DEGREE PROJECT

Stormwater hydraulic modeling

A comparative study of MIKE & InfoDrainage

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2026

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Abstract

Effective stormwater management is important in urban environments to mitigate flooding, manage peak flows, and support resilient infrastructure planning. Hydraulic modeling tools play a critical role in the design and analysis of drainage networks, yet different software tools often rely on different assumptions, numerical methods, and model structures which raise questions about comparability and reliability. This study compares two widely used stormwater modeling tools, MIKE+ and InfoDrainage. Identical drainage systems were simulated under identical input conditions, including synthetic rainfall events, Chicago Design Storms and block rain with 10- and 30-year return periods.

Results show that despite identical inputs, the two models produced notable differences in peak flow rates, timing of runoff, surcharging behavior, and flood extents, particularly under high-intensity rainfall events. These differences are largely attributed to differences in numerical solvers, surcharge handling and handling of node interactions. While MIKE+ typically produced higher peaks, InfoDrainage exhibited more numerical instability in the hydrographs and fewer instances of surcharging. The study also highlights the implications of uncertainty in model structure and solver design, especially in the absence of field calibration.

The findings demonstrate that MIKE+ and InfoDrainage are not functionally interchangeable, and model results must be interpreted in the context of each software's assumptions. This comparison contributes to a more informed selection of modeling tools in stormwater design and planning and emphasizes the need for calibration, sensitivity analysis, and model transparency in future applications.

Sammanfattning

Effektiv hantering av dagvatten är avgörande i urbana miljöer för att minska översvämningsrisker, hantera flödestoppar och stödja hållbar infrastrukturplanering. Hydrauliska modelleringsverktyg spelar en central roll vid dimensionering och analys av dagvattensystem, men olika programvaror bygger ofta på skilda antaganden, numeriska metoder och modellstrukturer, vilket väcker frågor om jämförbarhet och tillförlitlighet. I denna studie jämförs två vanligt förekommande modelleringsverktyg, MIKE+ och InfoDrainage, genom att simulera identiska dagvattensystem med harmoniserade indata, inklusive syntetiska regn (10- och 30-årsregn enligt Chicago Design Storm och blockregn).

Resultaten visar att modellerna trots identiska indata genereras märkbara skillnader i flödestoppar, tidpunkt för avrinning, överbelastningar och översvämning, särskilt vid mer intensiva regn. Dessa skillnader kan i huvudsak förklaras av olikheter i numeriska lösningsmetoder, hanteringen av överbelastade rör och hanteringen av brunnar. MIKE+ tenderar att ge högre flödestoppar, medan InfoDrainage genererade flödeskurvor med mer svängningar och färre överbelastningar. Studien belyser även betydelsen av modellstrukturell osäkerhet, särskilt när kalibrering mot uppmätta data saknas.

Slutsatsen är att MIKE+ och InfoDrainage inte är direkt utbytbara, och att resultaten bör tolkas med hänsyn till respektive programvaras bakomliggande antaganden. Denna jämförelse bidrar till en mer informerad modellvalprocess vid dagvattenplanering och betonar behovet av kalibrering, känslighetsanalyser och ökad transparens i framtida tillämpningar.

Acknowledgements

The study was conducted in collaboration with Luleå University of Technology (LTU) and the Climate Adaptation department at Ramboll Sweden. I would like to thank my supervisors Ico Broekhuizen (LTU) and Jorge Contreras Moreno (Ramboll) for their continuous support throughout my project. I would also like to address my appreciation towards Anton Blomqvist, Sara Karlsson, Emmie Kjellström, Frida Wistfors, Salwan Abbosh and Nils Brattgård for your valuable inputs and knowledge in the modeling process.

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1. Introduction

Proper management of stormwater in urban environments is one of the cornerstones of sustainable city planning. The amount of impermeable surfaces increase as cities are built and expanded, leading to a reduction of natural infiltration of rainfall and thus an increased surface runoff. Without proper planning and control this increased runoff can result in increased flood risks, infrastructural damage and increased pollutant transport to the receiving water bodies (Fletcher et al., 2014). Designing stormwater networks that are both cost-efficient and reliable require detailed hydrologic and hydraulic analysis to ensure sufficient capacity during more extreme rainfall events while avoiding non-cost-efficient over-dimensioning.

Urban drainage systems should also be designed to be able to handle future climate changes that can potentially increase the frequency and intensity of future rainfall events. Studies have shown that traditional design storms may underestimate future extreme events, which creates a need for adaptable modeling approaches which take long term reliability into consideration (Arnbjerg-Nielsen et al., 2012).

Tools that use numerical simulations to quantify runoff volumes, flow rates, flooding and network capacity are increasingly used in the stormwater design and evaluation stage to solve these challenges. Different modeling programs often use different assumptions, algorithms and governing equations, and thus they can vary in their respective simulation outputs and results. Differences in how software handles processes such as infiltration, surface runoff and flow distribution can therefore give different results between different modeling softwares under identical conditions (Deletic et al., 2012).

There is a wide range of tools available for professional practices, among them are MIKE+ by DHI and InfoDrainage by Autodesk. MIKE+ integrates hydrodynamic simulation capabilities for complex stormwater, wastewater and river systems using the MIKE 1D engine to model open and closed conduits. InfoDrainage focuses more on Sustainable Drainage Systems (SuDS) and design-friendly workflows. Despite the wide usage of both softwares, there is a notable lack of peer-reviewed studies comparing the two platforms directly under identical conditions.

2. Background

2.1 Stormwater Management

Urbanization has significantly increased the amount of impermeable surfaces, such as asphalt, concrete and roofs, that interrupt the natural hydrological cycle by limiting infiltration and accelerating surface runoff. This leads to higher peak flows, greater risks for flooding and increased pollutant transport into recipients (Barbosa et al., 2012; Walsh et al., 2016). Urban drainage systems are generally designed to manage more relatively common rainfall events, typically up to return periods of 10-30 years (Svenskt Vatten, 2019). Designing pipe networks to manage very extreme events would require larger dimensions which is neither technically nor economically viable. Instead, the network is generally dimensioned to handle these more frequent events, while larger cloudbursts are managed by surface-based flood management systems. Drainage systems are often not designed to manage these intensified flows, particularly under changing climatic conditions that may result in more frequent and severe rainfall events (Zevenbergen et al., 2018; Subramanian, 2016). There is already observational evidence of intensifying precipitation extremes under a warming climate (Fowler et al., 2021).

To address these challenges, hydrologic and hydraulic modeling tools are essential for the dimensioning and design of the stormwater network. The modeling tools allow simulation of the rainfall-runoff processes during different design storms before the design phase, validating the systems reliability during different rainfall events while also not over dimensioning the system, resulting in unnecessary costs. Incorporating model-based analysis into stormwater planning ensures that both conventional and natural based solutions, sustainable drainage systems (SuDS), are dimensioned properly in size and spatially to handle the stormwater load and thus improving the resilience of urban environments towards extreme rain events (Tota-Maharaj et al., 2024).

2.2 Hydrologic & Hydraulic Modeling

Hydraulic modeling describes the water flow through channels, such as pipes, open drains and rivers, and calculates water depth, velocity and pressure using principles of fluid dynamics (Butler & Davies, 2011). Hydrologic modeling focuses on the runoff generation from rainfall by simulating hydrologic processes like precipitation, infiltration and surface flow routing, while hydraulic modeling starts when the water has entered the drainage system. Hydrologic and hydraulic models are often integrated in urban drainage tools to create a more complete representation of catchment responses. Although hydraulic modeling is

typically associated with pipe flow in conduit systems, it is also used for surface flow and flood modeling (Mays, 2010).

2.3 Uncertainty in urban drainage modeling

Uncertainty is an aspect not to be overlooked and is a concurrent in all environmental modeling, including hydraulic modeling. Understanding model uncertainties is critical to properly interpret modeling results. In stormwater modeling, uncertainties can be broadly categorized into three domains: input uncertainties, calibration uncertainties and model structure uncertainties (Deletic et al., 2012).

Input uncertainty comes from errors or imprecision in measurements and representation of model inputs such as rainfall, land-use, digital elevation models (DEMs) and pipe attributes. Inaccurate or low-resolution data such as rainfall data can significantly affect runoff volume and peak flow predictions. Missing data or coarse spatial resolution can also increase the uncertainty of the model. Rainfall input uncertainties were found to spread through the calibration process and affect model output reliability according to the study by Deletic et al. (2012).

Calibration uncertainties can be introduced through errors in observed data and choices in calibration strategies. Deletic et al. (2012) highlighted that calibration datasets are often assumed to be error-free, but in reality, observed flow and quality data can be uncertain. Different event selections or suboptimal calibration algorithms can result in multiple parameter sets showing similar model fits, known as equifinality (Beven, 2007). This lowers confidence in model predictions and can complicate validation. Dotto et al. (2014) investigated how model calibration was affected by systematic and random errors in rainfall and flow data using the KAREN urban stormwater model coupled with a wash off water quality module. The study showed that systematic errors in input and calibration data generally had a greater impact on parameter distribution and model sensitivity than random errors. In most of the systematic error scenarios, the model parameters fully compensated for the errors in measured data, leading to acceptable model fits but biased parameter estimates. In more “worst case” input and calibration data scenarios, the parameters were unable to compensate, indicating degraded model performance. Overall, the study showed that traditional calibrations can mask the presence of systematic errors by shifting parameter values, highlighting the importance of both quantifying and modeling data uncertainty during calibration.

Model structure uncertainties originate from the governing equations and mathematical formulation of the modeling software itself, which can introduce systematic errors. Examples include flow routing

simplification, discarding of minor components or the choice of numerical solvers. Many models are sensitive to minor input or parameter changes which means that small input changes can create large output changes. This is a critical issue in urban drainage systems, as the model often contains complex topography, infrastructure and boundary conditions that need detailed spatial and temporal data (Silberstein, 2006).

Broekhuizen (2019) provides a detailed analysis on uncertainty in rainfall-runoff modeling in green urban drainage systems, including three sources of uncertainty - model structure, model input and model parameters values. This report highlights that uncertainty in model structure, such as flow routing methods or infiltration representation, can have as much impact on output variability as uncertain inputs. It was found through sensitivity testing that minor changes in infiltration and roughness coefficients significantly affected predicted surcharge and peak flows, particularly for more intense rainfall events. The report also points out that model calibration does not eliminate structural uncertainties even when simulated flows match observed data during calibration.

Deletic et al. (2011) propose a Global Assessment of Modeling Uncertainty (GAMU) framework to understand modeling uncertainty better, which interrelates the three mentioned modeling uncertainty categories. This approach explains how uncertainties interact and affect each other. The framework encourages the modelers to assess uncertainties by sensitivity analysis, Monte Carlo simulations, uncertainty propagation modeling and Deletic argue that confidence levels for all model outputs should become standard practice in modeling.

2.4 Comparative evaluation of modeling tools

Stormwater modeling is a crucial tool for the design and evaluation of urban drainage systems. Choice of modeling platforms is known to affect the output result (Deletic et al., 2012), yet the amount of academic research comparing the performance of different modeling platforms remains relatively sparse. While different modeling tools have been widely used in both research and engineering practices, comparative academic analysis between different softwares is quite rare.

In a study by Lundqvist (2020), MIKE FLOOD and FLO-2D were compared in a flooding simulation. The results showed that both models produced similar flood extents but differed significantly in terms of drainage rates and their responses to additional inflow. In this study MIKE FLOOD tended to simulate higher sewer overflow volumes and was more sensitive to inflow assumptions, while FLO-2D

experienced instability in certain flow conditions which indicated model-specific numerical sensitivities and output differences.

On the same note, a study was made by Bengtsson (2018) that compared MIKE URBAN and SWWM using identical catchment inputs and rainfall data. This study pointed out noticeable differences in peak flows, timing of surcharge and the magnitude of overflow volumes. These differences were attributed to how each model handles infiltration, surcharging thresholds and pipe-node interactions where MIKE URBAN offered more detailed control structures while SWMM performed more efficiently during event-based simulation.

Wistfors (2024) conducted a side-by-side comparison of MIKE+ and Fluidit Storm to model cloudburst scenarios in an urban Swedish setting. The study revealed that, even though identical boundary conditions and rainfall input data, the different models produced different results. Fluidit Storm generated faster flow propagation and higher peak flows, which seemed to be due to differences in node connectivity logic, numerical solvers and initial loss handling. MIKE+ allowed greater flexibility in handling surface-pipe interactions but required more manual calibration and setup effort.

In a study by Bisht et al. (2016), MIKE Urban was compared and evaluated against SWMM for urban flood modeling in India. The findings of the report were that there were clear differences in peak flow estimations, highlighting that model structure, assumptions made by the softwares and numerical solutions clearly influenced the simulation results.

Studies have also examined tools applied at broader watershed scales beyond direct comparisons of urban drainage models, which can give valuable insight for stormwater modeling. Yazdi et al. (2019) compared the hydrologic simulation software HSFP with SWMM in simulating stream flow, peak flow and baseflow in an urban watershed. The study showed that the models performed differently. HSPF represented the groundwater driven baseflow processes more accurately while SWMM simulated peak flow more accurately, indicating sensitivities to different hydrological parameters for the models. This highlights a broader perspective for the hydrological process, meaning that complementary models can address broader watershed questions, including groundwater flow and sustainable drainage structures.

3. Objectives & research questions

While the studied modeling tools are widely used in urban stormwater management, there is a noticeable lack of systematic comparisons between MIKE and InfoDrainage. This shows a clear research gap, despite both programs being widely used in stormwater management. Their respective strengths, limitations and performance during identical modeling conditions are still unknown. Therefore, a side by side, evaluation, using the same datasets would contribute to a better understanding and decision making when working with urban stormwater design.

3.1 Aim

The aim of this study was to compare the hydraulic modeling softwares MIKE+ and InfoDrainage. The parameters that were compared are the water pressure levels (flooding & surcharging), discharge, velocity and depth in a stormwater sewer network. The underlying equations and numerical solutions were examined to see which assumptions that possibly produced the different results between the two programs. Thus, the main objective of this study was to evaluate the differences between the two modeling tools in order to increase understanding of their respective strengths, limitations and areas of applicability.

3.2 Research questions

As there is a lack of comparative literature, this study examined the following research questions:

- To what extent do MIKE+ and InfoDrainage produce different simulation results under the same conditions?
- What are the key factors contributing to any differences in model output?
- What are the uncertainties associated with the model results, and how do they affect decision-making?

By addressing these questions, the study contributes to evidence-based decision support in software selection for stormwater modeling tasks.

4. Methodology

The following section will contain information about the software tools used for this study, how the models were set up, how they are compared and the theoretical framework on the hydraulic calculations from MIKE+ and InfoDrainage.

4.1 Software Tools

4.1.1 MIKE+ by DHI

MIKE+ is a simulation software developed by the Danish Hydraulic Institute (DHI) and is used for simulation and analysis of water networks, including stormwater conduit systems, overland flow and river networks (DHI, 2021).

4.1.2 InfoDrainage (Autodesk)

InfoDrainage is a stormwater design and analysis software developed by Autodesk, previously known as MicroDrainage under Innovyze. It is also used for simulation and analysis of water networks, like MIKE+ (Autodesk, 2024).

4.1.3 SCALGO LIVE

Scalgo Live is a cloud based geospatial platform developed by SCALGO (Scalable Algorithmics). It is designed to obtain terrain data, such as elevation and land cover, for water flow modeling based on digital elevation models (DEMs). Scalgo uses elevation data from Lantmäteriet (n.d.). The platform gives visualization and data over flow directions, catchment area properties and surface flow patterns even in areas with more complex topographies (SCALGO, 2024). In this study, SCALGO LIVE was used to obtain surface data for the DEM and landcover data for the surface runoff calculations.

4.2 Hydraulic Comparison

After the models were set up, the hydraulic performance was evaluated. Firstly, a mass balance analysis was performed by comparing total inflow and outflow volumes for each rainfall event in both softwares. The difference was quantified as a mass balance error which gives an insight into numerical stability and reliability of the simulation results. A mass balance error below 1% is considered very good, while values up to 10% can be acceptable if the time series of the mass balance remains stable over the simulation period (SVU, 2016).

Secondly, pressure maps were generated to identify the locations in the network that were affected by surcharge or flooding. In MIKE+, shapefiles for maximum link pressure and flooding were exported to QGIS where surcharge conditions were defined as pressure levels above the pipe crown and flooding defined pressure levels above the ground level. The same was done for InfoDrainage, though with an extra condition - Flood Risk, which indicated where the pressure levels were above the pipe crown and the flood risk level, but below ground level (InfoDrainage, 2024). This comparison made it possible to visualize and evaluate the spatial distribution of hydraulic network loads in the system, which is a recommended practice in capacity studies (SVU, 2016).

Thirdly, time series analyses were performed at three selected points of interest in the network system. Discharge, flow velocity and water depth were plotted in Excel to assess the hydraulic performance under the different rainfall events. This allows evaluation of how quickly the system responds, peak magnitudes and recovery times, recommended for hydraulic model elevation (Svenskt Vatten, 2019).

Finally, profile plots were created for three flow paths to visually compare the hydraulic pressure levels. The comparisons were made for the CDS and Block rainfall events with 10- and 30-year return periods. Profile plots allow for longitudinal assessment of network pressure conditions across an entire flow path. This is an effective way of identifying network sections where pressure builds up or capacity limitations start occurring. Longitudinal profiles of the hydraulic pressure lines are a recommended tool in capacity assessments as they show how the system operates in regard to its design limits and where surcharging or flooding might occur (Svenskt Vatten, 2019).

4.3 Study area

The study area is an urban drainage area with collection system network data provided by Lumire.

4.3.1 Elevation models

To ensure realistic surface data and flow behaviors, a DEM based on the extent of the study area was created in Scalgo LIVE (Figure 4.1).

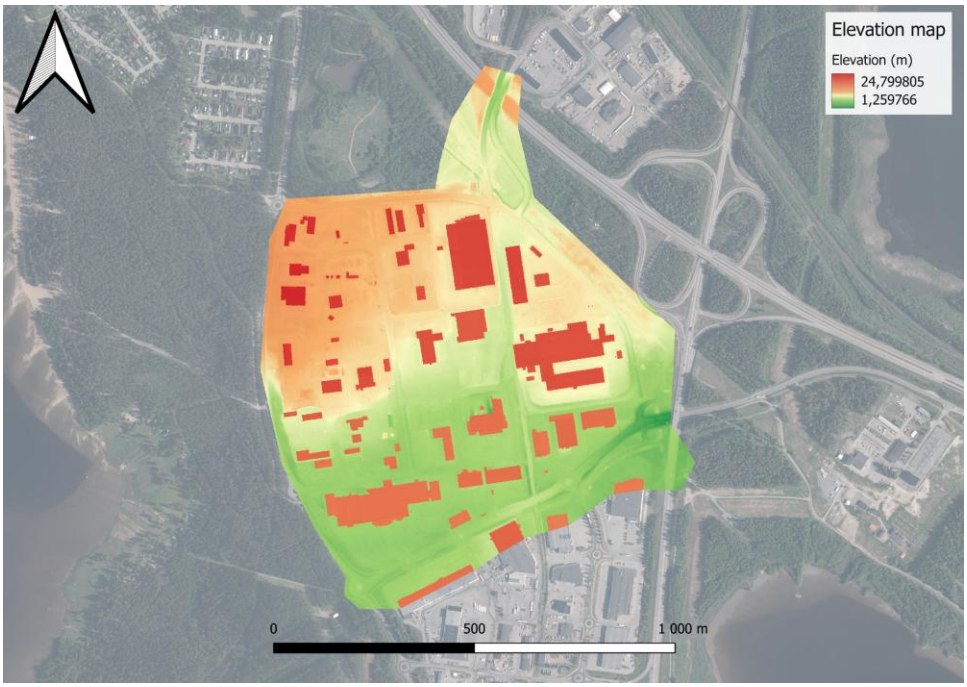
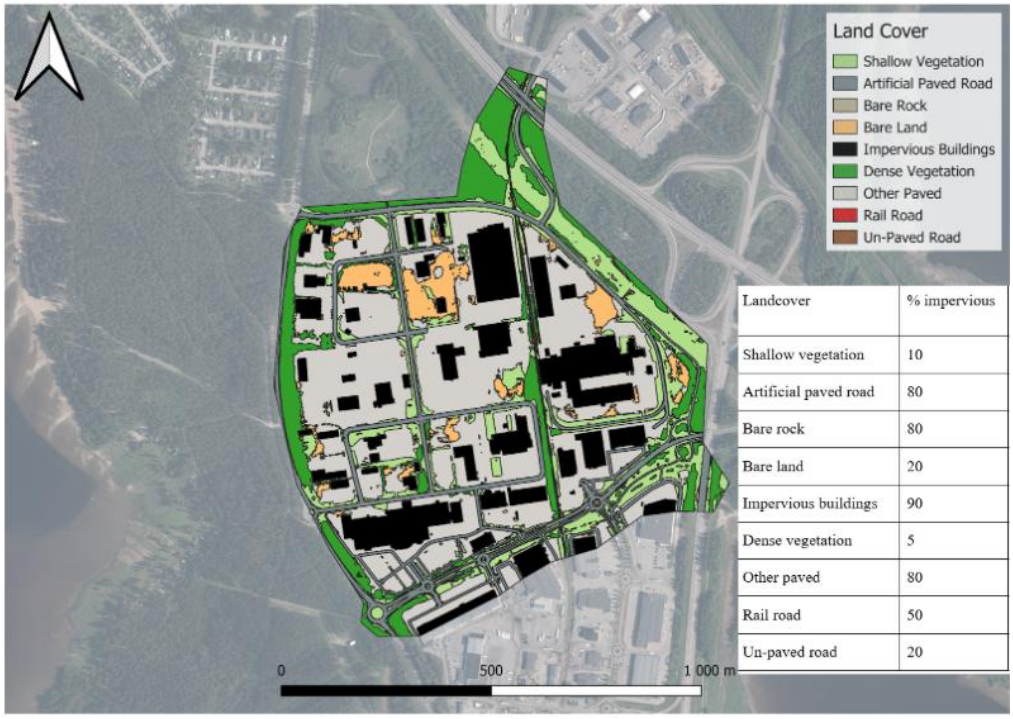


Figure 4.1: The Digital Elevation Model over the study area.

4.3.2 Landcover

The type of land cover determines how much of the water will flow into the stormwater network. Therefore, land cover data was collected from Scalgo Live to calculate the percentage of impervious areas each sub-catchment consists of. Harder surfaces like roofs and concrete will infiltrate less water and thus be more impervious while soft surfaces will transport less water and be more pervious. The landcover percentage impervious values were based on values from Svenskt Vatten (2019), though without exact matching landcover types which made the choice somewhat subjective. The type of land cover is presented in Figure 4.2 and with matching imperviousness.



Landcover	% impervious
Shallow vegetation	10
Artificial paved road	80
Bare rock	80
Bare land	20
Impervious buildings	90
Dense vegetation	5
Other paved	80
Rail road	50
Un-paved road	20

Figure 4.2: Study-area land cover types and percentage imperviousness.

4.3.3 Rainfall

Chicago Design Storms (CDS) and Block rainfall events at two return periods of 10- and 30-years were simulated in this study. The CDS is commonly used to generate design storms for urban stormwater evaluations. It is derived from the relationship between intensity, duration and frequency (Scalgo, n.d.). The CDS rainfall intensity is based on the Dahlström equation.

$$i_{Å} = \sqrt[3]{Å} * \frac{ln(T_R)}{T_R^{0,98}} + 2 \quad (1)$$

Where;

$i_{Å}$ = Intensity [l/s, ha]

T_R= Duration [minutes]

Å = Return period [months]

The CDS rain is constructed of multiple blocks that represent intensities for different durations that together create the CDS-hyetograph (Figure 4.3) with a sharp peak in the middle, that explains how the intensity varies with time (Svenskt Vatten, 2011). To transform the intensity from l/s, ha to mm/hr, the intensity was multiplied by a factor of 0,36.

The Block rainfall (Figure 4.4) was created by calculating the same amount of total rainfall volume and dividing it equally over the same time span as the CDS rainfall events. The simulation time for each event is 10 hours and the rainfall duration 6 hours.

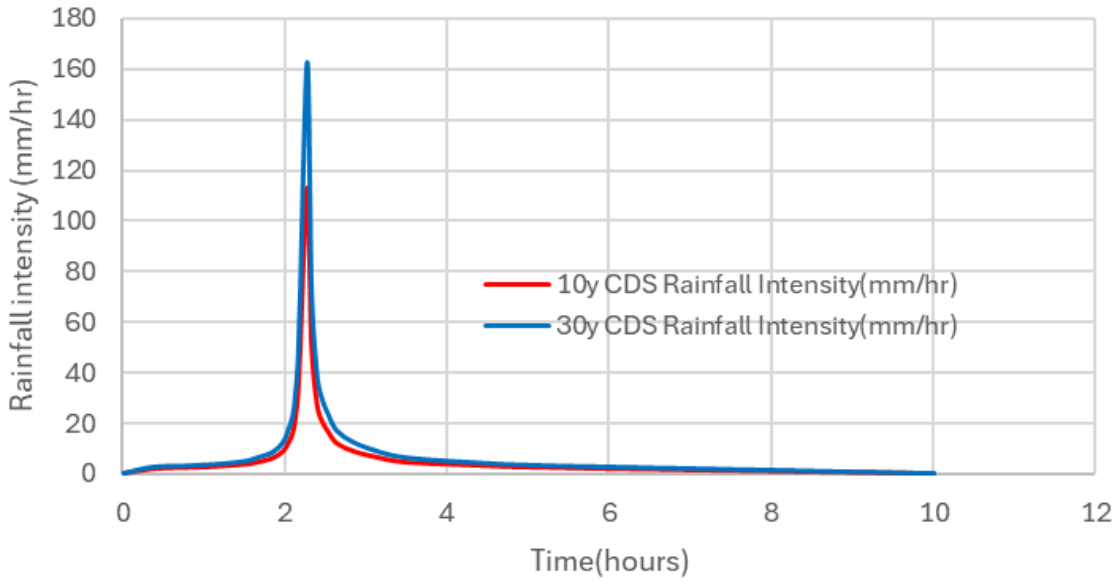


Figure 4.3: Rainfall hyetograph for the 10-year (red) and 30-year (blue) Chicago Design Storms.

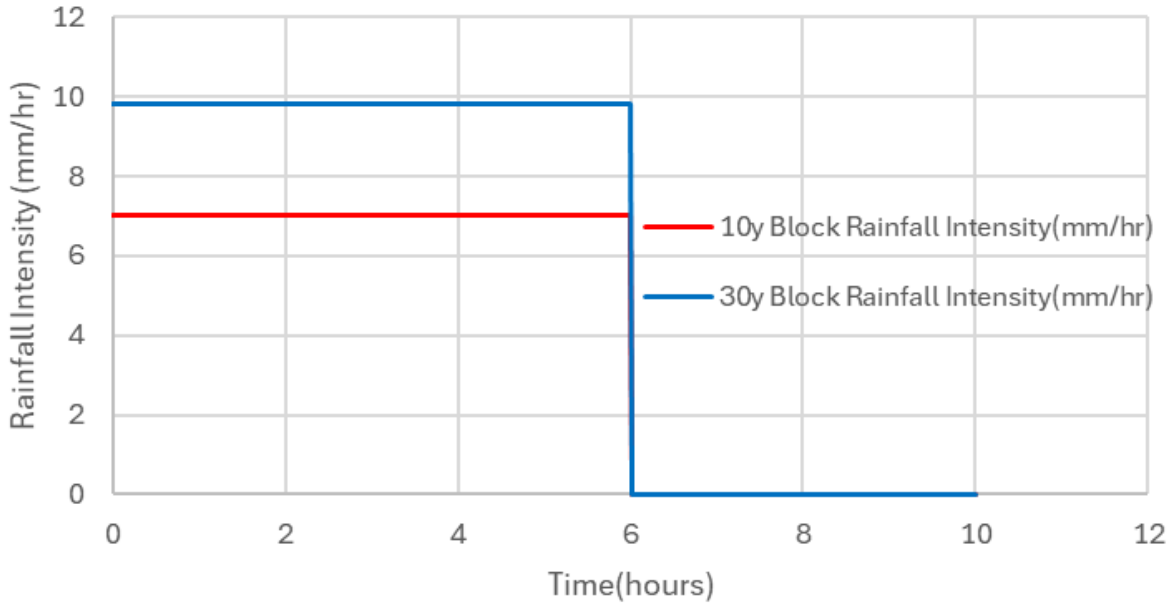


Figure 4.4: Rainfall hyetograph for the 10-year (red) and 30-year (blue) Block rainfall.

In this study, the Time-Area method was applied to create the run-off hydrograph. This method divides the watershed into isochrones, zones contributing with runoff at the same time, and accumulates their contributions to generate the runoff hydrograph, taking the land cover roughness, elevation and area into account when calculating the runoff (Her & Heatwole, 2016).

4.4 Model setup

The models were set up with identical input values to ensure that any differences observed could be attributed to differences in the hydraulic aspects of the models. Known information of the stormwater network, including node type, diameter, ground level, bottom level, location and pipe length, diameter, material, up- and down-stream level, was provided by Lumire and matched in both softwares. Figure 4.5 presents the stormwater network, including pipes, nodes, flow direction and basin outlet.

Figure 4.5: Overview of the stormwater network, including pipes, nodes, flow direction and basin outlet.

4.4.1 MIKE+

The MIKE+ model was built directly in the MIKE+ software based on the given values of the stormwater network. Firstly, all nodes and pipes were spatially distributed and connected. Ground- and bottom- level were then set for all nodes and after that all the properties for the pipes and nodes were set, including diameters, cover types and pipe materials. Catchments were created in the Catchment Delineation tool,

based on the DEM, with a grid resolution of 1x1 meter (Lantmäteriet, n.d.), and the basin area, where 98 sub-catchments were created. To calculate the percentage of impervious areas for each sub-catchment, the Catchment Processing tool was used with land cover input imported from Scalgo. To finish the catchment creation process, the Connection Tool was used to connect each sub-catchment to the nearest node, and the hydrological model Time-Area was assigned to each, as this method is available in both software. Four rainfall events were added as boundary conditions, 10- and 30- year Chicago Design Storm and 10- and 30- year block rainfall.

Model components type

The model type is set as Rivers, collection system and overland flows in MIKE+ with the unit system SI units (CMS), including the features Catchments and Collection System Network and the modules Rainfall-Runoff (RR) and Hydrodynamic (HD) with control rules.

The hydraulic model was configured as a combined setup with *River, Collection System and Overland Flow*. This allows for the simulation of surface runoff, pipe network hydraulics and potential interactions with river systems.

Two key feature groups were enabled, *Catchments* and *Collection System Network.* Catchments define the spatial area and represent hydrological processes, and the collection system network represents the stormwater infrastructure (pipes, manholes, outlets). This setup allows rainfall to transform into runoff and then collected and transported in the pipe network. In the model type, the modules *Rainfall-Runoff* and *Hydrodynamic* were assigned. The RR-module supports different runoff models.

In this study, the Time-Area method was assigned. This method calculates hydrographs from the precipitation based on travel time distributions within each sub-catchment and assumes rainfall is uniformly distributed across the catchment and the time runoff contributes to the node is dependent on the distance to the node. The catchment is divided into areas of equal travel time, and the cumulative contributing area is expressed as the time-area curve. The HD module is based on the full one-dimensional Saint-Venant equations. Describing conservation of continuity and momentum, described further in the Theoretical Framework (DHI, 2021).

Coordinate system

The coordinate system is set to SWEREF 99 21 45 as the study area is in the northern parts of Sweden (Lantmateriet, n.d.).

Nodes

Nodes were added manually based on the given coordinate and property data for each node. All nodes were set as Manholes, except the outlet. Manually in MIKE+, each node was given properties for diameter, ground level and bottom level. In the hydraulic setup the nodes were defined with cover type Normal. This allows surcharge above the ground, enabling temporary surface storage and re-entry into the network (DHI, 2022). Head losses at the nodes were calculated using the Weighted Inlet Energy method, which is a common practice for MIKE+ models. The method takes the energy level of a node as a flow-weighted average of all incoming flows and accounts for velocity head contributions from multiple inlets. Full Node Area was applied for the effective flow area, meaning that the wetted area is approximated as the entire manhole cross-sectional area (DHI, 2021).

Pipes

Circular pipes were added manually based on given coordinate and property data for each pipe. The wave approximation type was set as Fully Dynamic, it includes all terms in the momentum equation: pressure, inertia, convective acceleration, and friction which solves the complete Saint-Venant equations and thus capturing rapid changes, surcharging and backwater effects. The fully dynamic formulation is recommended when modelling urban drainage systems with surcharging manholes, steep-to-flat slope transitions, or downstream control structures, because only this approach can reliably simulate the hydraulic grade line and pressure distribution under such conditions (DHI, 2021). Hydraulic resistance was calculated using the Manning equation, where the Manning's n value was set to 0.01333333.

Catchments

The catchments were created with the *Catchment delineation* tool within MIKE+ and generated based on the DEM and the nodes. 98 catchments were generated (Figure 4.6), linked to a node through the *Connection Tool* and their properties were computed in the *Catchment Processing* tool, which computed the hydrological parameters for the runoff simulation. In the tool- model setup, the land use data retrieved from Scalgo Live was used to assign imperviousness percentages for the difference surface types. From this, MIKE+ calculated the impervious fraction for each sub-catchment. The Time-Area method was applied to describe the rainfall-runoff transformation. The hydrological reduction factor was set to 0.9 to represent abstractions such as interception and small surface depressions. The initial loss was set to 0, meaning all rainfall is assumed to contribute to runoff. Still, there are probably some initial losses, though not affecting the goal of the study. The created Time-Area curves describe how fast different parts of each catchment will contribute with flow. Larger catchments with longer flow paths produce longer times of

concentration and therefore a slower response, while smaller catchments respond more quickly with sharper hydrograph peaks (DHI, 2021).

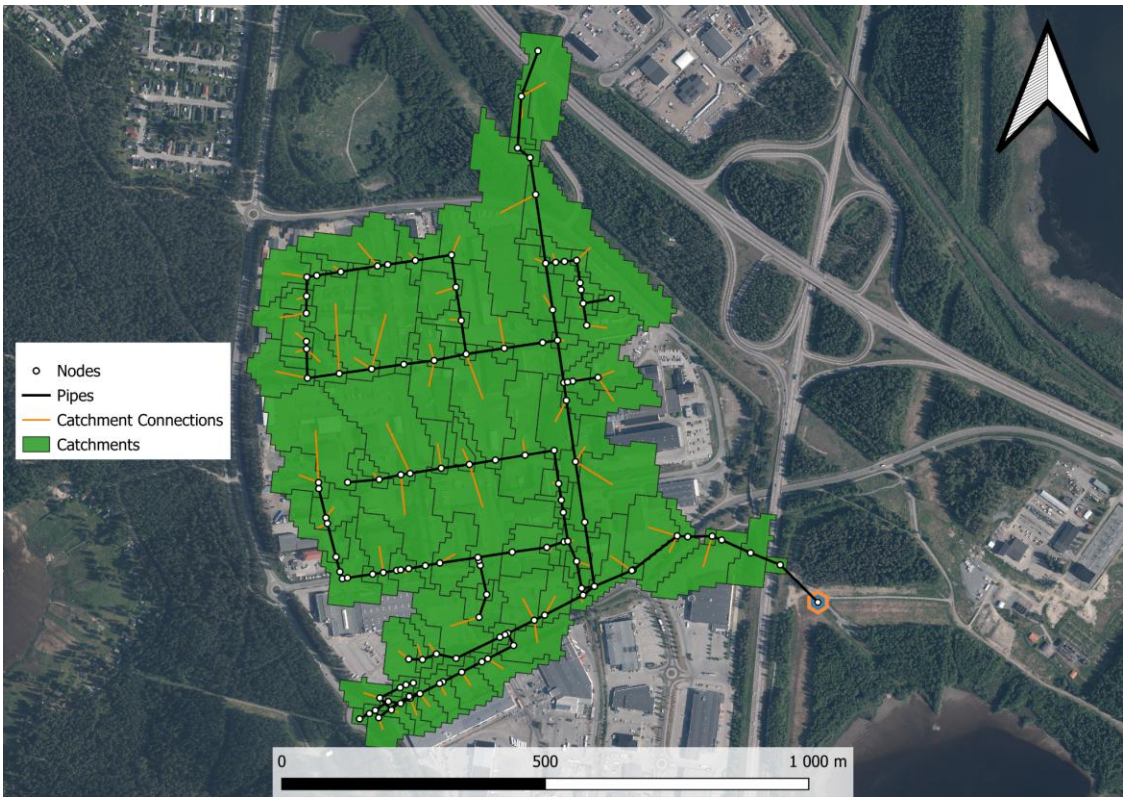


Figure 4.6: Catchment map, including sub-catchment outlines, catchment connections, nodes and pipes.

Boundary conditions/rainfall event

4 rainfall events were studied as presented in the "Rainfall"-heading. The scaling factor of 1.25 was set, meaning that the rainfall intensity was simulated as 25% higher than the actual rainfall-event to account for future climate changes, as recommended by Svenskt Vatten (2019).

Simulation setup

The features of the simulation type were set to Catchments and Collection System Network. The modules included in the simulation setup were Rainfall-Runoff, Catchment Discharge and Hydrodynamic and the simulation time was set to 10 hours. The hydrodynamic time step was set to adaptive with 5 seconds as minimum and 60 seconds as maximum. The project output was set to save every 60 seconds.

4.4.2 InfoDrainage

To ensure the similarity with the MIKE+ model, the nodes and pipes were first projected in Civil3D with the same coordinates. After all nodes and pipes were connected, a DEM was imported as a TIN-surface.

The pipes, nodes and surface were exported into InfoDrainage from Civil3D. All of the following attributes to the InfoDrainage model were assigned to match the settings and attributes of the MIKE+ model.

Junctions (nodes)

After the import, all nodes were given their belonging attributes manually. The junction type was set to Manhole, the part family set to Plastic Drainage Well and the cover elevation, depth, invert elevation and diameter was set for each. The outlet type from each manhole was set to free discharge except for the final outflow from the network that was set as orifice, as it is advised to be used as outlet. Free discharge will allow flooding, temporal storage on the fictive surface and re-entry of flooded volumes into the nodes. Free discharge also implies that water will leave the outlets based on the depth of the water in the system alone, without considering any downstream conditions (EPA, 2017). The inlet capacity type was set to no restriction.

Connections (Pipes)

Each pipe was given its respective property for diameter, upstream and downstream cover and inverted elevation, the friction scheme was set to Manning's n and given the value 0.013 to match the MIKE+ model (0.01333333).

Inflows (Catchments)

A shapefile of the catchment delineation from MIKE+ was imported into InfoDrainage and all inflows were drawn and matched to the right manhole manually in InfoDrainage with the snapping tool to match each area and outline perfectly. The percentage imperviousness of each inflow was copied from the MIKE+ model and here the runoff coefficient was set to 0.9, meaning that 90% of the rainfall will be converted to runoff and 10% will be lost to in the form of abstractions such as infiltration, interception, and evaporation (InfoDrainage, 2024). The time of concentration was also copied from the MIKE+ model and the runoff method set to Time-Area Diagram.

Rainfall

The same 4 rainfall events with an increased rainfall percentage of 25 were used in InfoDrainage as described further in the Rainfall heading.

Analysis

In the analysis tab, the runoff type was set as dynamic, meaning that the full rainfall hydrograph is utilized to produce the inflow hydrograph. The output interval was set to 1 minute and the time step to shortest (InfoDrainage, 2024).

4.5 Theoretical framework

4.5.1 Governing equations & assumptions MIKE+

MIKE+ uses the Saint-Venant equations to describe unsteady one-dimensional flow in pipes and channels, which consist of the momentum and continuity equations under following assumptions (DHI, 2021):

- The water is incompressible and of uniform density.
- The pressure is hydrostatically distributed, i.e. vertical acceleration is neglected.
- The flow is considered to be one-dimensional along the conduit.
- Mild slope assumption.
- Both subcritical and supercritical flows are handled.

The continuity equation (conservation of mass) takes the following form for a general cross section:

$$\Delta A/\Delta t + \Delta q/\Delta x = q_{lat} \quad (2)$$

Where;

A = cross-sectional area [m^2]

t = time [s]

q = discharge [m^3/s]

q_{lat}= lateral inflow [$m^3/s/m$]

x = distance in the flow direction [m]

The momentum equation (conservation of momentum):

$$\Delta q/\Delta t + \Delta(\alpha q^2/A)/\Delta x + gA\Delta h/\Delta x + gAI_f = F \quad (3)$$

Where;

q = discharge [m^3/s]

t = time [s]

A = cross-sectional area [m^2]

x = distance in the flow direction [m]

h = water level [m]

α = momentum correction coefficient [-]

g = gravitational acceleration [m/s^2]

I_f = friction slope [-]

F = forcing momentum [$m^2/s^2/m$]

The Saint-Venant equations are solved using the Abbott-Lonescu 6-point implicit scheme that is implemented on a staggered computational grid where the discharge (q) and water level (h) are computed at alternating spatial nodes. The basic principle of this numerical scheme is to approximate the derivatives in time and space using values from neighboring nodes - thus the continuous partial differential equations of Saint-Venant are transformed into a set of algebraic equations that are solved simultaneously. This scheme ensures numerical stability due to its implicit nature, even in more complex networks with large time-steps.

In this setup the hydraulic resistance was calculated with Manning's equation, with Manning's n set to 0.01333333. The friction slope is calculated as follows:

$$I_f = fq|q| \quad (4)$$

With the friction factor, f:

$$f = 1/(M^2 A_{fl}^2 R^{4/3}) \quad (5)$$

Where;

M = $1/n$, Manning's M [$m^{1/3}/s$]

A_{fl} = flow area [m^2]

R = hydraulic radius [m]

Surcharging, for example, can lead to pressurized pipe flow which invalidates the basic assumption for the derivation of the Saint-Venant equations. In these cases, MIKE+ resolves this problem by using the Preissmann slot method. The method basically means that a fictitious slot above the pipe crown can be included without modifying the Saint-Venant equation. This allows smooth transitions between free surface-flow and pressurized flow states (DHI, 2021).

4.5.2 Governing equations & assumptions InfoDrainage

InfoDrainage performs hydraulic routing using the SWMM engine. The software applies the dynamic wave formation, which is solved using a semi-implicit scheme. It is based on the full one-dimensional Saint-Venant equations for unsteady pipe and open channel flows, see previous section about governing equations in MIKE+ for more details. Pipes are represented as links in the SWMM engine, and the discharge is calculated from the water elevations at each end of the link and its properties (geometry,

slope and roughness). The hydraulic resistance is calculated using Manning's equation, using the same equations as MIKE+. Additional minor losses are accounted for at entries, exits and bends using the velocity head formulation (EPA, 2017):

$$h_L = Kv^2/2g \quad (6)$$

Where;

h_L = loss [m]

K = dimensionless loss coefficient depending on geometry

v = velocity [m/s]

g = gravitational acceleration [m/s^2]

Manholes are represented as storage nodes. InfoDrainage allows manholes to flood. Flooded volumes may pond above ground and re-enter the network once water level drops. Head losses at nodes are calculated and added to the entry losses of connected pipes following the energy head-loss approach (EPA, 2017).

MIKE+ and InfoDrainage share similarities but also differences in their hydraulic engines, as presented in Table 5.3.1. Both software hydraulics are based on the one-dimensional Saint-Venant equations, but they are solved using different numerical schemes. MIKE+ handles pressurized flow with the Preissmann-slot method to ensure the validity of the Saint-Venant equations during such conditions. Node head losses in MIKE+ were calculated using Weighted Inlet Energy which takes the energy level of a node as a flow-weighted average of all incoming flows and accounts for velocity head contributions from multiple inlets. InfoDrainage uses the velocity head formulation to account for losses in node entries, exits and bends. Both MIKE+ and InfoDrainage utilize Manning's equation to calculate hydraulic resistance in this study.

Table 5.3.1: Comparison of hydraulic calculations.

Aspect	**MIKE+**	**InfoDrainage**
Governing equations	Saint-Venant	Saint-Venant
Numerical scheme	Abbott-Lonescu, implicit staggered grid	Dynamic wave, semi-implicit
Pressurized flow	Preissmann slot method	Continuity, damping factors
Node interactions	Weighted Inlet Energy (nodes)	Velocity head formulation (entries, exits, bends)
Resistance	Manning's equation	Manning's equation

5. Results

5.1 Mass Balance Error

The volume balance shows slight mass balance errors in inflow and outflow volumes. In MIKE+, the inflow was slightly higher than outflow for the 10- and 30-year CDS events, giving a small positive mass balance error (Table 5.1). The inflow was slightly lower than the outflow for the 10- and 30-year Block rainfall events, giving a small negative mass balance error (Table 5.1). The block rainfall events thus gave a negative mass balance error though the network's initial conditions were set to zero, indicating a systematic error.

Table 5.1. Outflow volume compared to inflow volume in MIKE+ for the different rainfall events.

Rainfall event	System outflow volume MIKE+ (m^3)	System Inflow Volume MIKE+(m^3)	Mass balance error (%)
10-year CDS	18804	18851	0.25
30-year CDS	26393	26461	0.26
10-year Block	19159	19148	-0.06
30-year Block	26925	26916	-0.03

The volume balance in InfoDrainage, on the contrary, showed a minor negative mass balance error for the 10-and 30-year CDS events. The 10- and 30-year Block event gave a minor positive mass balance error (Table 5.2).

Table 5.2. Outflow volume compared to inflow volume in InfoDrainage for the different rainfall events.

Rainfall event	System outflow volume IDR (m^3)	System Inflow Volume IDR (m^3)	Mass balance error (%)
10-year CDS	19366	19364	-0,01
30-year CDS	27132	27129	-0,01
10-year Block	19373	19373	0,003
30-year Block	27145	27145	0,002

Overall, all events satisfy SVU's "very good" criteria (<1% error) (SVU, 2016), indicating sufficient numerical stability. InfoDrainage's smaller error values indicate greater numerical stability than MIKE+. Worth noting is that InfoDrainage produces larger inflow and outflow volumes for all events. Furthermore, both models have a higher error for the CDS rainfall, indicating more difficulties with higher peak intensities for both models. It was also noted that the simulation time of the models were approximately the same, though slightly faster in MIKE+ (+1-3 seconds) which could be one potential explanation for this minor difference in mass balance error.

5.2 Network Pressure lines

Overview of the maximum pressure levels is presented in this section. In MIKE+, the pressure levels are derived as maximum link pressure(m) from zero meters, where pressure levels do not exceed the pipe crown, categorized as surcharge where the pressure levels are between the pipe crown and ground level and derived as maximum link flood when the pressure levels exceed the ground level. InfoDrainage specifies network status conditions directly - No surcharge (OK), Surcharge condition, Flood risk and Flood. No surcharge (OK) is defined as when the maximum water elevation is below the outgoing pipe crown. Surcharge conditions are defined as when the maximum water elevation is below the cover elevation but is above the outgoing pipe crown. Flood risk is defined as when the maximum elevation is

above the outgoing pipe crown and above the flood risk margin depth but below ground level. Flood is defined as when the maximum water elevation is above the cover elevation (EPA, 2017).

5.2.1 Chicago Design Storm

The pressure levels for the 30-year CDS event for both MIKE+ and InfoDrainage are presented in Figure 5.1. Firstly, comparing the 30-year CDS event to the 10-year CDS event (Appendix A) both models show conditions with flooding or surcharging in similar network areas, but with flooding to a greater extent for the 30-year event. This indicates greater pressure levels for the 30-year event, which was expected. Secondly, comparing the MIKE+ and InfoDrainage model, there is a notably larger extent of flooding in MIKE+, indicating higher pressure levels overall. InfoDrainage shows flooding in a small section closer to the basin outlet to the east, which MIKE+ does not, making it the only network section with higher pressure levels in InfoDrainage, notable from the pressure level map.

Figure 5.1. Maximum link pressure map from the 30-year CDS event in MIKE+ (left) and InfoDrainage (right).

To summarize the pressure levels for the CDS event, both models show pressure levels following the same pattern. MIKE+ shows overall higher pressure, though InfoDrainage shows flooding in some sections where MIKE+ does not. Worth highlighting is that the sections where InfoDrainage possesses higher pressure levels are often by sections where multiple pipes are connected, which could be explained by how their respective engine handles node-calculations.

5.2.2 Block rainfall

The pressure levels for the 30-year Block event for both MIKE+ and InfoDrainage are presented in Figure 5.2. Firstly, comparing the 30-year Block event to the 10-year Block event (Appendix A), the main difference is that the pressure levels overall are higher for the 30-year event, showcasing surcharging to a greater extent and increased pressure levels in similar network areas, which was expected. Secondly, comparing MIKE+ and InfoDrainage for the Block event, MIKE+ shows surcharge to a greater extent and even some flooding. The increased pressure levels are showcased in the same area of the network though, to the west.

Figure 5.2. Maximum link pressure map from the 30-year Block event in MIKE+ (left) and InfoDrainage (right).

Similarly to the CDS event, MIKE+ shows greater pressure levels overall for the Block event. From the Block event no other conclusions can be drawn except for that MIKE+ produces higher maximum pressure levels, indicating differences in the models' hydraulic calculations.

5.3 Hydrographs

Discharge (m^3/s), Flow velocity (m/s) and water depth in the pipes will be compared between MIKE+ and InfoDrainage in three points of interest (Figure 5.3) in the network system. Point 1 consists of a pipe with a diameter of 1.4 m and a slope of approximately 1.65‰. Point 2 consists of a pipe with a diameter

of 0.8m and a slope of approximately 0.48‰. Point 3 consists of a pipe with a diameter of 1.2 m and a slope of approximately 1.35‰.

Figure 5.3. Points of interest used for the time series plots.

5.3.1 Point 1

Figure 5.4 shows the comparison of the simulated time series for discharge velocity and link depth at point 1 during the 30-year CDS rainfall event. As with the 10-year CDS (Appendix B), both MIKE+ and InfoDrainage produce the same general hydraulic response, but minor systematic differences are observed in the peaks and distribution.

The hydrographs for discharge from both models follow the same shape and timing. MIKE+ produces a slightly higher peak compared to InfoDrainage, pointing at a more concentrated runoff routing.

MIKE+ also produces a higher peak for flow velocity compared to InfoDrainage, but still with a similar pattern in shape and timing. This difference also reflects the same trend noted for the 10-year CDS (Appendix B), MIKE+ tends to simulate higher peaks in flow and velocity for these events.

For link depth, both models show similar rising limbs with filled pipes at 1,4m, but InfoDrainage shows a longer time span with filled pipe conditions as the link depths decrease earlier in MIKE+. This indicates

that MIKE+ contains more of the specific energy as velocity, while InfoDrainage translates it into higher water levels within the pipe with a slower runoff.

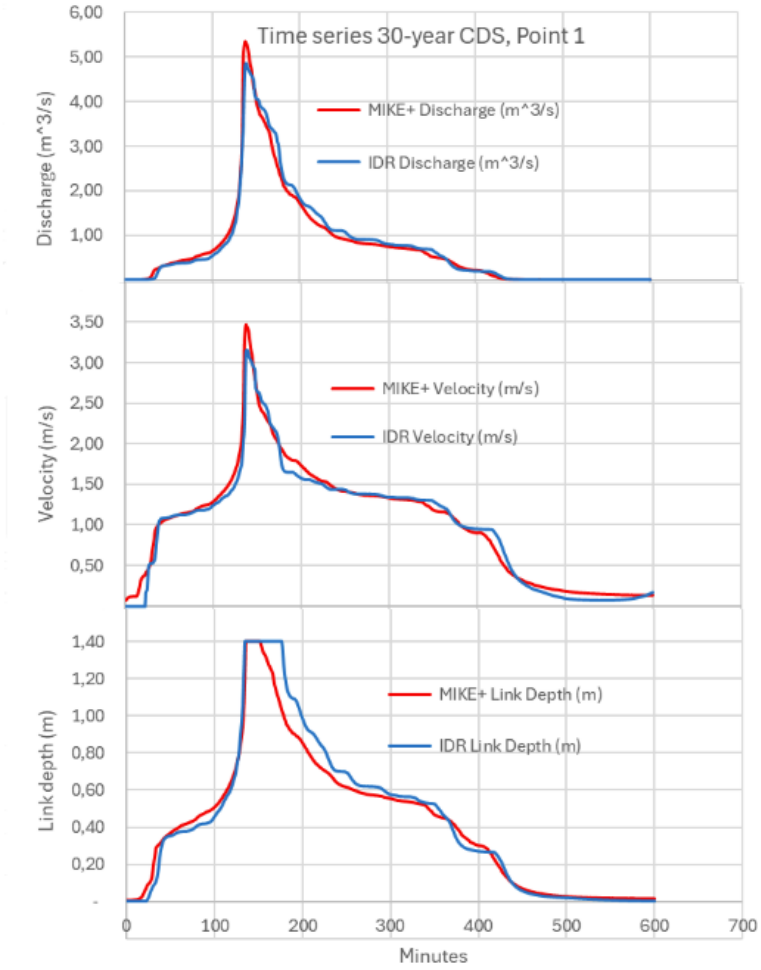


Figure 5.4: Time series graph for discharge velocity & link depth in point 1 for the 30-year CDS event.

Figure 5.5 shows the time series for discharge, velocity and link depth at point 1 during the 30-year Block rainfall event. In contrast to the CDS events, the Block rainfall produces a longer more constant inflow which is reflected in the hydrographs. Overall, the models show similar patterns in shape and timing for the 30-year Block event, the same for the 10-year Block event (Appendix B).

Both MIKE+ and InfoDrainage produce very similar discharge results, with a similar discharge peak, timespan and sharp decline as the rainfall ends. This suggests that flow routing is handled consistently by both model solvers under steady inflow conditions.

For velocity, both models show stable velocities throughout the storm duration with a sharp decline at the end, though a slightly higher peak in MIKE+. The similarity indicates that both engines produce hydraulic velocity consistently. The late spike for the InfoDrainage velocity can be regarded as an anomaly and

disregarded as it is most likely a numerical error and not physically meaningful yet, interesting that it produces this.

The link depth also shows a similar pattern in both models with a slightly higher depth in InfoDrainage, similar to the observations of the CDS event in point 1. Both models produce a similar rapid incline, decline and a nearly constant water depth during the storm duration. Notably for this Block event is that the link depth never reaches the full pipe diameter at 1.4 m, in contrast to the CDS event.

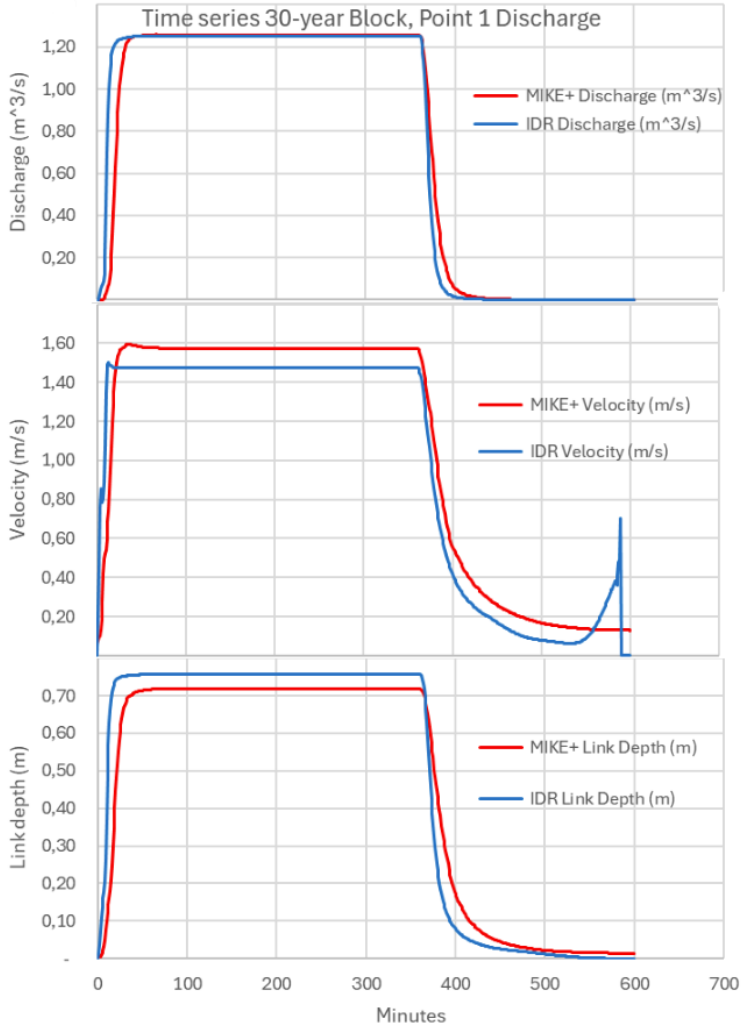


Figure 5.5: Time series graph for discharge velocity and link depth in point 1 for the 30-year Block event.

5.3.2 Point 2

Figure 5.6 presents the time series for discharge, velocity and link depth at point 2 for the 30-year CDS event. As with the 10-year CDS (Appendix B), both MIKE+ and InfoDrainage produce the same general hydraulic response, but minor systematic differences are observed in the peaks and distribution.

Both MIKE+ and InfoDrainage produce a sharp discharge peak in similar timing, but MIKE+ shows a slightly higher peak. Overall, the discharge graph shows a similar pattern between the models.

For velocity, MIKE+ also shows a higher peak value, but also declines faster as the InfoDrainage velocity sustains higher values after the peak. InfoDrainage also shows some oscillations after the peak, reflecting the engine's sensitivity to transitions of surcharging conditions and showcases an example of numerical instability.

The link depth reaches full pipe conditions at 0.8m and follows similar patterns for both models. The link depth in MIKE+ inclines faster and maintains higher values longer than InfoDrainage does.

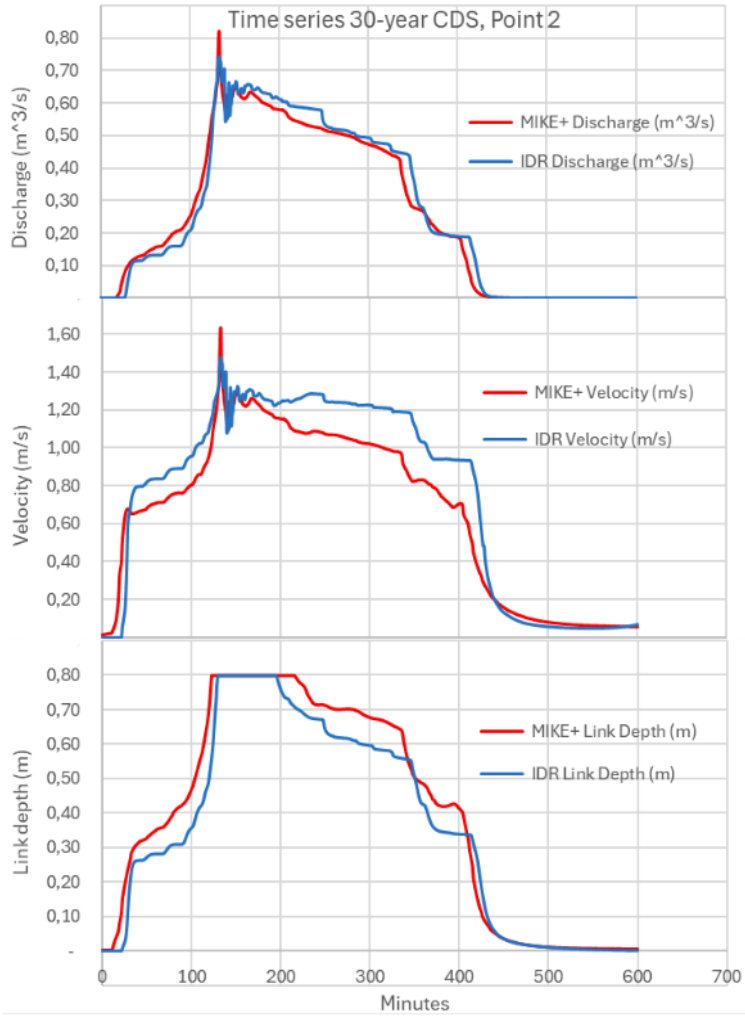


Figure 5.6: Time series graph for discharge velocity and link depth in point 2 for the 30-year CDS event.

Figure 5.7 shows the time series for discharge, velocity and link depth at point 2 during the 30-year Block rainfall event. In contrast to the CDS-events, the Block rainfall produces a longer more constant inflow which is reflected in the hydrographs. Overall, the models show similar patterns in shape and timing for the 30-year Block-event, the same for the 10-year Block event (Appendix B). Both models appear to have minor instability when they first approach the plateau and the steady state flow.

For discharge, both models show a pattern with very clear similarities with a rapid incline, decline and a sustained flow plateau throughout the storm duration. This suggests that flow routing is handled consistently by both model solvers under steady inflow conditions.

The velocities also follow the same pattern, but with a notably higher velocity in InfoDrainage. The late spike for the InfoDrainage velocity can be regarded as an anomaly and disregarded as it is most likely a numerical error and not physically meaningful.

The link depth graph follows similar patterns for both models, but with a notably higher link depth plateau in MIKE+, like the behavior observed for the CDS event in point 2. Also worth noting is that the link depth never reaches filled pipe conditions at 0.8m depth, in contrast to the CDS-event.

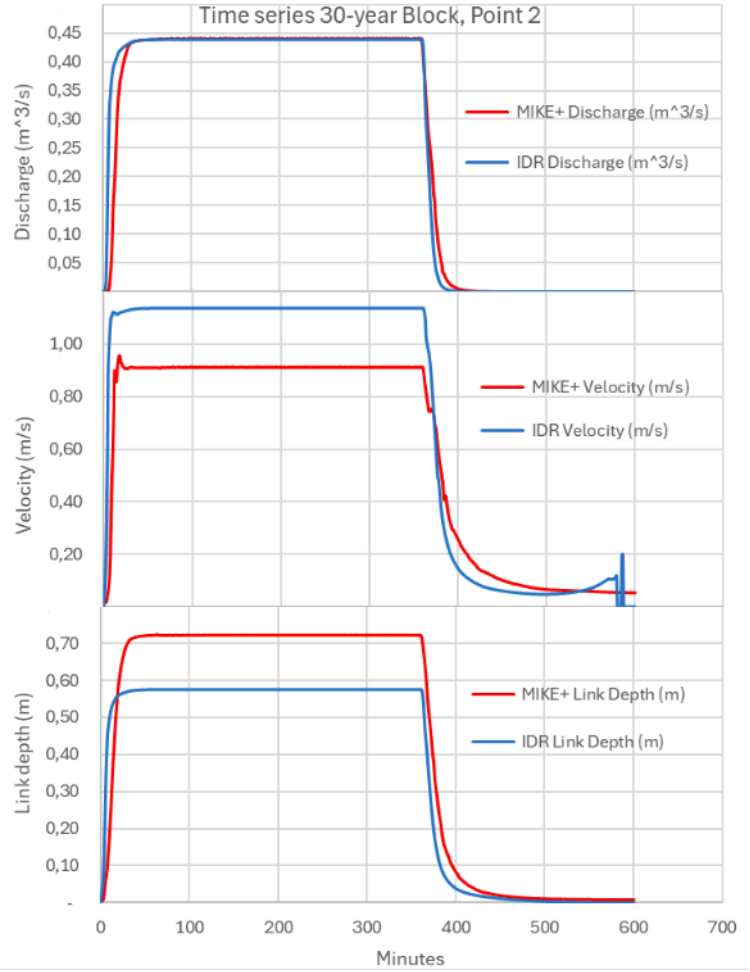


Figure 5.7: Time series graph for discharge velocity and link depth in point 2 for the 30-year Block event.

5.3.3 Point 3

Figure 5.8 presents the time series for discharge, velocity and link depth at point 2 for the 30-year CDS event. As with the 10-year CDS (Appendix B), both MIKE+ and InfoDrainage produce the same general hydraulic response but minor systematic differences are observed in the peaks and distribution.

MIKE+ and InfoDrainage produce nearly identical discharge graphs. Two peaks are observed, with the first peak to the left in the graph showing a clearly higher overall peak in InfoDrainage and the second peak showing higher values in MIKE+. The two peaks possibly indicate contributions from different network areas with different peak flow timings or possibly some numerical instability.

The velocity graph follows a similar pattern to the discharge graph with an initial higher peak in InfoDrainage followed by a second peak that is slightly higher in MIKE+. The MIKE+ velocity also declines faster compared to InfoDrainage. The link depth clearly follows the same pattern in both models in regard to incline, decline, plateau duration at full pipe conditions.

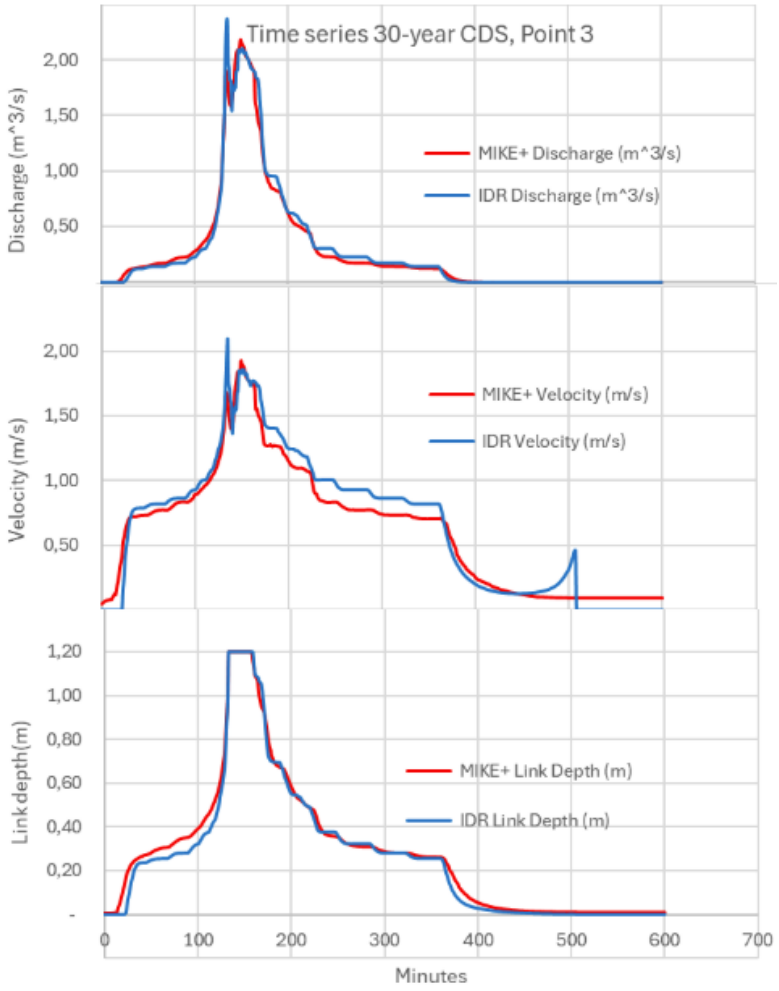


Figure 5.8: Time series graph for discharge velocity and link depth in point 3 for the 30-year CDS event.

Figure 5.9 shows the time series for discharge, velocity and link depth at point 3 during the 30-year Block rainfall event. In contrast to the CDS events, the Block rainfall produces a longer more constant inflow which is reflected in the hydrographs. Overall, the models show similar patterns in shape and timing for the 30-year Block event, the same for the 10-year Block event (Appendix B).

Both MIKE+ and InfoDrainage display great similarities, a prolonged discharge plateau that lasts for the storm duration and sharp incline and decline. InfoDrainage reaches its peak discharge slightly faster and discharge declines slightly later in MIKE+. This again suggests that flow routing is handled consistently by both model solvers under steady inflow conditions. For velocity, the models show similar patterns with a rapid incline, decline and a prolonged plateau, but with a higher peak velocity in InfoDrainage. The link depth shows a similar pattern between the models with a rapid incline, decline and a prolonged plateau, but the depth plateau in MIKE+ is slightly higher.

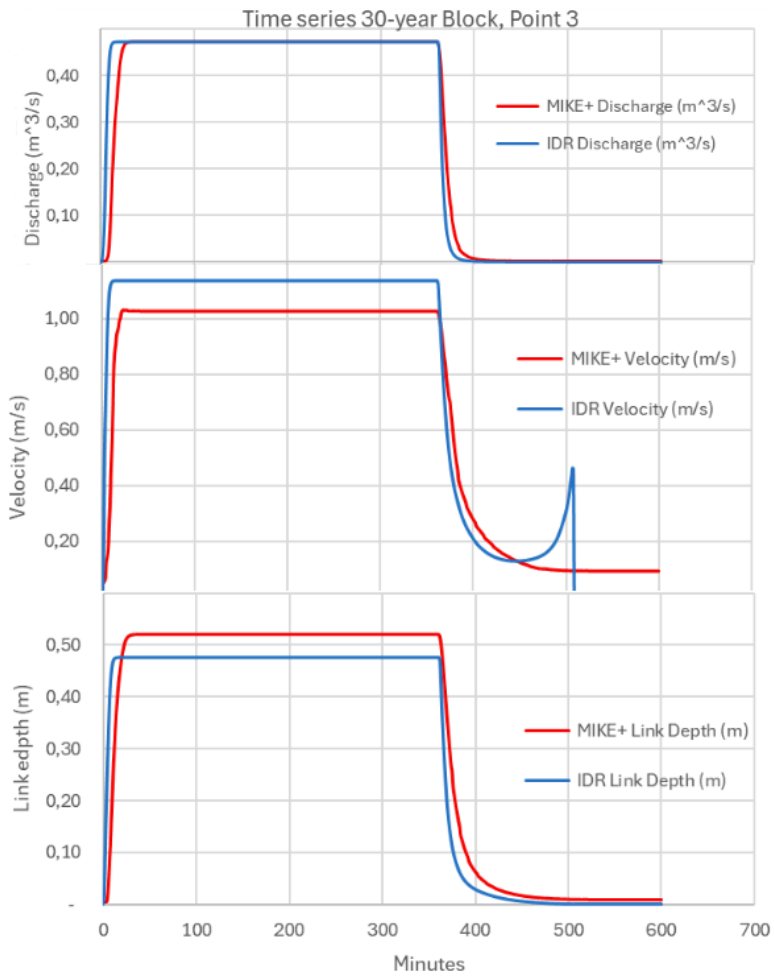


Figure 5.9: Time series graph for discharge velocity and link depth in point 3 for the 30-year block event.

Table 5.3 provides a summary of the key differences between the time series comparisons. For the CDS events both models reproduced sharp hydrograph peaks and similar patterns, but some differences emerged:

- At point 1, MIKE+ and InfoDrainage show similar patterns and peaks in discharge and velocity, but slightly higher peaks in MIKE+. InfoDrainage maintains a longer maximum depth plateau, suggesting longer surcharge periods but lower maximum pressure levels.
- At point 2, MIKE+ and InfoDrainage show similar peaks in discharge and velocity, but slightly higher peaks in MIKE+. In this point, MIKE+ maintains a longer depth plateau, suggesting longer surcharge periods but lower maximum pressure levels. As the slope and pipe-diameter were lower in this point, it reflects that smaller pipes with gentler slopes might amplify model differences in storage versus outflow.

- At point 3 MIKE+ and InfoDrainage show similar patterns and peaks in discharge and velocity, but a higher 1st peak in InfoDrainage followed by a higher 2nd peak in MIKE+.

For the Block events, all three points showed the same patterns with almost identical discharge graphs, higher velocity values in InfoDrainage and higher depth values for MIKE+. The higher depths in MIKE+ suggests that the MIKE+ model will likely be more prone to surcharging and flooding as the water levels generally seem to be higher.

Table 5.3: Summary of time series differences of discharge, velocity and depth for the different events and points between MIKE+ and InfoDrainage (referred to as IDR in this table).

Point & event	Discharge	Velocity	Depth	Note	Diameter (m) & slope (‰)
Point 1 CDS	Sharp peak, MIKE+>IDR	Sharp peak, MIKE+>IDR	Plateau, MIKE+=IDR	Depth plateau extent longer in IDR	1.4 m: 1.65 ‰.
Point 2 CDS	Sharp peak MIKE+>IDR	Sharp peak MIKE+>IDR	Plateau, MIKE+=IDR	Depth plateau extent longer in MIKE+	0.8 m: 0.48 ‰.
Point 3 CDS	Peak 1: MIKE+ < IDR. Peak 2: MIKE+>IDR	Peak 1: MIKE+ < IDR. Peak 2: MIKE+>IDR	Plateau, MIKE+=IDR	Depth plateau similar extent	1.2 m: 1.35‰.
Point 1 Block	Plateau, MIKE+=IDR	MIKE+< IDR	Plateau, MIKE+>IDR	-	1.4 m: 1.65 ‰.
Point 2 Block	Plateau, MIKE+=IDR	Plateau, MIKE+ < IDR	Plateau, MIKE+>IDR	-	0.8 m: 0.48 ‰.
Point 3 Block	Plateau, MIKE+=IDR	Plateau, MIKE+ < IDR	Plateau, MIKE+>IDR	-	1.2 m: 1.35 ‰.

5.4 Profile plots

Profile plots for three flow paths (Figure 5.10) for each rainfall event will be presented in this section. In MIKE+, the network system's pressure levels will be represented as the line between each node's

maximum water level and as the Energy Grade Line (EGL) in InfoDrainage. The profile plots for 10- and 30-year rainfall events showed the same patterns between return periods, the difference was only larger scaled pressure levels. Therefore, only the 30-year CDS and Block rainfall events will be compared in this result section and the 10-year CDS and Block rainfall event will be presented in Appendix C.

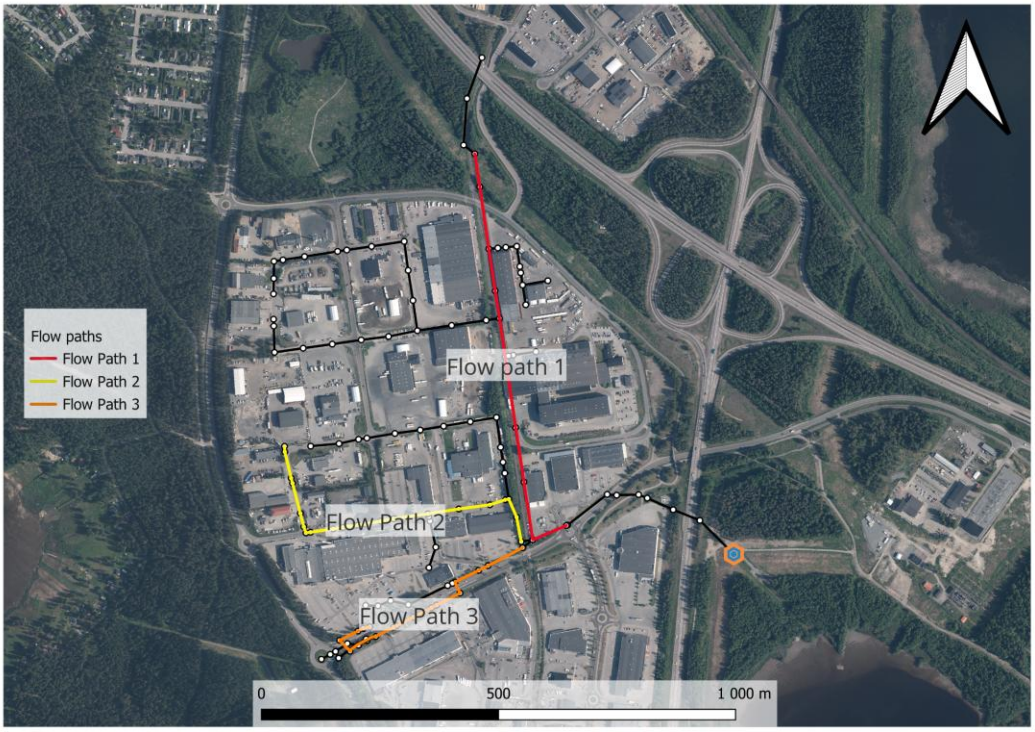


Figure 5.10: Representation of flow path 1, 2 & 3.

5.4.1 Flow Path 1

The pressure levels of flow path 1 for the 30-year CDS rainfall event are presented in Figure 5.11. Notably, the pressure levels exceed the pipe crown level throughout the system and exceed the ground level in the same areas. The pressure level is slightly higher in the beginning of the flow path (to the left) in MIKE+ and slightly higher for InfoDrainage in the middle of the flow path. Worth noting is that the pressure levels exceed the ground level where a connection transitions from a smaller diameter to a greater and where the slope gets notably steeper.

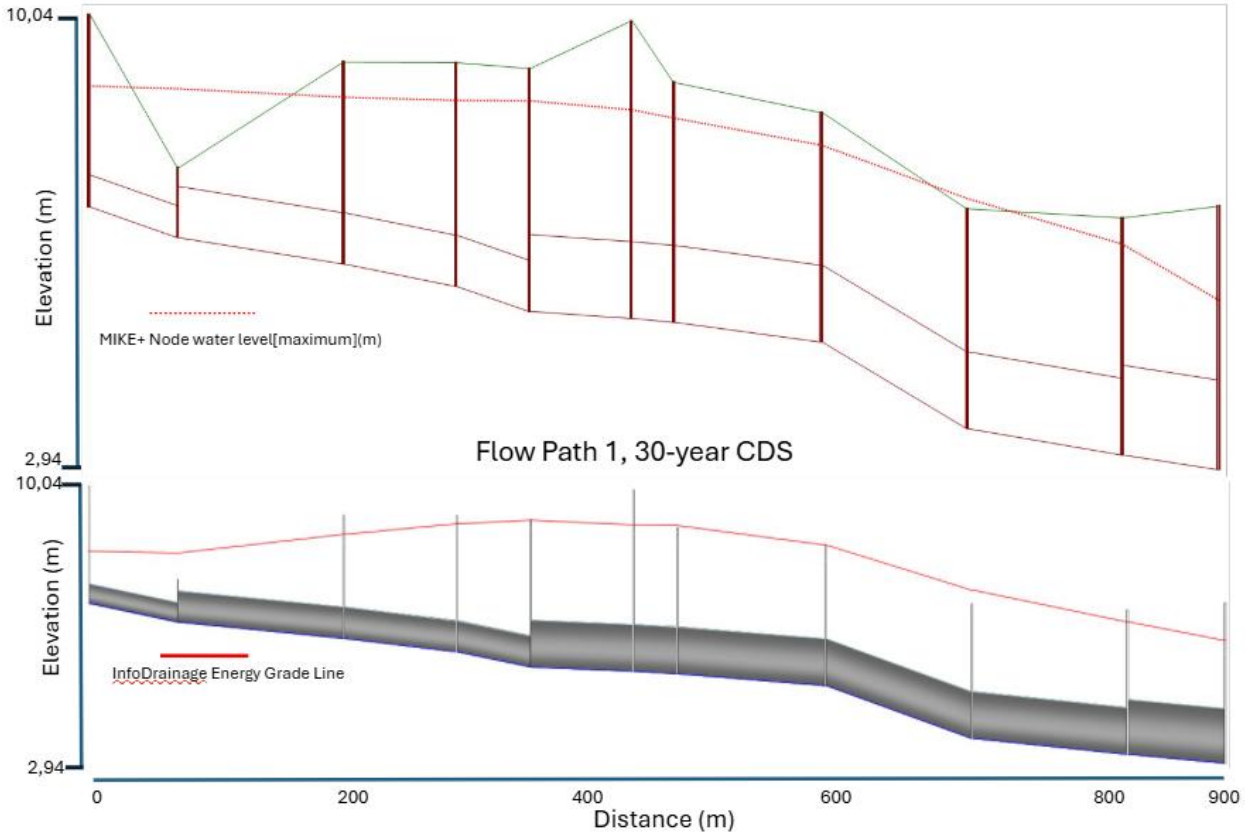


Figure 5.11: MIKE+ (top) maximum node water level(red) and InfoDrainage (bottom) Energy Grade Line (red) for the 30-year CDS event for flow path 1. Elevation on the y-axis, distance on the x-axis, vertical manholes, horizontal pipes.

The pressure levels of flow path 1 for the 30-year Block rainfall event is presented in Figure 5.12. For this rainfall event, the pressure levels do not exceed the pipe crown for either model. They also follow the same pattern for both models, indicating slight increases after steeper slopes or at transitions to greater pipe diameters.

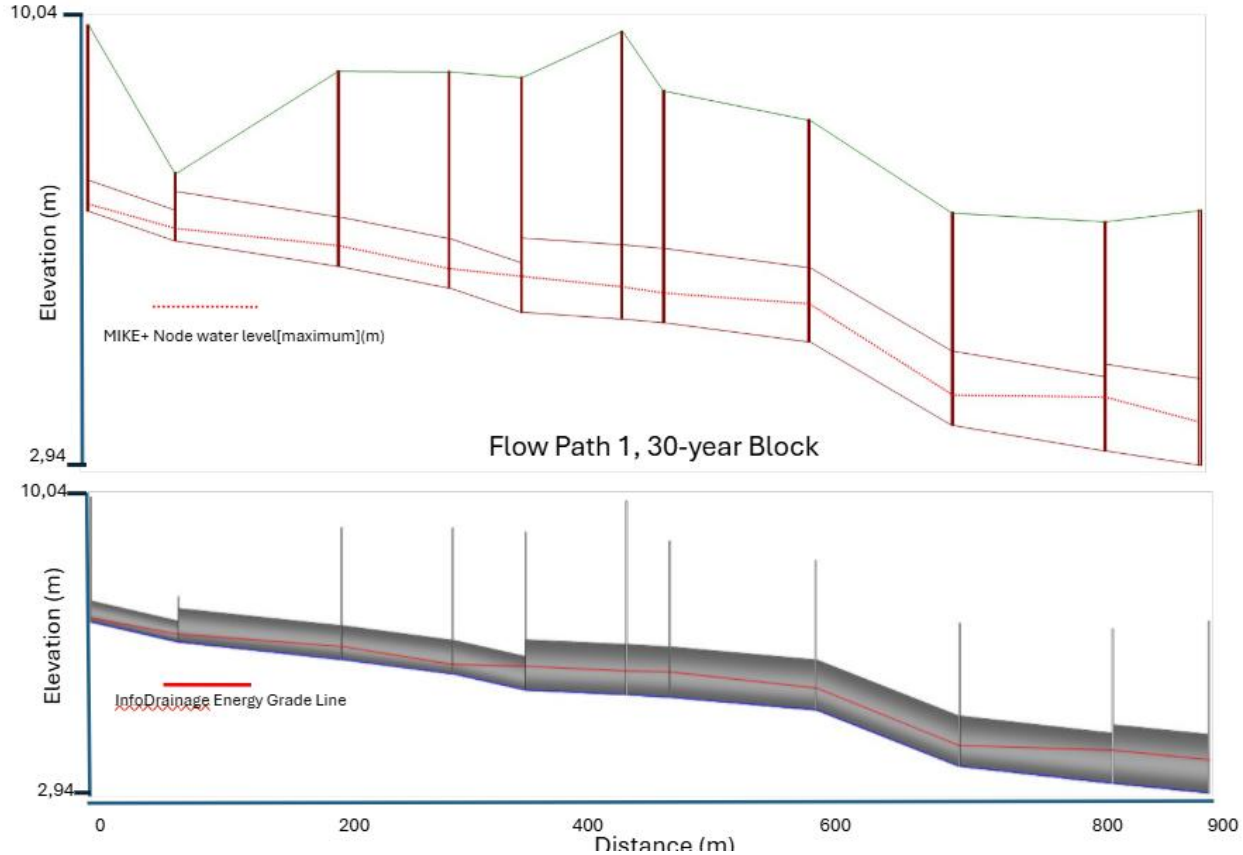


Figure 5.12: MIKE+ (top) maximum node water level (red) and InfoDrainage (bottom) Energy Grade Line (red) for the 30-year Block event for flow path 1. Elevation on the y-axis, distance on the x-axis, vertical manholes, horizontal pipes.

5.4.2 Flow Path 2

The pressure levels of flow path 2 for the 30-year CDS rainfall event is presented in Figure 5.13. Both models show similar patterns and pressure levels exceeding ground level in the greater extents of flow path 2. MIKE+'s pressure levels are slightly higher overall and both models' pressure levels go below ground level at the same node.

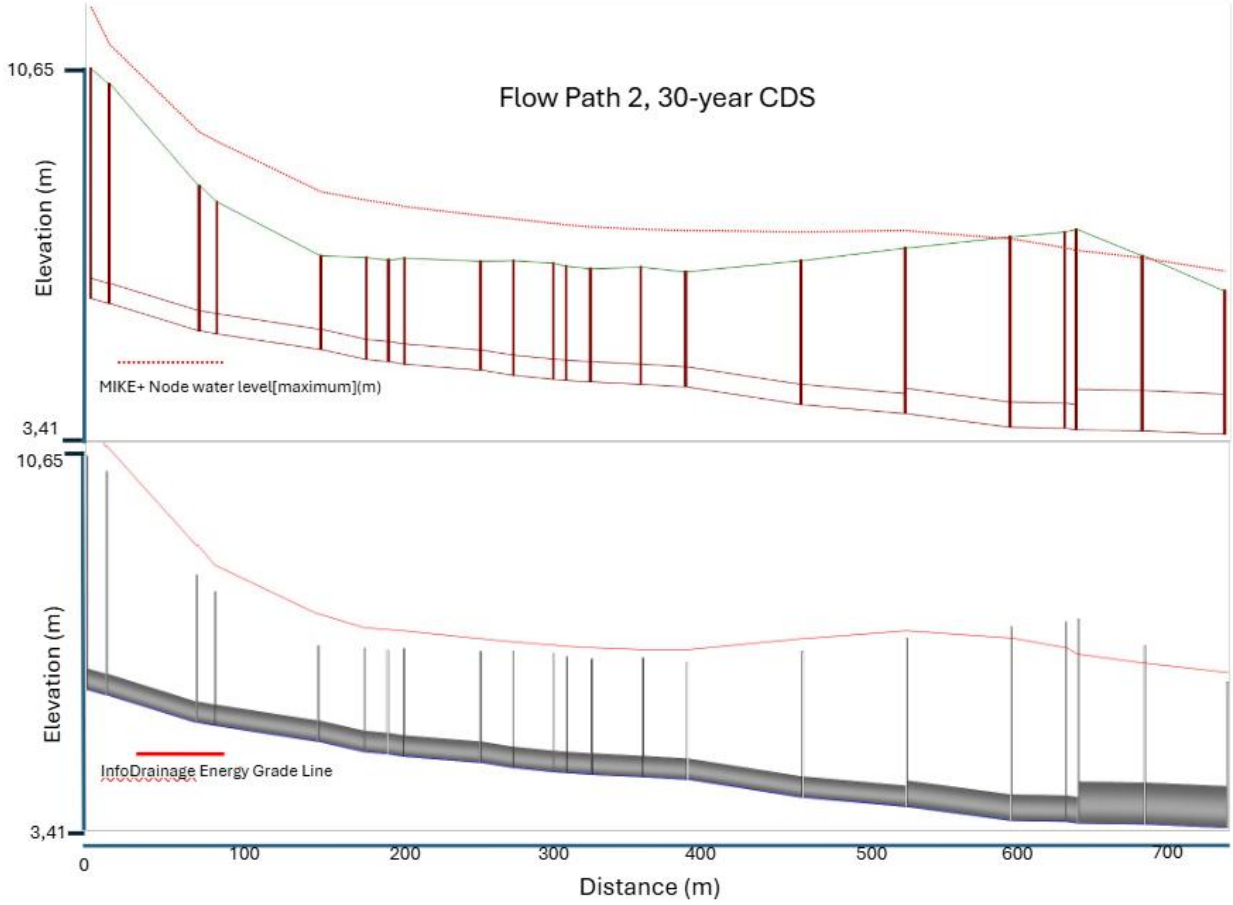


Figure 5.13: MIKE+ (top) maximum node water level (red) and InfoDrainage (bottom) Energy Grade Line (red) for the 30-year CDS event for flow path 2. Elevation on the y-axis, distance on the x-axis, vertical manholes, horizontal pipes.

The pressure levels of flow path 2 for the 30-year Block rainfall event is presented in Figure 5.14. Both models show pattern similarities with pressure level exceeding the pipe crown for most of the extent of the flow path. MIKE+ has higher pressure levels overall and an indication of pressure levels exceeding the ground level. For both models, the pressure went below the pipe crown as the pipe diameters increased at the end of the flow path further downstream.

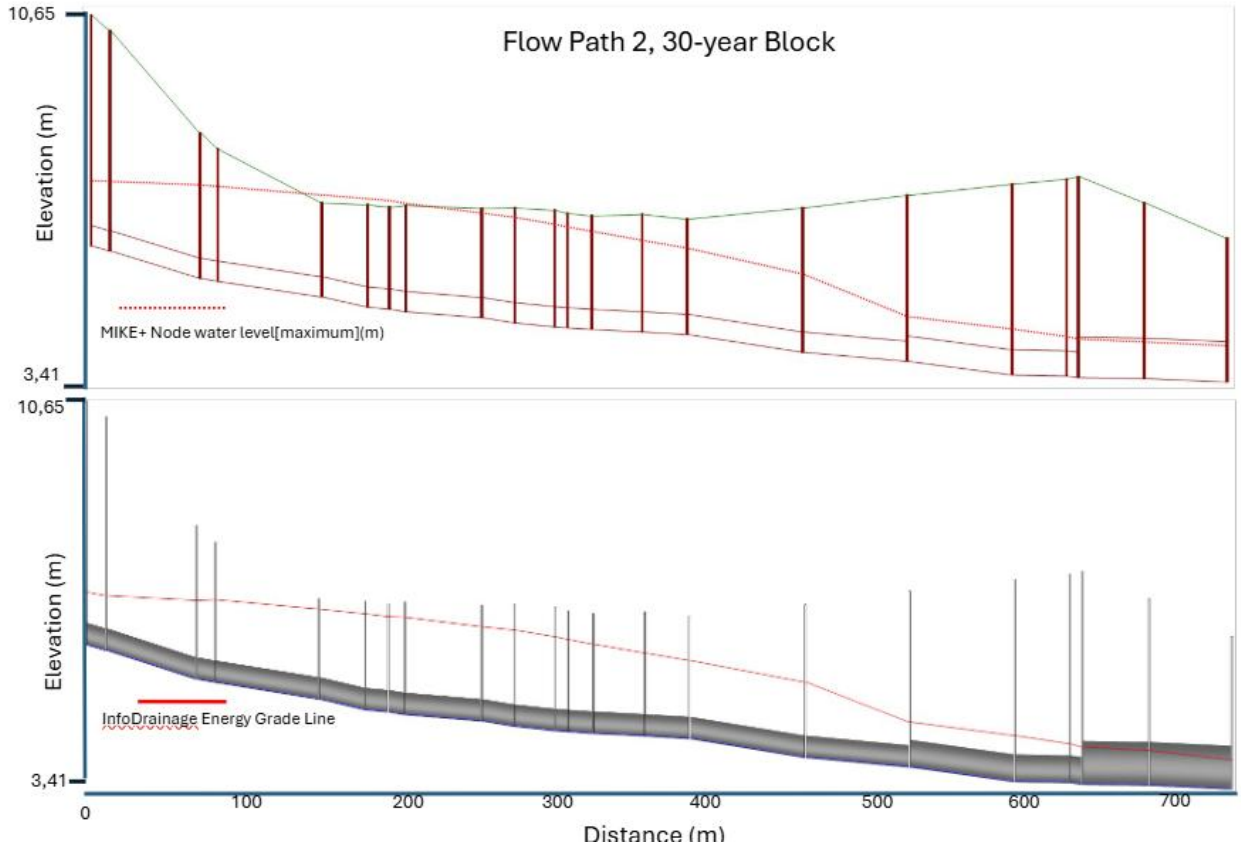


Figure 5.14: MIKE+ (top) maximum node water level (red) and InfoDrainage (bottom) Energy Grade Line (red) for the 30-year Block event for flow path 2. Elevation on the y-axis, distance on the x-axis, vertical manholes, horizontal pipes.

5.4.3 Flow Path 3

The pressure levels of flow path 3 for the 30-year CDS rainfall event are presented in Figure 5.15. For this flow path and rainfall event, MIKE+ has significantly higher pressure levels throughout the flow path, especially in the beginning of it. Both models show pressure levels exceeding ground level, especially MIKE+ to a greater extent.

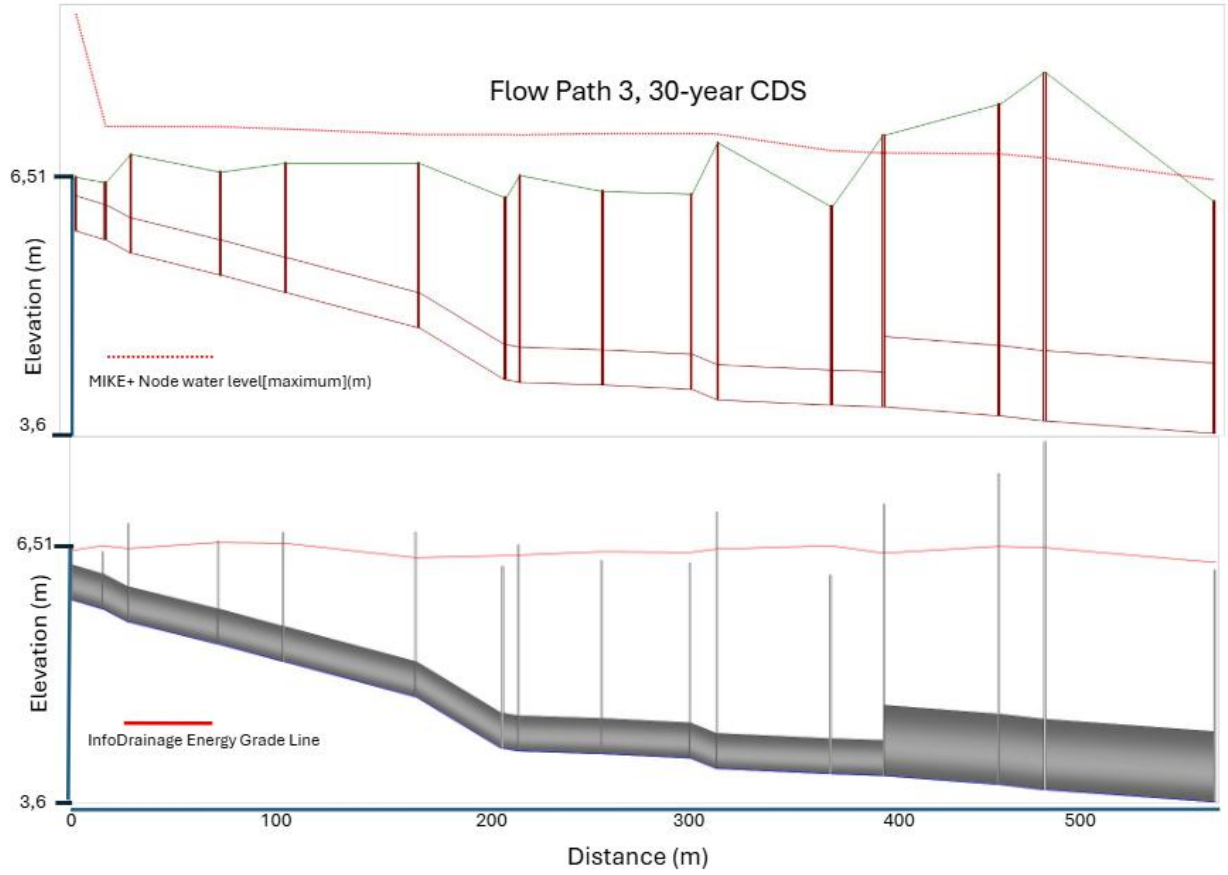


Figure 5.15: MIKE+ (top) maximum node water level (red) and InfoDrainage (bottom) Energy Grade Line (red) for the 30-year CDS event for flow path 3. Elevation on the y-axis, distance on the x-axis, vertical manholes, horizontal pipes.

The pressure levels of flow path 3 for the 30-year Block rainfall event is presented in Figure 5.16. For this event, the pressure level shows clear similarities and patterns. The level does not exceed the pipe crown at any point of the flow path.

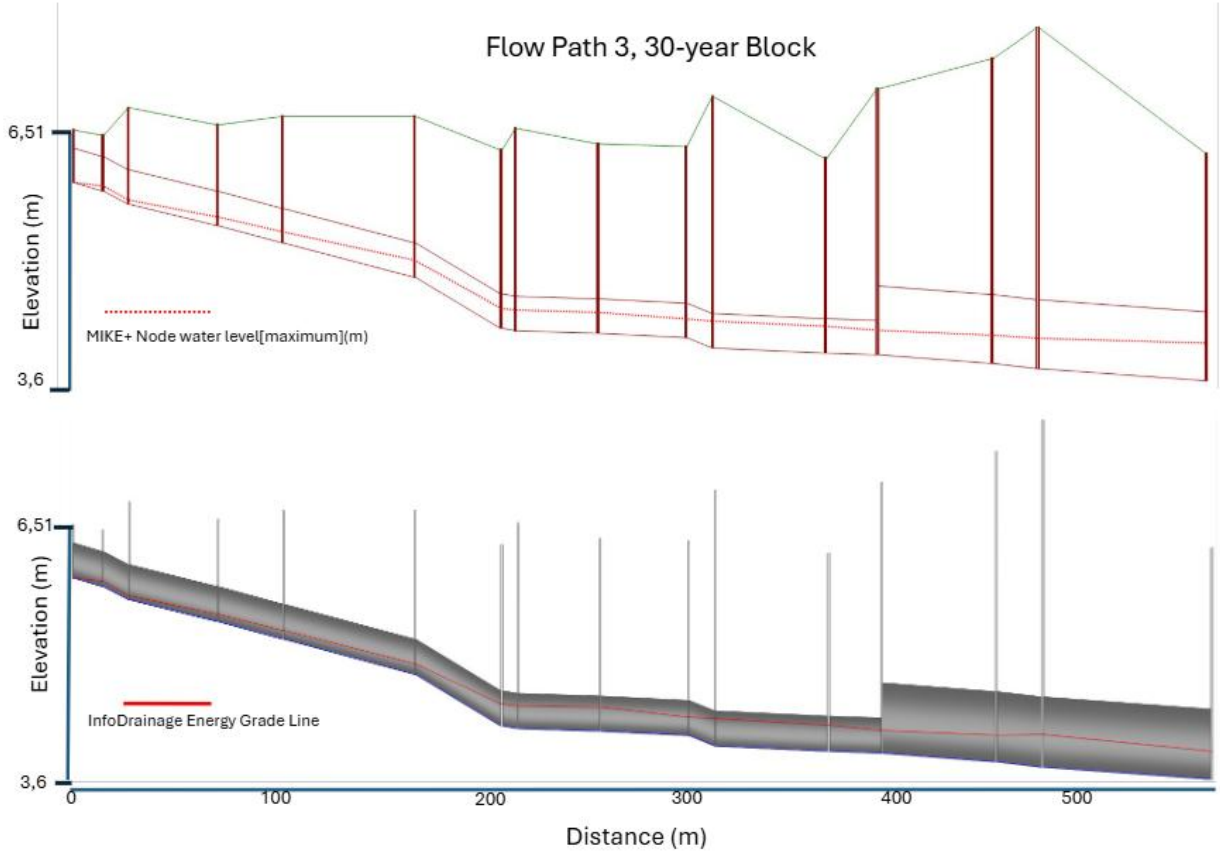


Figure 5.16: MIKE+ (top) maximum node water level (red) and InfoDrainage (bottom) Energy Grade Line (red) for the 30-year Block event for flow path 3. Elevation on the y-axis, distance on the x-axis, vertical manholes, horizontal pipes.

6. Discussion

In this section, the research questions will be discussed based on the hydraulic results, model setup and theoretical framework. The limitations of the study and suggestions for future research will also be discussed.

6.1 To what extent do MIKE+ and InfoDrainage produce different simulation results under the same conditions?

The mass balance analysis showed that both MIKE+ and InfoDrainage produced very small errors (≤0.26%) for all events, below the threshold of 1% (SVU, 2016). This gave an indication that both softwares produced accurate and stable results and neither introduced any significant volumetric bias. Although MIKE+ showed slightly higher errors than InfoDrainage, the difference is negligible in practicality as the errors are so small. This also means that any observation for the remaining hydraulic results will not be correlated with the mass balance error.

The pressure levels in the system generally identified the same critical parts of the system where surcharging or flooding occurred, but overall slightly higher pressure levels in MIKE+. The most visually significant difference in results was for the 30-year Block rainfall event, where MIKE+ indicated flooding in an area where InfoDrainage did not even indicate surcharging, i.e. the pressure levels were below the pipe crown in InfoDrainage and above ground level in MIKE+. The broad spatial conclusions for the network remain similar though, as the models generally highlight the same bottlenecks in the system.

The time series analysis of the three points showed that MIKE+ and InfoDrainage generally produced the same dynamic behavior in terms of discharge, velocity and link depth under both types of design storms for the two return periods of 10- and 30-years. The agreement between the models was very close for the Block events in all points - prolonged plateaus with similar timing for discharge, velocity and depth. The discharge was nearly identical in all points, but the correlation between velocity and depth for the two models differed. MIKE+ produced lower velocities, but higher depths whereas InfoDrainage produced higher velocities, but lower depth. This indicated a difference in how the models transferred and calculated the dynamic flow energies. MIKE+ had a slightly slower rise and decline in discharge and thus depth compared to InfoDrainage, indicating more flow resistance in the system in the MIKE+ model.

The model differences were slightly more apparent for the time series at the CDS events. MIKE+ produced higher peak discharges and velocities generally, except for point 3 where the 1st peak was

higher in InfoDrainage. The depth reached full pipe conditions in all points for the CDS event, but in point 2 the depth decreased faster in InfoDrainage as the velocity maintained higher values after the peak compared to the MIKE+ model. This also indicates a lower flow resistance in the InfoDrainage model as higher velocity values are maintained after the peak. Point 1 can be seen as the most representative point for how the models operate the network overall, as it is the second last pipe before the basin outlet. Therefore, all inflow is assumed to reach this point. This graph highlights higher discharge and velocity peaks in MIKE+ where the models follow an almost identical shape and timing. Here, on the contrary, InfoDrainage shows a slightly longer plateau extent for the link depth. Examining the graph more closely, a slightly faster velocity decline is notable for InfoDrainage as the discharge sustains the same pattern as MIKE+. The values seem reasonable as flow discharge equals to velocity times pipe-area filled (dependent on depth), so if the discharge remains its pattern and velocity declines, depth must increase - assuming non-changed conditions over the interval. From a practical standpoint, these differences are neglectable. MIKE+ points toward slightly higher risks of surcharging or flooding as it produces higher peak flows and either higher link depths or durations with filled pipes.

The profile plots provided great insights into the pressure levels on a longitudinal scale. For the CDS-events, the pressure levels followed a similar pattern for both models and showed pressure above the pipe crown in all profiles. But the pressure levels were slightly higher for the MIKE+ model in general and thus indicated more points of flooding where the pressure exceeded ground level. Flow path 1 and 3 for the Block event indicated pressure below the pipe crown in their full extent. The models also followed a similar pattern in flow path 2 for the Block event, but here the pressure levels exceeded the pipe crown and even the ground level at one stretch for the 30-year event in the MIKE+ model. These results went hand in hand with the pressure level maps, by showcasing how pressure levels differed - but from a different, longitudinal, perspective for the profile plots.

Overall, the results from the pressure maps, time series and profile plots showed very similar results, but with one common key difference showcased from each result type - The MIKE+ model generated higher pressure levels generally.

6.2 What factors contribute to differences in model output?

As elaborated, this study revealed differences in model outputs, even though identical inputs for catchments, network structure and boundary conditions were applied. But what are the contributing factors? One primary factor is the underlying mathematical formulations and numerical solvers used in

the softwares. Both software bases their hydraulics on the Saint-Venant equations but compute them using different numerical schemes and they use different approaches when accounting for surcharging and node energy distributions and losses. These results are in line with the findings of Wistfors (2024) who showcased that differences in solvers and internal structures led to differences in timing and flood prediction, when comparing MIKE+ and Fluidit Storm with identical inputs. Similarly in the study made in Kärrgruvan (Bengtsson, 2018), MIKE Urban and SWMM produced different peak flow and flood extents despite equal input data, pointing to differences in the solving engines and how surcharging is represented as key factors.

In MIKE+, Manning's n was set to 0.01333333, whereas in InfoDrainage it was set to 0.013. This minimally larger value (approximately 2.5 %) in MIKE+ means that the flow resistance value will be higher in MIKE+ compared to Info Drainage's. A higher flow resistance leads to lower velocities and staggered flow with more friction losses. Though this difference is very small and likely insignificant for the overall comparison, it is worth noting as small changes in parameter values have shown to have larger effects on output in prior studies (Broekhuizen 2019).

6.3 What are the uncertainties associated with the model result, and how do they affect decision-making?

Uncertainties in this study come from both input data and model structure. Input data uncertainties include the representation of rainfall and catchment landcover parameters. For example, the hyetographs used were design storms rather than observed rainfall events. This allows proper comparability between the models, but it simplifies the irregularity of a real rainfall event that often inhabits more variability in time and space. The land cover imperviousness is not based on direct field measurements, which introduces uncertainty in the runoff generation. Such factors are well documented sources of error in urban drainage modelling (Beven, 2007; Deletic et al., 2012).

Model structure uncertainties are linked to how the solving engines calculate the hydraulics. For example, MIKE+ utilizes the Priessmann slot for surcharge handling, weighted inlet energy for head losses and an implicit scheme solver with adaptive time steps for the Saint Venant equations, whereas InfoDrainage applies the velocity head formulation and a semi-implicit scheme solver with fixed time steps for the Saint Venant equations. Another structural uncertainty is that the Manning's n was set slightly higher in the MIKE+ model, leading to higher flow resistance and different dynamic behaviors.

In the comparison of MIKE Urban and SWMM in Kärrgruvan (Bengtsson, 2018), surcharging and flooding results differed when the input was matched, showcasing that each model handles storage routings and pressure transitions uniquely. The comparison of MIKE+ and InfoDrainage confirms that structural uncertainties, even in simpler one-dimensional models, can produce different outputs and provides new insight on how different solvers alone can affect model performance assessment, without added complexity of, for example, surface flow or green infrastructure.

Another uncertainty arises from the model's sensitivity to rainfall intensity. The difference between MIKE+ and InfoDrainage was more pronounced during the high intensity CDS-rainfall. The hydrographs showcased more oscillations and numerical instability in the InfoDrainage model during these events, suggesting that the model stability in rapidly changing conditions vary between the software. This goes along with the findings of Broekhuizen (2019), who highlighted how sensitive different models are to variations in rainfall when simulating rainfall-runoff from green infrastructures. The mass balance analysis showed that both solvers are stable. However, the absolute inflow and outflow volumes differed systematically. InfoDrainage produced higher inflow and outflow volumes for all rainfall events compared to MIKE+, even though the same design storms were applied in both models. This most likely indicates that the models handle the rainfall-runoff transformation differently, which creates uncertainty.

Another major uncertainty in this study is the lack of calibration against observed flows. As mentioned by Deletic et al. (2012), calibration is very important for urban drainage modelling as it reduces structural and parametric uncertainties. If calibration is not performed, there is a risk for equifinality, where different parameter sets produce equally reasonable results, and a risk for systematic bias. Without calibration, it is possible that the observed differences between MIKE+ and InfoDrainage are exaggerated or understated depending on how each software handles the parameters. The lack of calibration lowers the reliability of the models for absolute prediction of the network status, but the comparative insights for this study remain valid.

These uncertainties can significantly affect decision making when it comes to pipe-dimensioning, risk assessments and prioritization. For example, if one model predicts less surcharge at a critical node while the other model predicts flooding, decision makers may under-dimension that part of the system - increasing flood risk. On the other hand, a more conservative model might lead to costly over-dimensioning of the stormwater network. So, the challenge lies in interpreting the results, but also understanding how the model structure influences them, as Deletic et al. (2012) emphasized.

6.3 Limitations and future research

Several limitations need to be acknowledged, despite the structured study setup. This study contributes to a better understanding of how MIKE+ and InfoDrainage behave one-dimensionally under identical input conditions, but there are still several areas that need to be explored further to improve decision making.

Future research should include measured rainfall and flow data to calibrate the models and to assess their accuracy in real world conditions. This would create a more performance-based comparison where their predictive capacity could be assessed, not just their structural differences.

By coupling 1D pipe flow to 2D surface routing, the models could be examined and compared in a higher dimension, taking more parameters into account. It is a critical step in urban planning, and as Wistfors (2024) showcased it can reveal significant differences in flood mapping.

To compare the models further it would be useful to include different structures such as SuDS to evaluate the performance of those, as they are also a critical part of urban stormwater planning.

Quantifying the uncertainties more explicitly using probabilistic modeling techniques would allow the estimation of confidence intervals for the model outputs. Doing this could significantly increase the legitimacy of decisions made in urban planning.

7. Conclusion

This study has investigated the hydraulic modeling capabilities of the two widely used stormwater modeling tools MIKE+ by DHI and InfoDrainage by Autodesk. Their simulation outputs have been compared during identical input conditions, including four different identical rainfall events, identical network structure, catchments and other identical parameters. The primary objective of this study was not to determine which software is superior, but rather to understand how and why model outputs differ i.e. what structural differences there are and what they mean practically for urban stormwater planning and design.

The results showed that even when the input values were aligned, notable differences occurred between the models in peak flow rates, total in- & out-flow and the spatial distribution of surcharging and flooding, i.e. pressure levels, even though the results were somewhat similar. The differences were most evident for the more highly intensive CDS-rainfall events where MIKE+ showed higher peak flows, velocities and pressure levels, suggesting that the numerical solvers, structural assumptions and hydraulic routing differ in the handling of fast flow dynamics and pressure transitions. The hydrograph peak timing was identical though for the CDS-events, but InfoDrainage showcased slightly more numerical instability.

These variations in results can have direct implications if the models are used as base for decision-making regarding pipe-dimensioning and flood risk evaluation, especially if used directly without acknowledging the models' assumptions and limitations.

The study also highlights that uncertainties in model structure, solver calculations, and the lack of calibration can affect the confidence of the model outputs. Uncertainty was minimized by excluding certain parameters and using identical synthetic rainfall, the lack of calibration remains a limitation when it comes to evaluating respective models' accuracy and performance.

This study demonstrates that while both MIKE+ and InfoDrainage produce somewhat similar results, they are not interchangeable. Outputs should be interpreted with each software's underlying modeling philosophy in mind.

8. References

Arnbjerg-Nielsen, K., Willems, P., Olsson, J., & Nguyen, V. T. V. (2012). Climate change impact assessment on urban rainfall extremes and urban drainage: Methods and shortcomings. Atmospheric Research, 103, 106–118. https://doi.org/10.1016/j.atmosres.2011.04.003

Autodesk. (2024). InfoDrainage Help documentation

Barbosa, A. E., Fernandes, J. N., & David, L. M. (2012). Key issues for sustainable urban stormwater management. Water Research, 46(20), 6787–6798. https://doi.org/10.1016/j.watres.2012.05.029

Bengtsson, J. (2018). Dagvattenmodellering i Kärrgruvan med klimatanpassning för ett hållbart dagvattensystem. (Master's thesis, Luleå Tekniska Universitet, Department of Civil, Environmental and Natural Resources Engineering). https://ltu.diva-portal.org/smash/record.jsf?pid=diva2%3A1186003&dswid=8137

Beven, K. (2007). Environmental Modelling: An Uncertain Future? (1st ed.). CRC Press. https://doi.org/10.1201/9781482288575

Bisht, D. S., Chatterjee, C., Kalakoti, S., Upadhyay, P., Sahoo, M., & Panda, A. (2016). Modeling urban floods and drainage using SWMM and MIKE URBAN: A case study. Natural Hazards, 84(2), 749–776. https://doi.org/10.1007/s11069-016-2455-1

Broekhuizen, I. (2019). Uncertainties in rainfall-runoff modelling of green urban drainage systems: Measurements, data selection and model structure (Licentiate thesis, Luleå University of Technology). https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1300964&dswid=5542

Butler, D., & Davies, J. (2011). Urban Drainage (3rd ed.). CRC Press. https://doi.org/10.1201/9781315272535

Deletic, A., Dotto, C. B. S., McCarthy, D. T., Kleidorfer, M., Freni, G., Mannina, G., Uhl, M., Henrichs, M., Fletcher, T. D., Rauch, W., Bertrand-Krajewski, J.-L., & Tait, S. (2012). Assessing uncertainties in urban drainage models. Physics and Chemistry of the Earth, 42–44, 3–10. https://doi.org/10.1016/j.pce.2011.04.007

DHI. (2022). *MIKE+ Collection System: User Guide*. DHI A/S.

DHI. (2021.). *MIKE 1D Reference Manual*. DHI A/S.

Dotto, C. B. S., Kleidorfer, M., Deletic, A., Rauch, W., & McCarthy, D. T. (2014). Impacts of measured data uncertainty on urban stormwater models. Journal of Hydrology, 508(2), 28–42. https://doi.org/10.1016/j.jhydrol.2013.10.025.

EPA, 2017. SWMM Reference manual. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100S9AS.PDF?Dockey=P100S9AS.PDF

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., & Viklander, M. (2014). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. Urban Water Journal, 12(7), 525–542. https://doi.org/10.1080/1573062X.2014.916314

Fowler, H. J., Lenderink, G., Prein, A. F., Westra, S., Allan, R. P., Ban, N., Barbero, R., Berg, P., Blenkinsop, S., Do, H. X., Guerreiro, S., Haerter, J. O., Kendon, E. J., Lewis, E., Schär, C., Sharma, A., Villarini, G., Wasko, C., & Zhang, X. (2021). Anthropogenic intensification of short-duration rainfall extremes. Nature Reviews Earth & Environment, 2(2), 107–122. https://doi.org/10.1038/s43017-020-00128-6

Her, Y., & Heatwole, C. (2016). Two-dimensional continuous simulation of spatiotemporally varied hydrological processes using the time-area method. Hydrological Processes, 30(5), 751–770. https://doi.org/10.1002/hyp.10644

Mays, L. W. (2010). Water Resources Engineering (2nd ed.). John Wiley & Sons. https://books.google.se/books?id=Nh8Y3vIjXK8C&printsec=frontcover#v=onepage&q&f=false

Lantmateriet, Swedish Reference Systems. N.d.
https://www.lantmateriet.se/en/geodata/gps-geodesy-and-swepos/swedish-reference-systems/

Lundqvist, D. (2020). Sensitivity analysis of grate inlet representation and a comparison of two coupled hydraulic models for urban flood simulation (Master's thesis, Department of Civil, Environmental and Natural Resources Engineering, Geosciences and Environmental Engineering, Luleå University of Technology).
https://ltu.diva-portal.org/smash/get/diva2:1417188/FULLTEXT01.pdf#:~:text=To%20investigate%20the%20effect%20grate%20inlet%20representations%20have,the%20location%20of%20actual%20grate%20inlets%20were%20compared.

Nayeb Yazdi, M., Ketabchy, M., Sample, D. J., & Scott, D. (2019). An evaluation of HSPF and SWMM for simulating streamflow regimes in an urban watershed. Environmental Modelling & Software, 118, 211–225.
https://doi.org/10.1016/j.envsoft.2019.05.008.

SCALGO Live. (n.d.). Rain Events – Chicago Design Storm.
https://scalgo.com/en-US/scalgo-live-documentation/soil-vegetation-atmosphere-properties/rain-events/chicago-design-storm

Silberstein, R. P. (2006). Hydrological models are so good — do we still need data? Environmental Modelling & Software, 21(9), 1340-1352.
https://doi.org/10.1016/j.envsoft.2005.04.019

Subramanian, R. (2016). Rained out: Problems and solutions for managing urban stormwater runoff. Ecology Law Quarterly, 43(2), 421–448. University of California, Berkeley School of Law.
https://www.ecologylawquarterly.org/wp-content/uploads/2020/03/Rained-Out-Problems-and-Solutions-for-Managing-Urban-Stormwater-Runoff.pdf

Svenskt Vatten. (2019). P110 Del 1 och 2: Avledning av dag-, drän- och spillvatten. (Del 1 Policy och funktionskrav; Del 2 Hydraulisk dimensionering). Svenskt Vatten.

https://vattenbokhandeln.svensktvatten.se/produkt/p110-del-1-och-2-digital-avledning-av-dag-dran-och-spillvatten/

Svenskt Vatten Utveckling, SVU. Blomquist, D., Hammarlund, H., Härle, P., & Karlsson, S. (2016). Riktlinjer för modellering av spillvattenförande system och dagvattensystem. https://vattenbokhandeln.svensktvatten.se/produkt/riktlinjer-for-modellering-av-spillvattenforande-system-och-dagvattensystem/

Tota-Maharaj, K., Karunanayake, C., Rathnayake, U., Kunwar, k., Anil Chadee, A., Azamathulla, H. (2024). Evaluation of permeable pavement systems (PPS) as best management practices for stormwater runoff control. Water conservation Science and Engineering. 9, Article 32. https://doi.org/10.1007/s41101-024-00259-7

Walsh, C. J., Booth, D. B., Burns, M. J., Fletcher, T. D., Hale, R. L., Hoang, L. N., Livingston, G., Rippy, M. A., Roy, A. H., Scoggins, M., & Wallace, A. (2016). Principles for urban stormwater management to protect stream ecosystems. Freshwater Science, 35(1), 398–411. https://doi.org/10.1086/685284

Wistfors, F. (2024). Cloudburst modeling in Fluidit Storm and MIKE+: A comparative study of the two software [Master's thesis, KTH Royal Institute of Technology, School of Architecture and the Built Environment]. KTH Royal Institute of Technology https://kth.diva-portal.org/smash/record.jsf?pid=diva2%3A1874475&dswid=8800

Zevenbergen, C., Jiang, Y., & Ma, Y. (2018). Urban pluvial flooding and stormwater management: A contemporary review of China's challenges and "sponge cities" strategy. Environmental Science & Policy, 80, 132–143. https://doi.org/10.1016/j.envsci.2017.11.016

Appendix A

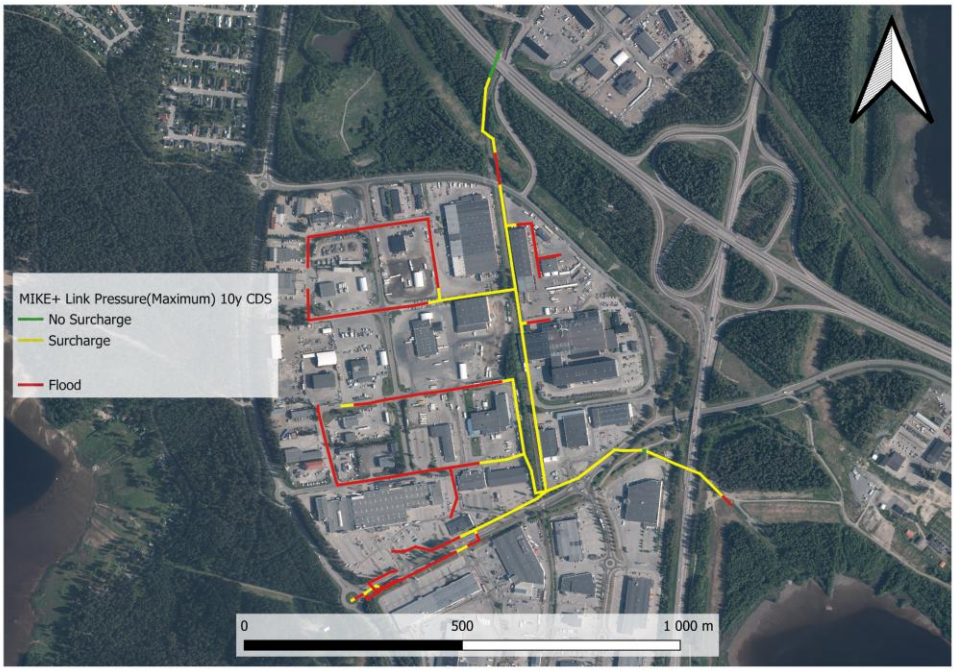


Figure 1A: Maximum link pressure map from the 10-year CDS event in MIKE+.

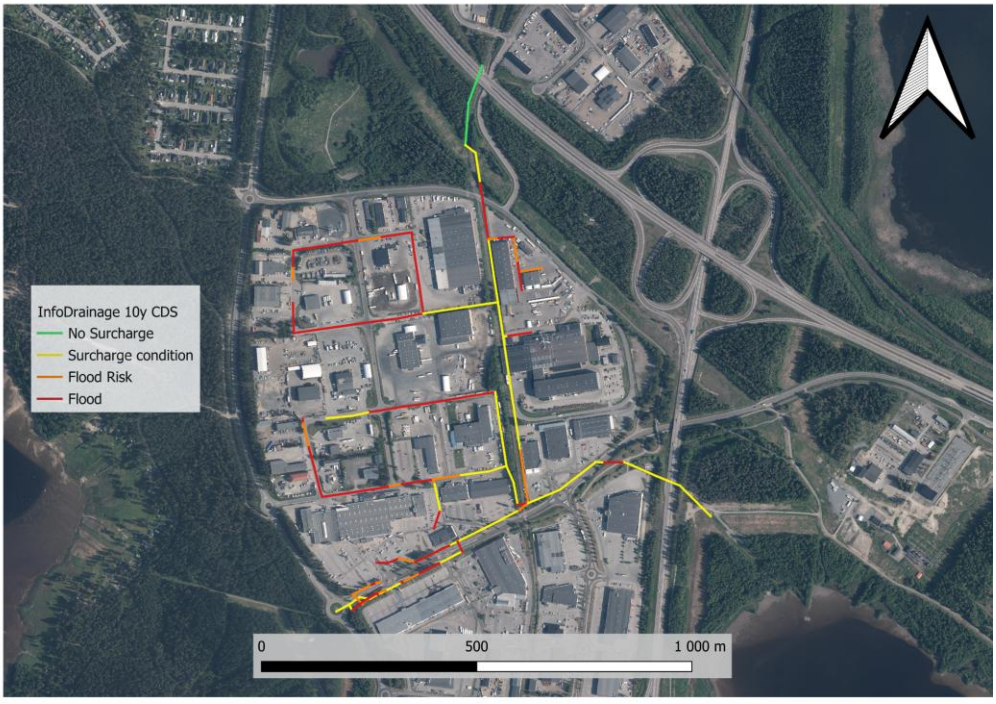


Figure 2A. Link status map from the 10-year CDS event in InfoDrainage.

Figure 3A. Maximum link pressure map from the 10-year Block event in MIKE+.

Figure 4A: Link status map from the 10-year Block event in InfoDrainage.

Appendix B

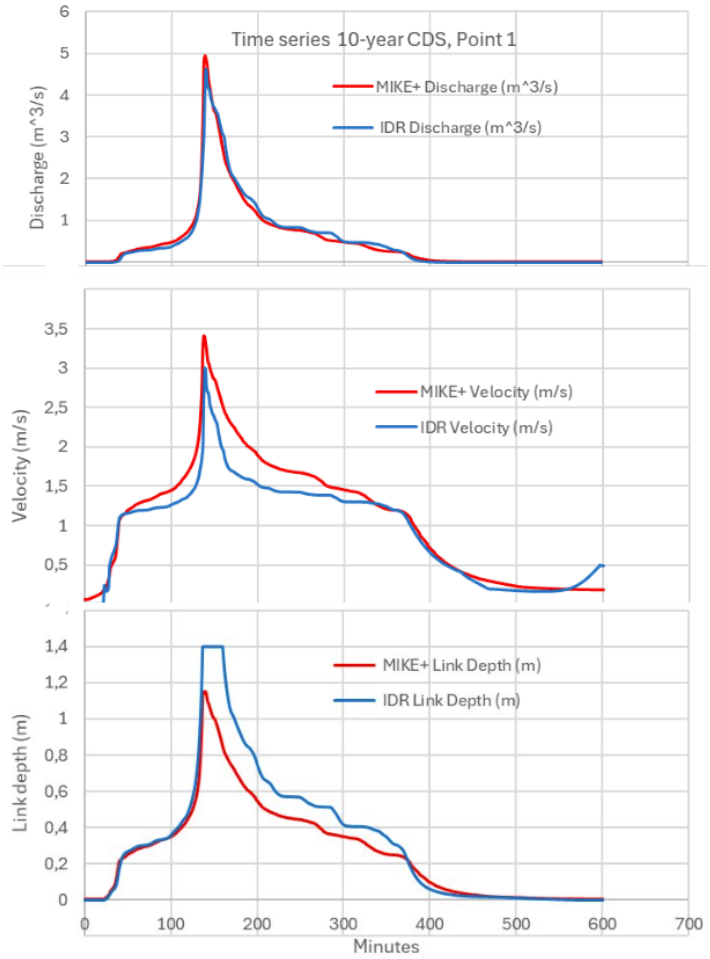


Figure 1B: Time series graph for discharge velocity and link depth in point 1 for the 10-year CDS event.

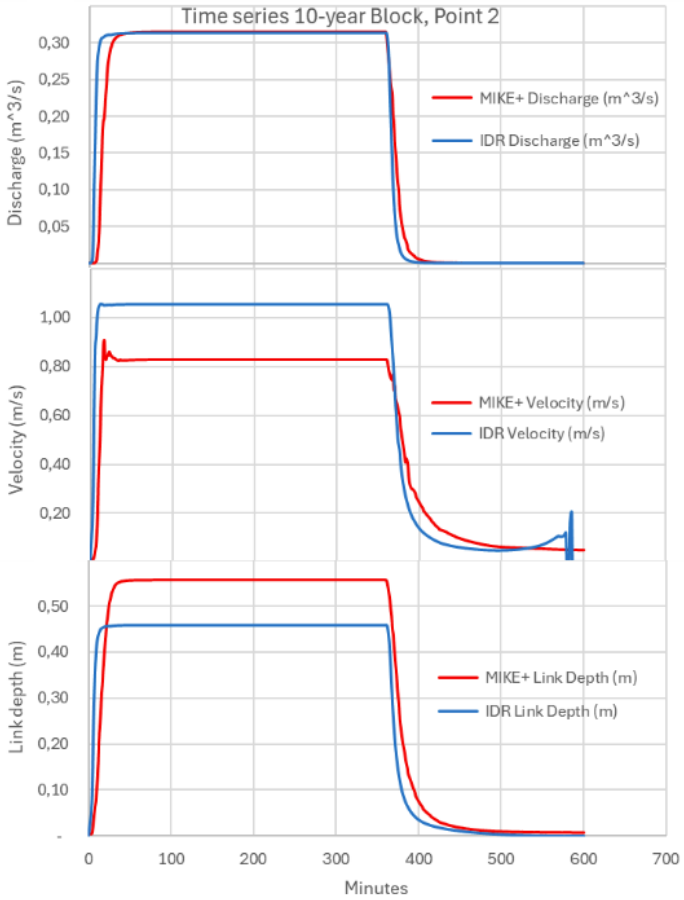


Figure 2B: Time series graph for discharge velocity and link depth in point 2 for the 10-year Block event.

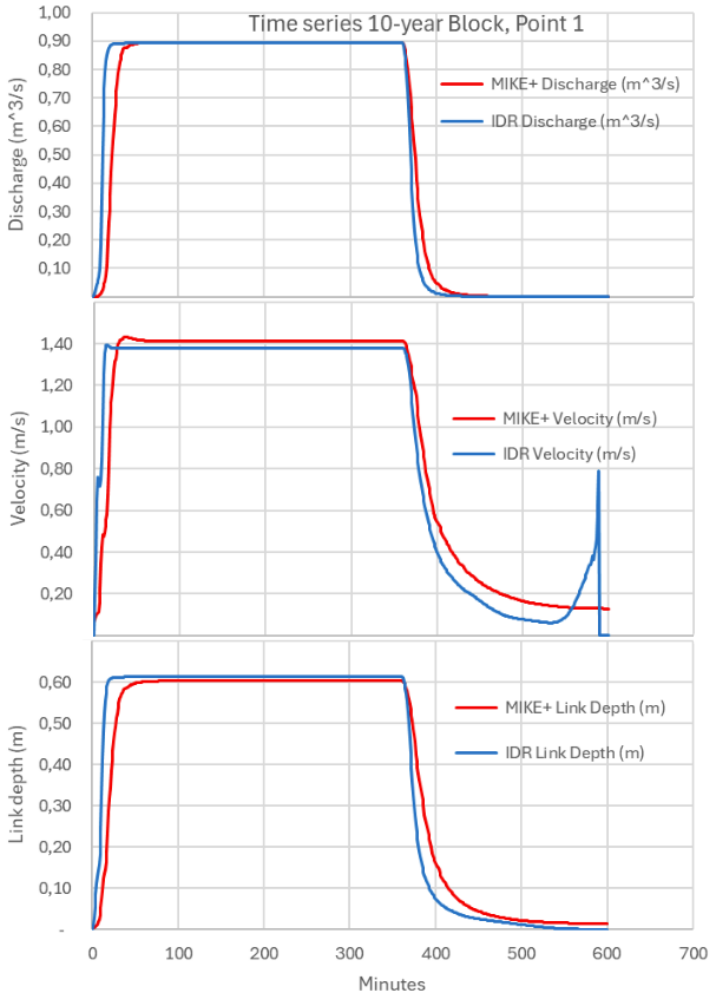


Figure 3B: Time series graph for discharge velocity and link depth in point 1 for the 10-year Block event.

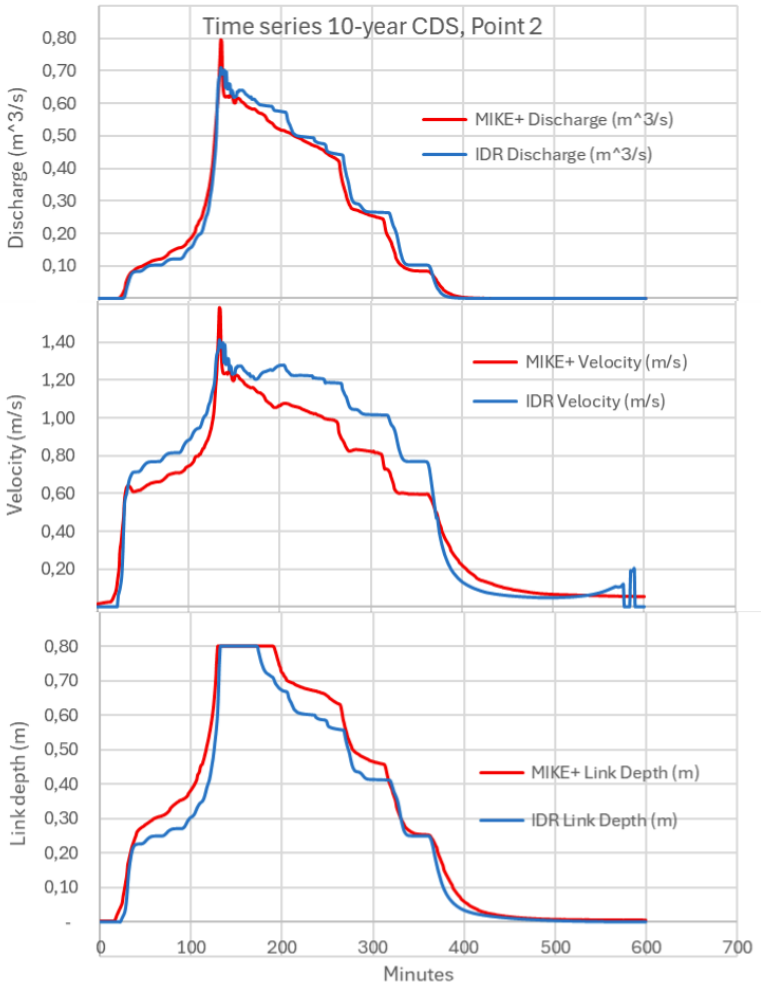


Figure 4B: Time series graph for discharge velocity and link depth in point 2 for the 10-year CDS event.

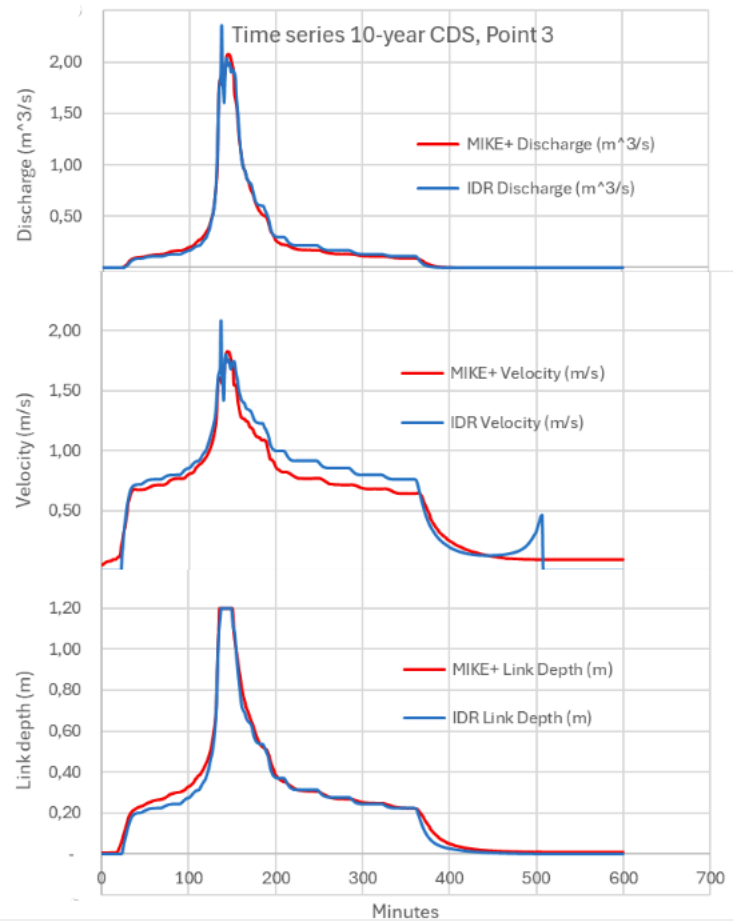


Figure 5B: Time series graph for discharge, velocity and link depth in point 3 for the 10-year CDS event.

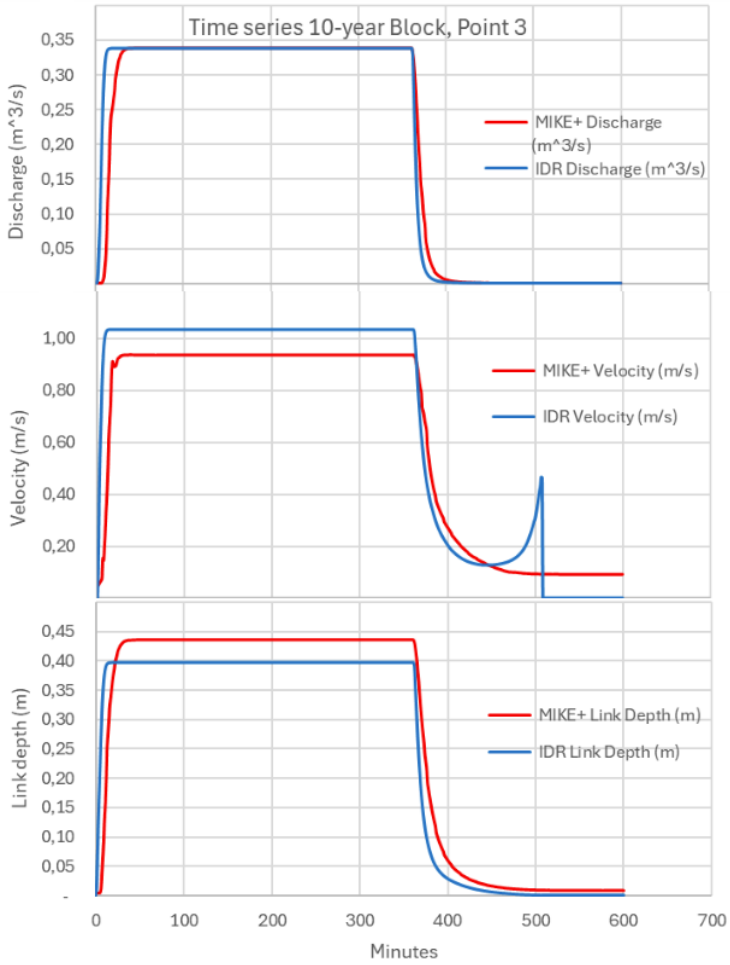


Figure 6B: Time series graph for discharge velocity and link depth in point 3 for the 10-year block event.

Appendix C

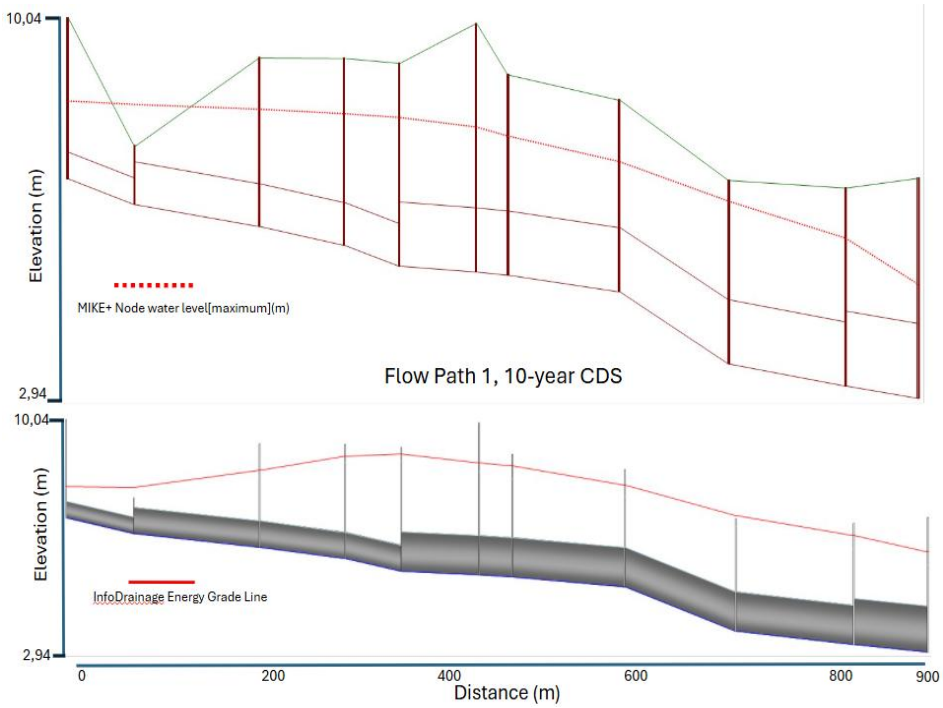


Figure 1C: Flow path 1, MIKE+ maximum node water level line(top) and InfoDrainage Energy Grade Line(bottom) for the 10-year CDS event.

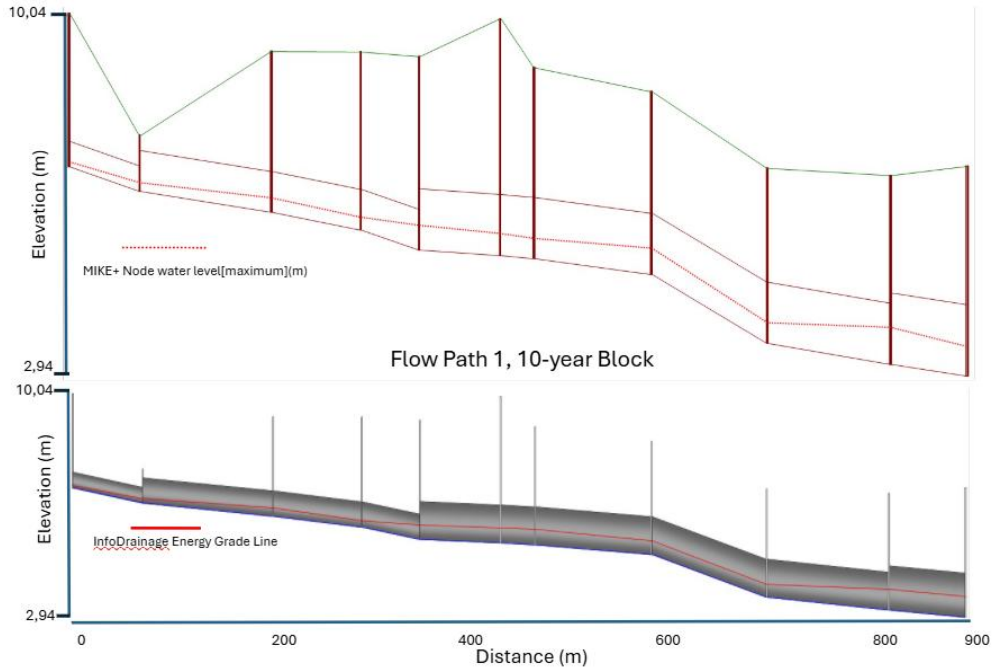


Figure 2C: MIKE+ maximum node water level(top) and InfoDrainage Energy Grade Line(bottom) for the 10-year Block event for flow path 1.

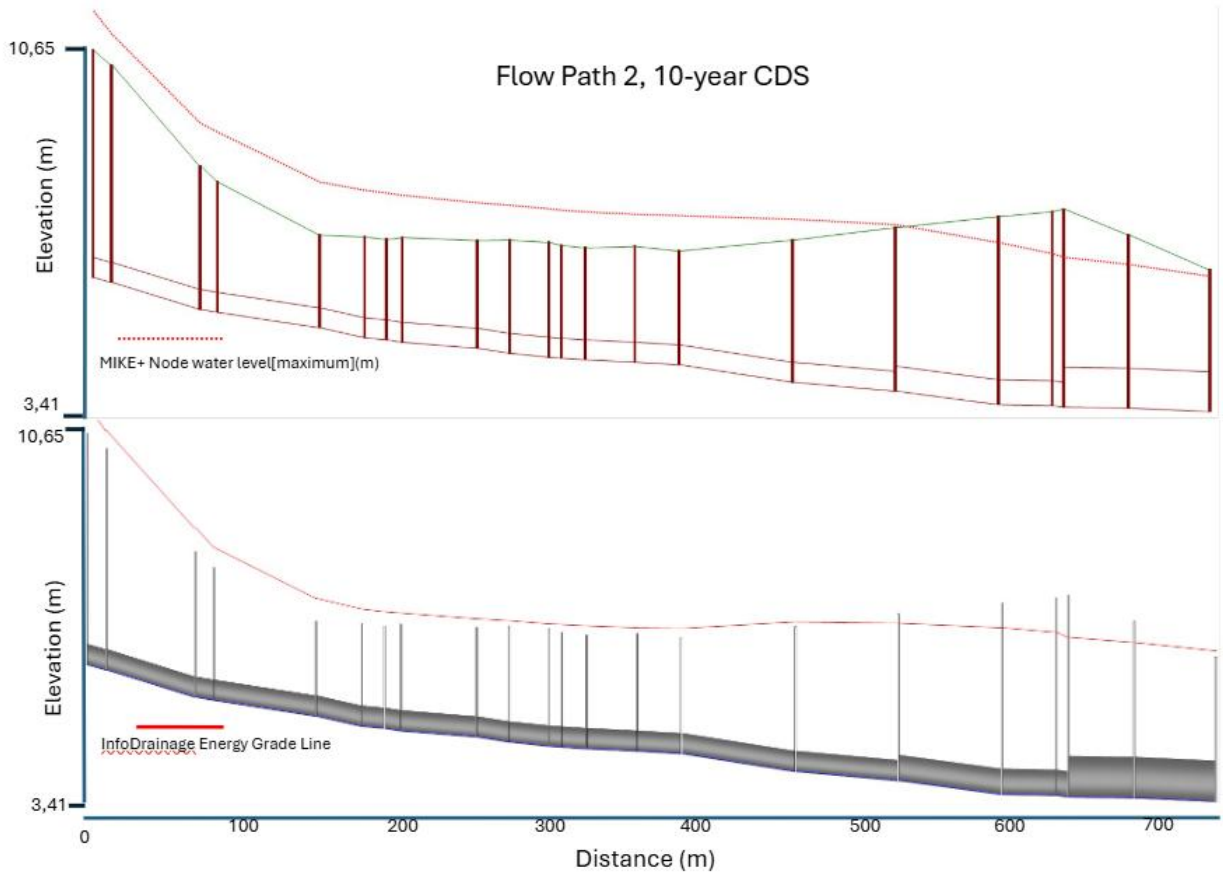


Figure 3C: MIKE+ maximum node water level(top) and InfoDrainage Energy Grade Line(bottom) for the 10-year CDS event for flow path 2.

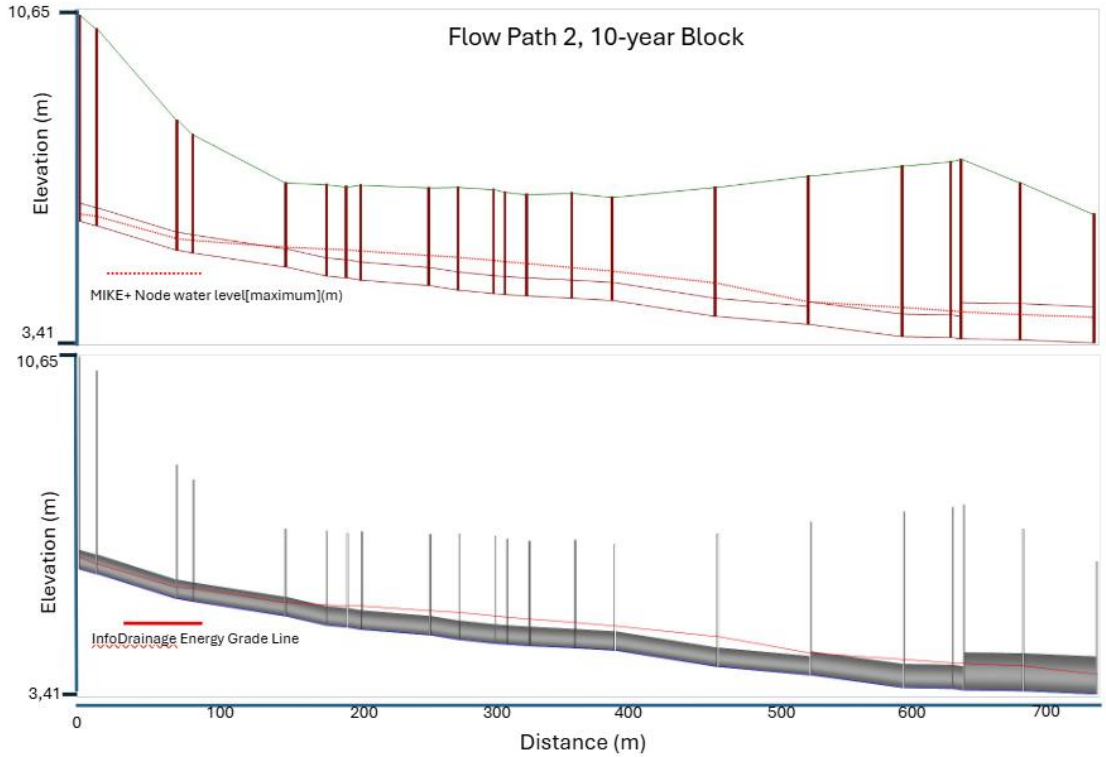


Figure 4C: MIKE+ maximum node water level(top) and InfoDrainage Energy Grade Line(bottom) for the 10-year Block event for flow path 2.

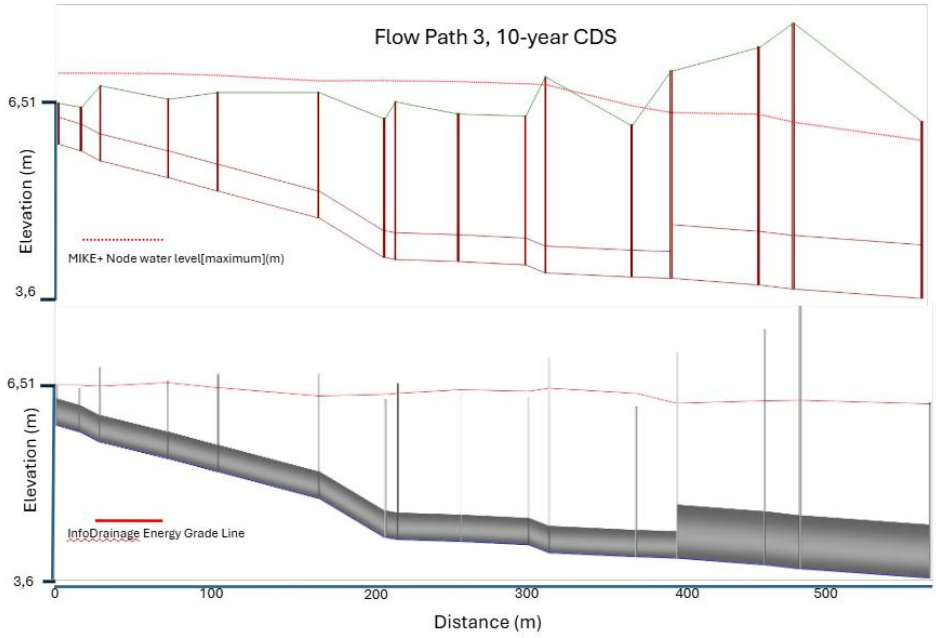


Figure 5C: MIKE+ maximum node water level(top) and InfoDrainage Energy Grade Line(bottom) for the 10-year CDS event for flow path 3.

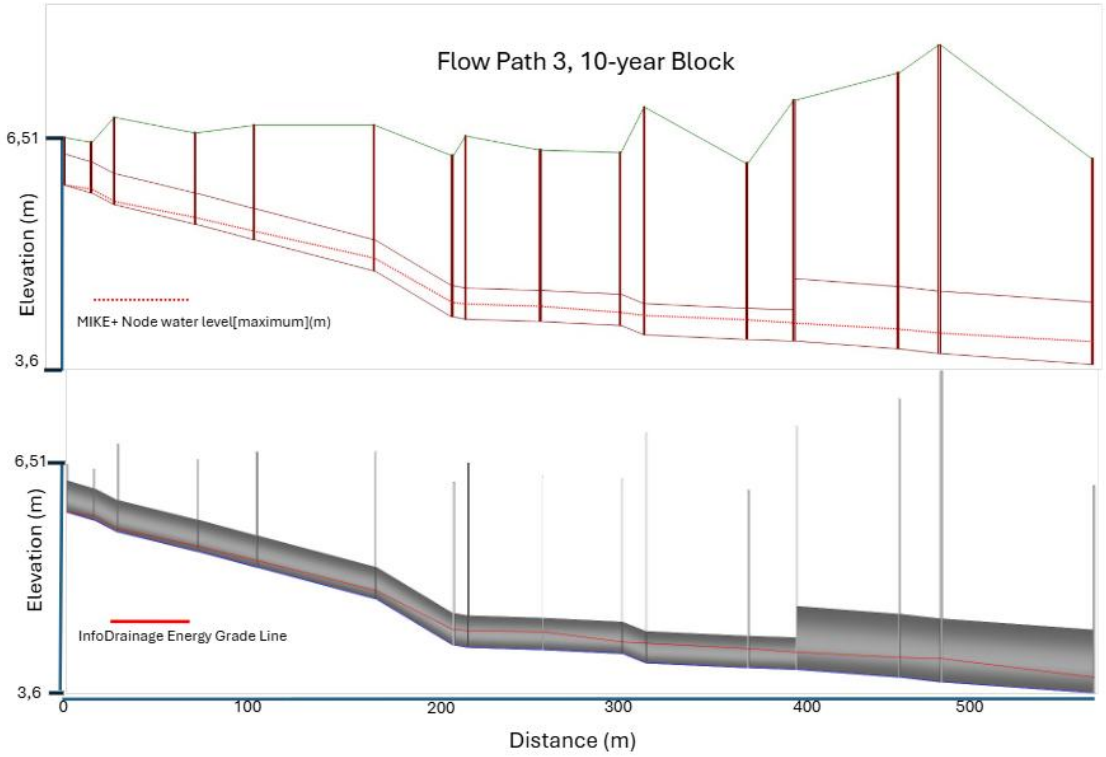


Figure 6C: MIKE+ maximum node water level(top) and InfoDrainage Energy Grade Line(bottom) for the 10-year Block event for flow path 3.