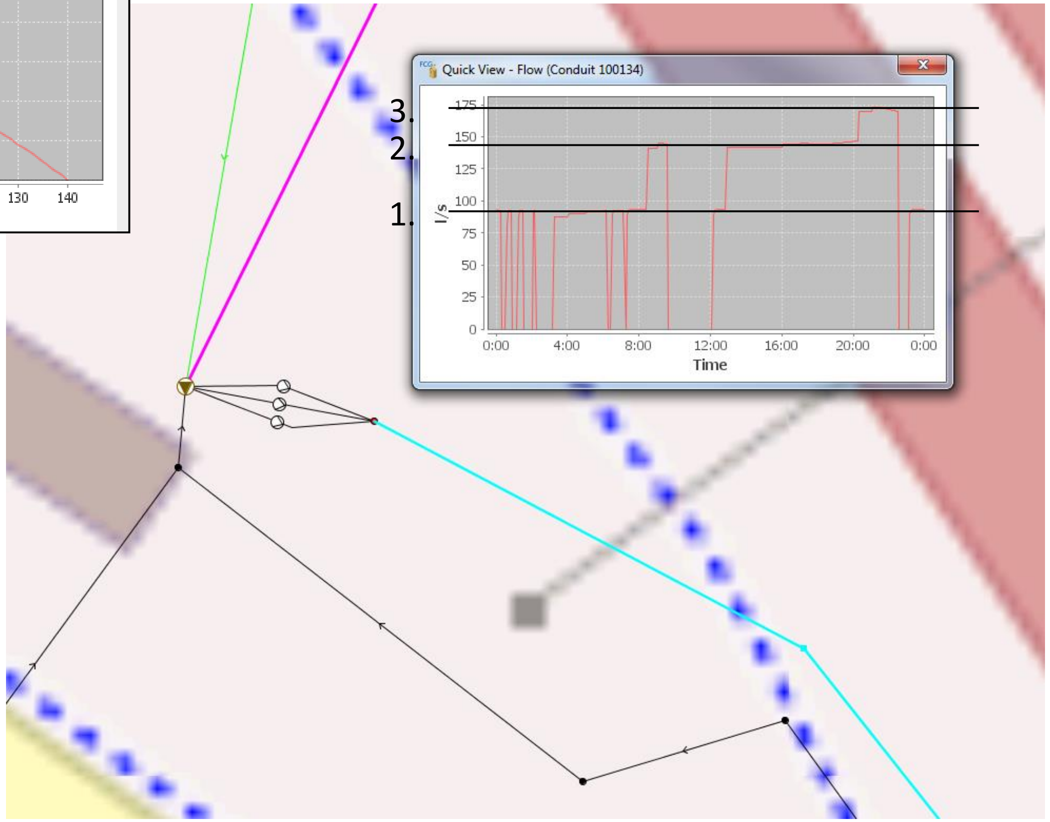
NON-PHYSICAL OBJECT: EFFICIENCY CURVE



- Efficiency curve depicts pumps hydraulic efficiency as Q-Ƞ (Flow-Efficiency) –relation
  - (Total efficiency in EPASWMM, as there is no separate motor/inverted loss calculation as in Fluidit Sewer)
- Efficiency curves are not compulsory – they have no hydraulic effect on the system. They are used only for energy calculations.
- In **Pump Definitions** a “whole” pump is assembled from pump curve, efficiency curve and other information (eg. electric motor efficiency)
- In Fluidit Sewer results:
  - **Electric Efficiency** is total efficiency from electric power to hydraulic power
  - **Hydraulic Efficiency** is the pumps efficiency from impeller shaft power to hydraulic power (ie. not including motor losses)

PUMPS IN PARALLEL





1. Pump pumping n. 90 l/s
2. Pumps pumping n. 140 l/s
3. Pumps pumping n. 170 l/s

Headloss increase in power of velocity:

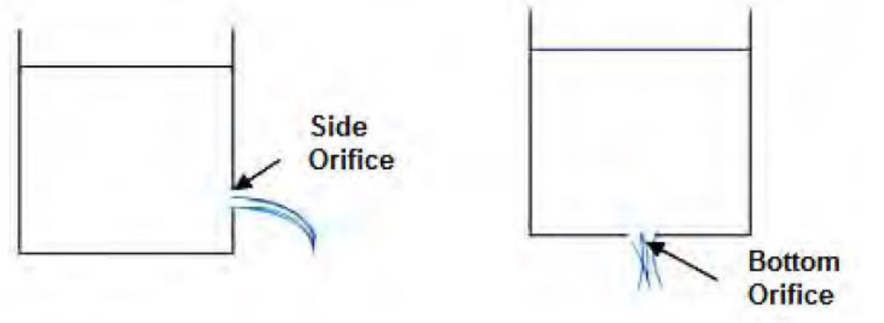
$$h_f = f \cdot \frac{L}{d} \frac{v^2}{2g}$$

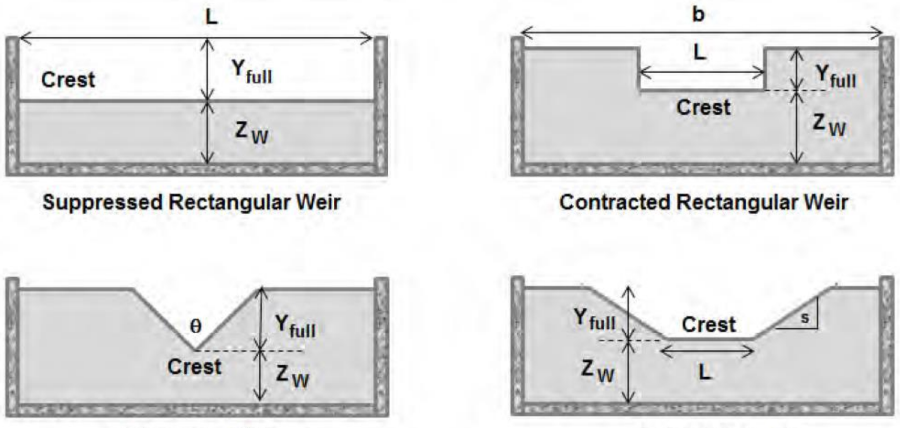
LINE OBJECT: ORIFACES, WEIRS, OUTLETS

- All of these are links that can be used to regulate flow from one node to another

- Oriface
- Weir
- Outlet
  - “a generic type of flow regulator with a user defined rating curve that relates flow rate to effective head”

- Quite rare in sewer networks, more used in storm networks
- Simple “overflow-pipes” can be modeled without these, with a normal pipe that has Z1 > 0
  - (pipe that does not start from the bottom of the manhole)





Suppressed Rectangular Weir
Contracted Rectangular Weir
Triangular Weir
Trapezoidal Weir

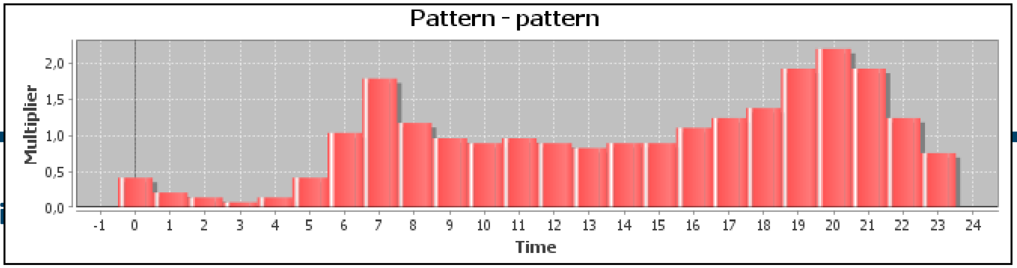
MODELING SEWAGE FLOW + LEAKAGE

CONSUMED WATER: GEOCODED DEMANDS

- Geocoded demands are just one way to bring inflow into model
  - Geocoded demands are assigned to a junction
  - For calculation purposes, it does not differ from direct junction inflow

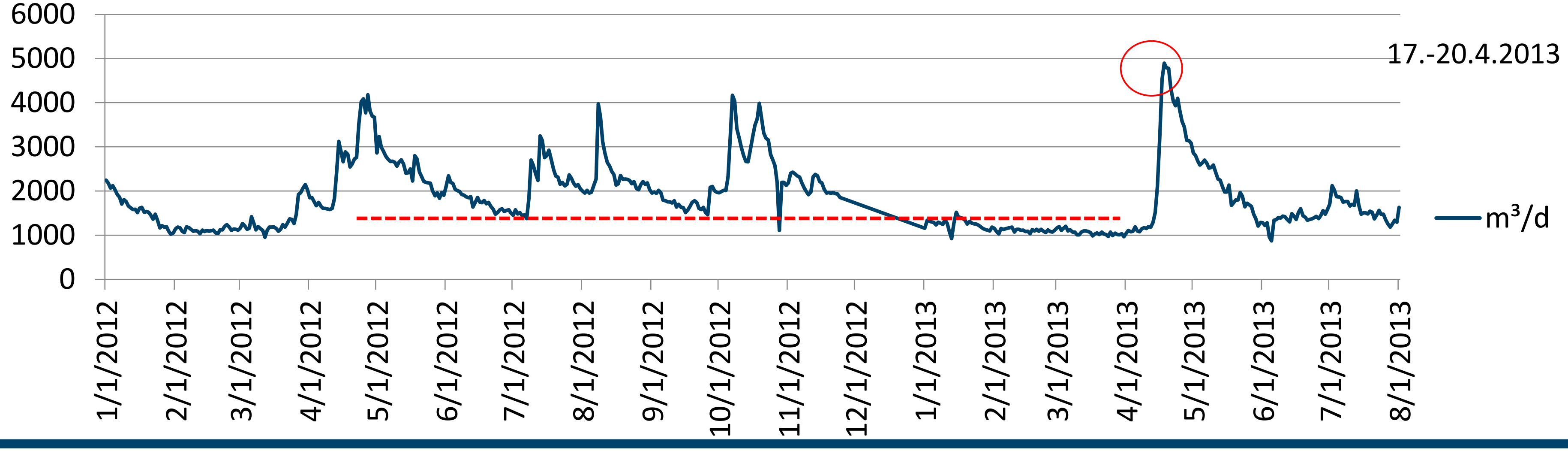
- Usually input data is actual billed water for every customer
  - Initial data: consumption (m^3/a), coordinates (or address), *user id, customer type*
  - Seasonal users may cause inaccuracies…
- …or literature values
  - Actual data not available or new users

- If you spectate a high enough number of people the inflow amounts from human sources start to follow a certain pattern, which is related to the time of the day and day of the week
  - This has already been discussed in WSS modelling
  - Usually it is assumed that all consumed water is directly flowing to sewer (as in billing)
  - Exceptions: factories, swimming halls… large users need attention



LEAKAGE

- Typical average (yearly) leakage water percentage in sewage network is 30…50 %
- Maximum leakage can be more than five times the average
- Flow peaks (on a whole network level) are typically caused by leakage, not consumed water
  - But for small areas this can be the other way around
- Amount and temporal change of leakage varies a lot between networks
- Normal inflow from the environment to the sewer is related to poor pipelines and manholes, with water originating from rain and groundwater
- Peaks are often caused by natural events, such as storms and snowmelt



LEAKAGE

- Leakage is usually estimated based on measured data
  - “Water pumped from the zone” - “water pumped into the zone” - “billed water in the zone” = leakage in the zone
  - Usually flow measurements are not available from all (if any) pumping stations
    - Often only pump running time & number of pump startups
    - → can be used to evaluate flow, but includes more uncertainties
- If no pumping station data is available at all or it is of bad quality, inflow to WWTP is almost always available
  - → can be used to calculate leakage, but only on whole network level
- Literature values (l/s/km, often different values for different diameter pipes)

- Leakage is usually modelled as a direct steady inflow into junctions
  - Steady → can give a “too good” estimate if directly calculated from daily/yearly leakage (what if it peaks at consumption peak?)
  - Has no natural daily pattern (compared to consumed water)
- Fluidit Sewer has tools to distribute leakage into junctions depending on the length and diameter of pipes connected to it
- Other approach is to use catchments → takes a lot more work and calibration, but can be more accurate
- In general, modeling leakage is the single largest source of inaccuracy in sewer models

LEAKAGE

- Smaller the area, the bigger role a single water consumer plays
  - → one house, consumed water varies considerably from average

- Bigger the area, the better statistical behaviour “smooths” consumed water
  - → on a city scale, variation is often diminished to about 0,8…1,2 factors for daily water usage

- Peak leakages are usually caused by storms or snowmelt
  - → Peak leakages often happen at the same time all around the network

BASE INFLOW

- Building block of 300 people
- Water consumption 150 litres / day / person → all discharged to sewage system

0.52 l/s

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EXTRA FLOW: LEAKAGE

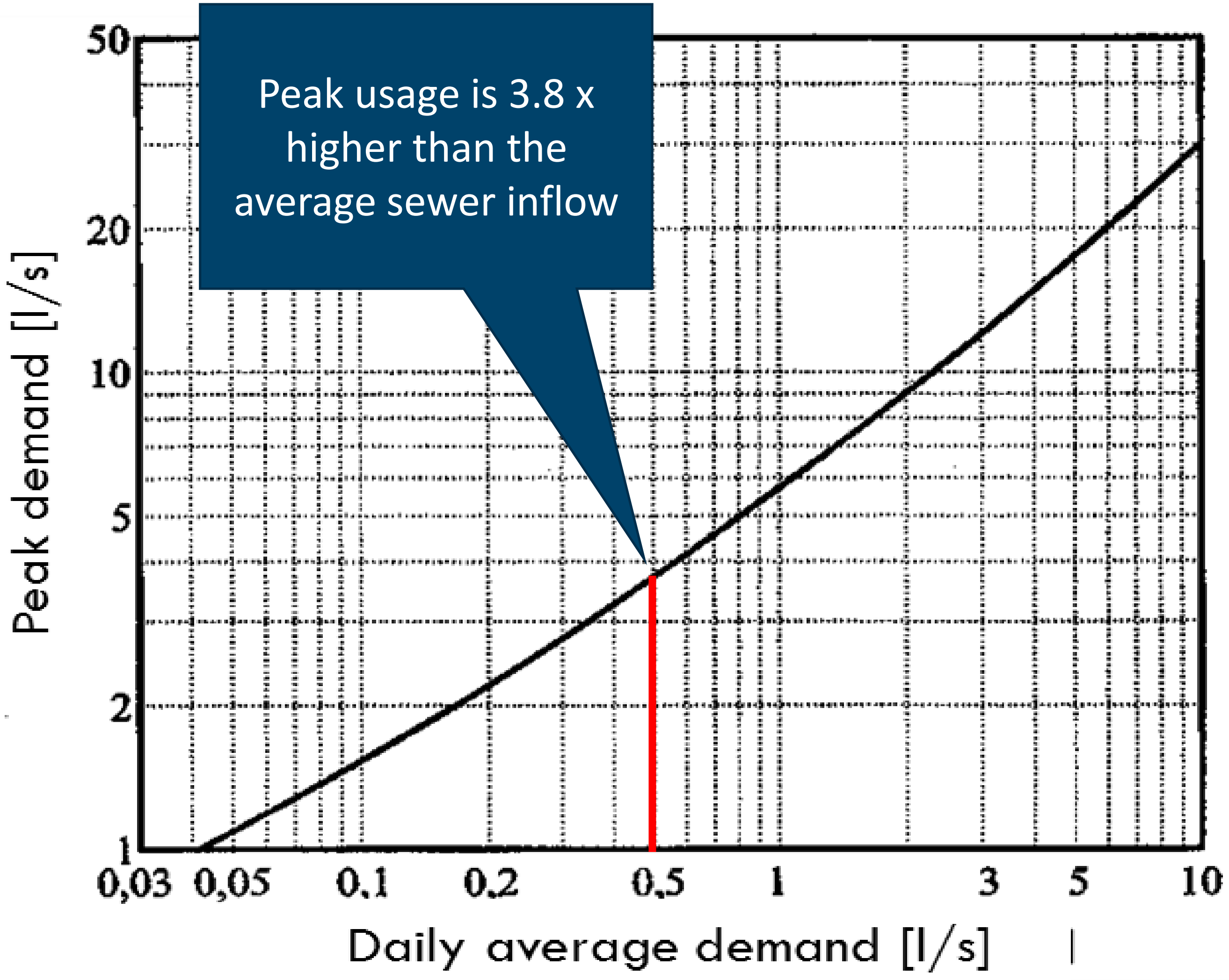
- Baseflow 0.52 l/s
- Amount of extra inflow (leakage into the system): leakage percent 33 %?
- Be careful with the term “leakage percent” (“vuotovesiprosentti”)!
  - Usually (and here) refers to the relation: *leakage water / total water*
  - Sometimes: *leakage water / consumer water*

0.26 l/s (→ 0,26 / 0,78 = 0,33)

PEAK USAGE

What is the peak flow to sewer from water consumption?

1.98 l/s



SMALL AREA: PEAK FLOWS

What is the peak flow to sewer from leakage?

Very area dependent

For example, a factor of 4

1.04 l/s

Peak usage 1.98 l/s + normal leakage 0.26 l/s = 2.24 l/s

Normal usage 0.52 l/s + peak leakage 1.04 l/s = 1.56 l/s

(Peak usage 1.98 l/s + peak leakage 1.04 l/s = 3.02 l/s)

→ Peak sewer flow is likely to be caused by peak consumption

LARGER AREA: PEAK FLOWS

But if we combine 5 similar blocks?

Let's say two of them have a peak consumed water, other's have normal. Leaks normal.

Consumed: 1.98 x 2 + 0.52 x 3 + Leak: 0.26 x 5= 6,82 l/s

Storm comes, heavy rain. All areas have a peak leakage, but normal consumption.

Consumed: 0.52 x 5 + Leak: 1.04 x 5= 7,80 l/s

→ Peak sewer flow is likely to be caused by peak leakage

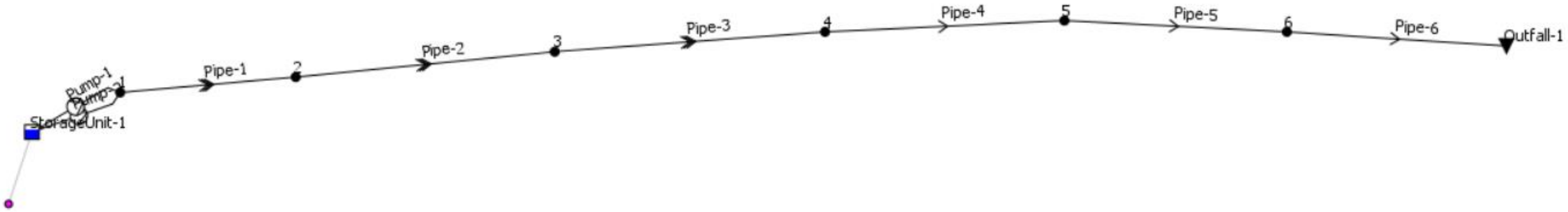
Rough simplification, but hopefully makes a point

TASK: MODELING A PUMPING STATION AND PRESSURIZED PIPES

MODEL OVERVIEW

New Model

Model Properties → Simulation time 1 day and Report step 60 (s) = 1 min



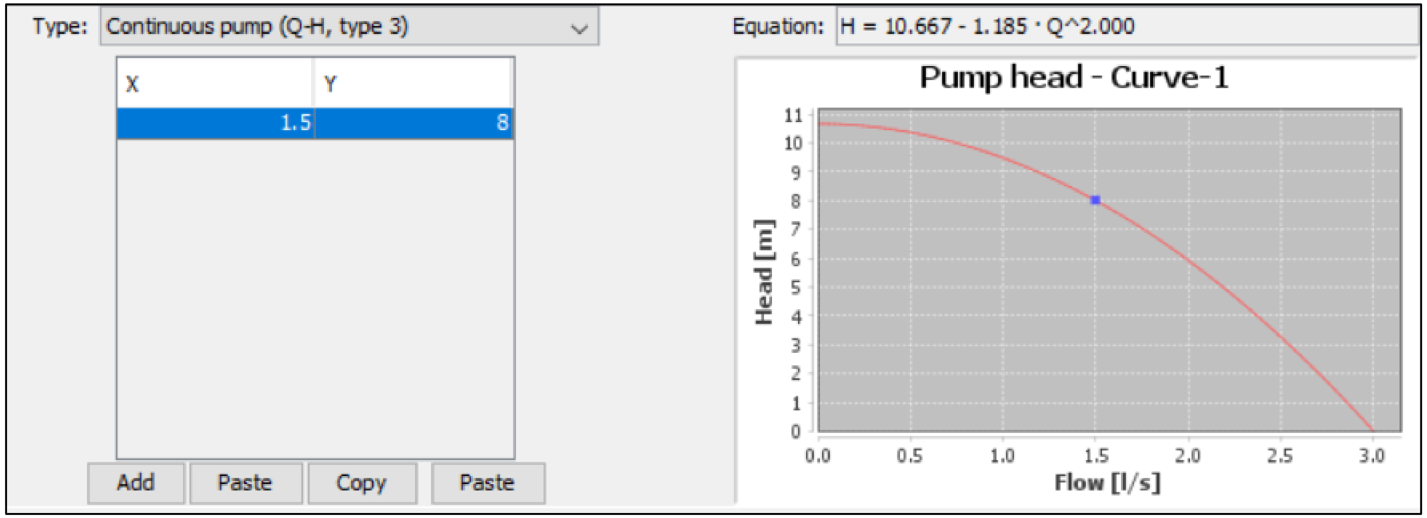
JUNCTIONS (MANHOLES)

Name	Elevation	Max Depth	Initial Depth	Surcharge Depth
1	0.0	0.0	0.0	100.0
2	4.0	0.0	0.0	100.0
3	5.0	0.0	0.0	100.0
4	6.0	2.0	0.0	0.0
5	2.5	2.0	0.0	0.0
6	1.2	2.0	0.0	0.0

PIPES (CONDUIT)

Name	Start	End	Length	Custom Length	Material	Z1	Z2	Shape
Pipe-1	1	2	35.0	true	90M	0.0	0.0	Force main
Pipe-2	2	3	45.0	true	90M	0.0	0.0	Force main
Pipe-3	3	4	45.0	true	90M	0.0	0.0	Force main
Pipe-4	5	5	40.0	true	200B	0.0	0.0	Circular
Pipe-5	5	6	40.0	true	200B	0.0	0.0	Circular
Pipe-6	6	Outfall	40.0	true	200B	0.0	0.0	Circular

PUMPCURVE



Model → Curve → New
Model → Pump Definitions → New → *pumpCurve*

PUMPS

Name	Start	End	Open	Pump Definition	Startup Depth	Shutoff Depth
Pump-1	Storage-Unit	1	true	Pump Definition-1	1	0.4
Pump-2	Storage-Unit	1	true	Pump Definition-1	1.2	0.4

STORAGE UNIT & DEMAND

Name	Elevation	Max Depth	Initial Depth	areaConstant	DWF
Storage-Unit	0.0	2.0	0.0	2.0	0.26

Extra flow

Name	baseDemand
Demand	0.52

Connect to storage unit

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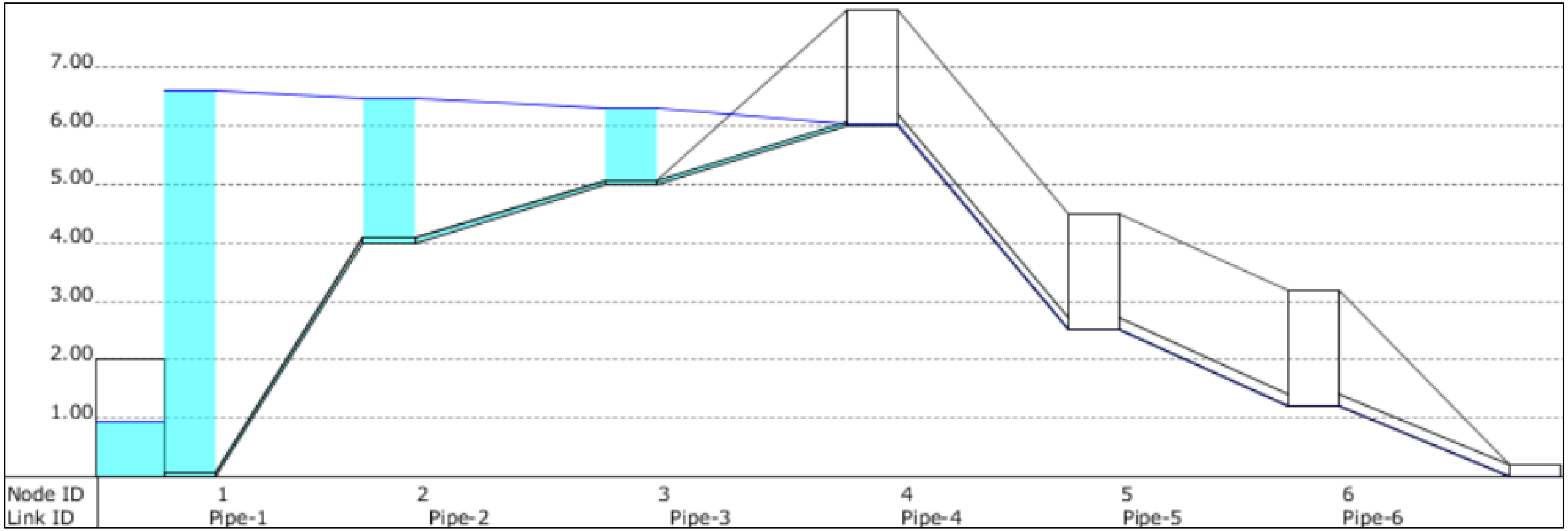
RESULTS


7.00
6.00
5.00
4.00
3.00
2.00
1.00
Node ID
Link ID
1
Pipe-1
2
Pipe-2
3
Pipe-3
4
Pipe-4
5
Pipe-5
6
Pipe-6

ESSENTIAL RESULTS IN SEWER MODELING

SEWER NETWORK RESULTS

- Total flows
- Flow (max)
- Velocity (avg, max)
- Depth (water level in manholes & tanks & pipes, pressure in pressurized pipes)
- Overflow
- (Slope)

- Capacity
  - Fraction of the pipe cross sectional area covered by water
- Free capacity (min)
  - Smallest flow (l/s) you can add to the pipe without reaching capacity = 1

- Electric efficiency
- Daily electric energy

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FEW LAST WORDS

THINK FORWARD – SEWER AND STORM

LEVEL I	LEVEL II	LEVEL III	LEVEL IV
OFFLINE MODELING		ONLINE MODELING	
STEADY STATE MODEL	DYNAMIC MODELS		
DESIGN MODEL	DESIGN MODEL	NOWCASTING MODEL	OPTIMIZING MODEL
	HINDCASTING MODEL	FORECASTING MODEL	EXPERT SYSTEM MODEL
	OPTIMIZING MODEL		MODEL BASED CONTROL

NO CONNECTION → CONNECTED TO REPORTING → CONNECTED TO CONTROL SYSTEM

”PROMISE” → ”TRUST” → ”PROVEN TRUSTWORTHINESS”

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21.3.2019
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SOME TIPS

- Remember, results are momentary results at reporting time step
  - Things that happen between reporting time steps are not observed
  - (Use small enough time step, as it is possible in these small networks)
- If a junction has more pressure than its *surcharge depth,* flooding occurs (water leaves model)
- In pressurized pipes, make several junctions to the pressure line to get elevations right
  - Velocity –result is better taken **not** from the last pipe, as its end's cross section might not be full of water
  - (and in general be a bit careful with pressure line results, as conditions in them change fast)
- Use Drawing States and Profile View

- EPASWMM manual covers most calculation/component/parameter issues
  - Almost everything included in EPASWMM is also found in Fluidit Sewer (but not vise versa)
- Information in Wiki is also useful

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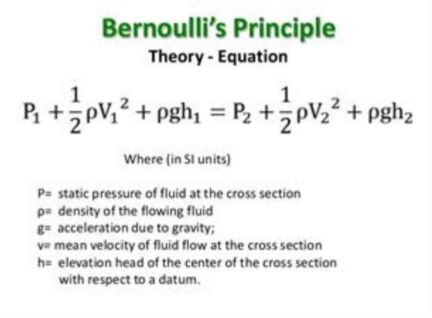
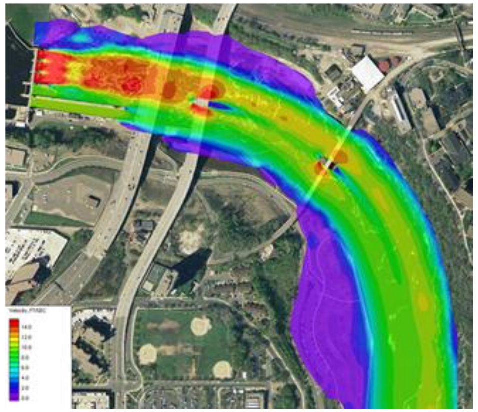
THANK YOU FOR YOUR TIME

- Let's start modeling!





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