SESSION CONTENT

- Introduction to modeling – 30 min
- Introduction to water supply system modeling – 30 min
  - Break – 10 min
- WSS modeling exercise – 45 min
  - Break – 5 min
- Introduction to sewerage modeling – 30 min
- Sewerage modeling exercise – 45 min

INTRODUCTION TO WATER SUPPLY SYSTEM MODELING

Aalto University – 2019-02-25

LEARNING OUTCOMES

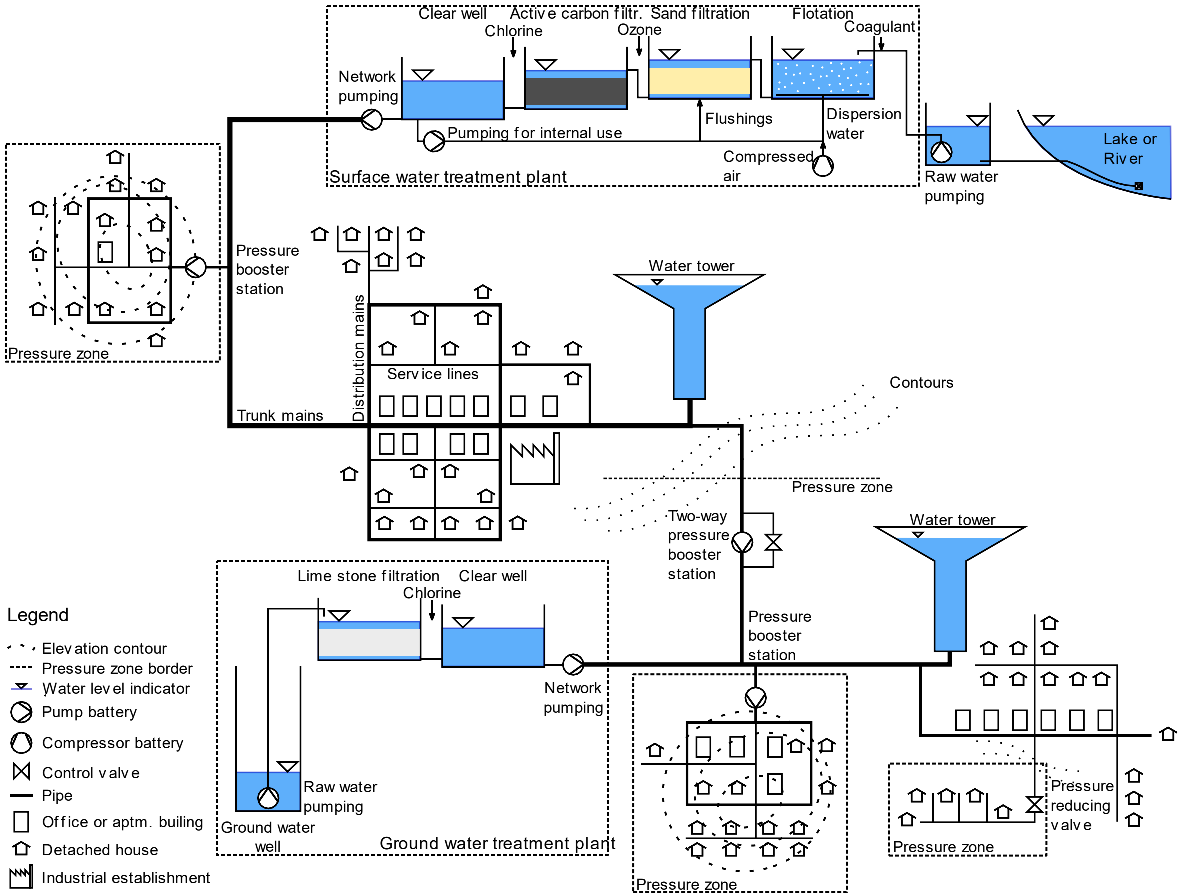
- Describe the water supply model structure
- Describe the difference and function of nodes and links
- List the most relevant water supply model components, their most important parameters, results and uses for each
- List some applications for the model

QUESTION TIME (5 MIN)

Discuss in small groups of 2-4 persons. What do you think that makes a water supply system model? What components are needed? What parameters are important?

Think of the basic hydromechanics equations

WATER SUPPLY SYSTEM STRUCTURE



Water flows due to head differences caused by pumps, valves, water demands and head losses (friction) in pipes.

Changes are practically immediate and affect the whole system. Pressure waves propagate at the speed of sound (about 300-1000 m/s). Network always full of water.

Typical flow velocities in the pipes are 0.1-0.5 m/s.

SOME MODEL APPLICATIONS

- Tool for general planning and design
  - Capacity analysis
  - Capacity problems
  - Network design, pipe sizing
- Design and sizing of pumps and water sources
  - Designing the automation algorithms
- Leakage analysis
- Renovation planning
- Operational analysis: how does the system work?
- Energy assessments and optimization
- Quality analysis
  - Water age
  - Source
  - Chlorine content
  - Pollutant spreading
- Resilience, flushing and fire flow analyses

INTRODUCTION

- On this course *Fluidit Water* will be used as the modeling solution for water supply systems. However, as the simulator in use, EPANET, is practically the same as in, for example, in *WaterCAD*, *MikeURBAN* and the free *EPANET*, the acquired skills can be applied to those other modeling solutions as well

- EPANET simulator is the most widely used and researched simulator
- The simulator is public domain and open source
- It can be used for modeling any constant-density fluid flowing through a pressurized system

WATER SUPPLY NETWORK MODEL

- Network modeling tools are usually map based – model components and results are presented on a map
- Pipes and junctions are digitized or imported automatically along with their properties
  - Diameter, material, elevation
- Pumps, water consumers, leakage, pump characteristic curves, daily water demand patterns, tanks, valves and control algorithms are modeled too
- Typically a few days long simulation is performed, and the results of the last simulated day are reported using 1...60 minute time resolution

WATER SUPPLY SYSTEM COMPONENTS

- Water supply systems can be divided into four parts
  1. Water sources
  2. Water distribution network and equipment
  3. Consumers
  4. Control system

- Water sources are modeled as **reservoirs**

- Distribution network is modeled as a network of
  - **Pipes**
  - **Pumps**
  - **Valves**
  - **Junctions**
  - **Tanks**

- Consumers and leakage are modeled as **water drawn from junctions**

MODEL LAYERS

CONTROL SYSTEM MODEL

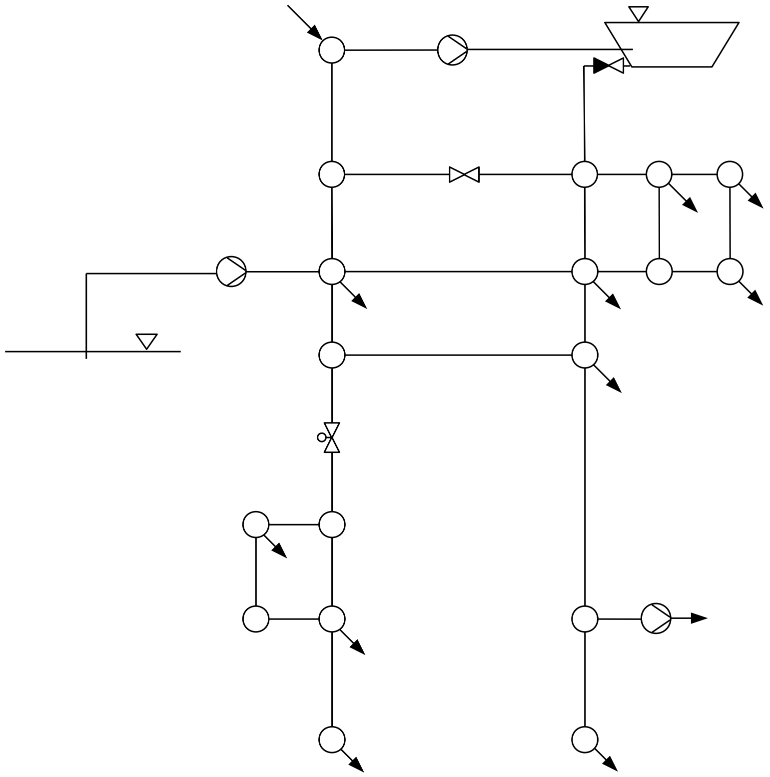
HYDRAULIC EQUIPMENT: TANKS, VALVES AND PUMPS

WATER DEMAND AND LEAKAGE MODEL

HYDRAULIC MODEL: PIPES AND JUNCTIONS

DIGITAL ELEVATION MODEL

WATER SUPPLY SYSTEM MODEL STRUCTURE



- EPANET supports practically all equipment and components present in water supply systems
- Demands, flows into the system, storage, head and pressure are modeled and solved as **node** component classes: junctions, tanks and reservoirs (graph theory's vertices)
- Flow, velocity and head loss (or gain) are modeled and solved as **link** component classes, that connect two nodes: pipes, pumps and valves (graph theory's edges)

PHYSICAL MODEL COMPONENTS

- Nodes – head
  - **Reservoir** is an infinite tank: head does not change no matter what the flow
  - **Tank** is a finite tank: flow into or out of tank changes the head (level and volume)
  - **Junction** is link crossing, a point where pressure is calculated and a point where water is drawn out of the system
  - Each model requires at least one node with known head: reservoir or tank

- Link – flow
  - **Pipe** allows flow between nodes. Head losses are modeled based on length, roughness and diameter.
  - **Pump** produces energy into system; supports setting relative speed
  - **Pump battery** produces energy into system; supports setting flow or outlet pressure setting
  - **Valve** throttles flow to meet the setting. PRV tries to keep outlet pressure at setting and FCV tries to limit flow to given setting

EPANET MODEL RESULTS

- Nodes
  - Pressure [m]
  - Head [m]
  - Demand [l/s]
  - Quality
- Links
  - Flow [l/s] + flow direction
  - Velocity [m/s]
  - Head loss [m/km, ‰]
  - Setting
  - Quality

- All parameters solved as a function of time for all components
- Further results can be derived, for example statistical values (min, max, avg…), power dissipation, resilience indices…

PHYSICAL COMPONENT PROPERTIES

- Pipes (models check and gate valves too)
  - **Length** [m] (can be automatically calculated)
  - **Diameter** [mm]
  - **Material/roughness** [mm]
  - Construction year (optional)

- Water towers (tanks)
  - **Elevation** [m] (NW; used for calculating level)
  - **Diameter** [m] or water level – volume **curve**
  - **Min and max water level** [m]

- Valves
  - **Type** (flow control, pressure reducing or sustaining)
  - **Setting** [l/s or m]
  - **Diameter** [mm]

- Water sources (reservoirs; infinitely large)
  - **Head** [m]
  - Optional head **pattern**

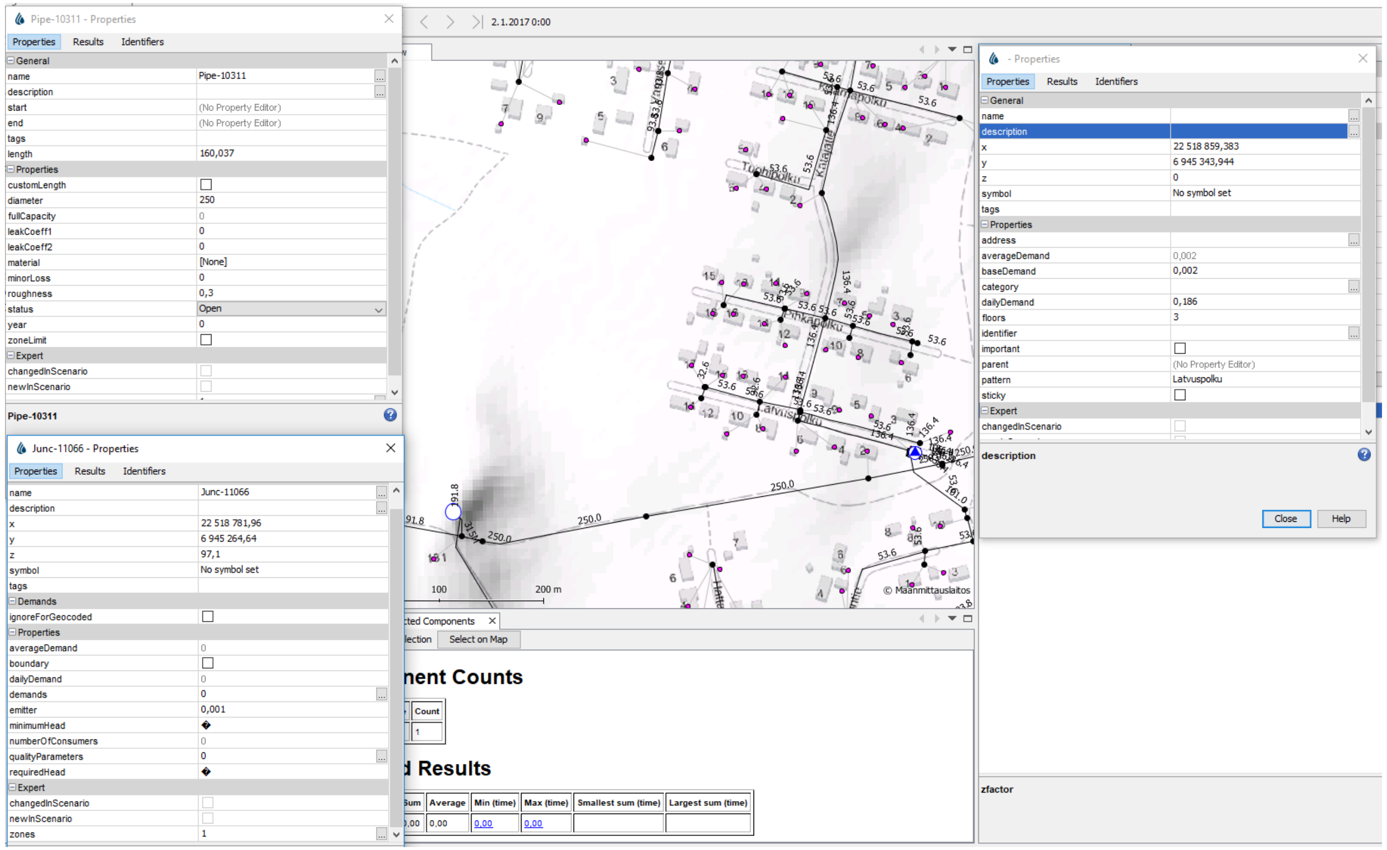
- Junctions/water use/geocoded demand
  - Water uses
    - Average (base) demand [l/s] (can be negative)
    - Demand **pattern**
  - **Elevation** [m] (can be automatically calculated; used for calculating pressure)

- Pumps and pump batteries
  - Pump **curve**
  - Efficiency **curve**
  - Control system behavior / setting [l/s or m]

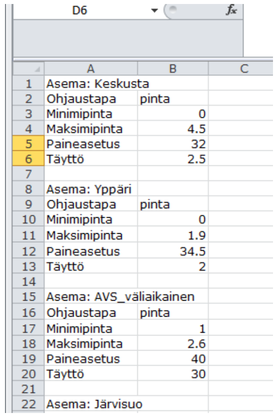
NON-PHYSICAL COMPONENTS

- Patterns
  - Describe repetitive changes in a value relative to the average value
  - Can be used for water demand, reservoir head and various settings (pump speed…)
  - Typically 24 values – one for every hour – but can be longer
  - Time step is controlled globally in model settings
  - Sum of coefficients should be 24 and average 1 – this way the base demand modeled in geocoded demands or junctions represents the average value
- Curves
  - Describe relation of two variables
  - Different types
    - **Volume curve** for non-right shaped tanks
    - **Pump curve:** one or three-point, or tabular; one or three point curve recommended
    - **Pump efficiency curve:** one or two point, or tabular curve; one or two point recommended
- Values can be pasted from clipboard (from Excel, for example) into Fluidit Water

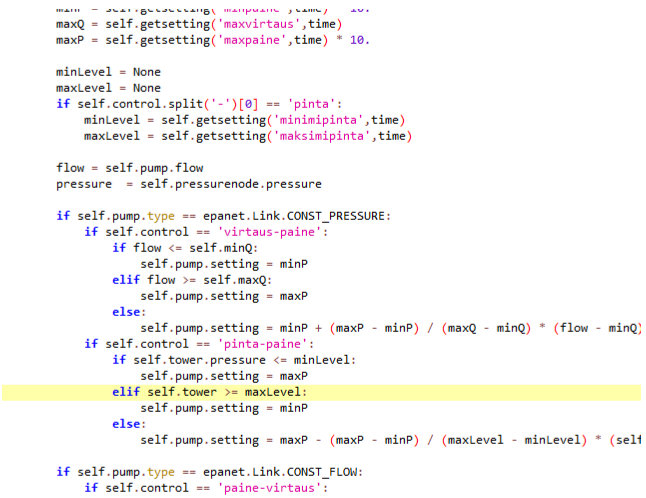
WATER SUPPLY SYSTEM MODEL



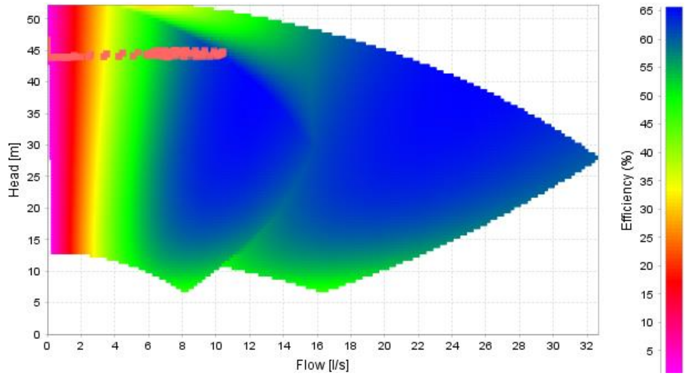
CONTROL SYSTEM MODEL

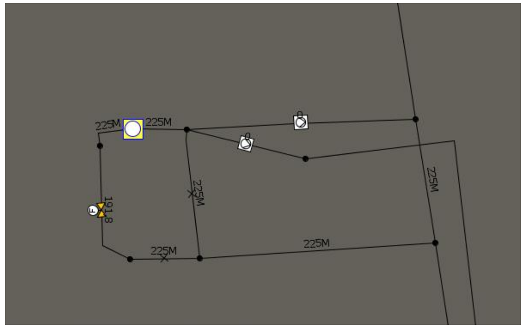


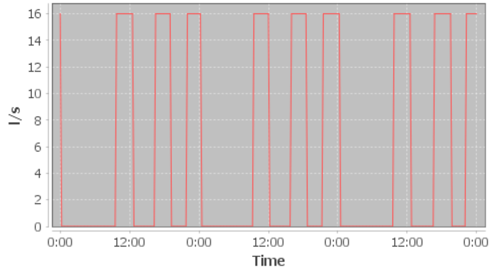
	A	B	C
1	Asema: Keskusta		
2	Ohjaustapa	pinta	
3	Minimipinta	0	
4	Maksimipinta	4.5	
5	Paineasetus	32	
6	Täyttö	2.5	
7			
8	Asema: Yppäri		
9	Ohjaustapa	pinta	
10	Minimipinta	0	
11	Maksimipinta	1.9	
12	Paineasetus	34.5	
13	Täyttö	2	
14			
15	Asema: AVS_väliaikainen		
16	Ohjaustapa	pinta	
17	Minimipinta	1	
18	Maksimipinta	2.6	
19	Paineasetus	40	
20	Täyttö	30	
21			
22	Asema: Järvisuo		

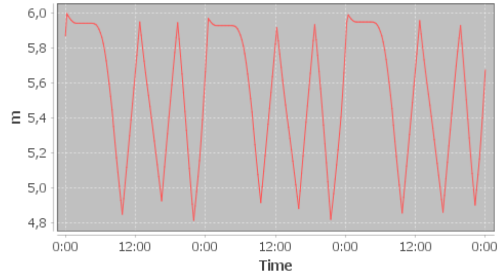


```
maxQ = self.getsetting('maxvirtaus',time)
maxP = self.getsetting('maxpaine',time) * 10.

minLevel = None
maxLevel = None
if self.control.split('-')[0] == 'pinta':
    minLevel = self.getsetting('minimipinta',time)
    maxLevel = self.getsetting('maksimipinta',time)

flow = self.pump.flow
pressure  = self.pressurenode.pressure

if self.pump.type == epanet.Link.CONST_PRESSURE:
    if self.control == 'virtaus-paine':
        if flow <= self.minQ:
            self.pump.setting = minP
        elif flow >= self.maxQ:
            self.pump.setting = maxP
        else:
            self.pump.setting = minP + (maxP - minP) / (maxQ - minQ) * (flow - minQ)
    if self.control == 'pinta-paine':
        if self.tower.pressure <= minLevel:
            self.pump.setting = maxP
        elif self.tower >= maxLevel:
            self.pump.setting = minP
        else:
            self.pump.setting = maxP - (maxP - minP) / (maxLevel - minLevel) * (self

if self.pump.type == epanet.Link.CONST_FLOW:
    if self.control == 'paine-virtaus':
```









CONTROL SYSTEM
Every time step measurements are done. Based on the measured values and given settings and parameters, the control system algorithm changes control device settings.

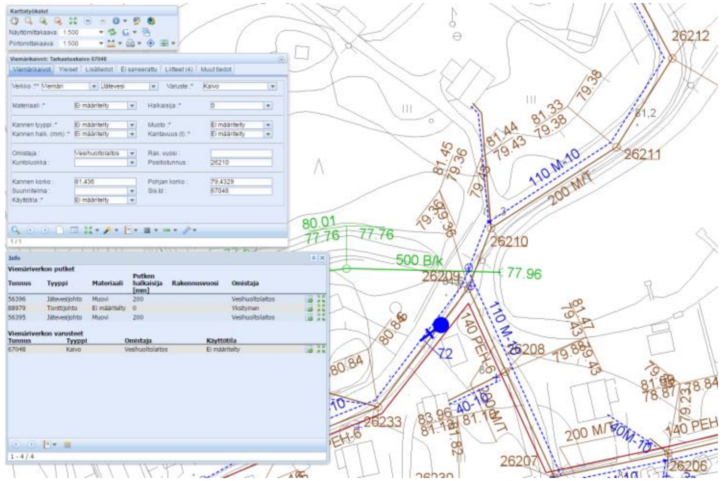
Modeled control system works the same way, but instead of using measurements, the simulated results are used.

CSM can be coded in Python or JS (in Fluidit Water) or simple control and rules (EPANET, WaterCAD, MikeURBAN…)

INPUT DATA NEEDS

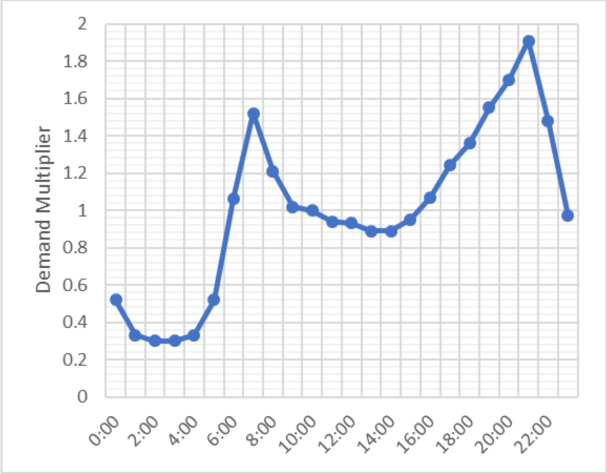
- **Network map** with pipe sizes and materials: DWG, DXF, SHP, GML, WFS
  - In real coordinate system
  - GIS formats, like SHP or GML, preferred – enables automatic model construction
- **Customer data** - client number, address or coordinates and billed volume
- **Tank data** – volume, NW, HW; shape if non-right (drawings)
- **Water source and pressure booster station data**
  - Pump data – number of pumps, pump QH and efficiency curves
  - Daily and hourly yields, and source head (lake surface or ground water level) for sources
  - Settings, parameters and control algorithms
- **Flow and tank level measurements** – for water balance and demand pattern calculation
- **Pressure and other measurement data** – for calibration

INPUT DATA REQUIREMENTS

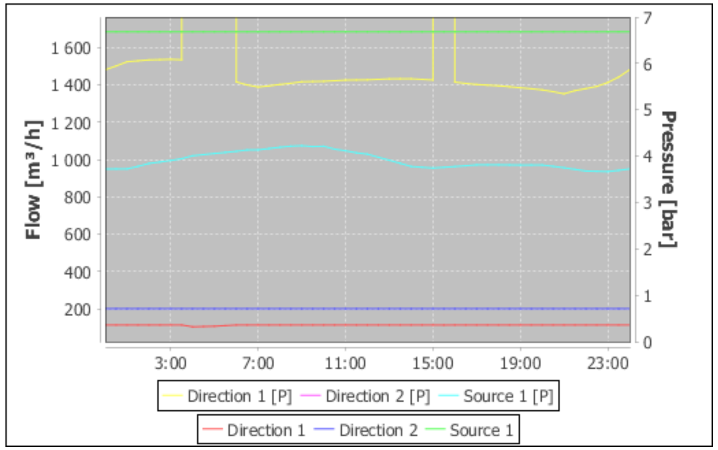


NETWORK MAP

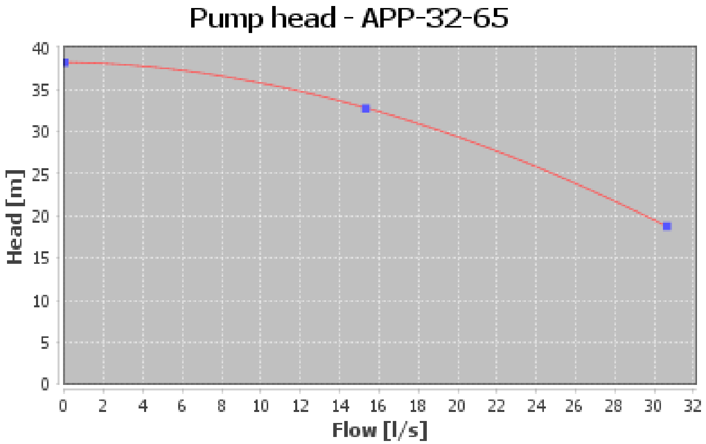
WATER USERS & USAGE



WATER USAGE PATTERNS



MEASUREMENTS



PUMP CURVES

SIMULATION

- Before any changes to the system are visible, model must be re-simulated (*Simulate->Simulate…* / F5)
- By default *Fluidit Water* runs simulation 1st Jan 2017 0:00 – 1st Jan 2017 23:00 (inclusive) with **hydraulic time step** of 3600 seconds and **reporting** results every 3600 seconds
- The simulation is **extended period simulation** (EPS): it's a series of steady-state simulations and the system state –tank levels, control setting and demands are updated based on time and assuming the system state (flows & heads) stay **constant between time steps**
- **Results are snapshots in time** – reported results are not averages

SIMULATION

- Simulation results often in warnings, especially if control system model, valves and or pump batteries are used. **Most of the warnings are harmless**, but if system is unstable or hydraulic equations cannot be solved the results cannot be trusted.
- It's good habit to check the simulation report.
- If needed, consult EPANET manual which describes the model behavior
- Simulation report can be viewed by selecting *Simulate->Show Simulation Report...* / F6

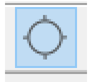
SIMULATION

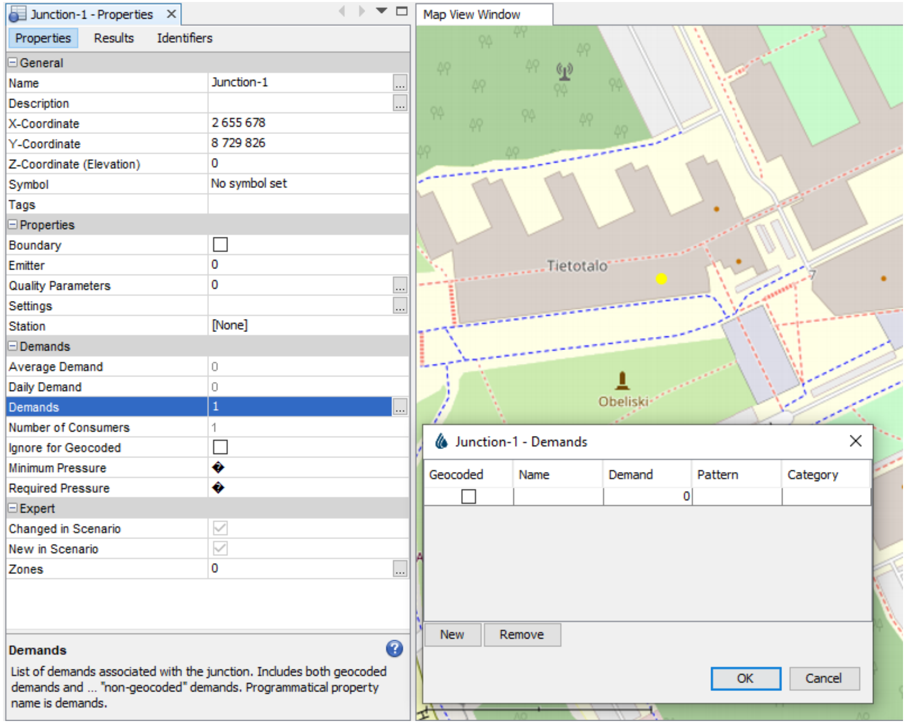
- EPANET is so-called **demand dependent model (DDA)**, which means, no matter what the pressures are, the modeled demand is always met (other option is pressure dependent model, PDA)
  - If there's too little or too much water coming into the model, weird things start to happen
  - Flow controlled valves and pump batteries can cause problems
  - Model becomes unstable, if tank goes completely empty or full

- Every model has to have at least one node with known (constant) head – reservoir or tank – and at least one junction

TYPICAL MODEL OUTPUT

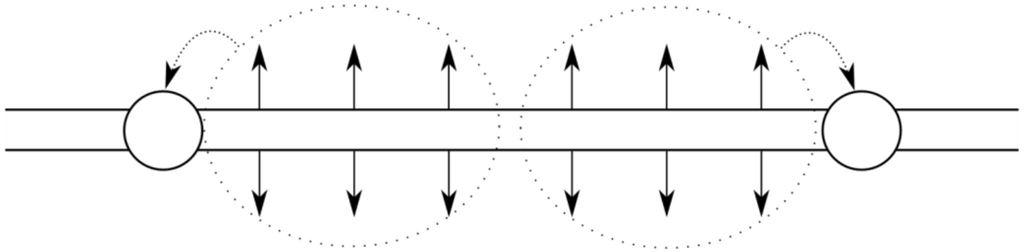
JUNCTION



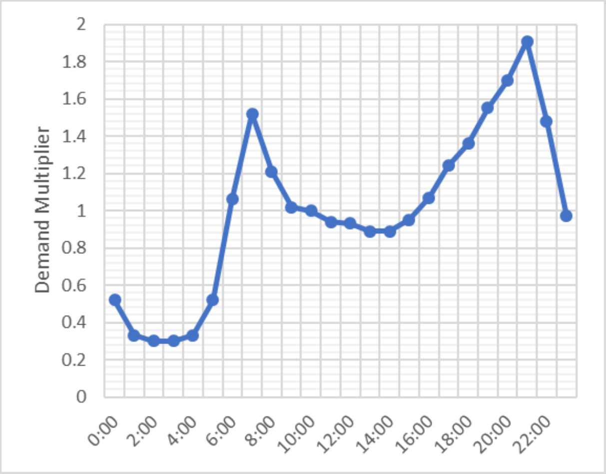


- Junctions are to be added
  - Whenever multiple links join
  - Whenever link type, or pipe size or material changes
  - Along pipe lines every 100…500 m
  - At otherwise critical or interesting locations, such as elevation extremes
- Junctions can ordinarily be named numerically, but all junctions that present real measurements should be named accordingly
  - For example pumping station’s suction and pressure junctions: xxx-PI1, xxx-PI2

MODELING WATER USAGE



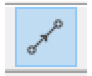
AGGREGATING DEMANDS INTO JUNCTIONS

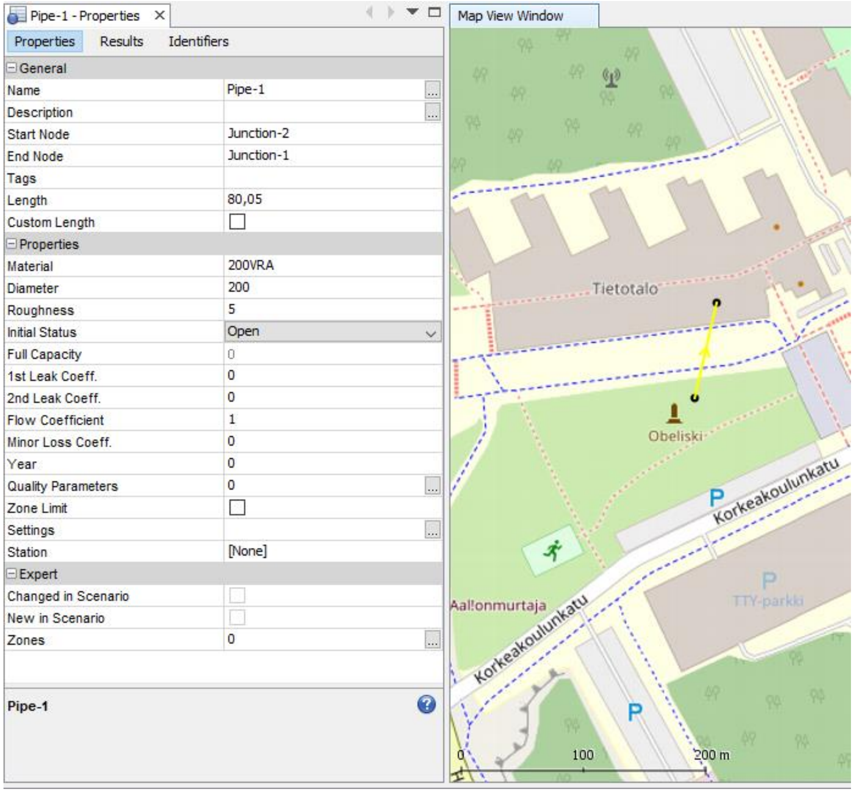


WATER USAGE PATTERN (avg multiplier = 1)

- Water users draw water along the pipe, however in EPANET model, water is always drawn out of the system from junctions
- Thus demand from multiple users are aggerated into junctions as demands
- Demand is modeled as daily average demand in [l/s]
- Each junction can have multiple demands with different patterns: water demand at an instant is calculated by multiplying the demand by specified pattern's multiplier
- Fluidit Water supports geocoded demands, that are visualised on map as separate objects, but are aggerated automatically to the junctions for EPANET

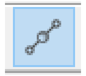
PIPE AND PUMP PROPERTIES

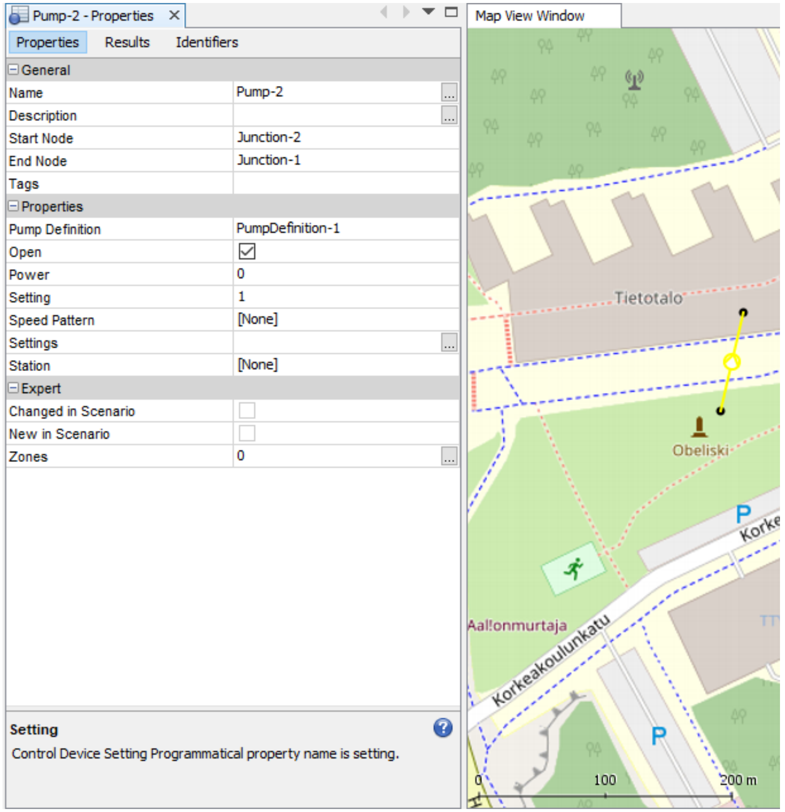




SELECT CUSTOM LENGTH CHECK BOX IF LENGTH IS SET MANUALLY

SET MATERIAL TO NONE TO MANUALLY GIVE D AND K

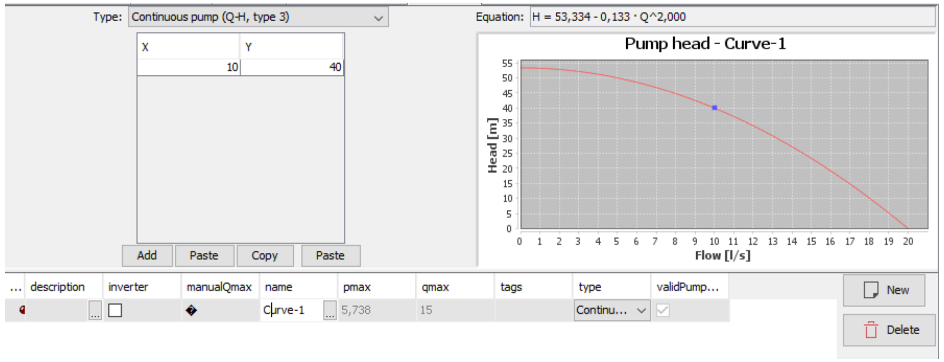




RELATIVE SPEED

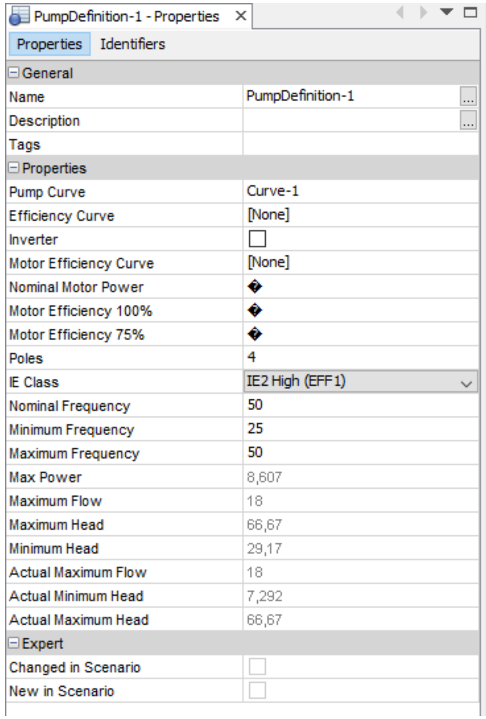
PUMP CURVES AND DEFINITIONS

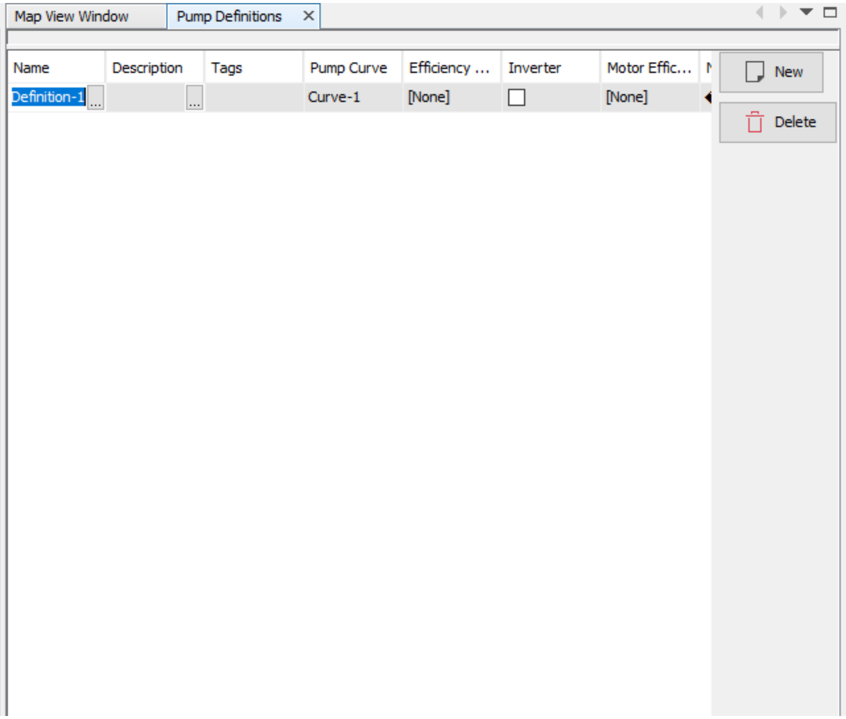
Model->Curves…



CREATE PUMP (TYPE 3) AND EFFICIENCY CURVES

Model->Pump Definitions…





SET PUMP AND POSSIBLY EFFICIENCY CURVES

DEMO TIME

- Let a system consist of two tanks: A with head of 100 m and B with head 120 m
- Water is pumped from A to B using a centrifugal pump P
- There's a 3000 m long 250VRA pipe between A and P and 3000 m long 200A pipe between P and B
- There's an consumer half way between A and P, that consumes on average 9 l/s of water with pattern WEEKDAY
- All junctions can have elevation of 60 m

- Your tasks
  - Model the system
  - What is the pump head range, if the pump pumps 100 m^3/h
  - Draw hydraulic profile of the system during maximum hour

YOUR TURN – EXERCISE (WITH A FRIEND OR TWO!)

- Open *base model.fwat* file in Fluidit Water (no DEM, ok settings, some colors available)
- Let a system consist of two tanks: A with head of 100 m and B with head 130 m
- Water is pumped from A to B using a centrifugal pump P
- There's a 4000 m long 315PVC pipe between A and P and 3000 m long 225PEH17 pipe between P and B
- There's an consumer half way between A and P, that consumes on average 10 l/s of water with pattern WEEKDAY
- All junctions can have elevation of 60 m

- Your tasks
  - Model the system
  - What is the pump head range, if the pump pumps 110 m^3/h?
  - Draw hydraulic profile of the system during maximum hour
  - How much Grundfos CR120-2 pump would produce flow? (Working point 120 m^3/h x 45 m)