SESSION CONTENT

- Water supply system modeling projects
- Demo of some more *Fluidit Water* features
- Modeling project kick-off
  - This is your graded homework project

WATER SUPPLY SYSTEM MODELING

Aalto University – 2018-03-18

LEARNING OUTCOMES

- List the different phases of modeling project and describe their importance
- List the most important input data
- Calculate water balance, estimate leakage
- List the most important model results and state their accepted/problematic values

CONTENT

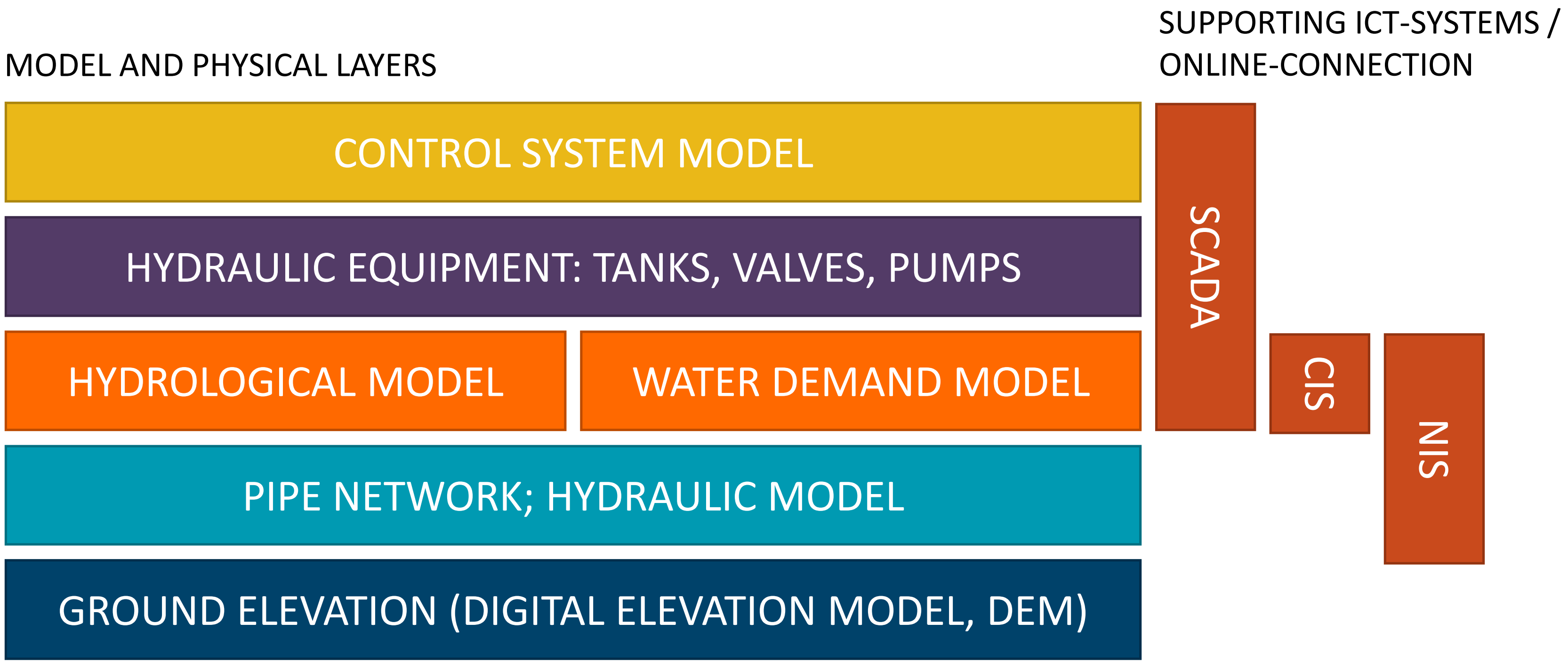
- Introduction
- Modeling project structure/phases
- Model preparation & input data processing
- Result analysis and reporting
- Conclusions

QUESTION TIME

Wakey-wakey! Ponder together with your (physically) closest colleagues:

What are the water supply system model layers and the ***main components*** *and their function in model building?*

MODEL STRUCTURE



MODEL AND PHYSICAL LAYERS

SUPPORTING ICT-SYSTEMS / ONLINE-CONNECTION

CONTROL SYSTEM MODEL

HYDRAULIC EQUIPMENT: TANKS, VALVES, PUMPS

HYDROLOGICAL MODEL

WATER DEMAND MODEL

PIPE NETWORK; HYDRAULIC MODEL

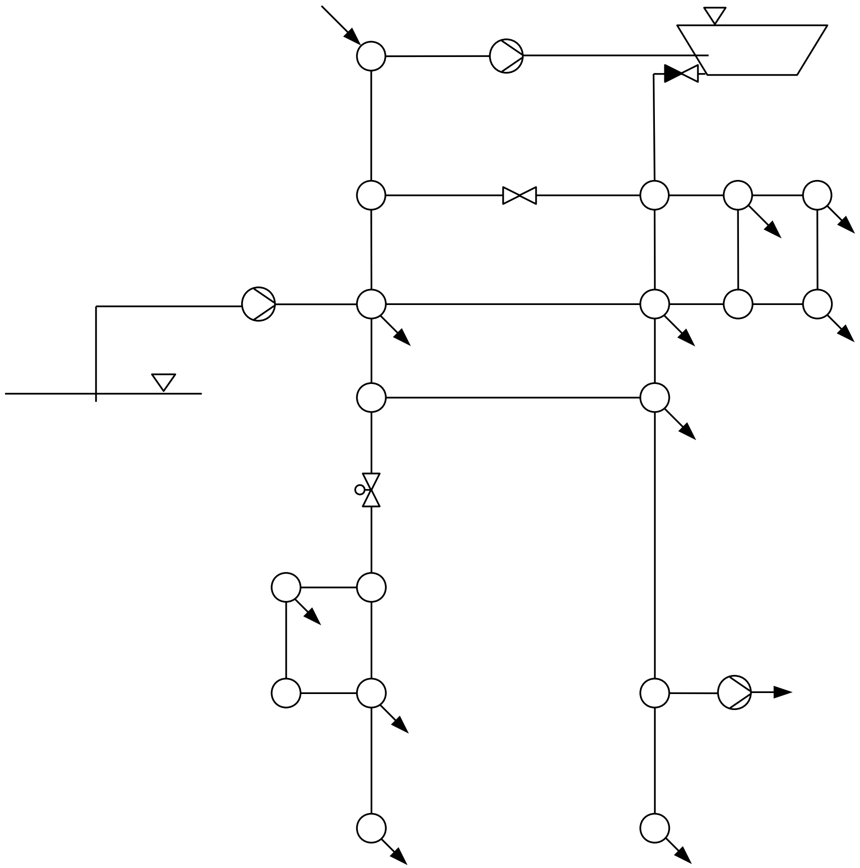
GROUND ELEVATION (DIGITAL ELEVATION MODEL, DEM)

SCADA

CIS

NIS

WATER SUPPLY SYSTEM MODEL STRUCTURE



- EPANET supports practically all equipment and components present in water supply systems
- Demands, flows into the system, storage 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 an 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

INTRODUCTION

- Modeling is done in order to gain insight into the target system
- The most important things are the results the model gives
  - Often not the simulation results *per se*, but the analysis based on those
- Define the goal of the project with the client before the modeling starts – quite likely, that more needs arise, when the possibilities are demonstrated
- Because a lot of assumptions, approximation and questimates are done during the modeling process, they need to be properly documented

MODELING PROJECT

- Collecting the input data – all in digital, *machine readable*, formats

- Model preparation
    - Building the network model
    - Building the water consumer model – find the coordinates and billed use
    - Water balance analysis and modeling
    - Modeling stations and pumps
    - Modeling control system
    - First run and presentation of preliminary results to client. Discussion on model performance, problems, doubts, questimates…

MODELING PROJECT

- Constructing other scenarios as per client's needs
  - Maximum demand day
  - Future water demand (remember neighboring utilities)
  - New areas
  - New stations, tanks, sources, pipe lines
  - Decommissioning of pipes, sources etc.

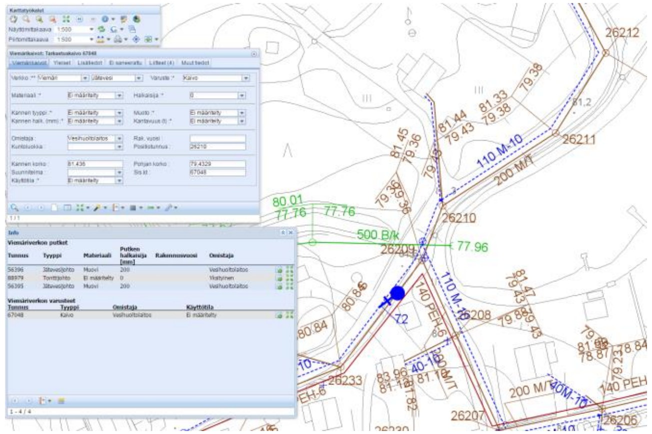
- Reporting – produce a proper written report, and append maps and tables
  - Introduction: goals, stakeholders etc.
  - Modeling principles used in the project
  - **Input data, its analysis, water balance calculations, assumptions and questimates made, system structure**
  - Description of other scenarios
  - Current system performance
  - Performance under the other scenarios
  - Suggested improvements, their costs and cost benefit analysis, scheduling
  - Conclusions

MODELING PROJECT

- Delivering all data, including the model, resulting from the project digitally to the client
- Any further tasks given by the client during and after the project
- Model upkeep, updates
- Model utilization at the utility?
- Other uses and integrations for model and its results?

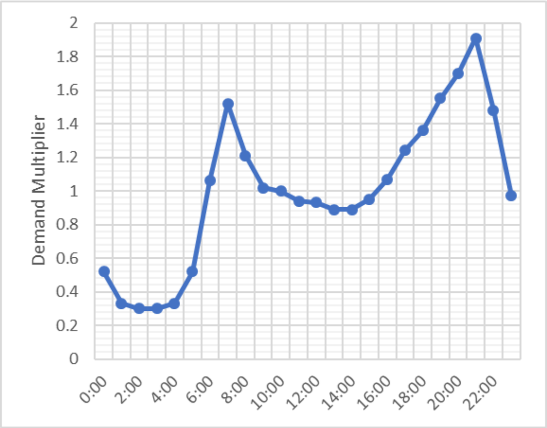
MODEL PREPARATION

INPUT DATA

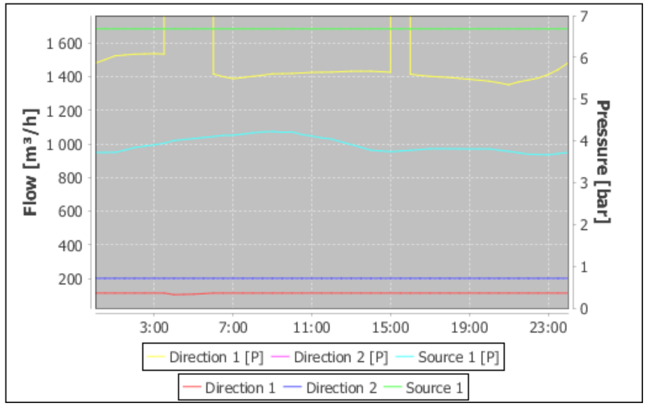


NETWORK MAP(S)

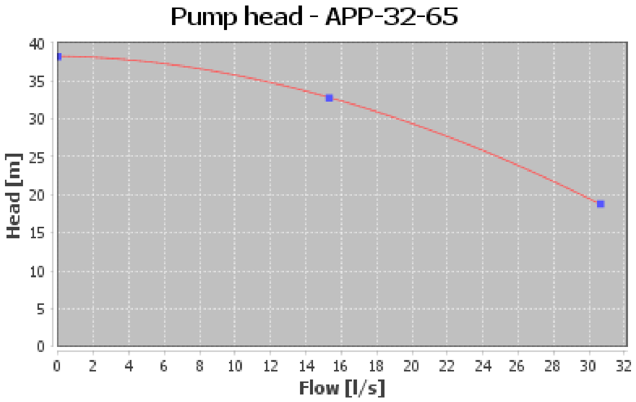
WATER USERS & USAGE



WATER USAGE PATTERNS



MEASUREMENTS



PUMP CURVES

```
@T =  TEMP:PAI1
#IF  %T> 90  #THEN  #BLOCK
#SET  C:PBO2=0
#PRINT  2  OVERHEAT
#BLOCK_END
#ELSE_IF  %T< 70 #THEN  #SET  C:PBO2=1
```

CONTROL SYSTEM CODE

INPUT DATA

- Collecting input data is labor intensive for the client and takes time – typically most of the time is spent waiting for the data
    - Network maps – DWG, DXF, DGN, SHP, MIF, GML, WFS…
    - Customer (billing) data – Excel, Access, *SQL, CSV…
    - WSS schematic drawings: logical structure, stations, water sources, tanks
    - Control system behavior: algorithms, parameters, settings, P&IDs… – often screenshots from all SCADA views
    - Pump curves & other info, motor information: the measured or catalogue curves, pump model and manufacturer
    - Data from **all measurements at hourly resolution** for at least a year, preferably three to five year period: most important info is the amount of water pumped into system, followed by tank volume or level measurements, other flow measurements and finally pressure measurements
    - Yearly reports, water safety plans, urban general and master plans, water utility strategic plans, info on leakage measurements and network construction methods etc.

- It's advisable to wait for all data to arrive before starting the modeling work (the pipe network model construction can begin right after receiving the map(s))

- Changes in input data can result in extensive (and expensive!) changes in the model

CALCULATING WATER BALANCE

- Some people mistakenly mix calculating and modeling water balance with calibration – they are different things – water balance is essential part of model building
- Total demand, billed demand (revenue water) and non-revenue water (or leakage), and demand pattern
- Without water balance calculation results, the model cannot perform right
- Calculate water balance for the smallest possible geographical areas: on a pressure zone level or on a district metering area (DMA) level

CALCULATING WATER BALANCE

- Start by processing the customer billing data
    - Find out coordinates for each client based on address
    - Import the demands into the modeling or GIS software

- Calculate average billed (revenue water, RW) for each zone in the network

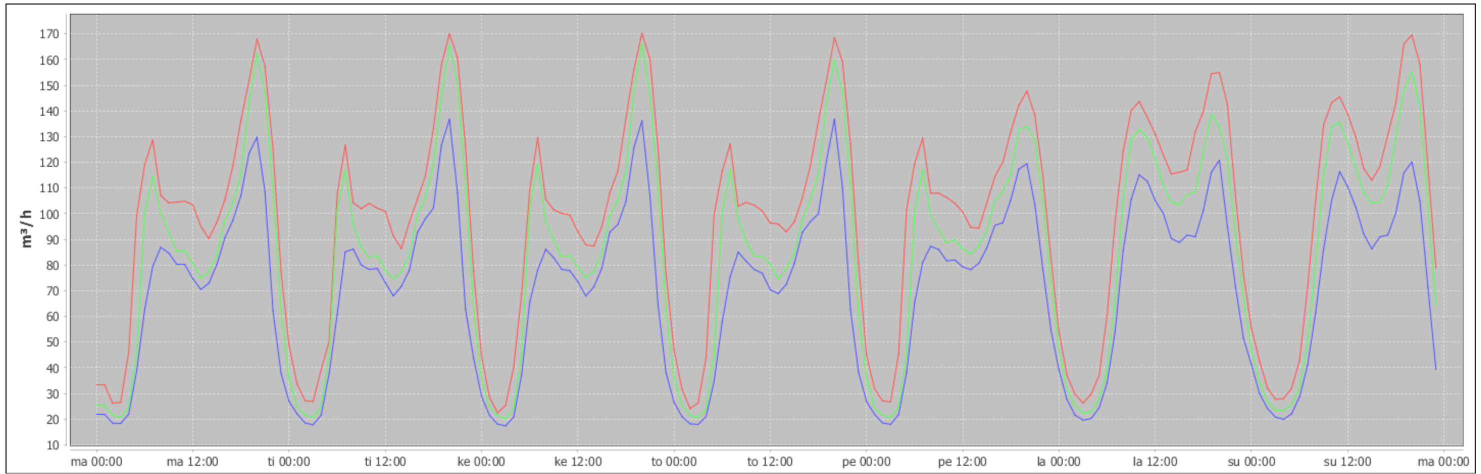
- While at it, calculate network length and number of inhabitants, too

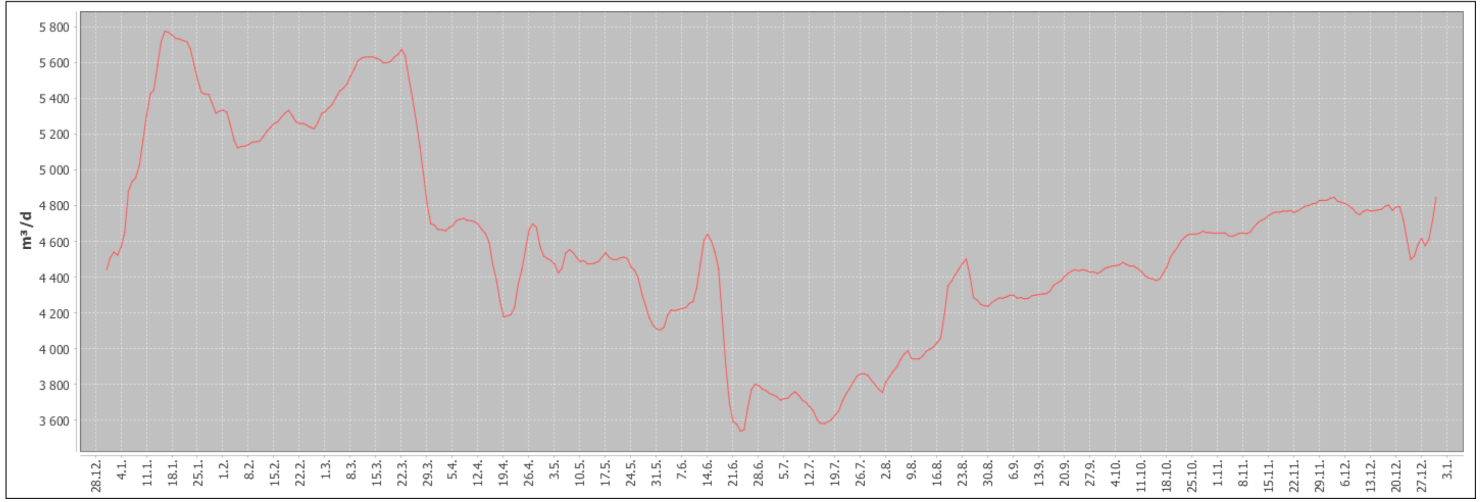
CALCULATING WATER BALANCE

- Calculate the hourly demand for each area for as long time period as you can
- Sum **flows in**, subtract **flows out** and the sum of **tank volume change** (positive volume change -> water flows into tank from the system)
    - $D = \sum Q_{in} - \sum Q_{out} - \sum \Delta V$
    - Calculate daily water use, analyze seven day moving average
    - Use hourly median values for week days from a few month period, when water usage is “normal”
    - Subtract **revenue water** (billed amount) from the daily use to give you the **non-revenue water** (NRW). Usually whole NRW is modeled as leakage.

- Often it is still useful to try to estimate **leakage** from total non-revenue water
    - Typically each inhabitant uses about 1 l/h·person during the minimum hour (around 03:00–05:00) – excess demand is probably leakage
    - Leakage can be estimated assuming that 0.3 x average hourly demand is used during the minimum hour – demand exceeding this is probably leakage
    - Finally it can be estimated that 30–60 % of minimum usage is leakage
    - Calibration, statistical methods, pressure analysis…

EXAMPLE OF WATER BALANCE





EXAMPLE OF WATER BALANCE

EXAMPLE OF WATER BALANCE

2015

Area	Pipe Length [km]	Billed [m^3/d]	Total [m^3/d]	NRW [m^3/d]	Leakage [l·s/km]	Inhabitants	Spec.demand [l/d·pers]
Zone 1	27	339	338	0	0.000	1 452	233
Zone 2	18	133	148	15	0.234	677	218
Zone 3	74	630	802	171	0.644	4 179	192
Zone 4	294	6 113	7 039	926	0.876	32 048	220
Zone 5	184	2 927	3 648	720	1.089	19 051	191
Zone 6	172	1 085	1 137	52	0.084	7 577	150
Sum	775	11 264	13 159	1 895	0.679	65 155	202

Area	Max Day Coefficient
Whole WDS	1.2
Zone 1	1.3
Zone 2	1.6
Zone 3	1.4
Zone 4	2.1
Zone 5	1.6
Zone 6	3.0

2035

Area	Pipe Length [km]	Billed [m^3/d]	Total [m^3/d]	NRW [m^3/d]	Leakage [l·s/km]	Inhabitants	Spec.demand [l/d·pers]
Zone 1	27	299	306	7	0.003		211
Zone 2	18	117	143	26	0.017		211
Zone 3	77	861	1 115	253	0.038		267
Zone 4	303	5 985	7 722	1 737	0.066		240
Zone 5	187	2 816	4 003	1 187	0.074		210
Zone 6	236	1 059	1 173	114	0.006		147
Sum	854	11 174	14 514	3 340	0.045		221

CALCULATING WATER BALANCE

- Subtract non-revenue water (or leakage) from total water demand
- If and when big consumers are modeled separately, subtract their hourly usage from the total demand too
- The resulting time series can be used for calculating **demand pattern for billed demand** – divide each hourly value by the average demand
- Each area has it's own demand profile – set the demands in the model accordingly

MODELING NON-REVENUE WATER AND LEAKAGE

- Divide NRW equally to all junctions in area as normal, constant demand – it is advisable to use separate pattern (named *leakage* or something similar) with all values set to one for NRW

- Divide the total NRW to junctions relative to the average pressure, pipe diameter, length / 2 and optionally pipe material and age – use constant demand

- The best and most accurate way without actual calibration
  - Use **junction emitters** – divide the total NRW to junctions relative to the average pressure, pipe diameter, length / 2 and optionally pipe material and age
  - Emitter values are coefficients *E* in equation $Q_{emitter} = E \cdot p^{\gamma}$, where *p* is pressure [mvp] and γ is globally set emitter exponent (File->Model Properties) – in range of 0.5 … 2.0, typically 1.0 … 1.5
  - Requires few iterations as changing emitter coefficients changes pressure, which changes the emitter flows…

- Calibration or leak location
  - Put the computer to work: find leak sizes and locations that minimize the difference between pressure measurements and model results
  - Hard to do (right)

MODELING WATER SOURCES

- Model water sources by using combination of a **reservoir** and a **pump battery** (any flow or pressure control) or **a set pumps** (on-off control, pumps running at nominal speed)
  - Reservoir can represent either clear well or ground water table, if water is pumped directly into the network
  - Reservoir elevation / head is the average water level
  - Model the pump and efficiency curves along with pump motor and VSD information, and select the right curves for pump batteries and pumps

- If an accurate model of raw water extraction and treatment process is needed, then the reservoirs are used only for the points of extraction

MODELING TANKS

- Set tank elevation to NW, *minimum level* and *minimum volume* to 0 and *maximum level* to HW-NW=maximum depth
  - This way tank pressure = water level in tank
  - Setting minimum volume to value other than 0 causes tank to transform into a reservoir when empty (endless supply of water – wrong results!)

- If tank is right, use the diameter to specify the cross-sectional area, otherwise set *diameter* to 1 and model a *volume curve* (water level – volume curve)
  - $A = \pi r^2$ -> *D=2r*
- If tank level stays constant, a reservoir can be used instead

MODELING STATIONS

- Valve stations can be modeled using valve component
  - FCV for flow control – (maximum) flow setting in l/s
  - PRV for pressure control (pressure reducing valve) – (max.) pressure setting in meters
  - PSV for inlet pressure control (pressure sustaining valve) – setting in meters

- Pressure booster stations
  - Use **pump batteries** for boosters with constant pressure or flow control
  - **Pumps** can be used, if pumps run only at nominal speed or are on-off controlled

- Some time a station can have both valve (for letting water into one direction) and pumps (for lifting water to the other direction)
  - Model both directions separately – they are two different stations logically

MODELING CONTROL SYSTEM

- Constant pressure and flow settings can be modeled by setting the initial type and setting field values in pump batteries

- The best way is to code the control system algorithms using Python modules
    - Create some fancy system to read settings and parameters from Excel sheets, for example
    - Create classes to present different station types and control types, using the previously read values
    - Create instances for all stations in the system

- Sometimes, if the system only has time and or on-off controls (based on tank levels), EPANET's built-in Controls and Rules can suffice – they can be used for simple IF … THEN … rules

ANALYSIS & REPORTING

GENERAL

- The best way to present values is to use thematic maps
  - Usually only minimum, maximum and daily total values are interesting
  - Color and size links according to different results
  - Use calculated layers for junction results, some times coloring and sizing junctions can improve readability

- Time series are useful, but typically should be used sparingly
  - Provide some pressure, flow, head loss etc. data for few representing points in the network
  - Tank levels and source & station flows are interesting

- Provide general network level overviews, more detailed analysis for each zone and focused analysis for any problematic locations you find

- Use scenarios
  - Use maximum day (set global inflow coefficient for scenario), when performing capacity analysis and sizing pipes and pumps
  - Other analyses, especially energy analyses, should be performed using average or normal day

VISUALIZATION

- Remember that color-blindness, especially red-green, is common – avoid using red, green and gray colors close together
- When classifying data, use meaningful limits, and limit the number of classes <10
- When using time series, avoid presenting more than 3–5 series in one chart and don’t mix data with many different units (sometimes it’s ok to use the second axis)
- Highlight problems, visualize changes

ENSURING MODEL WORKS

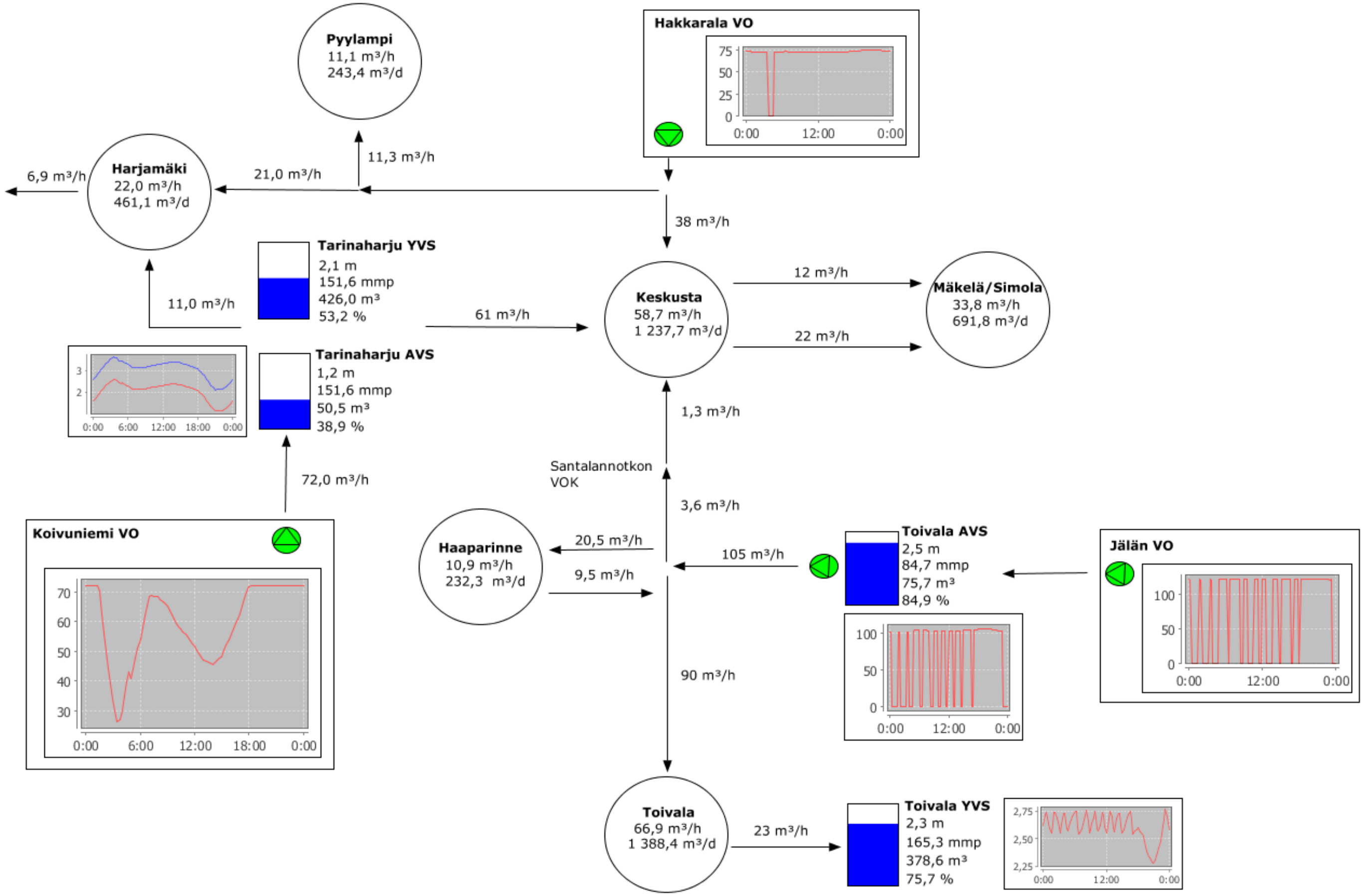
- You should build a *schematic view* that shows you, at least
  - Time serieses of flows pumped into network
  - Flows between different zones
  - Tank levels

- Total demand and pumped volume values along with pressure time serieses are also very useful

- This enables you to quickly control the **model works** correctly after **every single simulation**
  - Changes you make can break the model unintentionally
  - *Completely emptying or filling tanks*, too low (<10 m) and too high (>80 m) pressures and too small or large pumped volumes hint to problems

- Ensure the flows, pressures and tank level behavior (including timing) match the measurements before starting to use the model for analysis

GLANCE VIEW



Pyylampi
11,1 m³/h
243,4 m³/d
Hakkarala VO
75
50
25
0
0:00
12:00
0:00
11,3 m³/h
6,9 m³/h
Harjamäki
22,0 m³/h
461,1 m³/d
21,0 m³/h
38 m³/h
Tarinaharju YVS
2,1 m
151,6 mmp
426,0 m³
53,2 %
11,0 m³/h
61 m³/h
Keskusta
58,7 m³/h
1 237,7 m³/d
12 m³/h
22 m³/h
Mäkelä/Simola
33,8 m³/h
691,8 m³/d
3
2
0:00
6:00
12:00
18:00
0:00
Tarinaharju AVS
1,2 m
151,6 mmp
50,5 m³
38,9 %
1,3 m³/h
Santalannotkon
VOK
72,0 m³/h
3,6 m³/h
Koivuniemi VO
70
60
50
40
30
0:00
6:00
12:00
18:00
0:00
Haaparinne
10,9 m³/h
232,3 m³/d
20,5 m³/h
9,5 m³/h
105 m³/h
Toivala AVS
2,5 m
84,7 mmp
75,7 m³
84,9 %
Jälän VO
100
50
0
0:00
12:00
0:00
100
50
0
0:00
12:00
0:00
90 m³/h
Toivala
66,9 m³/h
1 388,4 m³/d
23 m³/h
Toivala YVS
2,3 m
165,3 mmp
378,6 m³
75,7 %
2,75
2,50
2,25
0:00
12:00
0:00

REPORTING AND ANALYZING RESULTS

- Typically capacity assessment is done in order to find too small pipes (bottle-necks), too low and high pressures, and circular flows between zones etc.

- The most important things to analyze are
  - Minimum pressure
  - Maximum pressure
  - Pressure difference
  - Gross and net flow
  - Maximum unit head loss
  - Maximum velocity
  - Energy usage, total pumped volumes at the stations
  - Quality parameters: water source, age, chlorine content…
- Prepare thematic maps of the values for each zone

- Describe the **range of each parameter** in every zone and **focus more on extremes**, eg. provide more detailed maps and descriptions of the locations with too low pressures or too small pipes, analyze the severity, effect and potential solutions

PIPES

- Velocity range
  - Typically velocities are 0.1–0.3 m/s for most parts of the network
  - For big transmission lines velocities can be higher
  - Anything over 0.5 m/s starts to be a bit suspicious
  - Velocities over 0.8 and especially over 1.0 m/s are too high, but may be acceptable in big trunk mains pipe lines

- Unit head loss range
  - Typically unit head losses are <1.0–3.0 m/km
  - Unit head losses over 5 m/km start to be on the high side
  - Over 8 and especially over 10 m/km are too high

JUNCTIONS

- Minimum and maximum pressures
  - Pressure must be over 10 m (5 m hard limit) everywhere in network
  - Pressure must be below 80 m (100 m hard limit) everywhere in network
  - Required minimum pressure depends on client (number of floors, technical requirements, sprinkler etc.): typically 20 m is minimum for single floor villas, 30 m is enough for four-storey building
  - Pressures over 50 m already waste energy, over 60–70 m start to cause problems (leakage and probability of pipe bursts high)

- Pressure difference
  - Pressure differences are typically <5 m/d – mostly caused by tank level changes and changes in station flows
  - Differences of <5 m/d are not noticeable, unless minimum pressure is too low
  - Differences over 10 m/s are too large and hint towards too small pipes or bad control system behavior

OTHER ANALYSES TO CONSIDER

- Water age
- Water source tracing
- Energy use, pumping efficiency
- Possibilities are unlimited

PROVIDE ANALYSIS AND SOLUTIONS

- Don’t just state problems

- Analyze the importance
- Analyze reasons
- Provide the client with all relevant information

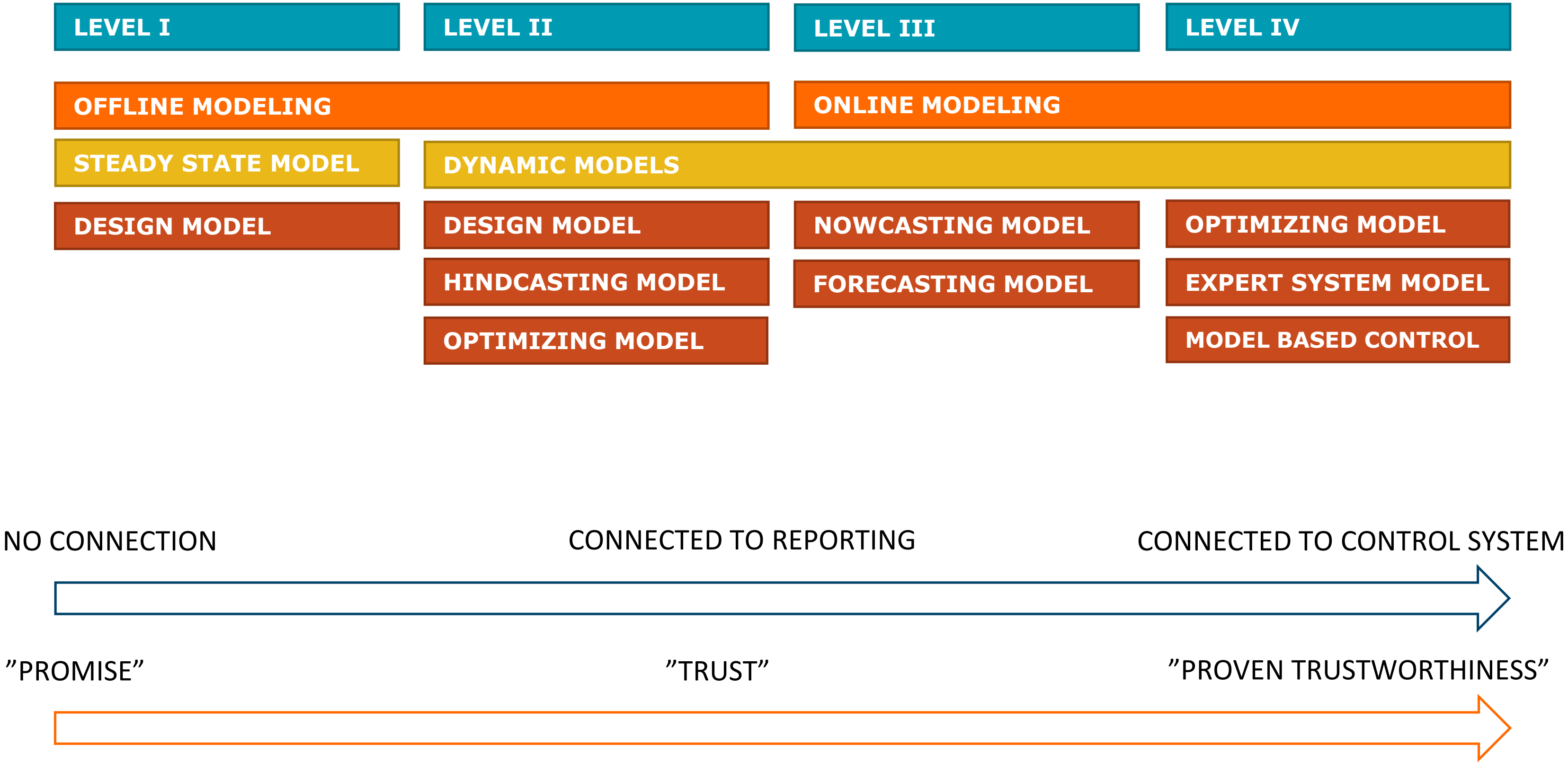
- Propose and test solutions – estimate costs and benefits

CONCLUSION

SURPRISE YOUR CLIENT (POSITIVELY)

- You, as an outside modeler, know the client’s WSS more intimately and from different angle that they do – share the things you discover
- Always think of something new and interesting you can come with using the model
- Think of new ways to use model and integrate information together
- Share your knowledge, insights, doubts, questions and ideas – and your data

THINK FORWARD



LEVEL I

LEVEL II

LEVEL III

LEVEL IV

OFFLINE MODELING

ONLINE MODELING

STEADY STATE MODEL

DYNAMIC MODELS

DESIGN MODEL

DESIGN MODEL

HINDCASTING MODEL

OPTIMIZING MODEL

NOWCASTING MODEL

FORECASTING MODEL

OPTIMIZING MODEL

EXPERT SYSTEM MODEL

MODEL BASED CONTROL

NO CONNECTION

CONNECTED TO REPORTING

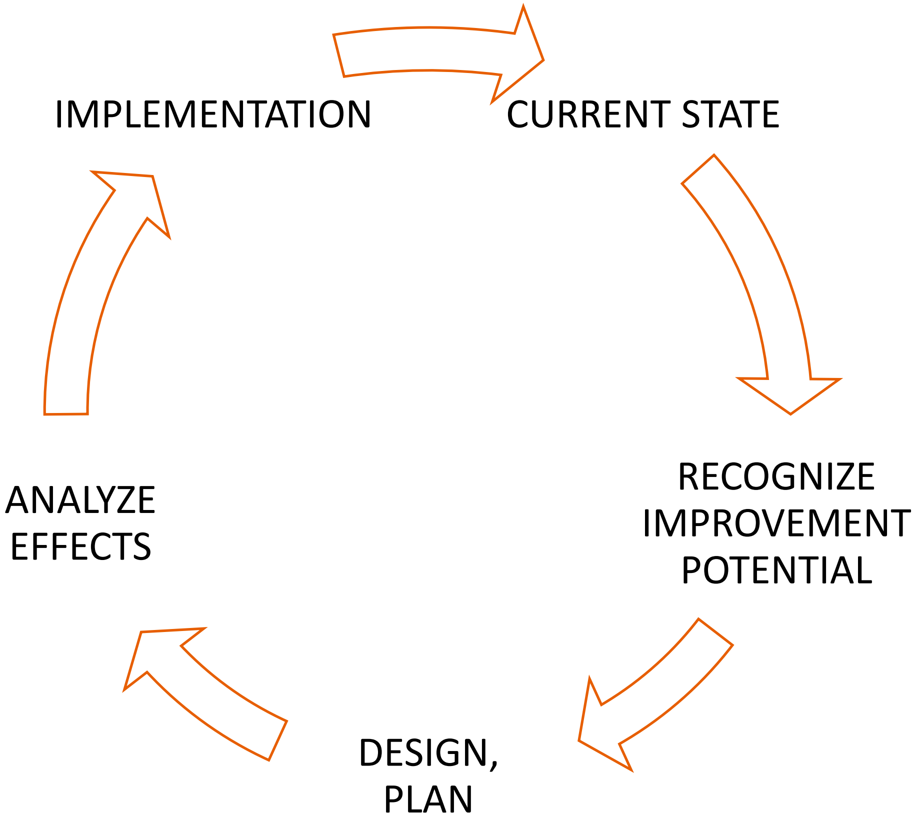
CONNECTED TO CONTROL SYSTEM

”PROMISE”

”TRUST”

”PROVEN TRUSTWORTHINESS”

CONTINUOUS IMPROVEMENT


IMPLEMENTATION

CURRENT STATE

RECOGNIZE IMPROVEMENT POTENTIAL

DESIGN, PLAN

ANALYZE EFFECTS

- There are always endless possibilities for improvement
- Analyze the current state
- Recognize the potential improvements
- Design ways to improve
- Test and analyze the outcomes
- Implement

THANK YOU FOR YOUR TIME

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