Observations on Surcharge Behavior: Comparing EXTRAN and Preissmann Slot Responses in Force Mains

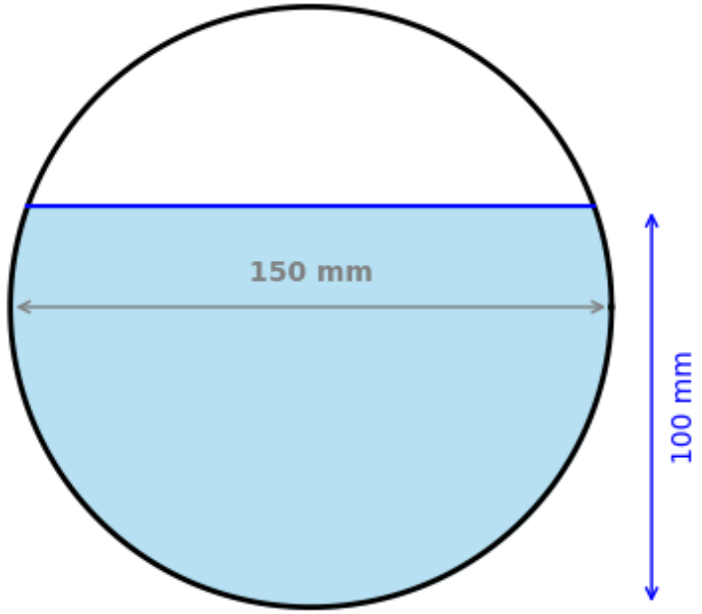
ICWMM 2026

Hardus Ehlers hardus@chiwater.com
Nandana Perera, Ph.D., P.Eng. nandana@chiwater.com

Hydraulic Conditions: Gravity Flow and Surcharged

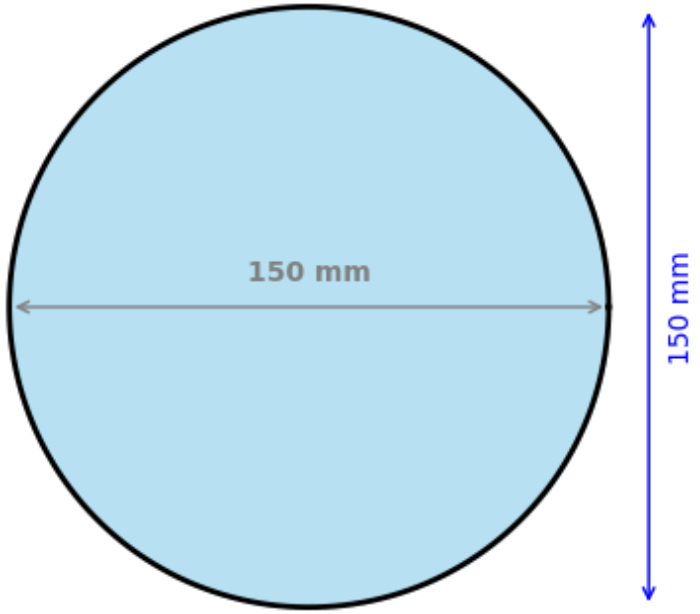
Gravity Flow

Movement of water driven solely by gravitational forces, from high to low elevation



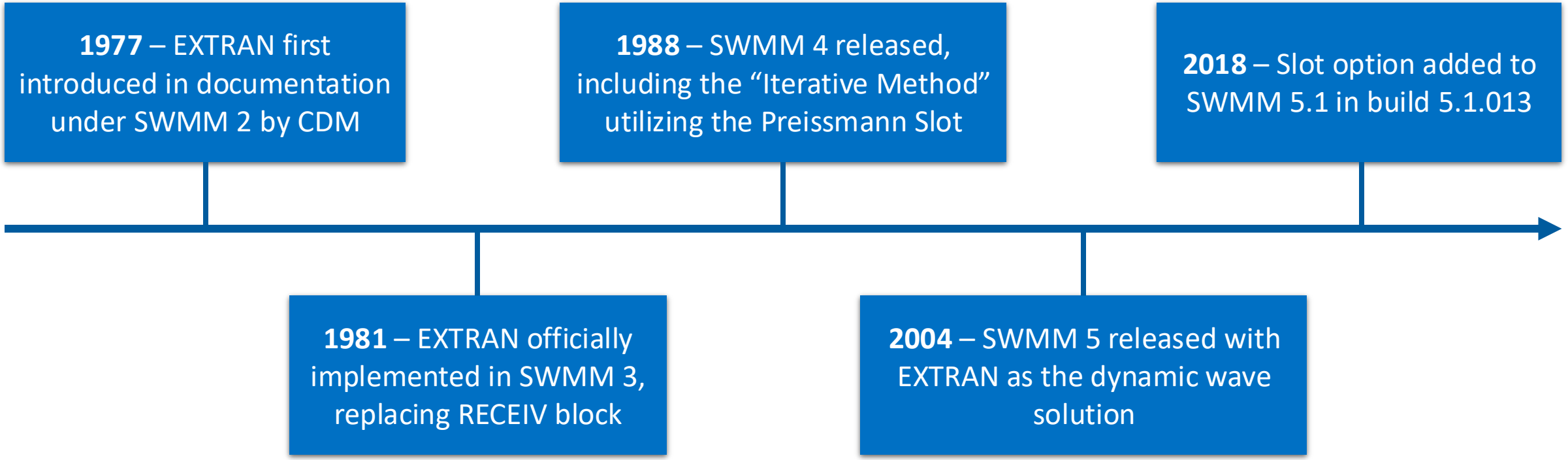
Surcharged

Pressurized flow, where the hydraulic grade line is above the crown of the pipe



SWMM5 Surcharge Methods Overview

History



(Dickinson; James)

EXTRAN

- Changes from gravity flow algorithm to surcharge algorithm, adopting a node continuity approach

- The inflows and outflows at a node must be equal, and the head is adjusted at each node accordingly.

- Can require a smaller timestep to provide stable, accurate solutions during surcharge conditions

Node Continuity Equation (3-25)

$$\sum \left[Q + \frac{\partial Q}{\partial H} \Delta H \right] = 0$$

Re-arranged for Head… (3-26)

$$\Delta H = \frac{-\sum Q}{\sum \partial Q / \partial H}$$

Flow Gradient in a Conduit (3-27)

$$\frac{\partial Q}{\partial H} = \frac{-g \bar{A} \Delta t / L}{1 + \Delta Q_{friction}}$$

Slot

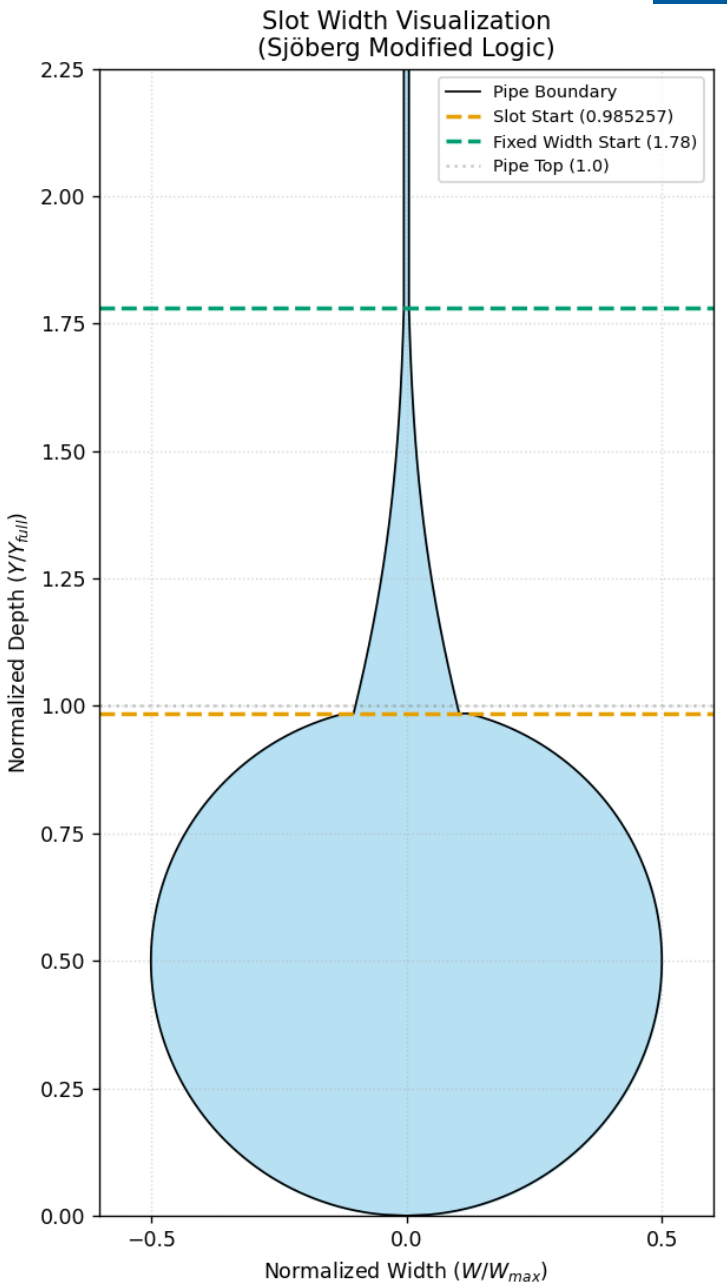
- A narrow, open slot is assumed at the top of the pipe, allowing the **original algorithm** to be used

- The slot width for $^{Y}/_{Y_{full}}$ values between ~0.985 and 1.78 follows a modified version of a formula proposed by Sjöberg (1982)

$$^{w_{slot}}/_{W_{max}} = 0.5423\exp(-(^{Y}/_{Y_{full}})^{2.4})$$

- For $^{Y}/_{Y_{full}}$ values above 1.78 the slot width is fixed at 1 percent of the maximum width

$$w_{slot} = 0.01W_{max}$$



Test Model – Simple Uphill Pumping

Simple Uphill Pumping – Model Setup

- A storage unit was connected to an uphill conduit via an inline pump, routing flow uphill to a secondary storage unit

- The routing timestep was set to 0.1 seconds for highest accuracy

- Models were simulated with EXTRAN and Slot surcharge methods

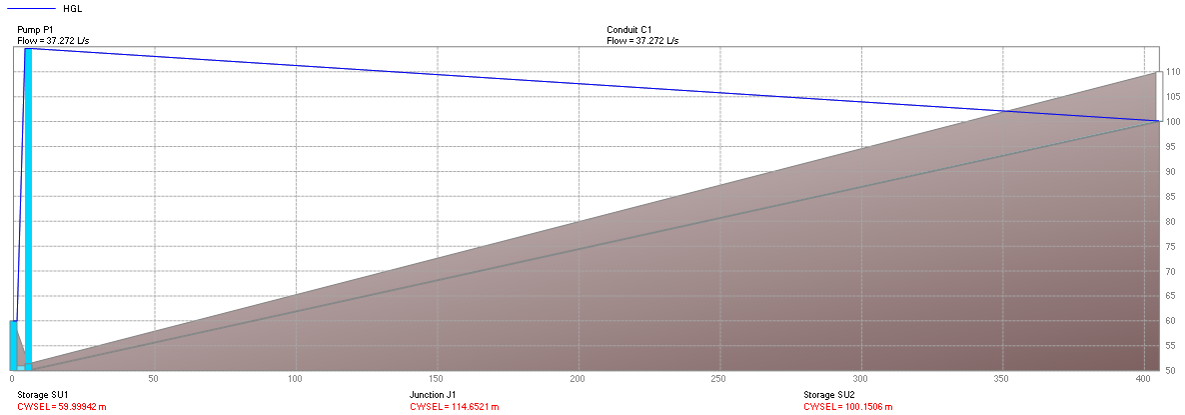
Conduit:
Length = 400m
Diameter = 0.15m
Manning's Roughness = 0.01
Flap Gate = YES
H-W Roughness = 120
Slope = 12.5%

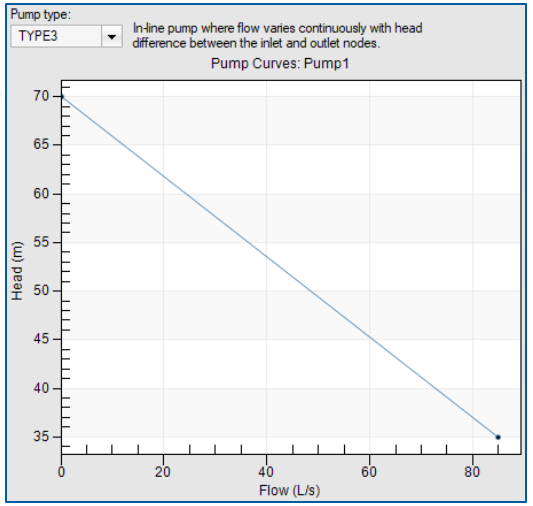
Storage Unit:
Invert Elev. = 100m
Rim Elev. = 110m
Initial Depth = 0.15m
Circular, 25m Diameter

Outfall:
Model run requirement
Just Chilling = YES

Junction:
Invert Elev. = 50m
Rim Elev. = 50m
Initial Depth = 0.2m
Surcharge Depth = 100m

Storage Unit:
Invert Elev. = 50m
Rim Elev. = 60m
Initial Depth = 10m
Circular, 25m Diameter



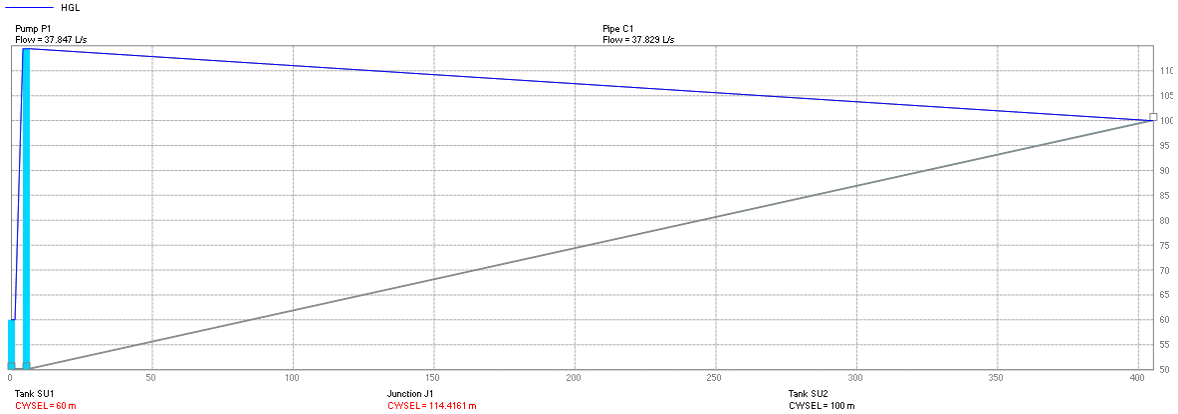


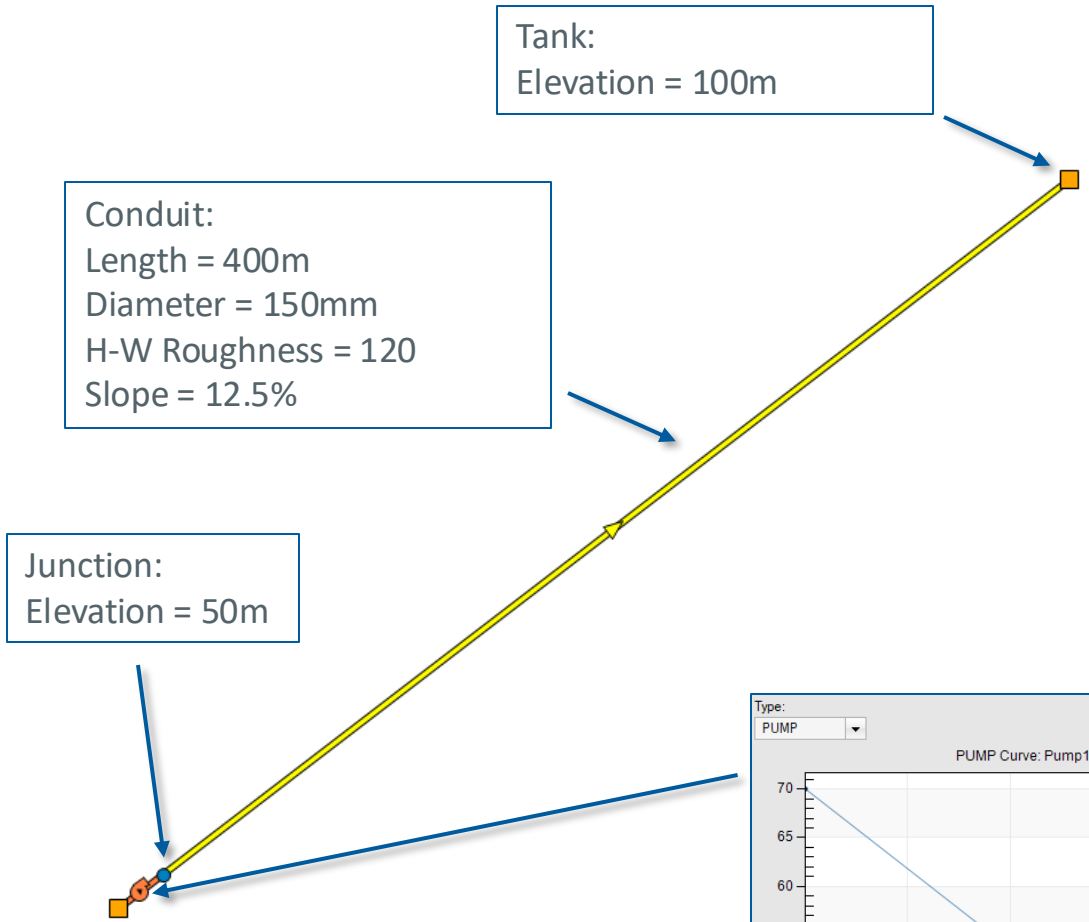
Simple Uphill Pumping – EPANET Baseline

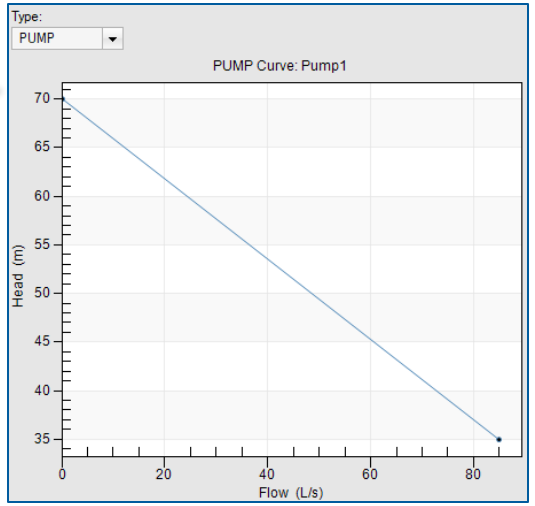
- A tank was connected to an uphill conduit via an inline pump, routing flow uphill to a secondary tank

- The hydraulic timestep was set to 1 second for highest accuracy

- EPANET is designed for pressurized flow, making it a good tool to use as a benchmark for the surcharge method comparison in SWMM







Results – Simple Uphill Pumping

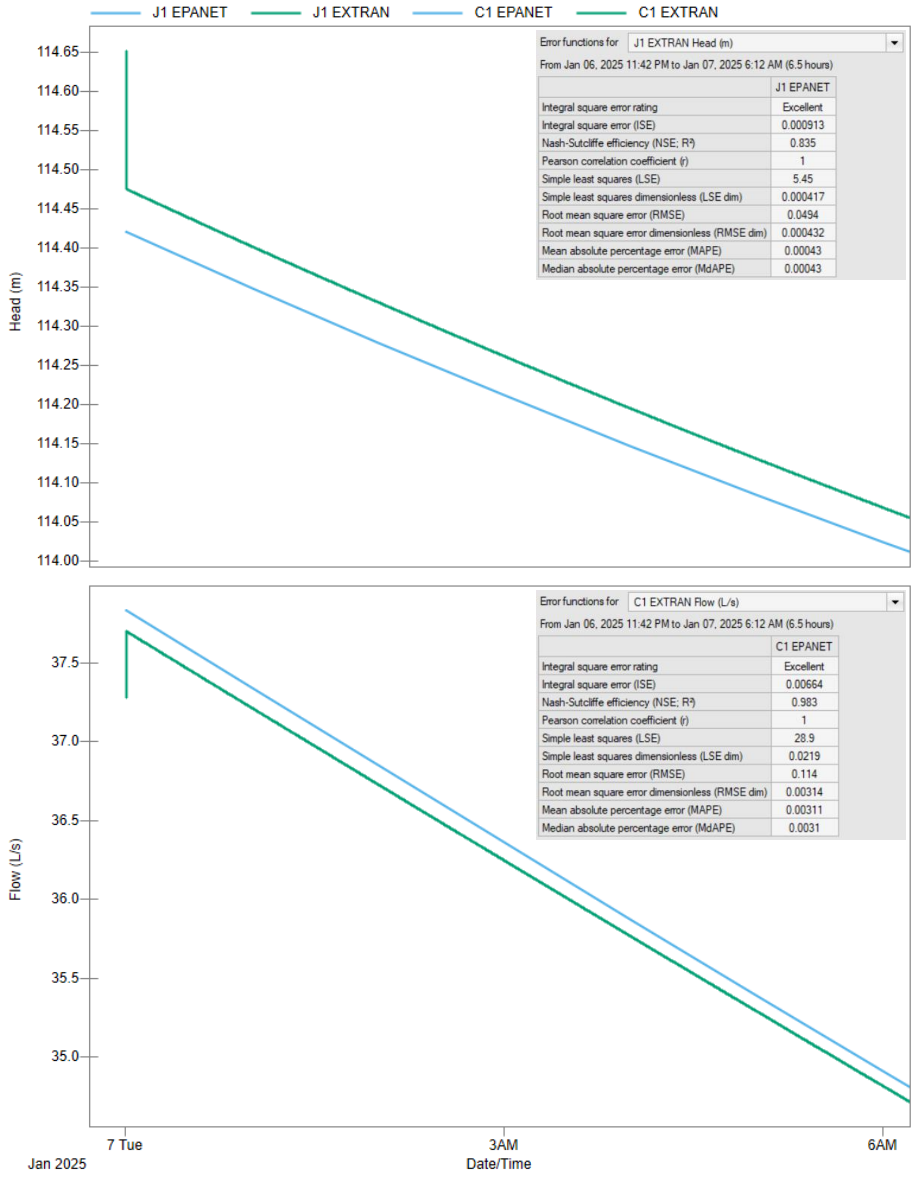
Simple Uphill Pumping - Results

EXTRAN

- The EXTRAN model matched the EPANET model very well.

- Note that in this test model the pipe *begins* the simulation surcharged. There is no algorithm transition.

- Continuity error is low, volumes match closely, and flow is also accurate according to the EPANET results



Simple Uphill Pumping - Results

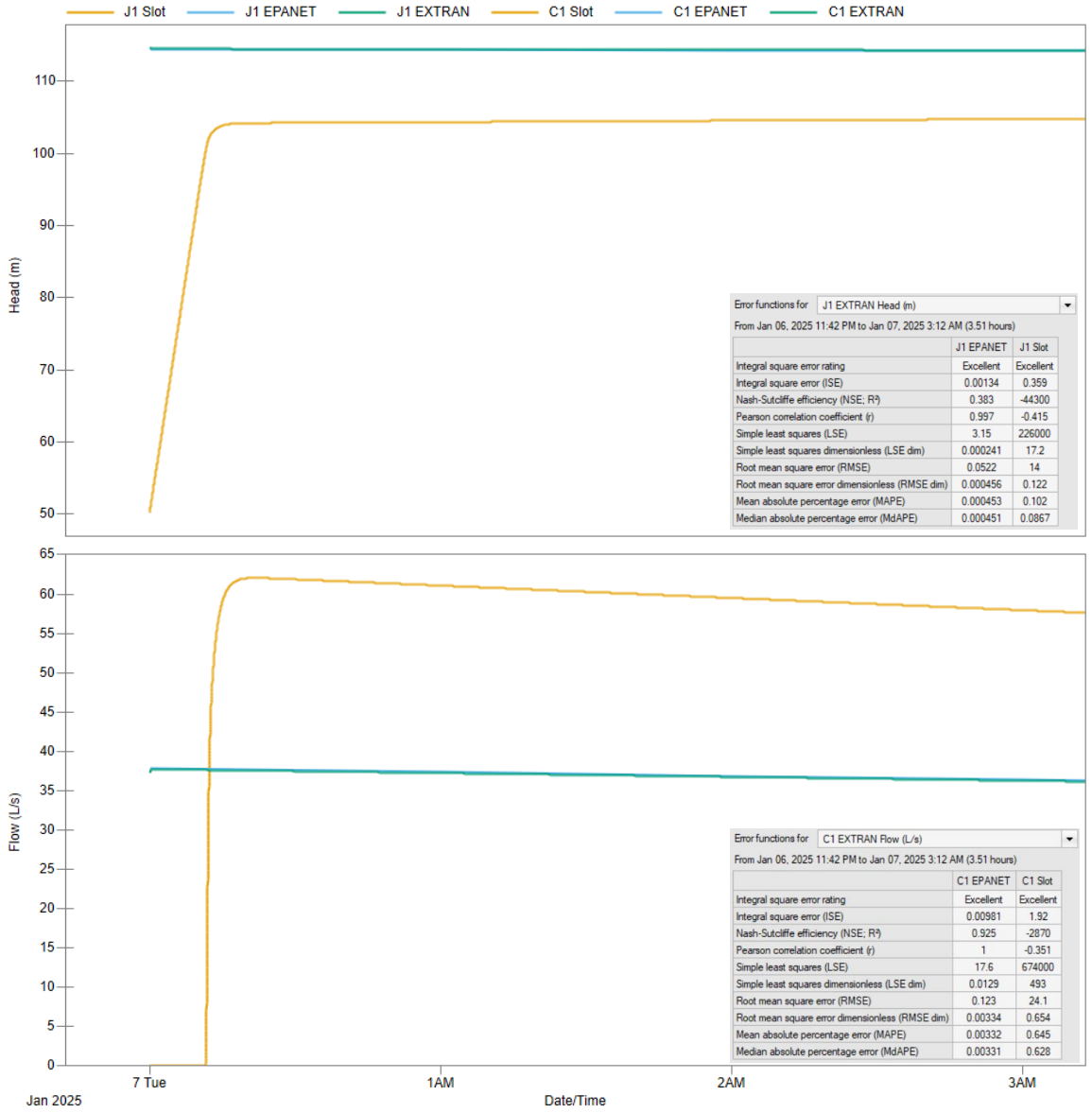
Slot

- The Slot method did *not* provide similar results to the EPANET model

- There was a delay in the large conduit showing any flow

- The head at J1 increased while the flow was zero

- The peak flow in the conduit was ~60% higher using the Slot method



Simple Uphill Pumping - Results

Slot

- The conduit does not show any flow until the artificial slot is ‘filled up’

- Once filled, the calculated flow is much greater than what the EPANET and EXTRAN models show

- Higher flow could be due to the additional link surface area contribution in the node continuity equation (3-6)

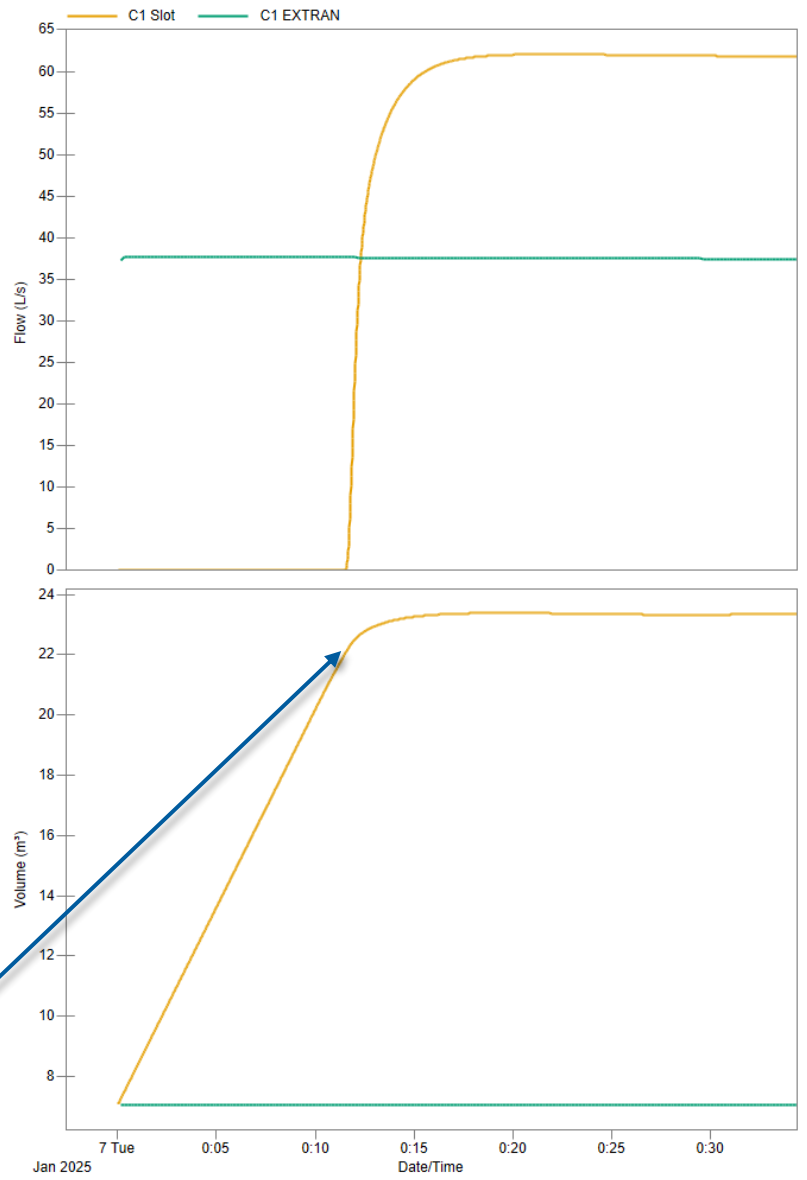
Node Continuity Equation (3-6)

$$\frac{\partial H}{\partial t} = \frac{\sum Q}{A_{SN} + \sum A_{SL}}$$

$$(400)\frac{1}{4}\pi(0.15)^2 = V_{C1} = 7.07\text{m}^3$$

$$0.01(0.15)\frac{1}{2}(400)(50) = V_{\text{Slot}} = 15\ \text{m}^3$$

$$\text{V}_{\text{Total}} = 22.07\text{m}^3$$



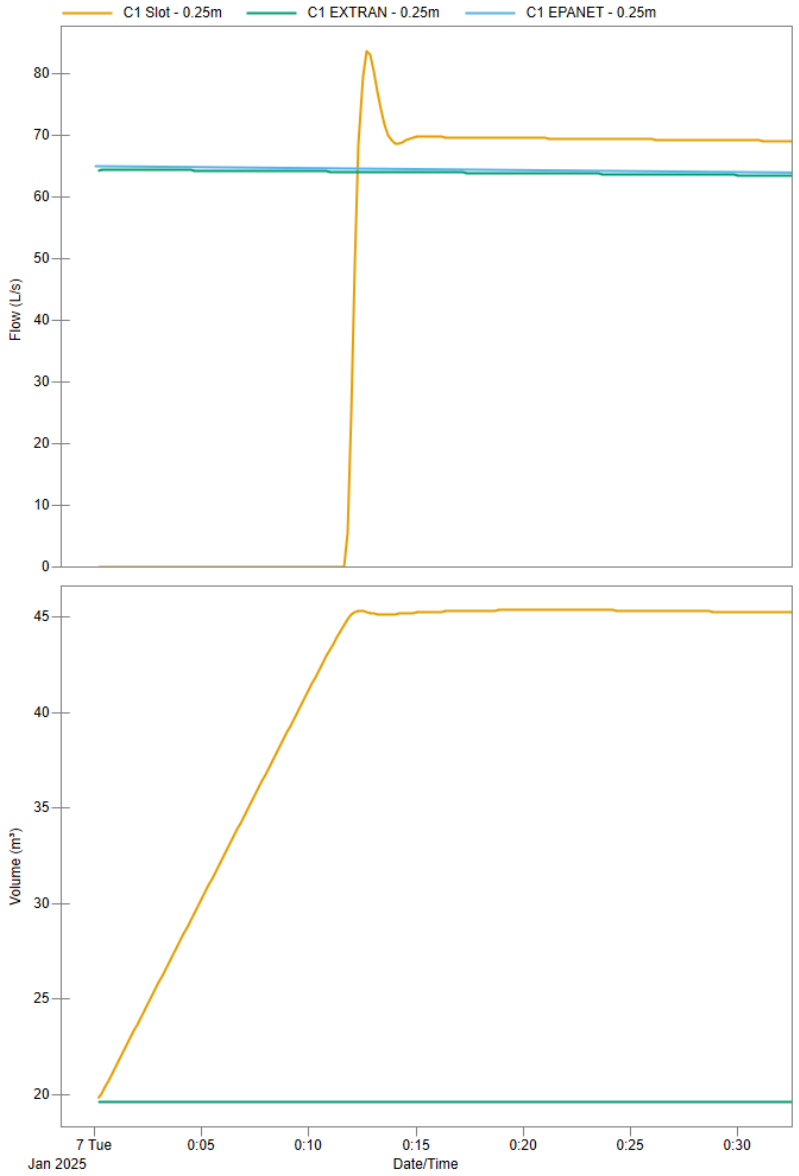
Simple Uphill Pumping - Alterations

0.25m Diameter Conduit

- The same model was used, this time with a force main diameter of 0.25m instead of 0.15m

- The larger conduit still did not show any flow until the artificial slot was ‘filled up’

- Once filled, the calculated flow was *closer* to the EPANET and EXTRAN model results

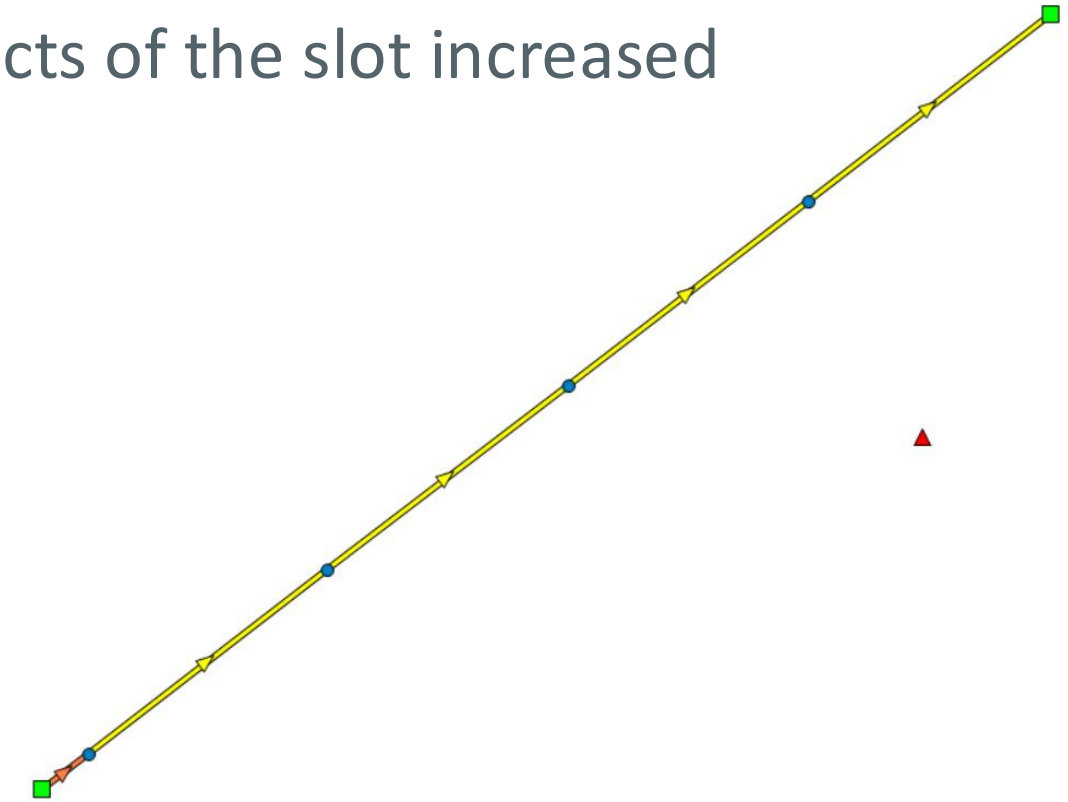


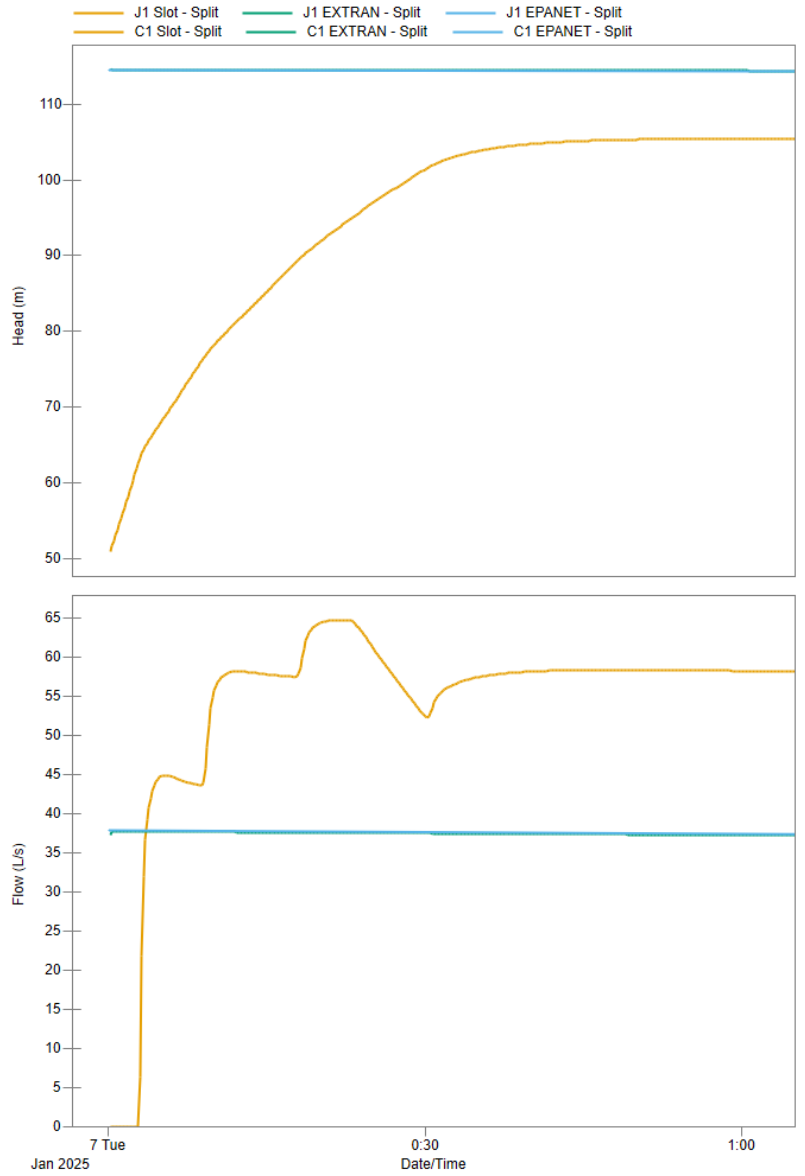
Simple Uphill Pumping - Alterations

Split Conduit

- The 0.15m force main was split into four force mains connected by dummy junctions

- The effects of the slot increased





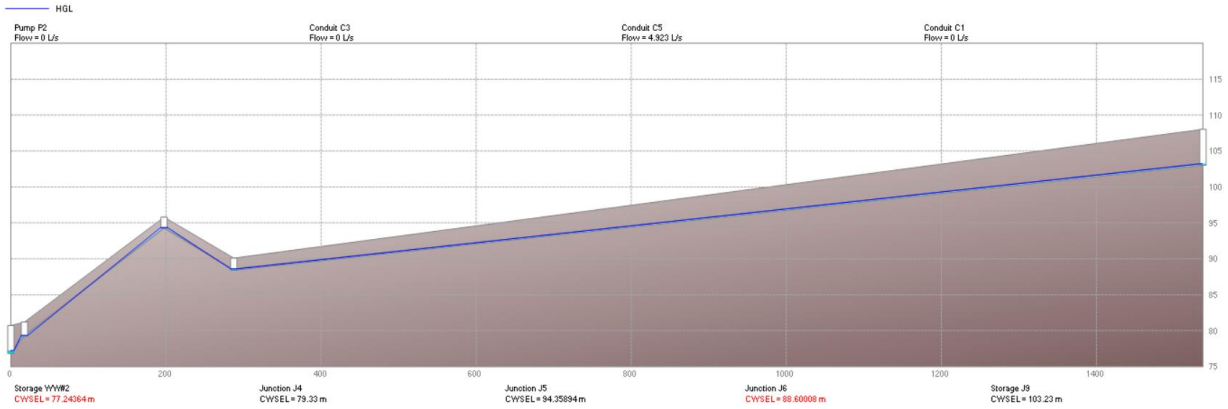
Test Model – Double Uphill Pumping

Double Uphill Pumping – Model Setup

- Two storage units were connected to uphill conduits via inline pumps, converging and routing flow uphill to a third storage unit

- The storage units had base inflows assigned and were able to empty

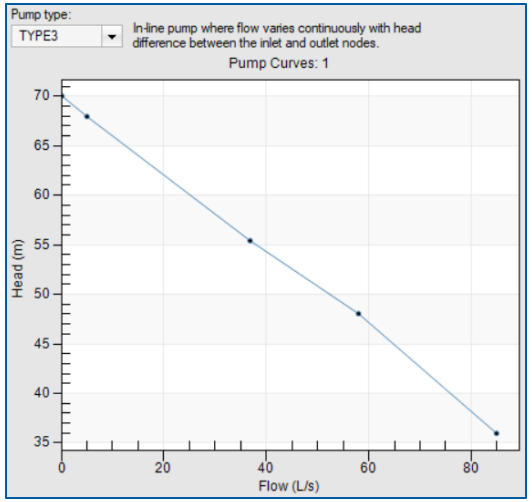
- Models were simulated with EXTRAN and Slot surcharge methods



Conduit:
Length = 1250m
Diameter = 0.2m
Manning's Roughness = 0.011
Flap Gate = YES
H-W Roughness = 120
Slope = 1.17%

Storage Unit WW1:
Invert Elev. = 59.47m
Rim Elev. = 74.1m
Initial Depth = 0.4m
Inflows = 35.57L/s

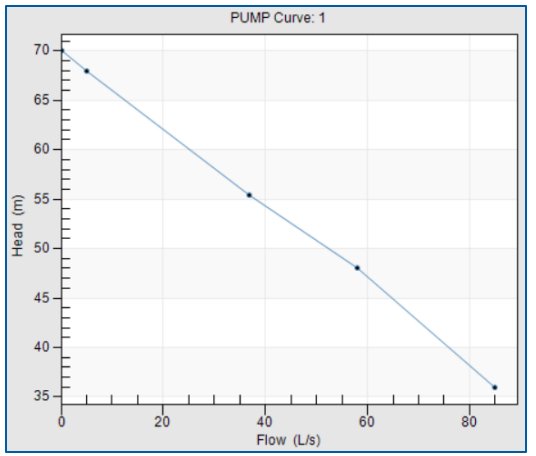
Storage Unit WW2:
Invert Elev. = 76.83m
Rim Elev. = 80.7m
Initial Depth = 0.41m
Inflows = 16.5L/s



Double Uphill Pumping – EPANET Baseline

- Two tanks were connected to uphill pipes via inline pumps, converging and routing flow uphill to a third tank

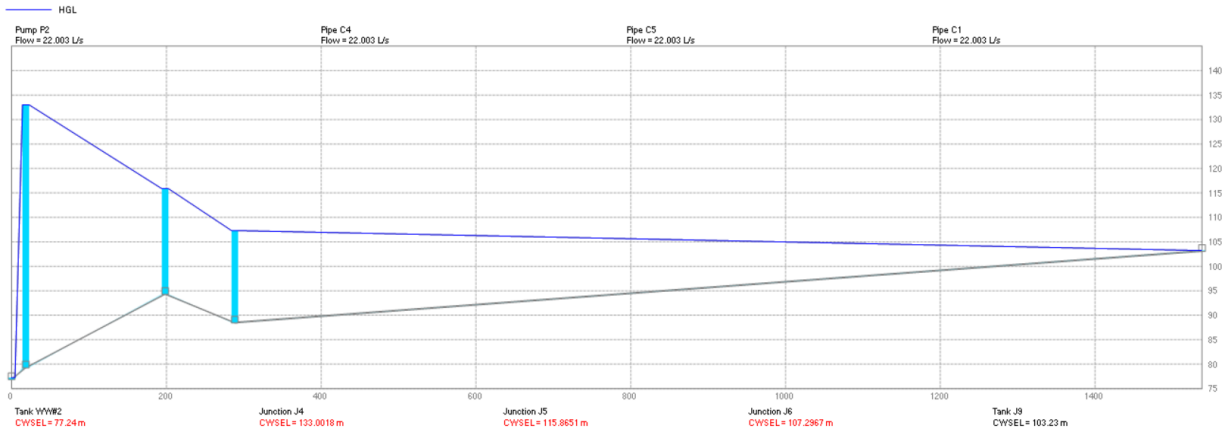
- The tank inflows were assigned via junctions with negative demand



Pipe:
Length = 1250m
Diameter = 200mm
H-W Roughness = 120
Slope = 1.17%

Tank WW1:
Elevation = 59.47m
Initial Level = 0.4m
Max. Level = 14.63m
Diameter = 2.4m

Tank WW2:
Elevation = 76.83m
Initial Level = 0.41m
Max. Level = 3.87m
Diameter = 2.4m



Results – Double Uphill Pumping

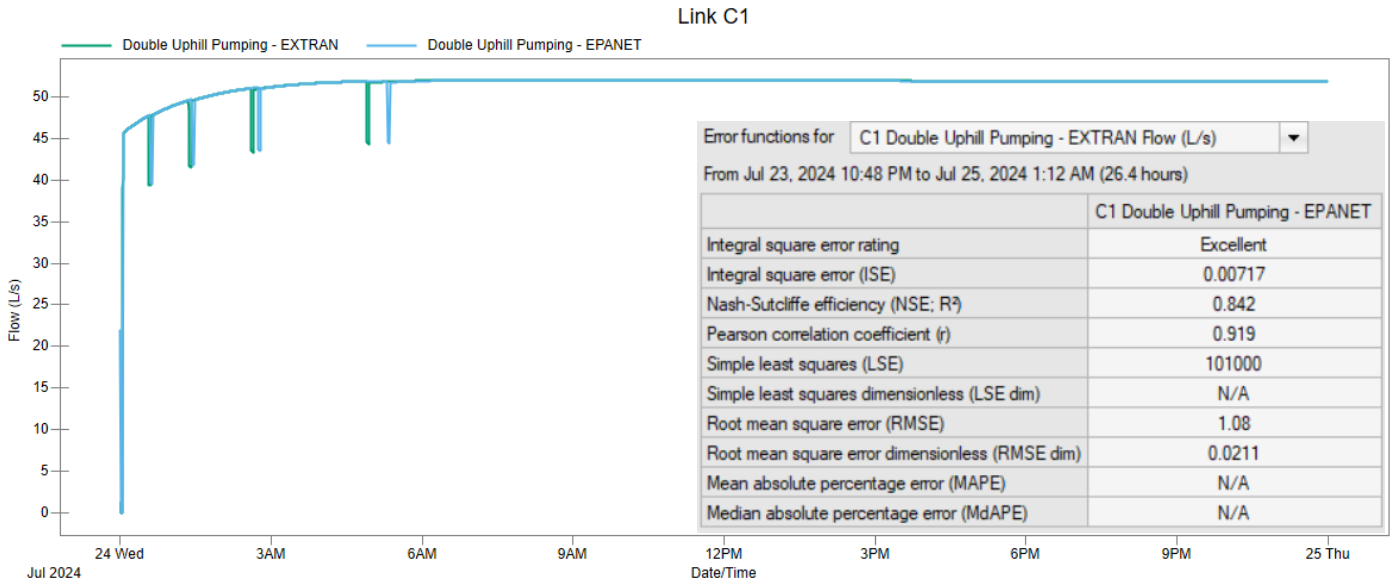
Double Uphill Pumping - Results

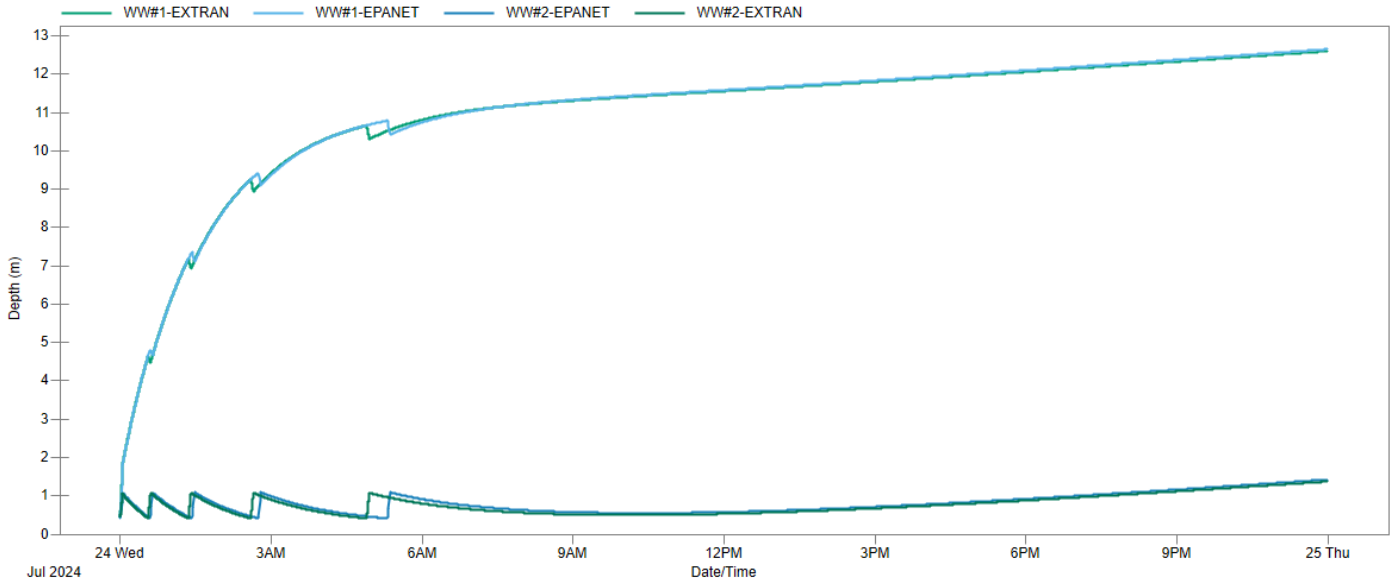
EXTRAN

- The EXTRAN model matched the EPANET model well, noting a slight offset in pump activation time

- Continuity error is 2.2%

- The number of pump shutoffs is consistent across EPANET and EXTRAN





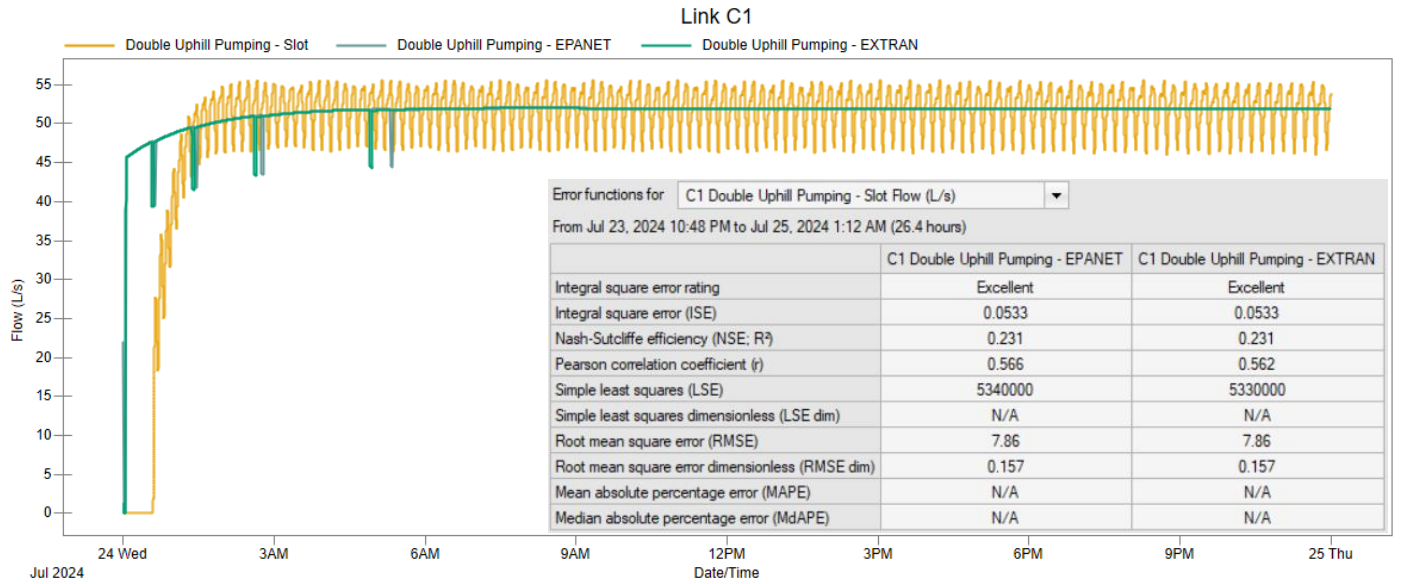
Double Uphill Pumping - Results

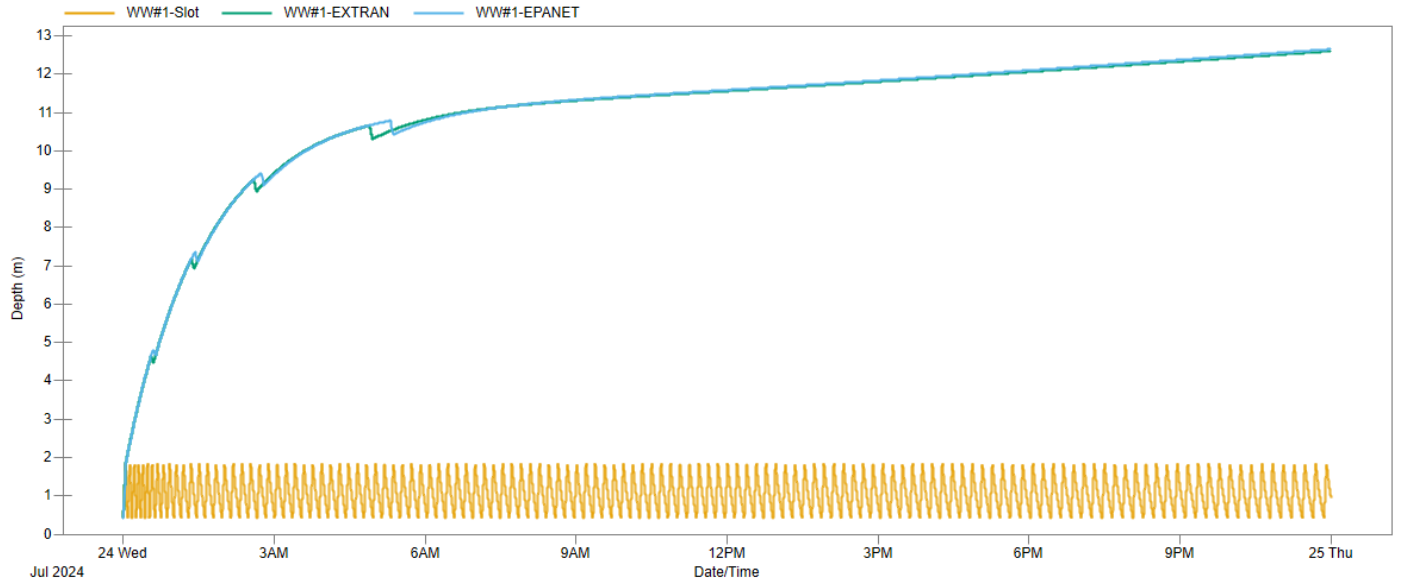
Slot

- The slot model showed significant differences when compared with the EXTRAN and EPANET model

- Continuity error is 2%

- The pump behavior is abnormal, resulting in unstable flows





Further Discussion

EXTRAN

- EXTRAN provided similar results to EPANET in the tests performed in force mains in SWMM 5.2.4

Slot

- The slot method had difficulties representing force main behavior accurately in the model setups tested

- Overestimated inline pump flow when used in uphill force mains in the scenarios tested

Next Steps

- Explore how different hydraulic conditions affect slot behavior

- Transitions between gravity flow and surcharged flow

- Looped networks

- Combined approach utilizing both surcharge methods could be explored

Thank you for listening!