MINNEHAHA CREEK
WATERSHED DISTRICT
QUALITY OF WATER, QUALITY OF LIFE

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Title: Pilot Model Outcomes

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Meeting Objective:
The Minnehaha Creek Watershed District (District or MCWD) has pursued its pilot model project, in part, to identify a modeling platform best positioned to support the District's needs for climate planning. This project is now complete and has led staff to recommend ICPR as the District's climate model. The Operations and Programs Committee meeting will be used to walk through the process, outcomes, and learnings that have led to this recommendation. The goal of the meeting is to establish a shared understanding of (1) why ICPR is being recommended and (2) how ICPR is meant to serve the District's long-range climate planning efforts, which is distinct from the District's operational XP-SWMM model.

Climate Context:
Climate change is measurably changing the distribution, frequency and intensity of rainfall in Minnesota. Between 2013 and 2019, the MCWD experienced the wettest seven years ever recorded. Over the past 10 years, Minnesota has experienced both record flood conditions and statewide drought that has negatively impacted aquatic ecology, stressed stormwater infrastructure and cost billions in property damage. To successfully adapt to the increasingly volatile extremes in weather, MCWD and communities must be able to identify what landscape interventions are needed, where they are needed, and how much investment is needed.

The first stage of the MCWD's Climate Action Framework is to "Understand and Predict" the impacts of climate change using new data sets and modeling to forecast scenarios, evaluate vulnerabilities, and make decisions about adaptation strategies. These data will create a foundation for MCWD to engage with partner agencies in climate conversations and develop actionable plans for resilience at a system and community scale.

Modeling Needs:

One of MCWD's principles is to "Rely on sound science to make credible, result-based decisions, and build trust", which requires decisions to be evaluated through a quantitative lens. One of the most common ways MCWD quantitatively assesses project and policy decisions is using watershed models. The District relies on multiple models, all constructed and designed to serve unique needs and answer specific questions. One critical model to the District's operations is its watershed-wide Hydrology and Hydraulic XP-SWMM model (XP-SWMM), which was developed in 2003. It was designed to characterize the total volume and pollutant runoff from the landscape and understand the impact of runoff on receiving water bodies. Over the years, this model has served as the District's day-to-day operational model and has been used to estimate pollutant loading, conduct creek flood forecasting, support floodplain management, aid permitting assessments, and provide boundary conditions to District partners. These uses are still needed and continue to be met today by the XP-SWMM model. However, a series of new questions surrounding localized impacts of climate change and potential adaptation strategies have been asked in recent years by policy makers, partner agency staff, and District staff that are beyond the limits of the XP-SWMM model. Thus, the District identified a need to build an additional watershed-scale modeling tool that would be designed to support long-range climate planning. To fund this work, the District applied for and successfully secured a grant of $738,000 from the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

This new watershed-wide climate model will take advantage of available high-resolution public datasets to develop a granular representation of the physical watershed. This provides the opportunity to not only quantify runoff volumes, but also represent how water moves across the landscape via runoff, storm pipes, wetlands, best management practices, and surficial groundwater. With the understanding that the model would be used to holistically understand volume management across the 178 square miles, while also characterizing localized flooding issues, District staff worked to evaluate and identify modeling software that would best serve the District's needs. Key components identified during the evaluation included the ability to (1) model overland flow (2D surface), (2) incorporate detailed stormwater pipe networks (integrated 1D-2D model), and (3) integrate a realistic representation of the water table (integrated surface-water groundwater model). District staff ultimately identified that the modeling software that met the most criteria to support MCWD's Climate Action Framework were Infoworks ICM and ICPR4 (ICM and ICPR).

Pilot Model Need

In 2021, with LCCMR funding still unsecured, the District chose to pursue the Pilot Model Project to mitigate for technical and relational risk and better position itself for effective watershed scaling. The pilot model was designed to further evaluate the two selected model platforms (ICM and ICPR) and to address the technical challenge of incorporating numerous high-resolution datasets into a modeling tool, specifically the challenge of integrating the unique stormwater datasets from the 29 different communities within the District.

MCWD pursued the pilot model in partnership with the City of Edina, pursuant to a Memorandum of Understanding approved by the Board of Managers on August 26, 2021. In December, 2021, the Board of Managers authorized a contract with Kimley-Horn for the Pilot Model Build, with a budget of $240,000. The scope of work had two distinct phases:

1. Data Processing: Develop an overarching automated framework for processing and modifying model input datasets while also flagging data gaps recommended for filling prior to the watershed-wide build.
2. Model Evaluation: Evaluate the strengths and weaknesses of ICM and ICPR through a model build and use lens to inform (1) which will better meet the District's climate needs and (2) how to effectively scale the model build.

Pilot Model: Data Processing Outcomes

While many spatial datasets are needed to build the upcoming 2D climate model, the stormwater infrastructure datasets posed the biggest challenges since each city/agency maintains its stormwater infrastructure in its own unique data structure. The pilot model effort solved for this challenge by developing a framework to process original (raw) datasets into model-ready datasets. A core strength of the data processing system is its use of a standard geodatabase structure that had been established specifically for standardizing stormwater infrastructure datasets (MGIS). Utilizing the MGIS is an important foundation, however, data gaps and issues within the datasets still exist that are critical to correcting for use in Hydrologic and Hydraulic (H&H) models. Therefore, the District's pilot framework passes datasets through two key areas of transformation where packages of scripts have been created:

- Raw to MGIS: These automated functions reference mapping tables, specific to the corresponding dataset owner (i.e. municipal, regional, or state agency), to translate the raw infrastructure dataset into the MGIS standard. No new data are added.
- MGIS to Model-Ready MGIS: These automated functions are focused on correcting abnormalities and filling data gaps within fields that are critical to building an H&H model.

Establishing this automated framework and testing it on two pilot geography datasets is an exciting milestone. However, since the pilot model only considered a small subset of stormwater infrastructure datasets, work is still needed, which is beyond the scope of the pilot model, for use at the watershed-wide scale. This additional work includes:

- Standardize Watershed-wide Stormwater Infrastructure Data: Standardizing all municipal/agency stormwater infrastructure datasets into the MGIS format will require an understanding of each dataset's structure and nomenclature, through coordination with each public entity, and the creation of field mapping tables. (*The Board authorized a contract with Bolton & Menk for $34,785, which is due to be completed this month.)*

- Refine the MGIS to Model-Ready Script Package**:** The automated process needs to be adapted to address the gaps and issues present across the 27-stormwater infrastructure datasets, to ensure the process is comprehensive and able to generate a watershed-wide model-ready dataset. *(This work is included within the Watershed-wide Model Input Refinement RFP, scheduled for contract award at the 9/14/23 meeting.)*

It's important to acknowledge that the work undertaken to establish a standardized model-ready stormwater infrastructure dataset will serve the District well beyond the upcoming climate model build. This allows us to keep the watershed-wide stormwater infrastructure dataset routinely updated, reference the dataset for internal opportunity screening, and make it available for any future model builds regardless of their scale and/or municipal boundary.

Pilot Model: Model Evaluation Outcomes

The Model evaluation phase of the pilot model identified which of the two tested modeling platforms (ICM and ICPR) best supports the District's climate planning needs and helped inform how best to scale watershed-wide. In addition, to ensure that the findings of the Pilot Model study received rigorous review, staff incorporated engagement of a Model Advisory Committee (MAC) and review by an academic with expertise in 2D watershed model use in climate evaluations. The outcomes of the pilot model evaluation, review by the MAC and academic expert have led staff to recommend ICPR as the District's climate planning modeling platform. Below, you will find a summary of how the insights of this process have shaped the recommendations by District staff.

Pilot Model Learnings

Assessment Structure

A key component to the model evaluation process is an evaluation matrix. The purpose of the evaluation matrix is to ensure that each model is evaluated across a variety of metrics to ensure it supports the Districts greatest needs. This matrix captures (1) capabilities of the model across a range of possible uses and (2) the functionality of the models, noting differences and challenges observed while building and using the models.

Model Use

From the onset of the pilot, the objective was finding a modeling platform that would best support the District's climate planning efforts (primary uses), however, staff recognized there may be an opportunity for it to serve additional uses. For example, the District's operational XP-SWMM model will eventually sunset and its functionality will need to be replaced, so staff wanted to be mindful of these secondary uses to see if the climate model could serve as a replacement. As shown in Table 1, no modeling software can do everything well. ICPR was found to fully support capabilities needed for climate planning, where ICM was not, with this being due to ICPR's unique advantage to model 2D surface-water groundwater interactions.

Table 1. Modeling capabilities evaluation across primary and secondary uses

Evaluation Category	Line ID	Evaluation Factor / Description	Rating (0 - not capable or weak; 1 - proficient; 2 - strong)	
			ICM	ICPR
MCWD Primary Model Uses	1	Produce channel and localized flood inundation maps	2	2
	2	Run long-term extreme wet or dry years to evaluate groundwater-surface water interactions	0	2
	3	Evaluate impacts of current and alternative regulation/policies on surface water quantity	2	2
	4	Quantify impact of regional volume management strategies on surface water quantity	2	2
MCWD Secondary Model Uses	5	Short-term channel and localized flood forecasting (consider snowmelt)	2	2
	6	Characterize water quality changes/impacts	1	0
	7	Provide boundary conditions for other models	1	1
	8	Establish updated FEMA certified flood maps	0	0

Model Functionality

When comparing functional components (ease of use/technical flaws), ICM has the advantage (Table 2). ICPR proved more challenging to build due to the added complexity of incorporating groundwater into the model. In addition, the pilot model flagged technical issues experienced with ICPR. The added challenges, and its lack of use in the mid-west region, made it less likely to serve operational (secondary) uses for MCWD, in contrast to ICM. It is important to remember that the ease of use is a secondary consideration because the District cannot avoid a model simply because it is challenging or difficult to build. Instead, the pain points and challenges experienced in the pilot model allow staff to proactively mitigate challenges where possible for the watershed-wide build.

Table 2. Model functionality evaluation

Evaluation Category	Line ID	Evaluation Factor / Description	Rating (0 - not capable or weak; 1 - proficient; 2 - strong)	
			ICM	ICPR
Data Processing	9	Accepted file formats of input datasets	2	2
	10	Repeatability of data process to model build ready data	1	1
	11	Manual processing effort to get model input data ready for model import.	1	1
	12	Manual data processing feedback loops. Ability to export manually adjusted data.	2	2
Model Build Processes	13	Model node limitations (scale capabilities)	2	2
	14	Default hydrology method and processing	1	1
	15	Watershed-wide construction considerations.	2	1
	16	Ability to carve out smaller sections of the model.	2	1
	17	Model resolution required to support primary uses	1	1
	18	2D overland mesh methodology	2	1
	19	1D-2D Connection Points	1	1
	20	Pump system functions/capabilities	1	1
	21	Method/approach to calibration	1	1
Model Function and Results	22	Ease and options for BMP evaluation	1	1
	23	Ease of land-use change scenarios	1	1
	24	Model runtime (common processing system)	2	1
	25	Results quality and output format	2	1
	26	Export process and format	2	2
Software Specifics	27	Sharing model versions	2	1
	28	Local versus network - processing ease	1	1
	29	License type and cost	1	2
	30	Model maintenance (version management, security, techncial support)	1	1
	31	User Community	2	1

MAC Learnings

Staff utilized the model advisory committee to stress-test the results of the pilot model and bring more definition to the technical and relational risks associated with each model choice. The objectives of the advisor group were to (1) gauge if the District is considering and weighing each platform's abilities and limitations appropriately based on the District's intended uses and (2) better understand how a future with each model will shape and/or impact work with our partners and consultants. The advisor group included a wide range of perspectives and technical expertise and included members from engineering firms, municipalities, regional agencies, and academia.

The focus-group style format provided many valuable insights and learnings, which are documented in more detail through the MAC Feedback Synthesis (Attachment B). A few findings were particularly critical to shaping staff's recommendation:

- The MAC confirmed staff's assessment that ICPR was more capable to deliver on the District's climate planning needs
- ICPR's technical issues, brought to attention during the pilot model, are not flaws inherent to the model itself and instead can be mitigated through model build improvements
- Relational risk and concern around model selection stems from the uncertainty on how the climate model would be used to replace some or all of the District's operational XP-SWMM model uses
- Both models have limited regional use and ICM's license cost will be a barrier for many groups; a similar scan and evaluation process should be done when looking for a modeling platform to replace the operational model

Academic Model Review

Suggestions and recommendations surrounding the underlying model build were given throughout the MAC process. To explore these further and sharpen staff's understanding of ICPR, the District continued its relationship with Dr. Siddarth Saksena from Virginia Tech to implement a suite of changes within the ICPR model. The goal of this academic model review was to evaluate how alternative construction approaches impact run-time, results, and provide insights into how the District could scale ICPR. Key findings to highlight from this work include:

- Implemented model build changes increased model resolution (more granular) while decreasing model run times and yielded more accurate results.
- Dr. Saksena's ability and ease to make positive alterations to the model highlighted the need for the District to pursue a model build team with extensive experience using ICPR specifically.

Recommendation and Next Steps

Selecting ICPR will allow the District to more holistically understand watershed volume management at a watershed-scale and fully support the capabilities needed for climate action planning. The process run to date has alleviated technical concerns with ICPR and provided methods on how to pursue effective scaling. The pilot model findings and learnings are discussed in much greater detail within the 2D Pilot Model Build Project Summary Report (Attachment A).

To ensure we keep partners informed in the District's direction and plans for climate planning, a city briefing will be hosted on September 21 to provide an overview of our climate action framework and provide an update on the pilot model process and findings.

Over the next month, staff will develop an RFP for the LCCMR funded watershed-wide build with the plan to release the RFP, following Board authorization, in mid-October.

Supporting documents (list attachments):

Attachment A: Full Pilot Model Project Summary Report

Attachment B: MAC Synthesis

Attachment A

2D Pilot Model Build

Project Summary Report

August 11, 2023

Prepared for:

MINNEHAHA CREEK
WATERSHED DISTRICT
QUALITY OF WATER, QUALITY OF LIFE

Prepared by:

Kimley»Horn

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EXECUTIVE SUMMARY

The Minnehaha Creek Watershed District (District or MCWD) identified the need for a watershed-scale, two-dimensional (2D) modeling tool to support its goal of characterizing present and future climate change impacts and evaluating adaptation strategies. The District first pursued a pilot model project to manage technical risks and guide model platform selection. The pilot aimed to:

(1) Develop a repeatable automated process for integrating diverse model input datasets, necessary for incorporating stormwater infrastructure datasets from the various communities within the District; and

(2) Assess the capabilities and alignment of two modeling platforms (ICM and ICPR4) with the District's needs for climate planning.

In the course of the project, a semi-automated data processing framework (framework) for model inputs was developed to streamline the model build process, successfully accomplishing a core project objective. This work included establishing a method that effectively addressed the challenge of standardizing unique stormwater infrastructure datasets. The framework output format is largely model-agnostic, meaning the work undertaken during the pilot will serve the District beyond the climate model. Refinement to the automated processing steps will need to occur next to support its use at a watershed scale.

Among the two platforms evaluated, ICPR emerged as a model that is particularly aligned with the District's needs for climate planning. While both models were found capable to characterize flood risk and evaluate project and policy adaptation strategies, ICPR's standout feature is its ability to model surface water and groundwater in one integrated platform, offering the District an opportunity to grow its understanding in surface water-groundwater interactions and characterize its influence on flood risk. However, this benefit comes with its challenges; ICPR is inherently more complex, making it more difficult and time-consuming to build, calibrate, and operate.

ICM's strengths are ICPR's weaknesses. ICM has a clear advantage when it comes to operational functionality, keeping the level of effort to build and run the model low, and the project team experienced minimal technical challenges compared to its counterpart. However, it falls short in some critical areas. Notably, its inability to model 2D groundwater presents a limitation for climate planning.

Insights gained from this project about each model's strengths and weaknesses will guide the District's model platform selection for climate planning. Additionally, the pilot model served as a valuable learning tool for the District. It shed light on critical decision points, highlighted the importance of specific datasets that guided data collection efforts, and provided foresight to potential challenges so the District can proactively plan to mitigate difficulties during watershed-wide construction.

This report highlights significant work areas, key learnings, and scaling considerations, all drawn from technical work and documentation across six project-related memorandums or reports:

- Data Discovery Memorandum
- Automated Script Design Report
- Model Build Technical Report
- Model Calibration Report
- Scenario Modeling Report
- Evaluation Framework Memorandum

1.0 INTRODUCTION

Over the last decade, Minnehaha Creek Watershed District (MCWD or District) has experienced the wettest seven years on record, followed by periods of severe and extreme drought. These changes in precipitation intensities and swings from wet periods to drought conditions appear to be here to stay and continuing to stress our natural and built systems, highlighting the importance of integrated land-use water resource planning. To help guide the District towards climate adaptation, the District developed its Climate Action Framework (CAF). The CAF lays out a pathway for the District to identify and implement high-impact solutions in collaboration with its partners. This pathway has three key pillars:

Pillar 1: Understand and Predict - Utilize and expand technical capabilities in data collection, analysis, and tools to understand and predict the impacts of climate change at a watershed scale.

Pillar 2: Convene and Plan - Bring together local, regional, and state agencies to build consensus around the issues, align goals, form partnerships, leverage resources, and develop a coordinated strategy.

Pillar 3: Implement, Measure, and Adapt - Coordinate implementation actions with partners to make measurable progress towards goals. Implementation actions may include projects, policy changes, and operational improvements.

Pillar 1 is centered around the need to first understand and characterize how and where the watershed is being impacted today, and in the future to facilitate the evaluation and prioritization of climate adaptation strategies. A key tool identified within pillar 1 is the development of a watershed-wide 2D model, designed to provide a high-resolution understanding of how water moves through the regional hydrologic system, location and frequency of flood conditions, and the range of possible impacts in the future. Furthermore, the District looks to use this tool to begin assessing regional strategies to adapt to climate change, which could include both capital projects and adapted policies and regulation. The importance of this modeling tool, paired with the inherent technical and relational risks associated with a large-scale high-resolution model, led the District to pursue this project, the 2D Pilot Model.

1.1 Background

The District relies on multiple models, all constructed and designed to serve unique needs. The current watershed-wide Hydrology and Hydraulic model (XP-SWMM) was developed in 2003 and was considered state of the art for its time. It was designed to characterize the total volume and pollutant runoff from the landscape and understand the impact of runoff on receiving water bodies. Over the years, this model has served as the District's day-to-day operational model and has been used to estimate pollutant loading, conduct creek flood forecasting, support floodplain management, aid permitting assessments, and provide boundary conditions to District partners. These uses are still needed and continue to be met today by XPSWMM, however, it was deemed that this model is not granular enough to also understand and predict the impacts of climate change on a localized scale or to evaluate adaptation strategies. This limitation stems from the model being one-dimensional, low resolution, and implausible to keep updated, which are common limitations for a model of its time.

Over the past 20 years, major advancements in computing power along with the availability of high-resolution digitized datasets, make building and operating a large-scale 2D model possible. Taking advantage of these technological advances provides the District with the opportunity to not only quantify runoff volumes, but also represent how water moves across the landscape via runoff, storm pipes, wetlands, best management practices, and surficial groundwater. Over the last decade, the District has experienced firsthand the important role surficial groundwater can play during periods of drought and also its influence on flooding during extended wet periods.

The District was particularly interested in understanding if any of the available modeling platforms could accurately characterize surface water-groundwater interactions and groundwater movement. Understanding the relative extent of groundwater contributions during wet conditions or during periods of drought could provide valuable insight to the District related to the effectiveness of stormwater management practices such as infiltration and irrigation reuse systems and provide a greater understanding of volume management across the entire system.

Understanding the needs and use of the modeling tool is critical to selecting the right platform. With the understanding that the model would be used to holistically understand volume management across the 178 square miles, while also characterizing localized flooding issues, District staff worked with internal workgroups, consultants, and external partners to evaluate and identify modeling software that would best serve the District's needs. Key components identified during the initial evaluation were the ability to model overland flow (2D surface features); include detailed stormwater pipe networks (integrated 1D-2D model); and integrate a realistic representation of the water table (integrated surface-water groundwater model).

District staff ultimately decided that the modeling software that met the most criteria were Infoworks ICM and ICPR4 (ICM and ICPR). The District chose to pursue this 2D Pilot Model Build study to further evaluate the two selected model platforms to address the technical challenge of incorporating numerous high-resolution datasets into a modeling tool, specifically the challenge of integrating the unique stormwater datasets from the 29 different communities within the District. The District intentionally selected the two geographically distinct pilot subwatershed areas show by the dots in Figure 1 to evaluate the models in a fully developed urban area in Edina and an undeveloped rural area in Carver County.

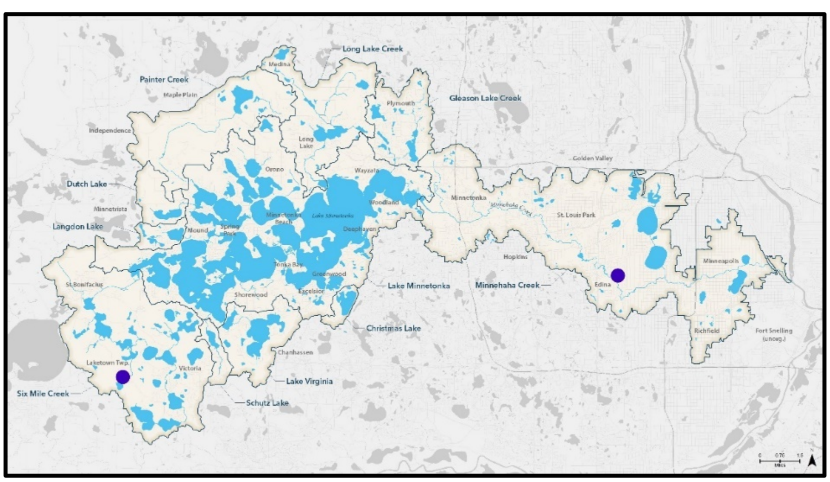

Figure 1. Pilot Subwatershed Locations in the Minnehaha Creek Watershed

1.2 Pilot Model Project Overview

The pilot model objectives were to establish an automated workflow for processing model inputs, understand the benefits and drawbacks of the two tested software suites, and inform which software is best suited for climate adaptation planning. To accomplish this, several tasks were outlined, which can be grouped into four key project phases:

1. Data Development: This phase of the project defines what datasets are needed, evaluates the quality of the available datasets, and establishes an automated framework with supporting scripts that create model ready datasets.
2. Model Build and Calibration: This phase of the project characterizes the process for constructing and calibrating each model while highlighting challenges and key differences between ICM and ICPR.
3. Model Scenario Runs: This phase of the project assesses the ability of each model to run a variety of scenario types and highlight functionality and operational differences.
4. Model Evaluation and Comparison: This closing phase of the project looks to summarize all the learnings and observations from previous task areas and describe each model's strengths and weaknesses, as they relate to the District's upcoming climate planning modeling needs.

Throughout this process, the project team identified and documented key observations related to the scalability of each software to a watershed-wide build and better understand some of the unique features of each model. These key observations are highlighted throughout this report.

Additional detail on each technical task area of the pilot model build project is provided in the following Technical Memorandums and Reports incorporated in full as Appendices A through F:

A. Data Discovery Memorandum
B. Automated Script Design Report
C. Model Build Technical Report
D. Model Calibration Report
E. Scenario Modeling Report
F. Evaluation Framework Memorandum

2.0 DATA DEVELOPMENT

A combined 1D-2D surface water model draws on a variety of spatial datasets, each collected and maintained from different agency/entity with its own unique schema. The ability to efficiently build and reasonably maintain a high-resolution watershed-wide model hinges on the idea that repeatable, largely automated, workflows can be developed to process and integrate the stormsewer datasets of the 29 communities within the District. A key objective of the pilot model build was to establish scalable automated workflows for processing required model data inputs, such as the stormsewer datasets.

The data development phase encompasses the work required to deliver on that project objective and included two essential steps: data discovery and script development. Refer to the Data Discovery Memorandum in Appendix A and the Automated Script Design Report in Appendix B for more information.

2.1 Data Discovery

The primary objectives of the data discovery phase of the pilot study were to collect and review the data types available through public sources and the direct project partners and to understand input needs of each model. Both aspects were intended to help identify gaps within available datasets that may impact the pilot model build process and guide scripting efforts.

District staff and project partners provided datasets in multiple formats and data types for use in the model development process. These data sets, often containing substantially more data than needed to build a working model, were reviewed and refined to the data needed for the model as described in the following section.

2.1.1 REQUIREMENTS FOR MODEL BUILD

Development of a combined 1D/2D model requires data that can be divided into two categories, model base data and hydraulic network features. For both categories, the data is needed as a direct input model parameter or is needed to generate (i.e., calculate) a required model parameter. Table 1 summarizes the major data input categories and the format that each model requires for import. Items in *italicized text* indicate that the input data needed or preferred is significantly different between the two models.

Based on a review of the available data, there was also a number of datasets that were not used in the automated pilot model build including:

- Pipe inspection and maintenance records and corresponding dates;
- Infrastructure ownership information including date constructed; and
- Detailed information for special drainage structures, including notes and descriptions of multi-stage outlet control devices.

While these data may have been noted in a municipal dataset, the process to collect as-built drawings and create the special structure manually in the pilot models was beyond the scope of the project. There may be a small number (less than 5) of the special structures that are critical hydraulic control devices throughout the watershed that should be considered further for the full watershed-wide model build out. Critical hydraulic control devices would be those structures that could significantly change the system response for larger events.

Table 1. Shared vs. Specific Data Inputs and Sources

Data Input	ICM	ICPR4	Source(s)
Coordinate System	NAD 1983 State Plane Minnesota South FIPS 2203 (US Feet)	NAD 1983 State Plane Minnesota South FIPS 2203 (US Feet)	NA
DEM/Ground Surface	*Elevation Point Data*	*Raster Data*	MnDNR (MnTOPO, 2011)
Soils Data	Soil Zones	Soil Zones	NRCS (2003)
Land use/Land Cover	Zones	Zones	Metropolitan Council (2016, 2020)
Lookup Tables	CN, Impervious, Manning's n, Inlet Head Discharge Curves	CN, Impervious, Manning's n, Inlet Head Discharge Curves	Created from various hydrologic references
Rainfall	Depth and Distribution	Depth and Distribution	NOAA precipitation data server, local weather stations for 2021 and 2022 event
Nodes	Subsurface Junctions (manholes), 2D Interface Nodes (inlets)	Subsurface Junctions (manholes), 2D Interface Nodes (inlets)	Edina
Links	Pipes, *1D/2D Links (Open Channel Crossings)*	Pipes, *Rating Curves, Percolation*	Edina, MnDOT (Turbid), Carver County (Turbid)
1D/2D Interface Elements	*Storage Area Volume Controls*	*Pond Control Volumes, Channel Control Volumes*	User created
2D Overland Domain	Grid (Triangular)	Grid (Triangular)	Created from DEM
2D Terrain Characteristics	Building footprints, Breaklines, Breakpoints	Building footprints, Breaklines, Breakpoints	DEM ground surface User created breaks
Groundwater	*Infiltration Parameters*	*2D Domain*	USGS Geologic Atlas, MCWD monitoring data
Boundary Conditions	Overland	Overland, *Groundwater*	User created from various reference sources

2.1.2 GAP ASSESSMENT

During the data development process, a number of anticipated data gaps and errors were observed. Data gaps were categorized as minor gaps if the data could be corrected or assumed and still support a base model build or as major gaps if the data were critical to building the model or supporting a specific function of a model. Minor gaps were expected to be present and are common within pipe datasets where data entries may have entered the wrong pipe size or have no data for a given pipe segment at all. Beyond the minor and major gaps identified below and specifically related to building a working model, additional data needs were identified through the pilot study that relate more to the quality of the model and ability to achieve a desired level of calibration quality. These data needs are discussed further in the calibration section of this report.

Minor Gaps

The most common minor gaps consisted of incomplete or missing data for pipes and structures, such as pipe size or pipe invert and rim elevations, leaving the District with two possible solutions:

- Solution A: Utilize a process to calculate or assign an assumed value to the incomplete or missing data based on Link data.
- Solution B: Field survey of incomplete or missing data.

For the pilot study, Solution A was used to fill the gap for most parameters. When considering the watershed-wide build, Solution B may be a more effective approach in certain areas to ensure accuracy, especially when considering the potential differences in model response due to having an assumed pipe size that is significantly different than what is actually in place.

Major Gaps

Overall, there were no major gaps in the available data needed to successfully build a functioning model in both ICM and ICPR formats within the two pilot geographies when considering the District's primary model use goals for evaluating a range of hydrologic and hydraulic responses in the pilot subwatersheds.

While there were no major data gaps related to building a functioning model, the pilot study identified a few critical data needs (or gaps) when considering what body of data is needed to build a more detailed model to support climate planning. One opportunity to improve model quality is to collect channel survey data to develop more accurate channel geometry data in critical stream channel areas. This survey data would allow the channel to be created in a 1D format or burned into the available lidar to at the below water surfaces and better represent the actual channel sections.

2.2 Data Processing (Script Design)

The overall objective of the data processing effort, or Automated Script Design, was to develop a set of scripts to support a more repeatable and automated data development process that would produce model-build ready datasets from the available raw datasets.

2.2.1 DATA WORKFLOW

One of the greatest technical challenges relating to developing a consistent dataset of model inputs is the range of raw stormwater datasets that exist in different schemas within the 27 cities, two townships and two counties. A set of automated scripts was envisioned from the outset that would process raw data to model-build ready data. Early in the project, the team recognized the need to rely on a standardized geodatabase as a central component to the overarching framework. The MetroGIS draft stormwater geodata transfer standard (MGIS) was selected since it has been vetted by industry experts and includes thorough documentation.

As the script design process advanced beyond the initial concepts, it became clear that there would need to be multiple scripts at particular stages of the processing pipeline. As illustrated in Figure 2, the dark blue boxes are where the scripting tools are applied.

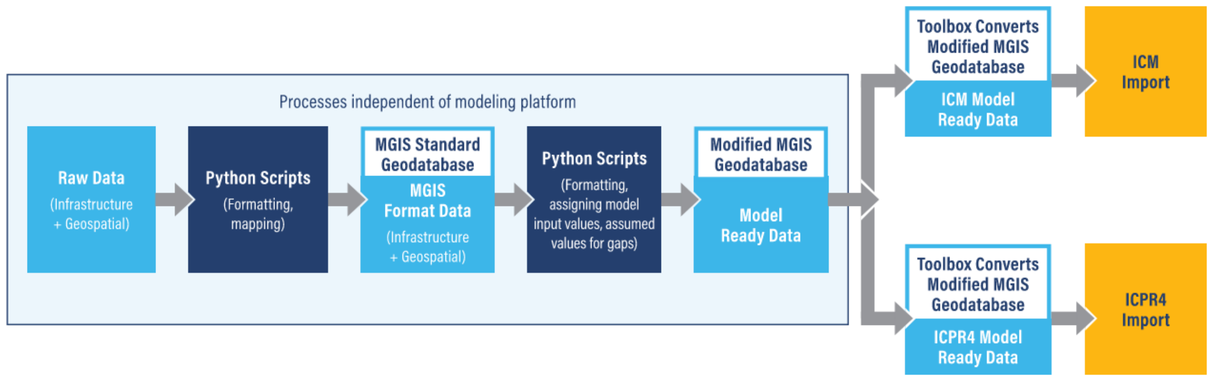

Figure 2. Datasets and Workflow Process to Produce Model Ready Data

First, the raw datasets are processed through a set of Python scripts to format the data and translate the datasets into the MGIS format. This set of scripts relies on mapping tables that are specific to each pilot stormwater dataset and note how each dataset's fields correlate to the MGIS fields. Standardizing each dataset into an established standard schema allows for reduced user input effort and errors and overall reduced complexity throughout the remaining processes to develop the model-ready datasets. It is important to note that within the baseline MGIS database, no new or assumed data is being added.

The second step is to process the MGIS format data through another set of Python scripts to further format the data into model ready data, including (1) calculating derived model input parameters from the raw data and (2) populate values to fill gaps and/or correct abnormalities. The resulting data is referred to as the Modified MGIS Geodatabase. There are three main ways the package of scripts looks to fill gaps and/or adjust values within the stormwater infrastructure datasets:

- Reference spatial datasets to correct elevation issues
- Reference downstream/upstream pipe segments to populate gaps
- Utilize engineering best practices/standards to fill remaining gaps

This decision-tree workflow allows for multiple pathways to fill a gap, which looks to first take advantage of known values before utilizing an assumption. An important feature to this package is that all adjusted values are annotated and labeled as an adjusted value to support the modeler's understanding of the source data. From that point, each model has its own required format for data import, with ICM the final toolbox function converts the data into a shapefile to be model import ready, while for ICPR, the final toolbox function converts the data to a GWIS Geodatabase format to be model import ready.

In total, a combined 20 scripts were developed to process the raw data to MGIS and the MGIS data to model-ready input format. An important benefit, by design, is that the bulk of the scripted processes are model agnostic. That is, the work completed during this project to establish repeatable processes for developing model-ready datasets will serve the District beyond the upcoming build and regardless of platform.

2.3 Learnings

Throughout the data development and script design process a number of important lessons were learned that will be beneficial for the District and its partners to understand when moving into the data development process for the initial watershed-wide climate model build and for consideration of maintaining a watershed-wide stormwater database long-term. The District's intent is for the data sharing process to become more efficient in the years ahead and become repeatable and reliable over the long-term. Key learnings include the following:

1. Even with automated processes designed to correct and fill data gaps, manual corrections within the software were still needed during the pilot model build. It is implausible to script for every potential data entry mistake or anomaly that may be encountered, meaning the data will always require some level of spatial and/or model-specific analysis to identify erroneous values that could impact model performance and results.

2. Data mapping tables created for the pilot stormwater datasets are unique to each municipality/agency and any changes in how a municipality/agency maintains their data will impact how the standard data mapping fields apply within the scripts and adjustments will need to be made. The overall process hinges on the consistent attribute naming of transformed data to develop model parameters. The raw attribute data mapping is an important step to successfully convert data from raw to MGIS. This step acts to ensure data types, formats, and naming conventions are documented so that the scripting process and data conversion steps are easily repeatable.

2.4 Scaling Considerations

Considerations related to scaling the data discover and processing efforts to the watershed wide model build effort include the following:

1. Individual data mapping tables will be needed for each local partner's dataset to bring into the standard. This includes obtaining a summary of basis and intent of each data field, ideally from the database owner that has the most recent knowledge of each dataset's schema. For example, the Edina dataset was provided with a summary document that defined which data fields were the most applicable where there were more than one field with what appeared to be the same data.
2. Since the scripts were created to account for issues observed in the pilot model datasets, the package of scripts will need to be refined to account for a wider range of issues and values that are expected to be encountered as the District reviews stormwater datasets watershed-wide.
3. The District and its partners will need to consider how the manual adjustments made within the modeling software (outside the automated script processing steps) will get incorporated back into the local partner's dataset. The intent would be that these modified values could and would be flagged such that the next iteration of data sharing would already have the previously manually adjusted value in the model ready dataset. By defining this process more clearly, it should decrease the level of effort needed during future model updates and could provide an added value for the corresponding city/agencies.

3.0 MODEL BUILD AND CALIBRATION

Following the data development phase of the pilot study, the data was imported into both model formats to initiate the model build process. The overall objective of this phase of the project was to build functioning existing conditions 1D-2D models in both model platforms, each in two distinct geographic areas, calibrate the models to a defined set of tolerances and document the challenges encountered during the model build process and the observed differences identified between the two platforms.

3.1 Model Build

The major elements of the build process for both models involved importing the pre-processed data, building the 2D surface mesh, executing the model under existing condition simulations, and then completing an iterative process to resolve remaining model functional errors, if any. Figure 3 illustrates the major steps in the model build process for both models, with the major difference being the addition of the groundwater mesh for ICPR. This additional step in ICPR seems to impede the user's ability to leverage automated mesh generation tools, resulting in heightened complexity and increased effort required to achieve a finalized model. In addition, the build scenarios box in the ICPR process includes the final step in the parameterization of the 2D surfaces for use within the simulation run in ICPR. Building the 2D surface mesh and 2D groundwater mesh is required to be finalized within the scenario building process. ICM performs this task automatically during the initial simulation initialization when a simulation is run.

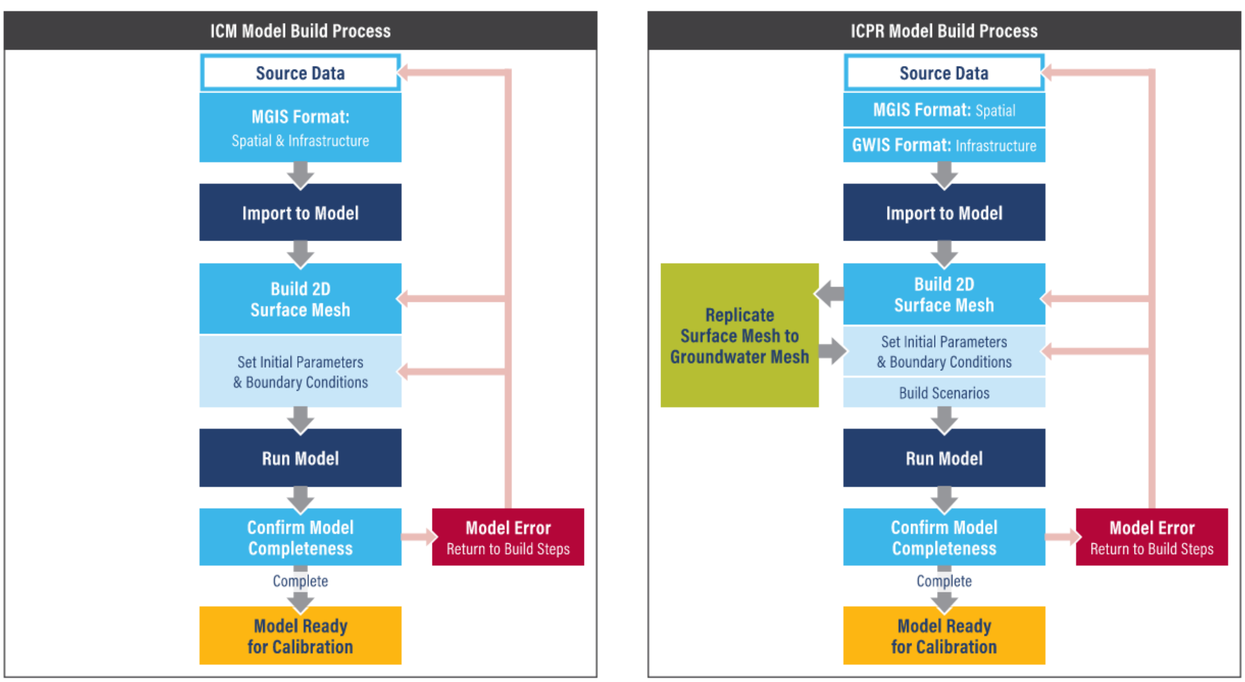

Figure 3. Comparison of ICM and ICPR Model Build Processes

Additional detail of the model build process is provided in the Model Build Report. The following section summarize the model build process for ICM and ICPR, respectively.

3.1.1 ICM

Data needed to create the ICM model can largely be imported using the Open Data Import Centre (ODIC). The ODIC accepts standard data types and allows the user to overwrite, append, and merge new datasets with previously imported datasets. The new datasets (including data attributes) can be assigned flags during the import process for future reference. Data flagging is beneficial to the modeler when updates to a model occur, during the calibration process and during model review processes.

Spatial datasets such as the hydrologic parameters and 2D surfaces typically require two data types: the delineation or boundary of the data; and the parameters that describe the impact of the dataset. These parameters include roughness zone (delineation), the boundary of landuse or ground cover types and the roughness definition contains the roughness parameter for each landuse/land cover. This two-step process for spatial data allows for large-scale changes to be made to the parameters or delineations with relative ease. ICM can use terrain-sensitive meshing feature when developing the 2D mesh which allows the modeler to specify the rate at which new 2D elements are created during the mesh generation process. To perform a simulation run, a run object must be created that references the scenario, simulation time, simulation run parameters, and other objects. The other objects can include rainfall files, initial conditions, inflow/outflow conditions as well as specifying that multiple scenarios be run simultaneously.

ICM Build Challenges:

- In areas with significant elevation changes, multiple mesh elements are required to accurately simulate the change in topography. Using the terrain-sensitive mesh generation technique, allows the user to specify a larger range of acceptable element sizes. Determining the correct size of mesh will be important to developing results at a scale that is functional for the full build.
- When GIS data has duplicate pipes (i.e., pipes that start and end at the same exact points), neither pipe was imported into ICM. The missing pipe error occurred once during the Edina subwatershed model build and was found by using the GIS Layer Manager to bring in the pipe data as a background file and verifying that all pipes were imported. This is a quick process but a necessary one to verify the automation.
- The ICM model encountered some model instability issues during the initial simulations that caused the model to crash within the initial 5 percent of the run time. The instabilities were most commonly due to 1D-2D connection elevation variances at the end of pipe runs. The most common causes for this issue include:
    1. A pipe discharges below what the model sees as the water level of a creek or pond. This can be due to LiDAR data not having a surface below the normal water level. This can be addressed by including storage below the normal water level in either a 1D or 2D format for wet features.
    2. Pipes that do not have raw invert data are automatically assigned inverts with a DEM offset from the user input parameter. This new downstream invert is then set below the DEM and will need to be adjusted during the model-build and verification process.

3.1.2 ICPR

ICPR uses the GWIS import process for the creation of 1D hydraulic data within a scenario. The spatial datasets are imported through the corresponding surface and map layer manager. Multiple surfaces and map layers can be imported at once and referenced to the corresponding scenario. Similar to ICM, the delineation and parameters for spatial layers live in separate locations can be adjusted separately. The overland flow region manager in ICPR creates and parameterizes the 2D mesh elements for surface flow. The overland flow manager allows for terrain-sensitive meshing but only when surface flow is going to be analyzed. The overland flow manager uses the specified roughness and infiltration spatial layers to parameterize the mesh.

ICPR can model two-dimensional groundwater flow using a triangular mesh like the two-dimensional overland flow mesh. The groundwater mesh and the surface water mesh can interact with each other through recharge, infiltration, seepage, and leakage. The pilot model build incorporated recharge, infiltration and seepage. The groundwater region should be setup by copying the previously created data from the overland region. Once the overland flow and groundwater regions are created and built within the respective manager tool, the scenario must be built. The scenario finalizes the various components (i.e., 1D, 2D overland, 2D groundwater) into a single file for use during the simulation run. The simulation manager can be used to specify rainfall, run times, and other simulation parameters.

Model Build Challenges:

- ICPR determines connectivity in the 1D network based on data associated with the pipe so when data entry errors are present or name data is missing, ICPR will not be able to connect pipes to nodes regardless of spatial relationship. When these errors occur, the modeler must manually define the names of upstream and downstream connections for each pipe. This occurred a couple of dozen times during the pilot build for the Edina subwatershed. It appears that the occurrences were generally located at or near where newer construction had taken place.
- When GIS data has duplicate pipes (i.e., pipes that start and end at the same exact points), both pipes are imported into ICPR. This causes a fatal error when the model tries to run. This error can be solved by deleting the duplicate pipes from ICPR.
- The ICPR model encountered instability when boundary conditions were not applied directly to the model boundary, when nodes were left in the model that did not attach to any pipes, and when inlets are placed very close to stage boundary conditions. Fixing the boundary condition to conform exactly to the model boundary and removing pipe inlets close to the downstream stage boundary condition stopped errors from crashing the model.
- The ICPR model encountered model instability issues when starting elevations within nodes were not properly assigned. The default water surface elevation is set to the rim of the structure/node at the beginning of the simulation. This produces high velocities and flow rates within the 1D pipe network. The starting water surface elevation at a node must be changed to correspond with the lowest pipe invert at the structure to eliminate this instability.
- A fully functioning overland flow model must be created prior to creation of the groundwater model. All edits to the overland flow model must be transferred into the groundwater model, including breakpoints, breaklines, and refinement areas.
- The size of the individual groundwater meshes begins to reach a practical limit around 12,000 groundwater cells based on the guidance provided by the model creator. During the pilot build, a mesh just below this practical limit was created and no issues were encountered. Multiple groundwater regions can be used within a single model but the interface line between groundwater regions must be wet (e.g., a lake, pond or creek) to allow flow across the boundary.
- The 2D flow methodology of ICPR only allows flow along the triangle faces of the overland flow region. This was found to significantly impact model run times and stability when the faces were

not aligned with the direction of flow. Aligning the triangle faces with principal flow paths is accomplished through the creation of breaklines. When considering a watershed wide build, the recommended approach is to create breaklines in GIS to allow for multiple users to create shapefiles that can be joined into a single large file for incorporation within ICPR. All breaklines created within the overland flow region should be transferred (copied) to the associated groundwater flow region for the area.

While ICPR poses some additional challenges with the model build process compared to ICM, several relate to the added complexity of the groundwater function that only ICPR offers. ICM and ICPR both need to preprocess the mesh to parameterize each 2D mesh element with infiltration and roughness values prior to use during model runs. While not a significant model build limitation, the models do require a different level of effort to preprocess the respective meshes. ICM completed the preprocessing in one to five minutes for two scenarios in the scenario evaluation process. ICPR completed the preprocessing for the same scenarios in under 30 minutes for the low-resolution scenario and between two and five hours for the high-resolution scenario.

3.2 Model Calibration

It is important for the upcoming watershed-wide climate model build to have a high level of accuracy in the model's ability to characterize the current system, so there is trust in the results projected for the future. Gaining confidence is significantly influenced by having a model that can be adjusted to match a known watershed response, or better yet, multiple known responses.

The Model Calibration Report provides the details of the calibration process for both models and how the calibration process may be improved during the watershed wide model build. Before the calibration process began, the team established primary and secondar categories of calibration metrics. Secondary metrics were intended to be more visual observation of differences in groundwater influence on results and observations of flood inundation levels compared to other reported data. The primary calibration metrics were:

- **R – Squared** represents the proportion of the variance between a modeled and measured value. For the model results in this study, R-squared is based on the model stage results with tolerance levels ranging from a poor rating (0.60 to 0.70) to very good for a result at or above 0.90.
- **Standard Deviation** relates to the differences in the stage (in feet) between the recorded monitoring data and model simulation results. Tolerance levels ranged from a poor rating from (2.0 feet to 0.5 feet) to very good for a result less than 0.1 feet.
- **Continuity Error (Volume)** is the total error that occurs within the simulation process and is a measure of the total volume of runoff retained and accounted for in the model results. Due to computational processes in a model, this error takes the form of either additional volume that is introduced to the model or a reduction of volume discarded from the model run. Tolerance levels ranged from a poor rating with greater than 5% error to very good for less than 1% error.
- **Stage Difference.** Stage corresponds to a measured water level in the pond, storage area, creek, or river. The average metric is the average difference calculated over the full model run time and indicates whether the data overall are higher (positive result) or lower (negative result) than the average stage. The goal is to have a lower average stage difference. Therefore, stage differences were reported as only numeric results and were not given a poor to very good rating.

To guide the pilot model calibration effort, a calibration process was established that included the following five steps:

1. Evaluating the Base Model Performance;
2. Adjusting Physical Components (e.g., mesh refinement, breakline adjustments);
3. Revaluating the Physically Adjusted Model's Performance;
4. Adjusting Model Parameters (e.g., hydraulic parameters, hydrologic parameters, groundwater parameters); and
5. Documentation of processes, results and observations.

An import aspect of a successful calibration effort is that true calibration is based on the availability of known results (i.e., recorded data) for the range of model conditions to be assessed. Due to a lack of available data within the Turbid-Lundsten model area, only the Edina model was brought through the calibration process outlined above. Recorded data within the Edina geography was still limited; and calibration largely relied on monitoring data within the creek (Mill Pond outlet and W. 56th street).

3.2.1 CALIBRATION RESULTS

The results of the calibration process have demonstrated that both models can be calibrated to within generally accepted calibration tolerances for the selected parameters: Stage (peak high-water level), Standard Deviation, R-Squared and Continuity Error.

Stage

Figure 4 shows the 77-day simulation for both calibrated models. Throughout the calibration process, ICM tended to have stage results higher than the recorded data at the 56th Street gage location while ICPR showed results lower than the recorded data.

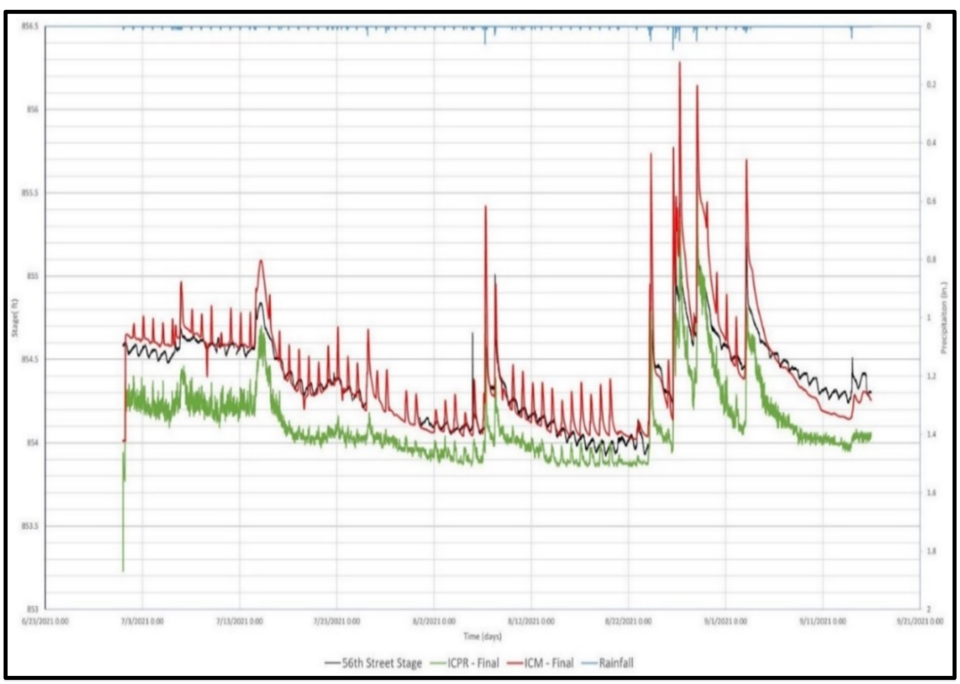

Figure 4. ICM – ICPR Long Term Stage Comparison

The overall shapes of both pilot model hydrographs follow the recorded data well. ICM tends to draw down at a slower rate after a peak stage than the recorded data and ICPR draws down much quicker than the recorded data. ICPR tends to have more "noise" in the hydrograph than ICM. The differences in the peak high-water level (stage) varies through a give storm simulation, although both models have produced peak elevation results that are within about 5 inches or less of the recorded data and average stage differences on the order of 1-4 inches for the September 2021 and July 2022 events.

R-Squared (RSQ), Standard Deviation, Continuity Error

At the outset of the calibration effort, the team established the goal of reaching a "Good" calibration rating for each of the listed calibration metrics. As illustrated in Table 2, both models were able to reach a calibration rating of Good to Very Good for the July 2022 long-duration event following the iterative calibration process.

Table 2. Model Calibration Results

July 2022 Event	R-Squared (Stage)		Standard Deviation (Stage)		Continuity Error (Volume)	
	Value	Rating	Value (ft)	Rating	Value (%)	Rating
ICM –Final	0.894	Good	0.168	Good	-0.01	Very Good
ICPR – Final	0.901	Very Good	0.106	Good	+0.77	Very Good

3.3 Learnings

Throughout the pilot model calibration effort, several key learnings were identified that impact the approach to the watershed-wide build. These include:

1. Both models achieved acceptable calibration tolerances for the purposes of the pilot study. With additional effort and additional monitoring data to calibrate the models to, we believe both models would be able to converge on a very similar model result. Calibration effort will be greater for ICPR primarily due to the added complexity of the groundwater function.
2. Accuracy and Resolution of Terrain Data.

   Additional surface feature data, such as channel cross-sections, are needed to supplement the baseline data provided from LiDAR. The largest constraint to developing a 1D-2D hydrologic/hydraulic model for extreme event analysis is the quality (or lack of) of terrain data in critical hydraulic control areas. Terrain files can be generated from survey data points, lidar files, contours, and a combination of all three. The original terrain surface was developed solely from LiDAR data. This data did not include information below the water line for Minnehaha Creek, for example, which did not allow for adequate drawdown of the creek to an elevation lower than the LiDAR surface. By including the channel information from available XPSWMM cross-sections and the Arden Park redevelopment topography, this challenge was effectively resolved.

   The surface discrepancies may not be apparent during extreme rainfall and flow events due to the scale of water flowing in the creek but will be critical to the understanding of minor storm events and drought conditions throughout the watershed. This may require additional survey and elevation data to be obtained either through manual processes or partnership with individual agencies throughout the watershed to gather the required data. The more accurate and complete terrain data in the geographic locations of calibration allow for more confidence in the calibration process over the range of small to large runoff event responses.

3. Vertically Varied Parameters

   Within ICM, the Manning's n roughness coefficient can be varied up to three times (three spatial zones) depending on the depth within a cell. Within ICPR, the Manning's n roughness coefficient can be varied twice (shallow and deep). Both models allow for changes to the roughness values at each inundation level and changes to the inundation level breakpoints by roughness zone. The flexibility to adjust the parameter and level allows for a higher degree of calibration. As future data collection efforts proceed with survey of channel sections, it will be beneficial to have photographs that correspond to the survey areas so that modelers can have a sense of what field conditions are when assigning these varied n-values with a give reach.

4. While the calibration process allows for additional confidence in the modeled results to be gained, the process is never truly finished. The calibration process can be reevaluated at any point for a given model when additional data is obtained and incorporated into the model including new monitoring data, terrain data or 1D infrastructure data.

5. The base data available from groundwater monitoring stations provided sufficient information to build and make assumptions relating to the starting depth for the groundwater surfaces in ICPR. As learned later in the ICPR scenario runs, the starting elevation for groundwater can have a noticeable impact on model response. Obtaining additional groundwater elevation data (or assumptions) would be beneficial to allow a larger model to be created with multiple 2D groundwater zones where the starting elevations can be different and the inflow areas to surface water features can be further refined.

3.4 Scaling Considerations

Considerations related to scaling the calibration process efforts to the watershed wide model build effort include the following:

1. Resolution of monitoring stations.

   Additional monitoring station data will be critical to the future calibration of the watershed-wide model build. Additional spatial distribution of the monitoring data will help to calibrate individual segments (subwatersheds) of the overall system. Adjusting parameters to meet a single comparison point may be valuable to understanding the sensitivity of the model in general, however, calibrating to a single location can result in too broad of assumptions of the runoff parameters, for example, throughout the entire watershed.

   More data collection locations and a higher data recording frequency during a runoff events are desirable to improve the calibration process and the corresponding confidence in subsequent scenario simulations. Emphasis should also be placed on collecting continuous stage and discharge data within each subwatershed, outlets of major tributaries, and key areas along Minnehaha Creek will be essential for proper calibration.

2. Range of calibration events

   The bulk of the available monitoring data was collected during the 2021 and 2022 open water seasons. Typically, two years of data provides a range of creek flows and responses to varying rainfall events (small, medium, large events). However, both 2021 and 2022 were drier than normal years for MCWD. For the watershed-wide build, there ideally will be access to monitoring data that spans a wider range of water-level and flow conditions. This is clearly outside anyone's control, but longer periods of recorded data should help yield a variety of conditions to reference.

3. Data inputs for groundwater.

   For ICPR, the extent of groundwater datasets provides a baseline for setting up and using the 2D groundwater surface in the model. Referencing all available hydrogeologic data will allow for improved definition of the groundwater region, initial water table settings, and inflow.

   This additional groundwater data will be helpful to support "phased" groundwater regions for watershed-wide scaling. As discussed elsewhere in this report, creating multiple groundwater regions may help manage the longer run times as well as providing a more complete picture of the relative groundwater contributions to key surface water resources, especially in the areas where field data is present.

4. Improved channel cross-sections.

   Additional channel survey/cross-section information at critical channel locations throughout the watershed that are spatially referenced should be collected to support the watershed-wide build. Additional detail is especially important at and near the current and planned flow and stage monitoring locations.

5. Both models encountered some model instability issues that caused the model to crash.

   - For ICM, the instabilities were most commonly due to 1D-2D connection elevation variances at the end of pipe runs. One of the most common causes resulted when a pipe discharges below what the model sees as the water level of a creek or pond. This can be due to LiDAR data not having a surface below the normal water level. This can be addressed by including storage below the normal water level in either a 1D or 2D format for wet features. Another common cause resulted from pipes that do not have raw invert data being automatically assigned inverts with a DEM offset from the user input parameter. This new downstream invert is then set below the DEM and will need to be adjusted during the model-build and verification process.

   - The ICPR model encountered model instability issues when starting elevations within nodes were not properly assigned. The default water surface elevation is set to the rim of the structure/node at the beginning of the simulation. This produces high velocities and flow rates within the 1D pipe network. The starting water surface elevation at a node must be changed to correspond with the lowest pipe invert at the structure to eliminate this instability.

4.0 SCENARIO ANALYSIS

The Scenario Modeling report provides an overview of the selected model runs, results, and learnings. Three categories of model runs were conducted, each aimed at learning something different about the two platforms. The objective of each category is described below:

- **Rainfall Scenarios**: These runs look to compare the results of ICM and ICPR to identify where we see differences and whether observations seen during calibration hold consistent in other areas of the watershed and under a wider range of rainfall conditions.
- **Geospatial Scenarios**: These scenarios look to reveal the differences and challenges associated with (1) incorporating adjusted spatial data and (2) model functionality and performance.
- **ICPR Groundwater Sensitivity:** These runs look to examine the level of influence ICPR's 2D groundwater component has on surface water results.
- **Run Time Scenarios:** These runs look to compare run times across varying degrees of mesh resolution.

4.1 Rainfall Scenarios

Several different rainfall scenarios were evaluated to compare results between the two models including:

- Comparing the modeled peak water surface elevations along Minnehaha Creek through the Edina subwatershed to the FEMA published Base Flood Elevation (BFE);
- Comparing the peak water surface elevations for the 10-year and 100-year events in the Edina subwatershed to the Edina localized flood maps;
- Comparing peak discharge rates leaving the Turbid-Lundsten subwatershed at Highway 5;
- Comparing peak water surface elevations and peak discharge rates along Minnehaha Creek through the Edina subwatershed for the 2014 Flood of Record rainfall event; and
- Comparing the peak water surface elevation, peak discharge rate and continuity error for the 2-year, 10-year and 100-year, Atlas-14 Design Storms in the Edina subwatershed.

In addition to the capabilities of each model related to simulating each of the event scenarios noted above, both models are fully capable of producing simple and complex graphical output results to illustrate important model results data. A sample of the more common and typical output from the ICPR Model (left) and ICM Model (right) is shown in Figure 5. The images illustrate the triangular mesh elements shown in the black outlines for ICM and the irregular mesh elements as the white outlines for ICPR. Both images also show the irregular size of the mesh elements with greater detail (smaller cells) in the areas of greater elevation change along the creek channel and larger cells in areas in the areas with smaller elevation changes.

Overland inundation depth results in both images are represented for each individual mesh element for each model. ICM displays the inundation depth as light to dark blue (shallow to deep), while ICPR displays the inundation depth as purple to green to blue to yellow to red (shallow to deep). The background colors in both images represent the elevation layer directly from the DEM.

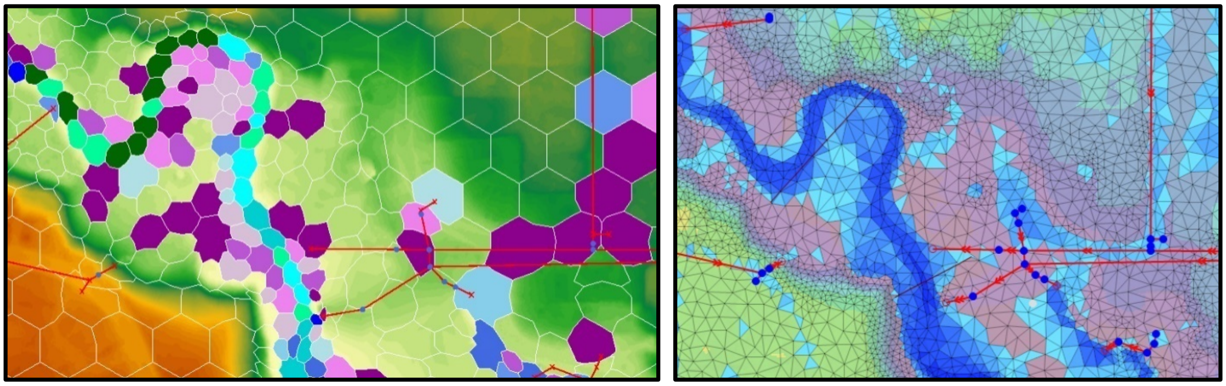

Figure 5. Sample Model Output Results for ICPR (Left) and ICM (Right)

4.2 Geospatial Scenarios

Two scenarios were evaluated to compare results between the two models related to geospatial changes including:

- Comparing peak discharge rates and volumes leaving the Turbid-Lundsten subwatershed at Highway 5 for the 2-year, 10-year, 100-year 24-hour events and the 100-year 10-day event, when changing the land use conditions from Pre-settlement to Existing to Future Development conditions; and
- Comparing the modeled peak water surface elevations to the results of the Edina Neighborhood flood reduction project for the 2-year, 10-year, and 100-year 24-hour design storm events.

ICPR and ICM were found to have a similar level of effort required to update landuse and swap out DEM files for the various land use scenario runs. ICM allows for multiple options when importing including overwrite, prompt, merge, and ignore when duplicate features are encountered during import. ICPR requires that the import dataset is clipped to only include the new/updated features. This allows for efficient updates and removal of previously created features. Figure 6 illustrates the results from both models for the discharge rates at Highway 5 leaving the Turbid-Lundsten pilot subwatershed. Both models show similar and expected trends of increased peak discharge from pre-development to existing and from existing to future conditions. The difference in results between the two models was not of concern since neither model was calibrated.

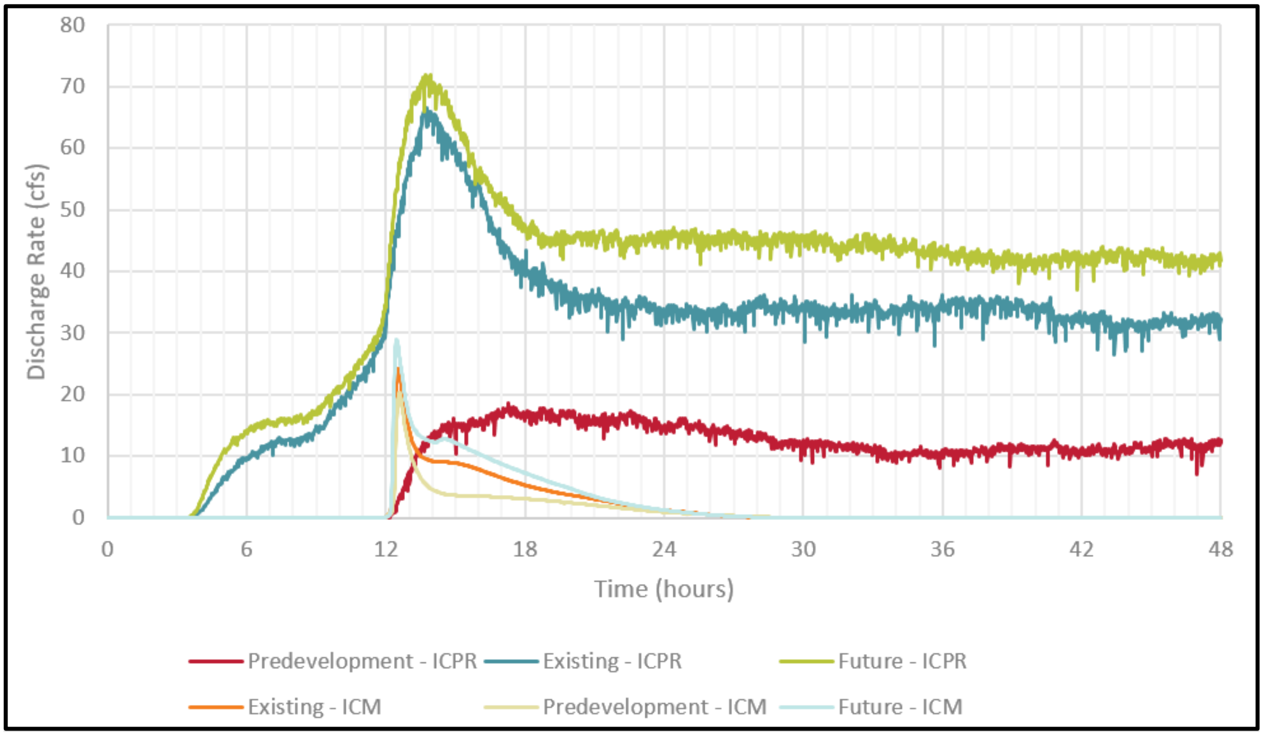

Figure 6. Discharge Rate Hydrographs – 2-year, 24-hour

4.3 ICPR Groundwater

To further understand the influence of the ICPR groundwater module and its impact on results, three model runs were completed to assess the impact of the starting groundwater level condition on the model results:

1. Low: Constant elevation of 853 feet for the entire model area;
2. High: Matching the terrain (e.g., water table is at the ground surface level); and
3. Varied: 6-feet below the terrain. (the level used for all model build, calibration, validation and scenario analyses).

Results showed that the initial groundwater elevation assumption can have a significant impact for smaller storm event results when assessing high-water level results on ponding and low areas as shown in Figure 7. Groundwater level assumptions had a smaller impact on larger events results and on creek peak flow and stage results.

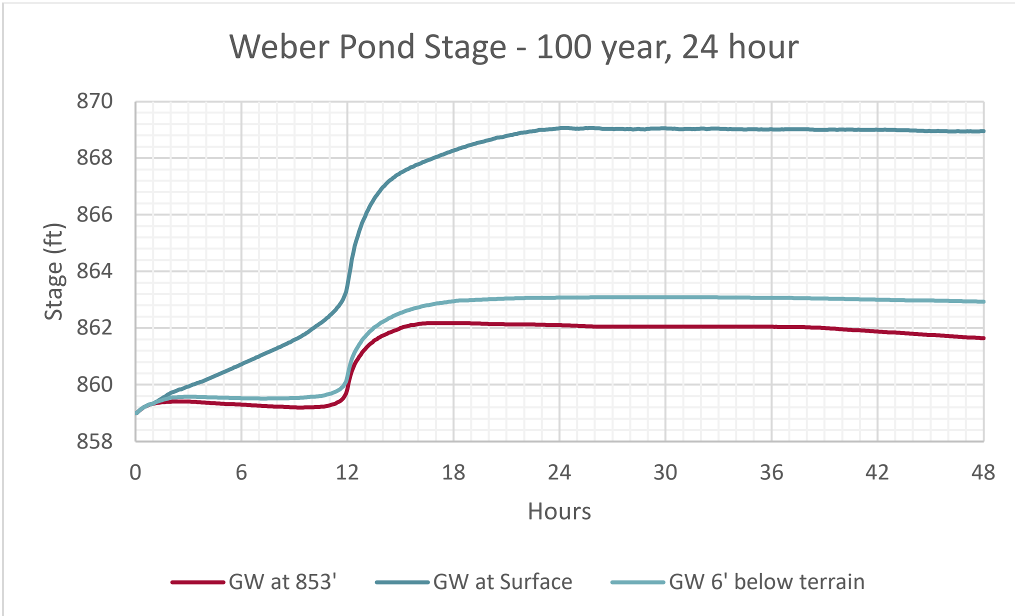

Figure 7. ICPR: Impact of Groundwater Initial Conditions on Weber Pond Stage

At a minimum, the modeled differences in high-water level for both Weber Pond and 56th Street highlight the need for greater emphasis on having confidence in the groundwater elevations throughout the watershed if ICPR is the selected model for the watershed-wide build. Over long simulation time periods, including a 77-day simulation, the influence of groundwater is allowed to equilibrate as the model "warms-up" at the beginning of the simulation time. This allows the ICPR model to simulate groundwater more accurately over longer periods such that the influence of the starting groundwater elevation becomes less significant.

4.4 Model Run Times

Model run times can be an important factor for modelers, primarily when considering the model build and calibration process. As each iteration of model adjustments are made, the model is executed to confirm initial build steps to debug the model and, once built and running, calibration adjustments are made to refine the results; longer run times mean fewer iterations can be completed for a given time period. The net result may be on the order of a few hours to several days if the model crashes towards the end of a long run or crashes during an overnight run, for example. Model run times are not as critical once the initial model is created and calibrated since there is generally not such urgency to obtaining results for a given scenario run.

The models were developed and run using various laptop setups to assess the overall usability and processing power needs and considerations. A computer with a good graphical processing unit (GPU) will be beneficial to reduce simulation run times for ICM. A computer with a fast CPU is beneficial for performing ICPR simulations and reduce overall run times.

Run times were recorded and compared for the full range of scenarios described in the previous sections. While ICM run times were generally lower for most scenarios, these results do not represent a true apples-to-apples comparison, considering that the models built at different resolutions and included different adjustments to achieve acceptable calibration tolerances.

To evaluate run times on a more representative apples-to-apples basis, model resolution was set to be comparable between the two models. The purpose of these runs was solely to evaluate run times, and the impact the resolution change had on results was not considered. A computer with NVIDIA Quadro T2000 with Max-Q Design GPU and an Intel Core i7-10850H CPU was utilized for the comparison. Results for a 100-year, 24-hour design storm event run are presented in Table 3.

Table 3. Model Run Times for the Turbid-Lundsten Pilot Area

Resolution	ICM		ICPR		
	Run Time (minutes)	# of 2D Elements	Run Time (minutes)		# of 2D Elements
			Overland Only	With Groundwater	
Low	20	12,053	33	47	11,900
High	42	92,931	78	106	50,842[1]
			169	N/A	105,498[2]

[1] ICPR high-resolution run developed from hand-delineation tools (breakpoint offset, breaklines)
[2] ICPR high-resolution run developed from automated build tool

The results indicate that longer run times will be experienced with ICPR, even if the groundwater portion isn't included. ICM is known for its fast run times and this advantage over ICPR stems from its ability to process on GPU's vs CPU's. These run times will increase for both models as they are scaled watershed-wide and as greater resolution is created.

4.5 Learnings

Throughout the scenario analysis processes a few important lessons were learned that will be beneficial for the District and its partners to understand when moving into the watershed-wide model build. Key learnings include the following:

1. For both models, adding sufficient detail to the mesh and manually refining mesh elements through breaklines and break points within critical hydraulic areas is critical to allow the model to move water in a more representative manner for a wider range of hydrologic conditions.
2. One interesting observation with ICPR relates to a consistently higher peak discharge rates which appears to relate to the computational processes within the pilot models. As we have discussed previously, ICPR shows much more variation in the peak discharge results with relatively high values shifting to lower values in subsequent time steps while ICM produces a much smoother hydrograph. For ICPR we recommend a standard process to use the values taken from a consistent approach (model or exhibit) based on the model users best professional judgement of viewing the hydrograph and reviewing the exported data.
3. The level of effort to swap land use files and set up new scenario runs with modified geospatial datasets required a similar level of effort for both models. No significant difference was experienced between the two models.

4.6 Scaling Considerations

Key considerations related to scaling the model build, calibration and scenario analysis process to the watershed wide model build effort include the following:

1. There are multiple decision points throughout the build process, such as mesh resolution, detail of pipe network to include, etc., and these decisions (both in number and their importance) will only increase as you scale watershed-wide. Further defining and prioritizing scenarios will help guide how those decisions should be made.
2. The inclusion of selected 1D features within the watershed-wide model build will allow for increases in efficiency and reduction in simulation run times. 1D features (ponds, lakes, channels) remove portions of the simulation area from the 2D calculation. This reduces the overall size of the model without losing accuracy within the model when the 1D features are accurately created and implemented. The 1D features should be created outside of the model as shapefiles and imported. This allows for creation of multiple model scenarios with consistency and for updates to be completed with new data as major surface water features are created within the watershed. The greatest value in creation of 1D features will be for the larger lakes and pond such as Lake Minnetonka, Lake Minnewashta, Lake Harriet and Long Lake.
3. Considering “phased” groundwater regions in ICPR may be important for watershed-wide scaling and would likely help manage the longer run times as well as providing a more complete picture of the relative groundwater contributions to key surface water resources.

5.0 MODEL EVALUATION AND COMPARISON

A critical aspect of the pilot model build project and the first task within the scope of work was to establish a clear, comprehensive evaluation framework that the District would ultimately use as a resource to inform which of the two models is best suited to meet the District's current needs; and to understand the operational considerations and challenges of scaling the selected model watershed-wide. This section outlines the evaluation approach and framework that was developed, along with a summary of each model's strengths and weaknesses.

5.1 Evaluation Approach

The framework was developed with two categories of evaluation factors, MCWD Model Uses and Model Operations. As shown in Figure 8, the first two sections (lines 1-8) address model uses and the remaining sections focus on model operations, function and model specific factors. The right-hand columns indicate the relative capabilities of each model for each of the evaluation factors.

Evaluation Category	Line ID	Evaluation Factor / Description	Rating (0 - not capable or weak; 1 - proficient; 2 - strong)	
			ICM	ICPR
MCWD Primary Model Uses	1	Produce channel and localized flood inundation maps	2	2
	2	Run long-term extreme wet or dry years to evaluate groundwater-surface water interactions	0	2
	3	Evaluate impacts of current and alternative regulation/policies on surface water quantity	2	2
	4	Quantify impact of regional volume management strategies on surface water quantity	2	2
MCWD Secondary Model Uses	5	Short-term channel and localized flood forecasting (consider snowmelt)	2	2
	6	Characterize water quality changes/impacts	1	0
	7	Provide boundary conditions for other models	1	1
	8	Establish updated FEMA certified flood maps	0	0
Data Processing	9	Accepted file formats of input datasets	2	2
	10	Repeatability of data process to model build ready data	1	1
	11	Manual processing effort to get model input data ready for model import.	1	1
	12	Manual data processing feedback loops. Ability to export manually adjusted data.	2	2
Model Build Processes (Including Calibration and Validation)	13	Model node limitations (scale capabilities)	2	2
	14	Default hydrology method and processing	1	1
	15	Watershed-wide construction considerations.	2	1
	16	Ability to carve out smaller sections of the model.	2	1
	17	Model resolution required to support primary uses	1	1
	18	2D overland mesh methodology	2	1
	19	1D-2D Connection Points	1	1
	20	Pump system functions/capabilities	1	1
	21	Method/approach to calibration	1	1
Model Function and Results (Scenario Analyses)	22	Ease and options for BMP evaluation	1	1
	23	Ease of land-use change scenarios	1	1
	24	Model runtime (common processing system)	2	1
	25	Results quality and output format	2	1
	26	Export process and format	2	2
Software Specifics	27	Sharing model versions	2	1
	28	Local versus network - processing ease	1	1
	29	License type and cost	1	2
	30	Model maintenance (version management, security, techncial support)	1	1
	31	User Community	2	1

Figure 8. Evaluation Matrix: Categories, Factors and Ratings

Within the model uses category, the framework distinguishes between primary and secondary uses. The District recognizes that while this upcoming model build is intended to first and foremost serve climate planning needs, its understood that a model at the watershed scale could serve as a replacement to some or all of the functionality that XPSWMM currently provides to the District and its partners. It was important that these two categories of uses were distinguished during the evaluation process.

Primary Uses*:* The Primary uses section lists modeling capabilities that were deemed essential to the District's ability to support climate adaptation planning. Emphasis will be placed on this category during model selection. The primary uses and how each factor supports the District's primary needs are provided in Table 4.

Table 4. Primary Use Factors to Support District Needs

Evaluation Factor	District's Need
Produce channel and localized flood inundation maps	It is critical that the District can characterize the areas, frequency, and magnitude of flooding issues under current and future climate.
Run long-term extreme wet or dry years to evaluate groundwater-surface water interactions	It is important for the District to characterize how groundwater will respond to predicted rainfall patterns and how those responses impact flood risk.
Evaluate impacts of current and alternative regulation/policies on surface water quantity	The District needs to be able to quantify the impact varying policies/regulation will have on flooding and volume management at a systems scale.
Quantify impact of regional volume management strategies on surface water quantity (projects/BMPS)	The District needs to evaluate and quantify the impact of varying project strategies to prioritize actions within each subwatershed.

Secondary Uses*:* The secondary model uses section includes capabilities from which the District and its partners would benefit, although these metrics will not drive model selection. Many of these secondary uses have historically been or can be obtained from other modeling tools. It's important to characterize how ICM and ICPR could serve these needs so the District can understand if any of the day to day operational needs and uses of XPSWMM could be replaced.

Operational Factors*:* The remainder of the matrix includes Model Operations factors that address each model's ability to efficiently be built, run, and for data to be exported to a usable format, as well as factors addressing how each model may be scaled and maintained considering a watershed-wide application.

Additional detail on the list of secondary uses and operations factors is presented in the Evaluation Framework Memorandum.

Observations in the matrix were first populated by the data development and modeling team members, then supplemented by the model software developers and finally were refined into a single set of observations and ratings.

The following sections summarize the key findings presented in the matrix for the District's defined primary and secondary uses and for the overall model operations. These sections are intended to highlight any observed strengths and limitations of each model.

5.2 Model Use Comparison

5.2.1 PRIMARY USES

Both models are able to characterize and quantify flood risk across the watershed and both are capable of evaluating how changes in policy and/or projects may impact the surface water runoff contributions to water bodies and the creek. This is due to their matched ability to include detailed 1D pipe networks and track 2D overland flow. However, by far the most distinguishing difference between the two platforms comes down to how they represent groundwater. ICPR is unique and one of few models that has a true integrated surface-water groundwater component. This means that ICPR positions the District to understand how surficial groundwater is responding to forces on the surface, such as land-use change or increased precipitation, and characterize surficial groundwater flow. ICM models groundwater in a much more simplistic way and the user is not able to characterize how the water table itself is responding to surface adjustments.

Evaluation Category	Line ID	Evaluation Factor / Description	Rating (0 - not capable or weak; 1 - proficient; 2 - strong)	
			ICM	ICPR
MCWD Primary Model Uses	1	Produce channel and localized flood inundation maps	2	2
	2	Run long-term extreme wet or dry years to evaluate groundwater-surface water interactions	0	2
	3	Evaluate impacts of current and alternative regulation/policies on surface water quantity	2	2
	4	Quantify impact of regional volume management strategies on surface water quantity	2	2

Differences: The primary difference in the two models is that ICPR is able to track and simulate horizontal groundwater movement and ICM is not.

5.2.2 SECONDARY USES

Of the four secondary uses, both models are fully capable to complete short-term channel and localized flood forecasting and capable to provide boundary condition inputs to other models. Neither model is currently nationally accepted by FEMA as a model format for producing official flood mapping. Both models have one or more local or regional examples of being accepted. ICM is currently in the process of seeking approval.

Evaluation Category	Line ID	Evaluation Factor / Description	Rating (0 - not capable or weak; 1 - proficient; 2 - strong)	
			ICM	ICPR
MCWD Secondary Model Uses	5	Short-term channel and localized flood forecasting (consider snowmelt)	2	2
	6	Characterize water quality changes/impacts	1	0
	7	Provide boundary conditions for other models	1	1
	8	Establish updated FEMA certified flood maps	0	0

Differences: The primary difference in the two models is in the capabilities to characterize water quality changes and impacts. It is important to note that this capability was not directly evaluated during the pilot study and the capability assessment is based on review of the materials available from the model creators. ICM is capable of modeling total phosphorus (TP) and other parameters of interest to the District. ICPR does not currently have capabilities to track nutrients or other urban runoff pollutants.

5.3 Model Operations Comparison

5.3.1 DATA PROCESSING

Both models draw on the same underlying datasets to construct the model. Furthermore, the automated processing framework established during the pilot project is primarily model agnostic, leaving only the final step dependent on platform, which processes datasets into each model's required input format. No significant differences were identified between the two models when considering the pre-processing work.

Manual adjustments will be required within ICM and ICPR to make additional corrections to the underlying datasets. Both models flag these changes and would support the development of a feedback loop process to prevent repetitive changes always being made to 1D infrastructure elements.

Evaluation Category	Line ID	Evaluation Factor / Description	Rating (0 - not capable or weak; 1 - proficient; 2 - strong)	
			ICM	ICPR
Data Processing	9	Accepted file formats of input datasets	2	2
	10	Repeatability of data process to model build ready data	1	1
	11	Manual processing effort to get model input data ready for model import.	1	1
	12	Manual data processing feedback loops. Ability to export manually adjusted data.	2	2

Differences: There were no significant differences identified between the models related to data processing. ICPR requires one additional step to get the infrastructure data in the GWIS format for model import, but that is accomplished easily through the automated scripting tools.

5.3.2 MODEL BUILD PROCESSES

For six of the nine factors in this evaluation category, both models are equally capable with only minor differences in the approach each model takes for a given factor and the associated level of effort. The primary difference in the effort needed to build the models relates to the added groundwater function in the ICPR model. That is, this additional step to add a second 2D surface requires the modeler to import and create the second 2D surface for groundwater including replicating the surface 2D grid and creation of new breakpoints for the groundwater mesh. When considering the build process and calibration, this effort could be twice the effort needed to build and calibrate a similar resolution ICM (surface only) model.

Evaluation Category	Line ID	Evaluation Factor / Description	Rating (0 - not capable or weak; 1 - proficient; 2 - strong)	
			ICM	ICPR
Model Build Processes (Including Calibration and Validation)	13	Model node limitations (scale capabilities)	2	2
	14	Default hydrology method and processing	1	1
	15	Watershed-wide construction considerations.	2	1
	16	Ability to carve out smaller sections of the model.	2	1
	17	Model resolution required to support primary uses	1	1
	18	2D overland mesh methodology	2	1
	19	1D-2D Connection Points	1	1
	20	Pump system functions/capabilities	1	1
	21	Method/approach to calibration	1	1

Differences: The factors where ICM has an advantage related to:

- Watershed wide construction considerations. The groundwater surface adds a level of complexity to building the ICPR model and poses questions on creating separate groundwater regions within a single model (which was not tested during the pilot build). Both models have the terrain sensitive meshing tool, although creating a model with groundwater eliminates the ability to use the automated function in ICPR.
- Ability to carve out smaller sections of the model. Both models have a scenario manager function/option that allows for separate/discrete model areas to be created and saved, which will be beneficial as the District evaluates numerous future climate scenarios. However, ICM retains a direct connection of sub-models to base model whereas ICPR scenarios are not linked to the base model after creation. This difference gives a slight edge to ICM in terms of building separate smaller sections of the model in specific areas of interest. In addition, providing BC to other models is easier in ICM through the use of 2D results objects. Which are essentially point, lines, and objects that allow you to extract more complete information form the model.
- 2D overland mesh methodology. The more complex mesh element build process in ICPR requires the user to expend more time to build and refine the model (mesh) to produce a working and calibrated model. Without the use of automated tools when using ICPR with groundwater, the modeler must manually place additional breaklines and breakpoints to define flow directions and critical hydrologic/hydraulic features.

5.3.3 MODEL FUNCTION AND RESULTS (SCENARIO ANALYSES)

For three of the five factors in this evaluation category, both models are equally capable with only minor differences in the approach each model takes for a given factor. For model run times in general for a common processor and comparable resolution, ICM is generally faster even when comparing only 2D surface runs without an ICPR groundwater layer. Based on the model runs from the automated 2D builds under this pilot study, ICM was observed to have better visual results (less noise) and more stable hydrographs. ICPR stability may improve by going to 1D channels and ponds as was mentioned previously in this report.

Evaluation Category	Line ID	Evaluation Factor / Description	Rating (0 - not capable or weak; 1 - proficient; 2 - strong)	
			ICM	ICPR
Model Function and Results (Scenario Analyses)	22	Ease and options for BMP evaluation	1	1
	23	Ease of land-use change scenarios	1	1
	24	Model runtime (common processing system)	2	1
	25	Results quality and output format	2	1
	26	Export process and format	2	2

Differences: ICM was observed to have an edge in processing speed when comparing only the 2D surface runs and more consistent output results format (i.e., the same exported result as what was shown in the model compared to ICPR where differences were observed between the internal model results and exported result for peak flows. ICM runs on a GPU and has the ability to run true parallel processes.

5.3.4 SOFTWARE SPECIFICS

For two of the five factors in this evaluation category, both models are comparable with significant differences in the specific software related factor. For ease of sharing model versions, ICM has transportable database which is more portable from a file size transfer standpoint compared to copying a full folder for ICPR.

For the user community factor, Innovyze reports over 450 consultant and communities using ICM in the US and the users in Minnesota are starting to see ICM be used in some areas. ICPR is widely used in Florida and the model developer is currently working with more than a dozen universities for research and teaching. We are not aware of any communities in Minnesota utilizing ICPR at this time.

Evaluation Category	Line ID	Evaluation Factor / Description	Rating (0 - not capable or weak; 1 - proficient; 2 - strong)	
			ICM	ICPR
Software Specifics	27	Sharing model versions	2	1
	28	Local versus network - processing ease	1	1
	29	License type and cost	1	2
	30	Model maintenance (version management, security, techncial support)	1	1
	31	User Community	2	1

Differences: ICM's transferrable database is a nice feature that allows sharing with much smaller file sizes than ICPR. Related to licensing and costs, ICPR has a substantially lower cost with an annual subscription cost of $2,400 per simultaneous user. ICM has a significantly higher annual subscription cost of $18,000 for the high-end version.

5.4 Conclusion

From the outset of this pilot study the District's goal was to evaluate how ICM and ICPR could be built with the assistance of automated tools to a watershed-wide scale and to assess how each model would allow the District to meet their climate planning goals. Both models can meet the District's primary uses for characterizing flood risk and evaluating impacts of regulation and policies on runoff quantity.. However, only ICPR has the ability to meet the District's primary use goal to better understand and quantify groundwater-surface water interactions within the watershed.

While ICPR's capabilities are well aligned with the District's needs for climate planning, it does score lower across many operational categories; this indicates that ICPR has less refined operational features than ICM and/or is more challenging to build and operate than ICM.

Climate Planning with ICPR

ICPR will allow the District to more holistically understand watershed volume management through the inclusion of groundwater, while still serving the other primary uses relating to assessing flood risk and evaluating adaptation strategies. However, this added benefit comes with increased technical challenges and level of effort to construct and operate the model. To build ICPR at a watershed-wide scale, while still maintaining a high-resolution surface, close attention will be needed when constructing the groundwater region(s). Difficulties were experienced during the pilot model build that led to surface resolution being sacrificed in order to manage the need to effectively mirror the groundwater and surface water meshes. There are alternative techniques to construct the groundwater region that may help alleviate those issues.

While ICPR will be strong in serving the District's primary uses, it does pose more relational challenges. ICPR is not well accepted within this region, meaning consultants and partners are largely unfamiliar with this software and it will be more difficult to interplay with partner models. Because of this, ICPR will likely not serve the District as well as other models beyond immediate climate planning needs.

Climate Planning with ICM

ICM is limited in its ability to grow the District's understanding of surface water-groundwater interactions, however it can serve the other primary needs for climate planning very well. ICM is known for its fast run-times and as the District looks to evaluate a wide range of future climate challenges and related policy changes to adapt, ICM has a greater ability to create, track changes and manage multiple model scenarios.

ICM would also allow the District to better coordinate and share model information with partners due to the broader base of model users and the more simplified processes to carve out sections of the model for use in areas of focus. ICM's strengths make the model better suited to serve District and partner modeling needs beyond immediate climate planning.

APPENDIX A – DATA DISCOVERY MEMORANDUM

Kimley»Horn

MEMORANDUM

To: Kailey Cermak, Project Manager | Minnehaha Creek Watershed District

From: Ron Leaf, Project Manager | Kimley-Horn

Date: June 1, 2022

Subject: 2D Pilot Model Build – Data Discovery Memorandum

BACKGROUND AND PURPOSE

The Minnehaha Creek Watershed District's (MCWD) current modeling tools do not provide the required granularity and features to answer pressing climate change questions and evaluate adaptation strategies. The District identified the need to build a new tool that not only quantifies volume but represents how water moves through the watershed via runoff, storm pipes, wetlands, best management practices and surficial groundwater. However, maintaining such a detailed, large-scale model hinges on the premise that repeatable automated workflows can be established to process and integrate the storm sewer datasets of the 29 municipalities within the District. The District pursued a pilot model build, in part, to help mitigate for and better understand this technical risk.

A key objective of the pilot model build is to establish scalable automated workflows for processing model inputs. An essential step in the development of the automated processes is to understand the base data available for building the models and to define the extent of data gaps that may impact the automated model build process for both models.

This data technical memorandum documents existing datasets supplied by the District, City, and other sources; provides a summary of the data input needs for the ICM and ICPR4 models; and identifies the gaps in data that will require further review and action to produce a model-build ready dataset. While this memorandum focusses on data for the pilot model build areas in Edina and the Turbid-Lundsten subwatersheds, Kimley-Horn has also completed a screening level review of four datasets from other municipalities within the larger MCWD jurisdictional boundaries. This screening level review was intended to provide a general awareness of data formats and potential issues that may arise beyond the scope of this pilot study.

Review and evaluation of available datasets is expected to be an iterative process that will conclude with the identification of gaps between the data import requirements for each model and the actual data available.

DATA SETS PROVIDED

Several datasets were provided in multiple formats and data types for model development. Table 1 summarizes the base files publicly available or provided by the District and its partners. Data types include shapefiles, geodatabases, and LiDAR (.laz) files. Shapefiles are used to store spatial data in the form of points, lines, or polygons. The shapefile includes an attribute table which lists data for each shape included in the shapefile. The attribute table can hold data in the following data types: integer, float, double, text, and date. Geodatabases are typically used to provide file and folder management of large spatial datasets. Geodatabases can also be easily zipped and transferred to another folder location. Geodatabases can hold multiple shapefiles of the same or different types of spatial data. The geodatabase holds the shapefiles as a feature class. Feature classes can be grouped under a Feature Dataset within the geodatabase. This folder structure allows for increased file management ability.

Table 1. Summary of Datasets Provided for Pilot Areas

Item	Dataset Description	Data Type (Subtype)	Provider / Source (Source year)	Spatial Reference
A	Watershed Boundary – PilotAreas.gdb	Shapefile (polygon)	Edina – Subwatershed Dataset	NAD 1983 HARN Adj MN Hennepin (US Feet)
		Shapefile (polygon)	Minnehaha Creek Watershed District – HHPLS	NAD 1983 UTM Zone 15N
B	Landuse/Land Cover – plan_generl_lnduse2020.gdb	Geodatabase (polygon feature class)	Metropolitan Council (2016, 2020)	NAD 1983 UTM Zone 15N
C	Soils Data	Shapefile (polygon)	NRCS (2003)	WGS 1984
D	Geologic Atlas	Geodatabase (polygon feature class)	Carver County University of Minnesota (2009)	NAD 1983 UTM Zone 15N
			Hennepin County University of Minnesota (2018)	NAD 1983 UTM Zone 15N
E	LiDAR	LAZ	MnDNR (MnTOPO, 2011)	NAD 1983 UTM Zone 15N
F	Pipes – DGravityMain	Geodatabase (line feature class)	Edina	NAD 1983 HARN Adj MN Hennepin (US Feet)
	Pipes - pipes.shp	Shapefile (line)	MnDOT (Turbid Corridor)	WGS 1984
	Pipes – CG_StormCulverts	Geodatabase (line feature class)	Carver County (Turbid Corridor)	NAD 1983 HARN Adj MN Carver (US Feet)
G	Manhole - DManhole	Geodatabase (point feature class)	Edina	NAD 1983 HARN Adj MN Hennepin (US Feet)
H	Flared End Section - End_Sections.shp	Shapefile (point)	MnDOT (Turbid Corridor)	WGS 1984
	Flared End Section – CG_StormOutlets	Geodatabase (point)	Carver County (Turbid Corridor)	NAD 1983 HARN Adj MN Carver (US Feet)
I	PW_Storm_Features	Geodatabase (feature dataset)	Edina	NAD 1983 HARN Adj MN Hennepin (US Feet)

Additional detail on specific dataset parameters for the municipal infrastructure (i.e., pipes, culverts, catch basins and manholes is provided in Table 2A within Attachment B to this memorandum. Table 2A identifies the minimum preferred data needed to build a functional model and which parameters are more suitable for using assumed or assigned values where project are-specific data is not available.

LAZ files are used to store point elevation (LIDAR) data in a compressed format. To access and use the LIDAR data, the file must be decompressed and transferred into the LAS format. The LAS file can then be used to create a digital elevation model (DEM). The DEM is included directly in the modeling software to create the 2D surface. The LAS point files can also be used directly within the modeling software to develop the 2D surface. The final column in the table lays out the spatial reference that each dataset uses. The spatial reference for each will need to be transformed to Universal Transverse Mercator (UTM) Zone 15 North for use in both of the modeling software packages. This spatial projection was chosen due to the size of the future watershed-wide model.

Within several of the base datasets, additional detail is available for specific features. For example, within Edina's *PW_Storm_Features* file, there are more than a dozen subcategories of storm sewer features including *BMP, DManhole and DOutlet*, for example. The City's database also includes a number of files that are not needed for the model build processes including those listed from *StormGravityMain_Jetting* to *StormMS4_OutletInspectionHasOutlet*. A screen clip of the detail for this portion of the City's database file is provided in Attachment A. Attachment A also includes a screen clip of the detail for the Turbid pilot subwatershed.

MODEL INPUT NEEDS

This evaluation of available data is driven by the District's goal to develop automated processes that will process existing infrastructure and geospatial data into a standardized central geodatabase and then processed into hydrologic and hydraulic model input data with both one-dimensional (1D) and two-dimensional (2D) elements. Both models require very similar data to support building a functioning model. The following sections describe the data that is generally required to build each model to a level that would yield meaningful model results in support of District goals. As the scripting process workflow is developed, these datasets will be mapped from raw input files to model build ready formats. Table 2 defines the shared and specific data inputs that each model requires.

Coordinate Systems

All input spatial datasets need to be in matching coordinate systems. The overall watershed spans two counties and is approximately 26 miles long. The standard coordinate system to be used for the spatial datasets and model build will be Universal Transverse Mercator Zone 15 North (UTM 15N). Coordinate system transformation will need to be performed on any dataset that does not match the standard.

ICM vs. ICPR4 Model

Development of a combined 1D/2D ICM model or ICPR4 model requires data that be divided into two categories, **model base data** and **hydraulic network features**. In both categories, the data is needed as a direct input model parameter or is needed to generate (calculate) a required model parameter. These model input categories can be characterized and further subdivided as summarized in Table 2. Items in *italicized text* indicate that the input data needed or preferred is significantly different between the two models.

Table 2. Shared vs. Specific Data Inputs

Item	Data Input	ICM	ICPR4
A	Coordinate System	NAD 1983 State Plane Minnesota South FIPS 2203 (US Feet)	NAD 1983 State Plane Minnesota South FIPS 2203 (US Feet)
B	DEM/Ground Surface	*Elevation Point Data*	*Raster Data*
C	Soils Data	Soil Zones	Soil Zones
D	Land use/Land Cover	Zones	Zones
E	Lookup Tables	CN, Impervious, Manning's n, Inlet Head Discharge Curves	CN, Impervious, Manning's n, Inlet Head Discharge Curves
F	Rainfall	Depth and Distribution	Depth and Distribution
G	Nodes	Subsurface Junctions (manholes), 2D Interface Nodes (inlets)	Subsurface Junctions (manholes), 2D Interface Nodes (inlets)
H	Links	Pipes, *1D/2D Links (Open Channel Crossings)*	Pipes, *Rating Curves, Percolation*
I	1D/2D Interface Elements	*Storage Area Volume Controls*	*Pond Control Volumes, Channel Control Volumes*
J	2D Overland Domain	Grid (Triangular)	Grid (Triangular)
K	2D Terrain Characteristics	Building footprints, Breaklines, Breakpoints	Building footprints, Breaklines, Breakpoints
L	Groundwater	*Infiltration Parameters*	*2D Domain*
M	Boundary Conditions	Overland, *Groundwater*	Overland, *Groundwater*

DATA GAPS

During this initial data review process, we have categorized data into one of three groups based on how well the current raw dataset is suited to automated model build processes. Categories range from model-build ready to major gaps, where the dataset does not have required data to build a working model.

- Model-build ready. These data sets are complete and can be processed for model import without having to supplement data using engineering assumptions.
- Minor gaps. These data gaps can generally be addressed through the automated scripting process. An example of a minor gap is a pipe segment that is missing the pipe size that is located between two adjacent pipes with known pipe sizes. This is considered minor as the automated scripting process can resolve the gap by assigning the missing pipe size as the size of the downstream adjacent pipe (or any assigned rule) and flagging it in the database as an assumed data value. Another example is development of a runoff curve number for a drainage area. While the base data do not directly contain curve numbers, the data can be processed/calculated based on the land use and soils data, for example.
- Major gaps. These data gaps consist of missing data or parameters that cannot be assumed unless additional data is provided and data that may require additional field work or data collection efforts by the District or City of Edina.

Based on our initial review of the data, we have identified the following minor and major gaps. In general, these gaps apply to both models, although where specific to one model, that model is identified directly.

Minor Gaps

- Node Data:
  - Invert Elevations
    - Issue: Incomplete or Missing Data.
    - Solution A: Develop process to calculate or assign an assumed value to the incomplete or missing data based on Link data.
    - Solution B: Field survey of incomplete or missing data.
  - Rim Elevations
    - Issue: Incomplete or Missing Data.
    - Solution A: Develop process to calculate incomplete or missing data
    - Solution B: Acquire new lidar data for areas of incomplete or missing data using the process developed in Solution A to assign elevations.
    - Solution C: Field survey of incomplete or missing data.
  - Inlet restrictions
    - Issue: Request for varying levels of inlet restriction to simulate in-place conditions
    - Solution A: Adjust orifice size to simulate inlet restriction
    - Solution B: Vary the head-discharge curve to simulate inlet restriction
- Link Data:
  - Invert Elevations
    - Issue: Incomplete or Missing Data
    - Solution A: Develop process to calculate or assign an assumed value to the incomplete or missing data based on Node data.
    - Solution B: Field survey of incomplete or missing data.
  - Pipe Roughness
    - Issue: Parameter is not within data sets.
    - Solution: Parameter calculated based off pipe material.
  - Pipe Size
    - Issue: Incomplete or Missing Data.
    - Solution A: Develop process to calculate or assign an assumed value to the incomplete or missing data.
    - Solution B: Field survey of incomplete or missing data.
- Standard Hydrologic Parameters
  - Standard values for curve numbers, impervious percentages, and Manning's roughness parameters will be needed to generate the hydrologic parameters. One example of an area of further discussion is to define the assigned value of impervious cover for each land use category.
- Terrain
  - Extrusions/Blockages
    - Issue: Raw LAS data missing building data
    - Solution: Utilize Building Footprints shapefile to simulate building locations.

- Standard Coordinate System:
    - Files in Table 1 including Items C and F (Turbid) will need to be converted to NAD
    - 1983 State Plane Minnesota South FIPS 2203 (US Feet)

Note/Discuss: For models with 2D overland flow, the 1D/2D connection points may run better in the model if every node rim elevation is set based on the terrain data. This data field may be critical to effective modeling of the 1D/2D interface and further review of the variations in the data are needed to develop options for defining the model build input parameters. For example, with the surface being from 2011, it may not be advisable to use the surface elevation instead of rim elevations as some could be significantly off. Maybe not in the two pilot subwatersheds, but other areas where significant development may have occurred since 2011. We anticipate some type of screening process to evaluate how close the number are, and if close, then use the surface elevation so it matches the 2D surface. Example of one area where more discussion is needed.

Major Gaps

- Water Quality Data
    - ICM Model specific: The water quality modeling tools within the ICM simulation are set up to run point source pollutants that are either expressed in terms of concentration, for dissolved pollutants, or potency factor, for attached pollutants. If there is a desire to model specific pollutants for water quality, a pollutograph with time-varying water quality determinants would be needed to input into the system.

- Groundwater Modeling Data
    - ICM Model specific: ICM models groundwater using a soil storage reservoir and a groundwater storage reservoir. There is no interaction between ground water levels in adjacent subcatchmments. To run a groundwater infiltration module event, initial soil saturation and initial groundwater levels are required in addition to soil parameters and baseflow threshold levels.

SUMMARY

For a successful automated build of the models in each software, at a minimum the data in rows A-H from Table 1 is required. Supplemental data included within the PW_Storm_Features feature database include BMP outlines, pump and forcemain locations, outlet control structures, sensors, flow control features, and unknown structures. These data types can be used for additional detail built into a model, although may not be suitable for direct automated model build processes due to their highly variable attribute data.

Overall, there are no major gaps in the available data needed to successfully build a functioning model in both ICM and ICPR formats. The primary differentiators between the two models in terms of data sources and data needs will be understood more fully as the scripting workflow and actual script writing and testing processes advance.

ATTACHMENTS

ATTACHMENT A – DATABASE DETAIL

Edina Database

- Edina
  - 2022_0203
    - EDINA_STORM_FEATURES_20220124
      - v10
        - gis_sde.gdb
          - PW_Storm_Features
            - BMP
            - DCatchBasin
            - DConnectPts
            - DDischargePoint
            - DFitting
            - DFlood
            - DFlow_Control_Area
            - DFlow_Control_Feature
            - DFlow_Control_Structure
            - DGravityMain
            - DInletPoint
            - DLiftStation
            - DManhole
            - DOutlet
            - DPressurizedMain
            - DScadaSensor
            - DSumpClean
            - DSumpdraintile
            - DUNKStructure
            - Storm_GeometricNetwork
            - Storm_GeometricNetwork_Junctions
          - StormGravityMain_Jetting
          - StormGravityMain_JettingHasDGravityMain
          - StormManhole_Jetting
          - StormManhole_JettingHasDManhole
          - StormMS4_InletInspection
          - StormMS4_InletInspectionHasDInletPoint
          - StormMS4_ManholeInspection
          - StormMS4_ManholeInspectionHasDManhole
          - StormMS4_OutletInspection
          - StormMS4_OutletInspectionHasDOutlet
        - 0000STORM FEATURES.lyr
      - v104
    - EDINA_STORM_FEATURES_20220124.lpk

MnDOT – Carver County Data

- TurbidCorridor
  - TurbidCorridor
    - CarverCounty
      - LaketownTownshipStormSewer.mpk
    - MnDOT
      - End_Sections.shp
      - pipes.shp

LaketownTownshipStormSewer.mpk

- **gis_cartegraph.gdb**
  - CG_Bridges
  - CG_Culverts
  - CG_StormBasins
  - CG_StormCasings
  - CG_StormCleanOut
  - CG_StormControlValve
  - CG_StormFitting
  - CG_StormGravityMain
  - CG_StormInlets
  - CG_StormManhole
  - CG_StormNetworkStructure
  - CG_StormOpenDrain
  - CG_StormOutlets
  - CG_StormPressurePipe
  - CG_StormSystemValve
  - CG_StormVirtualDrainline
  - CG_StormWeirStructure

ATTACHMENT B – TABLE 2A ADDITIONAL DETAIL

Municipal Infrastructure Dataset Review Table

Dataset/Parameter	Note	Yes/ No	Notes/Assumptions
Pipe			Overall Storm Sewer File (polyline shapefile or layer file)
Pipe Global ID			If no, can be assigned
Length	1		If no, can be spatially calculated
Shape			Can be assumed as circular.
Diameter (Size)	1		Can be assigned.
Width			Only used for non-circular pipes
Material			Parameter used to derive pipe roughness
Upstream Invert	2		If no, can be derived from connected structure invert elevation
Downstream Invert	2		If no, can be derived from connected structure invert elevation
Slope			If no, can be derived from US Inv., DS Inv., Length
Upstream Structure			If no, can be derived from Manhole/Catch Basin files
Downstream Structure			If no, can be derived from Manhole/Catch Basin files
Culvert			Culvert File (polyline shapefile or layer file)
Included in Overall Pipe File			Are culverts included with overall storm sewer file?
Pipe Global ID			If no, can be assigned
Length	1		If no, can be spatially calculated
Shape			Can be assumed as circular.
Diameter	1		Can be assigned.
Width			Only used for non-circular culverts
Material			Parameter used to derive culvert roughness
Upstream Invert			If no, can be derived from DEM surface
Downstream Invert			If no, can be derived from DEM surface
Slope			If no, can be derived from US Inv., DS Inv., Length
Manhole	1		Overall Structure File (point shapefile or layer file)
Structure Global ID			If no, can be assigned
Rim Elevation			If no, can be derived from DEM surface
Invert Elevation	2		If no, can be derived from connected pipe invert elevation
Catch Basin	1		Overall Catch Basin File (point shapefile or layer file)
Structure Global ID			If no, can be assigned
Included in Overall Manhole File			Are catch basins included in overall manhole file?
Rim Elevation			If no, can be derived from DEM surface
Invert Elevation	2		If no, can be derived from connected pipe invert elevation
Grate Length			Can be assumed.
Grate Width			Can be assumed.
Combination Style			Can be assigned.

1. Items listed with 1 in the note column are the minimal basic data preferred to build a functional model. While a model can be built without these data by making assumptions, the reliability of the model may be significantly reduced. Manhole-catch basin refers to the structure being an inlet or not.
2. Items with a 2 in the note column are also beneficial for basic model build, although are more easily assumed and still resulting in a fairly reliable 2D model.

APPENDIX B – AUTOMATED SCRIPT DESIGN REPORT

2D Pilot Model Build Automated Script Design Report

Prepared by:
Kimley-Horn

Prepared for:

MINNEHAHA CREEK
WATERSHED DISTRICT
QUALITY OF WATER, QUALITY OF LIFE

Date:
January 2023

Kimley»Horn

Kimley»Horn

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Document History

Date	Version	Description of Change
April 2022	1.0	Initial version started to kick off design.
September 2022	2.0	Additional revisions following comments and script development.
November 2022	2.1	Updated figure formats and addition of new Figure 2 (Data Workflow)
January 2023	3.0	Addition of Raw to MGIS automated field mapping script

Definitions

- API – Application Programming Interface is a way to interface from one system to another
- ArcGIS – a desktop and cloud solution provided by Esri for GIS analysis, storage, data management, and data processing
- Automation – any process that is modified through scripting
- File Storage – cloud or physical file storage location utilized as a central repository for raw, input, and output datasets
- Geodatabase (GDB) – GIS file and data format that allows for standardization and template creation
- GIS – Geographic Information System
- GIS Process – queries and tools built into the Esri ArcGIS environment used to convert and transpose data. These scripts are executed directly within the Esri ArcGIS environment
- Graphical User Interface (GUI) – a system (or single set) of interactive visual windows that allow the user to input data, read output messages, and perform the functions of a tool
- ICM – InfoWorks ICM software package developed by Innovyze to perform 1D and 2D hydrologic/hydraulic simulation modeling
- ICPR – Interconnected Channel and Pond Routing (ICPR) software package version 4 developed by Streamline Technologies to perform 1D and 2D hydrologic/hydraulic simulation modeling
- IDLE – Integrated Development Environment
- MetroGIS (MGIS) – a GIS format designed for use by Twin Cities Metropolitan-area municipalities for the standardization of infrastructure data
- Microsoft SQL Server – relational database system that supports data processing, data management, and data analytics
- Python Script – software programs written in the Python programming language
- Toolbox – includes a single or multiple individual tools, scripts, or manual processing steps to be run in conjunction to create and format data for use in the MGIS database and model creation

1 INTRODUCTION

Major technological advancements have taken place since the District last built its watershed-wide model in the early 2000's. These advancements in both computing power and availability of high-resolution spatial datasets now make it possible to build and operate a high-resolution, large-scale model. However, maintaining such a detailed, large-scale model hinges on the premise that repeatable automated workflows can be established to process existing infrastructure and geospatial raw datasets into a model-ready dataset. The District pursued the pilot model build, in part, to help mitigate for and better understand this technical risk.

This memorandum provides an overview of the automated system that was developed for the 2D Pilot Model Build. This overview will include a summary of the overarching IT elements, a high-level design of the three key workflows, and a detailed breakdown of the individual scripts created to support the project workflow.

2 SYSTEM AND SOFTWARE DESIGN

The first step of developing a useable and maintainable information technology (IT) process is developing a system infrastructure plan and data processing strategy to ensure that the system can be properly maintained after it has been built. The two components of this planning process include:

- The information technology (IT) ecosystem that will house the data transformation process.
- The generalized workflow for data processing, model development, and model storage.

The section includes:

- A description of the software and hardware components needed to deliver the solution.
- Details of the data flows from third-party systems or hardware, and software components.

2.1 IT System Overview

The system overview provides descriptions of the IT ecosystem (i.e., software and hardware components) used in the implementation of the modeling and scripting process. This description includes definitions and detailed breakdown of each user, software components, and data flow within MCWD's data processing and modeling system. Figure 1 provides a context diagram of the system that illustrates the overarching location, development process, stakeholders, data locations, and flow of modeling from raw data to model development, to scenario analysis, to external projects and analysis.

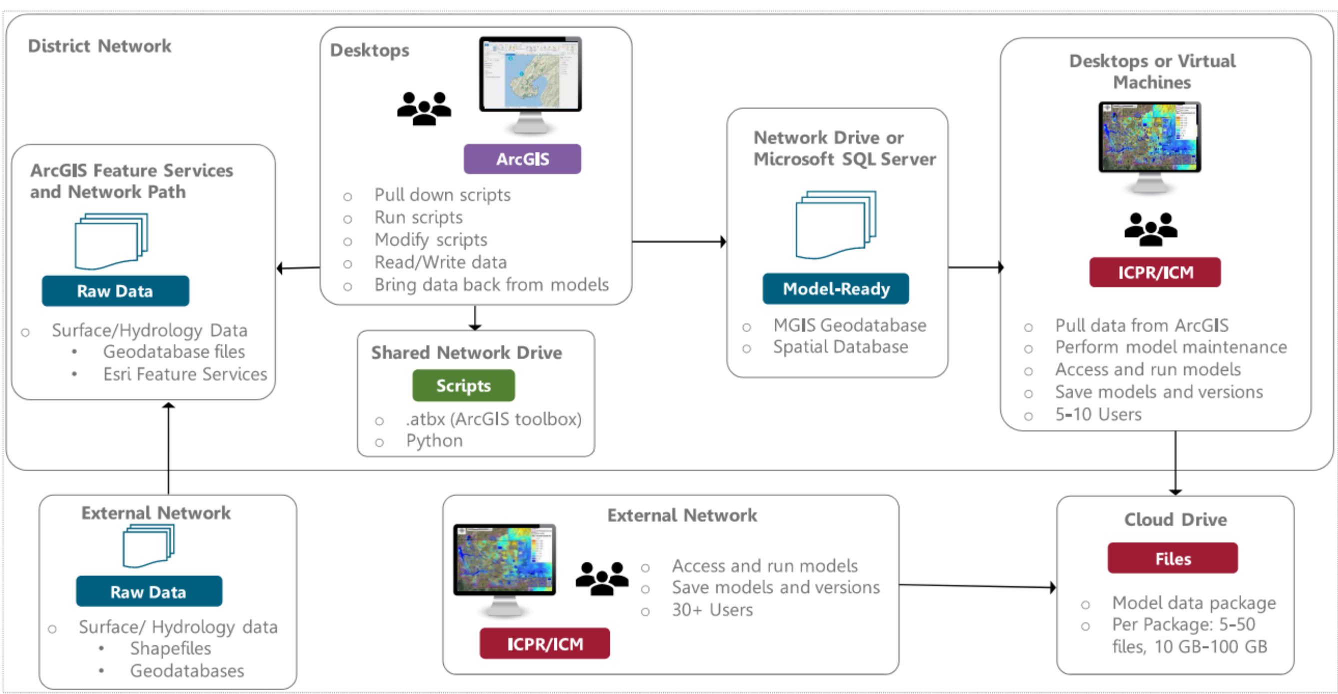


Figure 1. 2D Pilot Model Build System Context

- **<u>Users</u>**
  - **MCWD/Consultant on behalf of MCWD**
    - ArcGIS Users
      - Run scripts to move from pre-processed data into model-ready files
      - Modify scripts to meet new needs, or make other improvements
      - Bring data back from the modelers to keep GIS data up to date
      - Place raw surface and hydrology data from stakeholders in the District Esri instance. This may be used for scripting in the 2D modeling effort where access will be available through the Esri feature services.
    - ICPR/ICM Modelers
      - Pull post-processed data from ArcGIS for use in the models
      - Perform model maintenance
      - Access and run models to perform scenario analysis
      - Save models and scenarios into different versions
      - Push model updates to a cloud accessible drive for access by external stakeholders
  - **External Stakeholders**
    - Local Geospatial Data Authority
      - Provide non-publicly available GIS files for MCWD GIS staff. These will be provided in Geodatabase format primarily, though it may also include access to Esri feature services and raw shapefiles.
      - *In the future, the District would benefit from a regional GIS dataset in Esri Online or agency provided cloud Esri instance.*
    - ICPR/ICM Modelers
      - Access models in a cloud drive and download to perform scenario analysis.
      - Push updates to the cloud drive following scenario analysis.

- **<u>Data Formats</u>**

Figure 2 the general workflow of data from the raw available data to data that is ready for import into each modeling platform. Datasets for each step in the process are defined below.

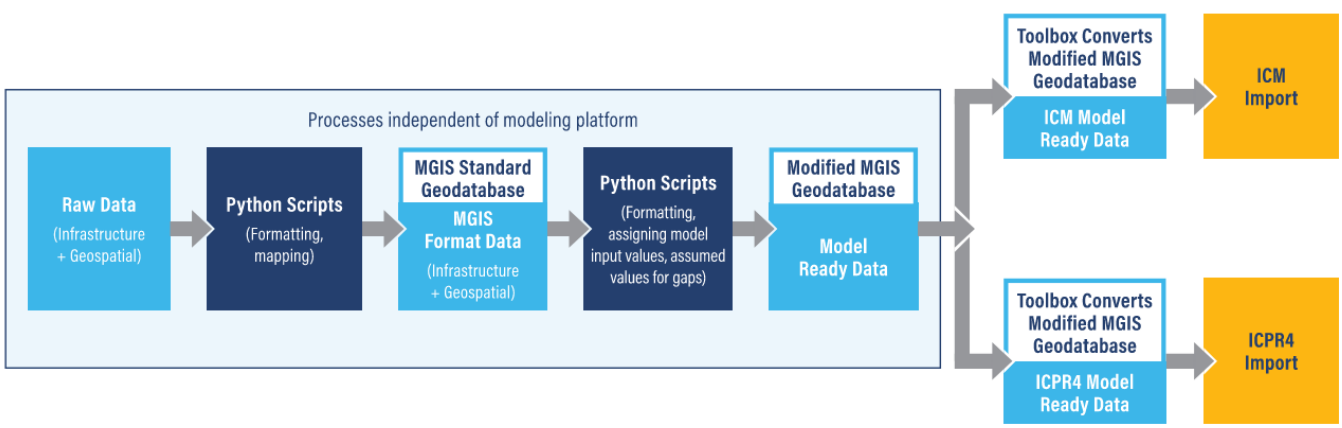


Figure 2. Datasets and Workflow Process to Produce Model Ready Data

- **Raw Input Files –** the agency provided raw data will need to be converted and processed into the MGIS standard geodatabase. These raw datasets are typically provided in Geodatabase format, although may be provided in a shapefile or with access through an Esri feature service for download to the District's network.
- **MGIS Standard Geodatabase –** Populated with raw data files that have been transformed to standard attribute fields. Consolidation of multiple input fields to a single field occur during the transformation. A MGIS database will be created for each agency. Multiple versions of the MGIS database can also be created. A watershed-wide database could be developed along with multiple smaller subwatershed (or municipal) databases.
- **Modified MGIS Geodatabase (GWIS/ICM) –** Datasets for model creation. These datasets include interpolated, assumed, and calculated data for missing data and model parameter input. Model parameter inputs include loss coefficients, roughness coefficients, inlet capacities, etc.
- **Output Files –** Result files incorporating data such as inundation depths and locations, overland flow velocities and directions, pipe flow conditions, and groundwater saturation levels. Other datasets may be extracted from the modeling software for additional comparison of results. These output files will range in size depending on level-of-detail in the underlying model, simulation length and complexity, and output scale. The output packages may range in size between a single gigabyte (GB) to over 100 GB per scenario. These files are contained in a single file structure which may be neatly pushed to the Cloud storage for archive and access from external stakeholders.

3 HIGH LEVEL DESIGN

This section provides a high-level overview of the process that was designed to convert raw datasets into cleaned and processed model-ready data. 2D models reference three primary spatial data types, that include:

- Surface Data: Landuse and LiDAR (DEM)
- Sub-Surface Data: Soils
- Infrastructure: Stormwater Pipes, Inlets, and Manholes

These datasets are referenced in two ways to create model input parameters. Parameters are either directly sourced from a dataset/field (ex: Surface DEM) while others are a derived parameter that references two or more datasets/fields (ex: Green-Ampt Parameters). Figure 3 shows how each dataset supports the required model input parameters. This high-level overview walks through the key workflow processes and shows how each dataset supports the overall model build requirements.

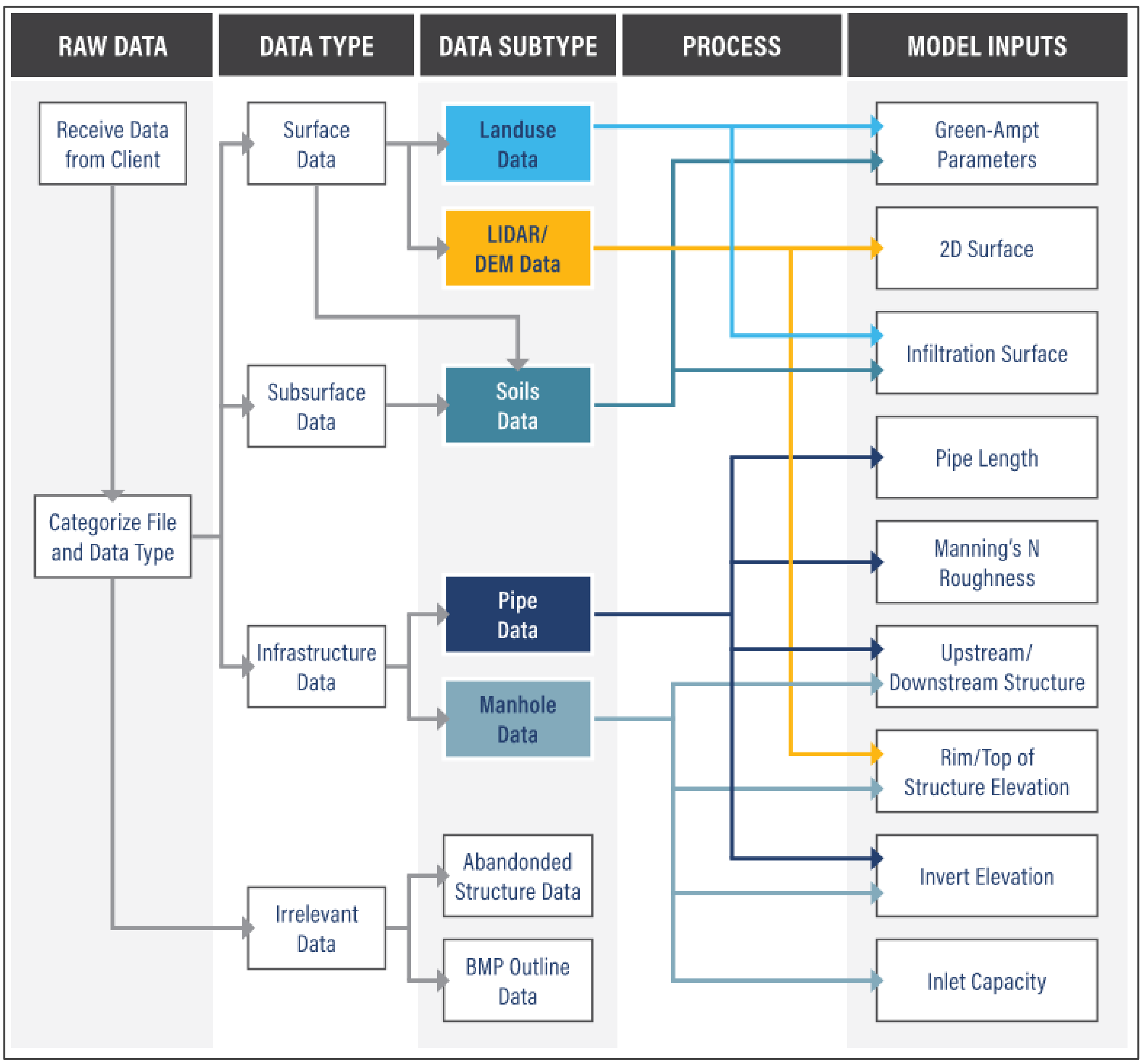


Figure 3. Overall Data Conversion Process Flow Diagram

To generate the model input parameters, each dataset needs to be processed into a standard format and cleaned to address formatting and data gap issues. While each dataset requires varying degrees of formatting, they generally flow through a similar pathway. Figure 3 shows at the highest level how datasets flow through the automated processing steps, become model-ready to be directly imported into each modeling software.

- Raw to MGIS: Infrastructure data is received from a source (municipality) and is transferred to the MGIS standard GDB;
- Spatial Data: Spatial data is received or developed and is utilized to create spatial model input layers;
- MGIS to Model Input Dataset: MGIS infrastructure dataset utilized to calculate model input parameters, spatial model input layers utilized to fill infrastructure data gaps.

3.1 Raw to MGIS Standard Flow

Raw stormwater infrastructure data from several sources (individual project, local, regional, and state municipalities) are needed to develop a comprehensive model-ready infrastructure dataset. It is understood that, currently, each raw dataset may be stored in different data formats and sub-formats for individual attribute fields, as well as varying degrees of accuracy and completeness. A key step in the overall process is standardizing each dataset into an established standardized schema. The standardization allows for reduced user input and complexity throughout the remaining inputs and processes to model-ready dataset.

This step in the process does not generate any new data, simply mapping data that exists into the standard. Each municipal dataset will need to be reviewed to correctly map the raw input fields to the corresponding MGIS standard attribute field. The full data mapping tables are shown in Appendix A of this memo. Multiple raw data fields may be used for a single MGIS field and some raw data fields may not be utilized in the MGIS standard. The most common fields for raw inputs are invert elevation, rim elevation, pipe diameter, and notes/comments. The Python script was modified to allow for the user to specify a pre-made csv file that contains the raw data field names and the corresponding MGIS output field. Mapping of multiple raw fields allows for partial datasets to be utilized and mapped into the MGIS field. Partial datasets may be contained within the raw dataset due to multiple surveys, joined datasets, user inputs, or spatial tools. In addition to mapping, mild formatting may need to take place to standardize how a field's data is populated. For example, the same pipe material might be written in three different ways or date fields may be empty and require a null data value at a minimum. It is important to standardize the attribute data so it can be referenced properly in subsequent automated steps.

An important aspect to this workflow is that the raw data field mapping will need to be performed for each individual infrastructure dataset. This is due to the varying attribute naming conventions, number of multiple raw fields, or separated input datasets. Meaning, as the District scales watershed-wide, a thorough understanding of each source's data will be required to correctly map and format into the MGIS Standard. Reviewing and understanding the Draft Stormwater Geodata Transfer Standard document and required inputs and outputs is key to successful long-term implementation of the scripts and processes developed in this memo. The Draft Stormwater Geodata Transfer Standard is included in Appendix B of this memo.

3.2 Spatial Data Flow

The raw spatial data is supplied through publicly available sources, municipal dataset, or project-specific creation. Elevation data is available through the MnTOPO download portal or through the USGS download portal. The elevation data may be located within a compressed format for ease of data transfer.

Multiple sources of current landuse/land cover (LULC) datasets at varying levels of detail are publicly available. These sources include the National Land Cover Dataset, the Twin Cities Metro Area (TCMA) landcover dataset. Landuse/land cover datasets are commonly developed by municipalities for current and future planning efforts. Landuse/land cover datasets can also be created by a user to reflect a future condition to be used in scenario analysis. The TCMA dataset was used as a basis for the LULC automated process development. User-created LULC dataset that reflect future scenarios can be utilized but are required to follow the standard SCS LULC codes (e.g., 100 = Agriculture, 151 = Industrial, etc.) to be utilized with the automated process.

The soil datasets (Hennepin and Carver counties) were downloaded from the Natural Resources Conservation Service (NRCS) Web Soil Survey (WSS). The county-wide WSS datasets were downloaded to encompass the entirety of the District. Multiple soil data tables must be extracted from the soil database for each county to calculate the representative values for the Green-Ampt Parameters. Additionally, the NRCS WSS dataset can be supplemented through site-specific soil borings, previous soil investigations, and historical data to reflect in-place soil conditions. Separate GIS processes for Hennepin and Carver counties were developed to reduce the amount of required user inputs and increase efficiency.

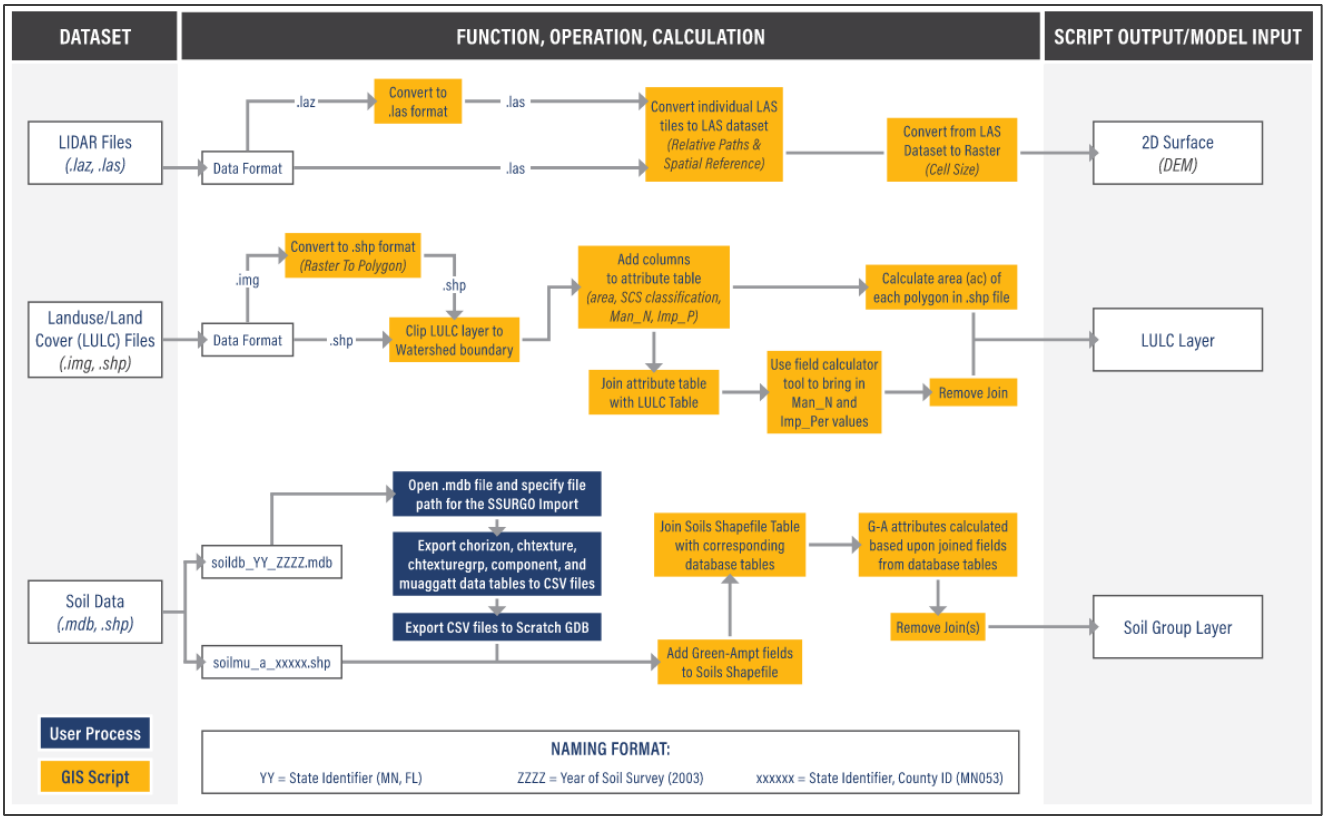


Figure 4. Spatial Data Conversion Process Diagram

Figure 4 lays out the general workflow and required steps to process the spatial data (elevation, landuse, and soil) from raw files to the model-ready datasets. These steps will be the same between the ICPR and ICM model development pathways.

The processes to produce the model-ready datasets for the Soil and LULC data layers can be completed once for the entire watershed then clipped down to the required model area. The processes can also be rerun as new data is collected or becomes available. The same technique can be completed for the surface (DEM) layer and clipped down to the model area. This may produce a very large raster file depending on the user-defined cell spacing. It is recommended to produce a new DEM for each model area or group of model areas to reduce the size of storage required.

3.3 MGIS to Model Input Dataset Flow

Once the raw infrastructure has been standardized and surface data has been processed, data gaps can be addressed, and model parameter generation can occur. This workflow includes multiple scripts/toolboxes and is centered around creating a clean, complete infrastructure dataset and generating required model input parameters.

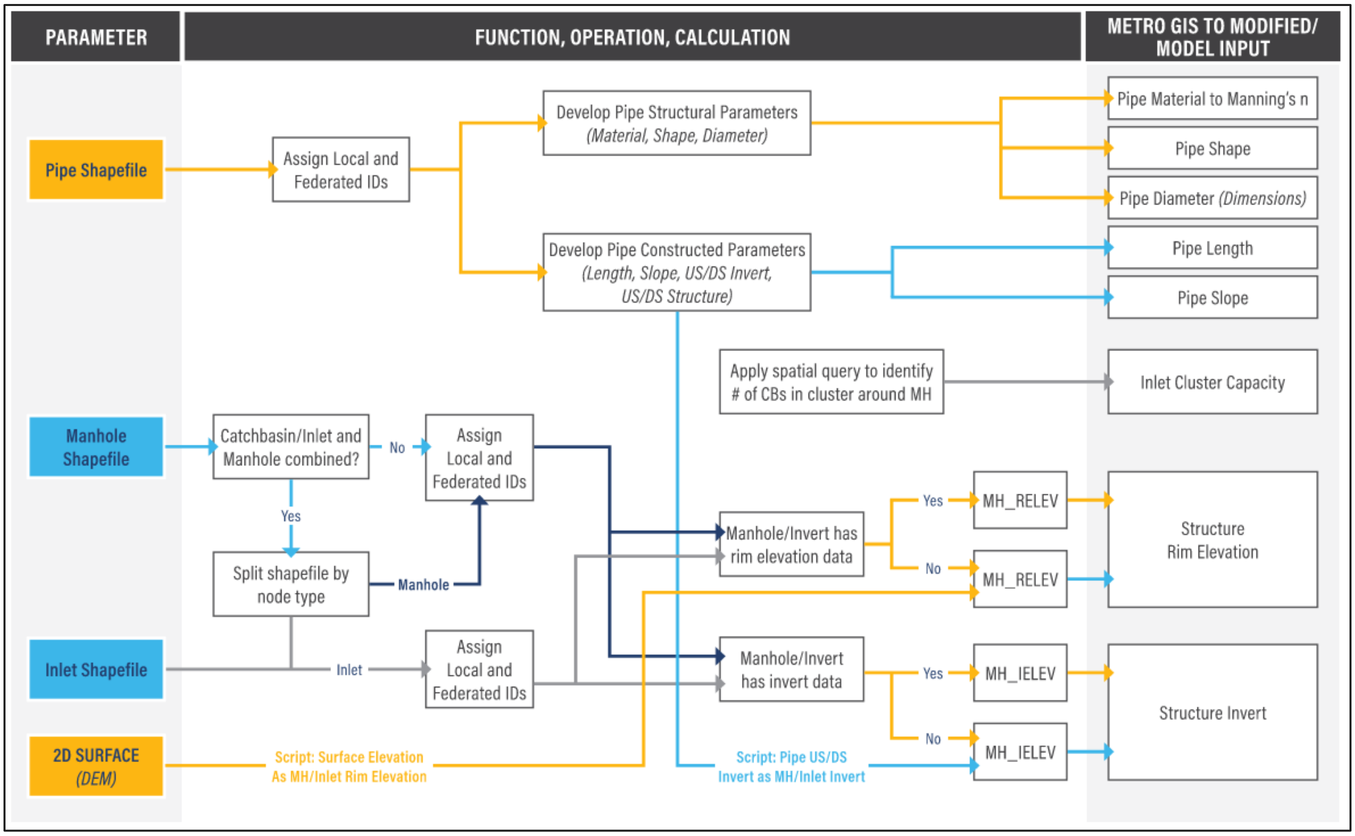


Figure 5. Infrastructure Data Gap Filling and Model Parameter Process Diagram

The first step is to evaluate the completeness of the infrastructure data. Upon review of the raw infrastructure datasets within the pilot geographies, missing data was identified such as manhole invert data, roughness type data, and others. To fill infrastructure data gaps, three methods were utilized:

- Reference spatial datasets to correct elevation issues
- Reference downstream/upstream pipe segments to populate pipe data
- Utilize engineering best practices/standards to fill remaining gaps

Additional user review and updates to assumed standard values may be required during the model build process to accurately represent in-place conditions. User inputs may be necessary to specify the desired model parameter value.

Figure 5 outlines the processes needed for the development and the overall flow of individual data subtypes to model inputs. Figure 5 is further detailed in Section 3.4 for additional MGIS data attributes that are not shown in Figure 5. The infrastructure data transformation and data filling steps will be the same between the ICPR and ICM model development pathways.

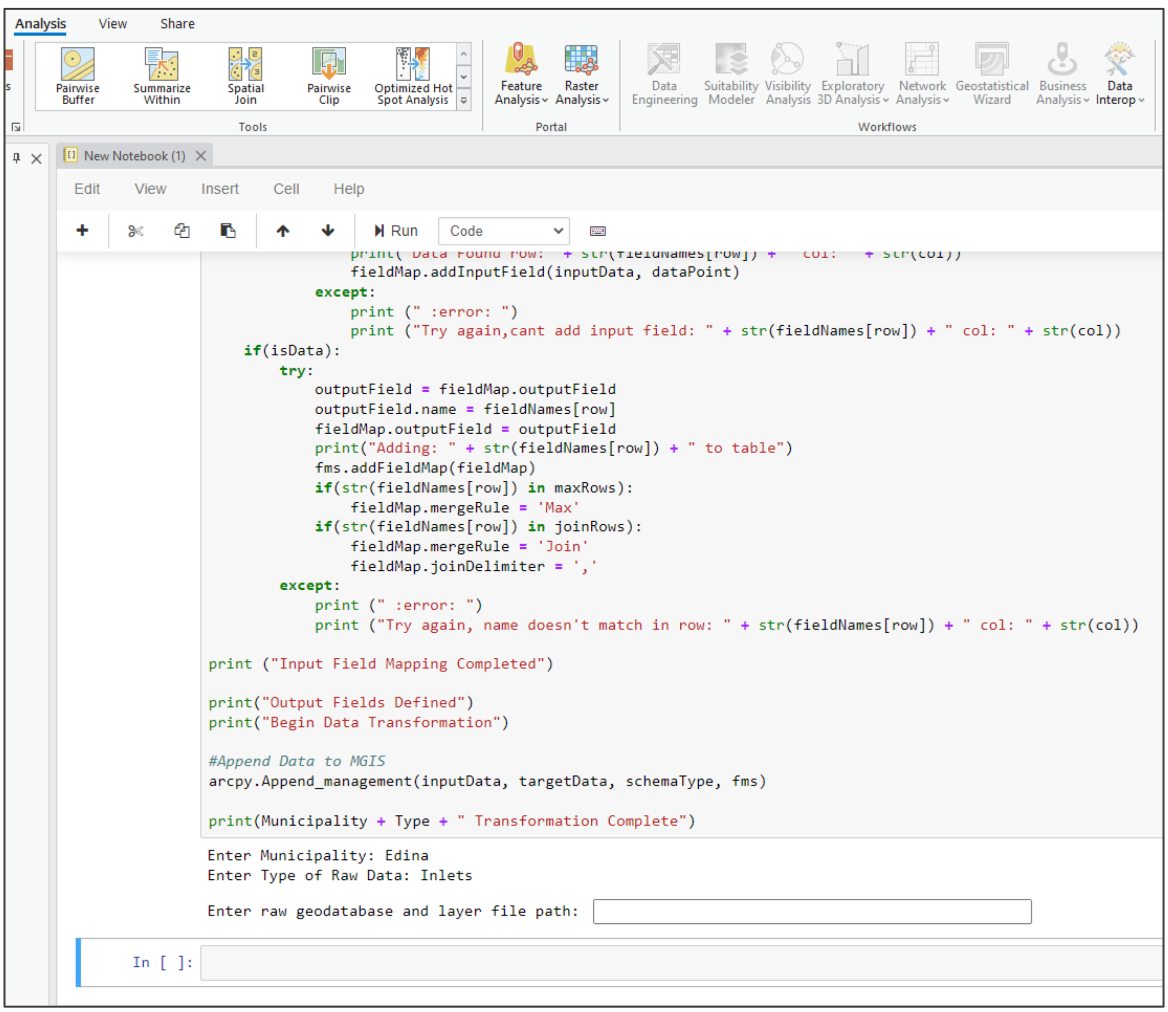
4 DETAILED DESIGN

The detailed design section includes user interface snapshots, manual processes, and pseudocode for automated processes. The overall process hinges on the consistent attribute naming of transformed data to develop model parameters. The raw attribute data mapping is an important step to successfully convert data from raw to MGIS. This step acts to ensure data types, formats, and naming conventions are documented so that the scripting process and data conversion steps are easily repeatable. The Raw Data Mapping tables for the Edina and Turbid-Lundsten Subwatersheds are shown in **Appendix A**.

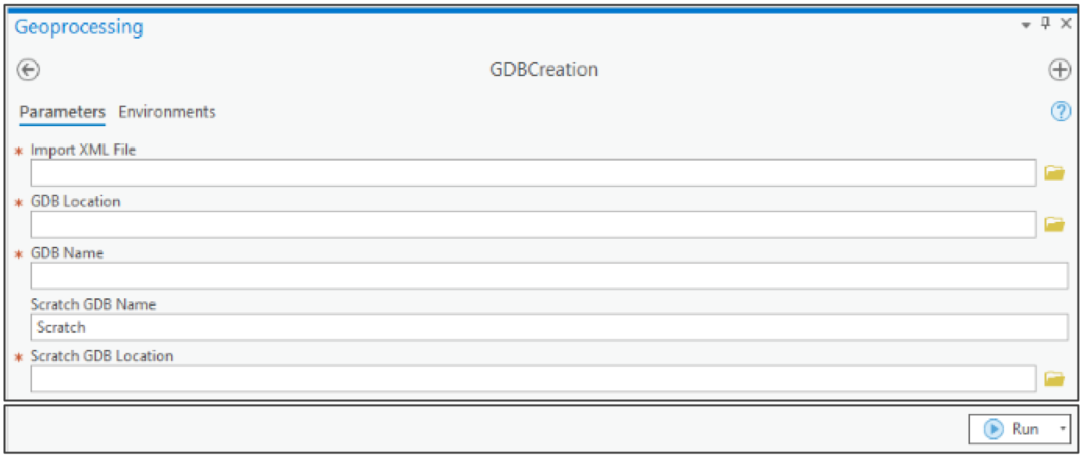
4.1 Graphical User Interface

There are two main GUIs that are utilized through the automated process are the Python IDLE window and the ArcPro Geoprocessing window.

- Python ArcPro GUI – this is the Python interface that comes standard with ESRI ArcGIS. This can be used to execute the Python scripts to transform the data from raw attributes to the MGIS standard directly within ArcPro. Alternative IDLE packages may be utilized to perform the Python scripts outside of ArcPro as the GIS users processing skills and abilities allow. A new Python window is opened within an ArcPro project, python code inserted, and the tool run. User inputs are requested along the bottom of the notebook with additional runtime messages that populate as well to log the progress of the tool.



- ArcPro Geoprocessing – This GUI is located within ArcPro and is accessed as any standard GIS tool would be accessed. The interface allows for user input in the form of folder and file specification. Some tools allow for additional user inputs such as cell spacing, search radius, and others. The GIS Processes may also be viewed through Model Builder within ArcPro depending on the GIS user processing skills and abilities. Model Builder allows the user to specify the inputs for each process independently and change additional parameters that are not shown in the Geoprocessing window.



4.2 Manual Process

The Web Soil Survey data for determining the Green-Ampt parameters must be manually extracted from the Microsoft Access Database file for each county. This process must be completed prior to executing process 4d. The steps to extract the files are listed below.

1. Open Microsoft Access Database file
2. Select the chtexture table and right-click
    a. Select the Export, Excel option
    b. Browse to desired output location
    c. Check "Export data with formatting and layout" box
    d. Check "Open the destination file after the export operation is complete" box
3. Once exported excel file opens, perform Save As to XLS file type
4. Repeat steps 2-3 for chtexturegrp, component, muaggatt, and chorizon database files

4.3 Pseudocode (Python Script and GIS Process)

1. **Project Setup (GIS Process)**

    a. Folder Creation

    This tool creates a standardized folder structure for a new project. The user specifies the desired location of the project folder and the project folder name. The folder structure includes folders for documents (DOCS), calculations (ENG), GIS files (GIS), ICM and ICPR model files (Models), and reference data (xIN).

    i. Pseudocode

    1. Create overall project folder [Create Folder]
        a. User Specified Location
    2. Create main subfolders [Create Folder]

<table>
<tr><th>Folder</th><th>Subfolder</th><th>Sub-Subfolder</th></tr>
<tr><td rowspan="2">DOCS (Documentation and Reports)</td><td>Working</td><td></td></tr>
<tr><td>Final Report</td><td></td></tr>
<tr><td rowspan="2">ENG (Engineering Calculations)</td><td>Hydrologic Folder</td><td></td></tr>
<tr><td>Results Comparison</td><td></td></tr>
<tr><td rowspan="3">GIS (Files, Raw & MGIS)</td><td>MGIS</td><td></td></tr>
<tr><td rowspan="2">Model Inputs</td><td>Raster</td></tr>
<tr><td>Shapefiles</td></tr>
<tr><td rowspan="2">Models</td><td>ICPR</td><td></td></tr>
<tr><td>ICM</td><td></td></tr>
<tr><td rowspan="6">xIN</td><td>Infrastructure Data</td><td></td></tr>
<tr><td rowspan="5">Spatial Data</td><td>LULC</td></tr>
<tr><td>DEM</td></tr>
<tr><td>Soils</td></tr>
<tr><td>Groundwater</td></tr>
<tr><td>Boundary</td></tr>
</table>

b. GDB Creation – MGIS and Scratch

This tool creates an empty standard MGIS geodatabase (GDB) and a scratch GDB. The scratch geodatabase is utilized to perform manipulations and calculations of the raw data. Some GIS tools work best when files are located within a geodatabase, instead of a shapefile format. The user specifies the import XML file (MGIS), output MGIS GDB location and name, and the scratch GDB location and name. The XML file holds the MGIS format to reproduce the standard MGIS GDB.

i. Pseudocode

1. Specify MGIS import XML file [Import XML Workspace Document]
2. Specify MGIS GDB location
3. Specify name of MGIS GDB [Create File Geodatabase]
4. Specify scratch GDB location
5. Specify name of scratch GDB [Create File Geodatabase]
    a. Recommendation: Same name as MGIS GDB with _Scratch at end

c. GDB Creation – MGIS

This tool performs the same function as the previous tool but only creates the MGIS GDB.

i. Pseudocode

1. Specify MGIS XML file [Import XML Workspace Document]
2. Specify MGIS GDB location
3. Specify name of MGIS GDB [Create File Geodatabase]

d. ***Data Transfer***

This tool transfers the data from the raw format to the scratch GDB. The user specifies the input file(s) and the scratch GDB location and name. There are no data transformations or calculations that take place with this tool. Perform this tool on all raw shapefile data, not necessary for lidar datasets.

i. Pseudocode

1. Specify Input Feature(s)
2. Specify target Scratch GDB [Feature Class to Geodatabase]
3. Files transferred from xIN folder to scratch GDB for future processing

2. Raw to MGIS (Python Scripts)

a. ***Inlets / Manholes / Pipes***

This tool takes the user-specified scratch GDB inlet (or manhole or pipes) layer and performs data mapping via user-created csv file with raw attribute field names to create the MGIS inlet (or manhole or pipes) layer.

i. Pseudocode

1. Specify location (Municipality) of raw input data
2. Specify folder location of scratch GDB and input file (layer) name
3. Specify output MGIS GDB location and corresponding layer (Inlets, Manhole, Pipes)
4. Specify the corresponding field mapping csv file
   a. The csv file should follow this format for the top row:
      I. MGIS Field Name, Raw Data Field, Raw Data Field2, Raw Data Field3, Raw Data Field4
   b. Fields with a singular raw field input should be placed in the Raw Data Field column. Additional raw field inputs should be placed across the row. A maximum of 4 raw field inputs can be specified for any MGIS output field.

b. ***Scratch Conversion***

This tool takes raw dataset and transfers them into the scratch GDB. The tool also takes user input to specify where data is located to calculate municipal, county, and state codes and standard names. This data is used to develop the federated ID field within the MGIS GDB. This tool should be used with all infrastructure data.

i. Pseudocode

1. Specify folder of raw data to be transferred
2. Specify scratch geodatabase
3. Specify location (i.e., City) of origin of data
4. Script creates CTU Code and ID, County Name and ID, State Code data fields [Add Field]
5. Data fields filled with appropriate codes and IDs from user specification [Calculate Field]
6. Data is transferred from raw format to layer format within geodatabase

c. ***Value Data Null Fill***

This tool takes a user input file and field to fill with a value or null. This tool is utilized to fill columns in the raw datasets that need a null value for tools to run. Typically, at least null values are required for date fields to be processed into the MGIS GDB. Other processes may require or be requested by the user to perform the same type of field fill process.

3. **Surface Generation (GIS Process)**

a. LAZ to LAS

This tool iterates through a user specified folder, searches for any files in the folder that end with .laz and decompresses the files to the .las format for processing by the following tools. The user specifies the input folder, wildcard (.laz), output format (.las), and the output folder name for the final files, and the output LAS file(s) name. The output LAS file name contains the wildcard %Name%. This wildcard is used to specify the original file name will be utilized in creation of the new file name. Without the wildcard, the name of each file would need to be specified individually.

i. Pseudocode

1. Specify folder on of all LAZ files to be uncompressed to LAS format [Iterate Files]
2. Specify input wildcard (file extension)
    a. .LAZ is the standard
3. Specify output format
    a. .LAS is the standard
4. Specify output folder location
5. Specify output name for uncompressed (.LAS) files [laszip]
    a. %Name%.las will utilize the original name of each file and append .las to the end. Keep this format unless change is required.

b. Create LAS Dataset

This tool creates a LAS dataset (LASD) collection within the GIS environment. The LASD allows for batch processing and manipulation of a group of LAS tiles. LAS tiles are generally limited to 250 MB per tile. The user specifies the input LAS files, the output spatial coordinate system, the initial LASD file location and name, the projected LASD file location and name. The tool runs through the processes twice, thus the "Create PRJ for LAS Files" input twice in the dialog box. The first instance should be set to All LAS Files and the second instance set to No LAS Files. This was done to correct a spatial projection error in the underlying MnTOPO data.

i. Pseudocode

1. Specify folder location where .las files are saved
2. Specify coordinate system
    a. UTM Zone 15N is standard for region
    b. Watershed spans multiple counties
3. Specify where initial LAS dataset file will be saved [Create LAS Dataset]
    a. Typically, saved in same folder as .las files
4. Specify final LAS dataset file will be saved [Create LAS Dataset]
    a. Same location as 3.a.
5. Final option must remain "No LAS Files" for Create PRJ for LAS files

c. LASD to TIF

This tool creates the geotiff (DEM) raster file from the LASD that was created previously. The user specifies the input LASD name and location, cell spacing (meters), class code (2), intermediate location, final raster file location, and the output spatial coordinate system. The class code of 2 filters the LASD to only use the ground elevation points. The cell spacing is specified in meters due to the MnTOPO data setup. 1 foot = 0.3048 meter for conversion purposes.

i. Pseudocode

1. Specify the previously created final LAS dataset file to be used in DEM creation
2. Set cell spacing (in meters)
    a. Smaller cell spacing = increased detail in DEM but larger output file
    b. Default set to 2m, can be reduced or increased as needed
    c. Z factor (height) of 3.28084 is applied automatically to transform elevation from meters to feet.
3. Class Code = 2 for only ground elevation points [Make LAS Dataset Layer]
4. Intermediate DEM Location [LAS Dataset to Raster]
    a. Can be deleted after processing [Delete Raster (after completion of tool)]
5. Output DEM (raster) location
6. Output Coordinate System [Project Raster]
    a. Can be projected to a different coordinate system

d. ClipDEM

This tool clips the created DEM to the input file limits. The user specifies the input raster (DEM), the output raster (final DEM) name, the output extent (clipping feature). The "Use Input Features for Clipping Geometry" check box should be checked. If the box is unchecked, then the input raster will be clipped to the minimum bounding rectangle surrounding the output extent.

i. Pseudocode

1. Specify Input Raster to be clipped
2. Specify clipping boundary shapefile
    a. Must be in same spatial projection as input raster (UTM Zone 15N)
3. Input Distance for Buffer [Buffer]
    a. Applies a buffer to the clipping boundary
4. Check Use Input Feature for Clipping Geometry, if user wants DEM boundary to follow input file exactly [Clip Raster]
    a. Unchecked uses a minimum bounding rectangle of the input file
5. Specify output raster name and location

4. Spatial Tools (GIS Process)

a. File Reproject

This tool reprojects an input dataset from one spatial projection to the standard spatial projection for the project. The tool also checks the input dataset for the current spatial projection, if the spatial projection matches the standard spatial projection, then the tool does nothing.

i. Pseudocode

1. Specify input shapefile for spatial transformation
2. Specify output file folder location

3. User specifies output file name [Project]
    a. Recommended to include new spatial projection (UTM) in file name
4. Raw shapefile current spatial projection displayed on screen for reference

b. Input File Clip Model

This tool takes an input dataset and clipping feature to produce a clipped version of the input dataset. This tool also buffers the clip by 500 feet. The buffer reduces the need to rerun tools for model build, in the case that a model area boundary is adjusted slightly, or input data stretches across the desired model boundary.

i. Pseudocode
    1. Specify input file or dataset
    2. Specify clipping boundary [Clip Features]
    3. Specify distance for buffer [Buffer]
        a. Default = 500 feet
    4. Specify output file path and name

c. WSS Data – Add Fields

This tool adds the required Green-Ampt parameter fields to the specified table. The G-A parameter inputs are not consistent between modeling software packages. ICPR takes the underlying soil parameters and generates runoff values internally, ICM takes preprocessed soil parameters. The underlying soil parameters are found in the web soil survey (WSS) database and the preprocessed soil parameters are based on a look-up table specified by the user.

i. Pseudocode
    1. Specify raw Soils shapefile name
    2. All Green-Ampt (G-A) parameter fields added to attribute table [Add Field]
        a. Fields that are added include:

Field Alias	Field Name	Type
Component Key	CompKey	Text
Percent Clay – Representative	pClay	Double
Percent Sand – Representative	pSand	Double
Percent Organic – Representative	pOrganic	Double
CHorizon Key	ChorzKey	Text
Bulk Density 1/3 Bar	BD_13bar	Double
K saturated	Ksat	Double
Moisture Content 1/3 Bar	MC_13bar	Double
Moisture Content 15 Bar	MC_15bar	Double
Initial Water Table	WT_Int	Double
Soil Type	Soil_Type	Text
Suction	Suction	Double
Hydraulic Conductivity	Hyd_Cond	Double
Porosity	Porosity	Double

d. WSS Data – Carver County & Hennepin County

i. Pseudocode

1. Load database tables into ArcPro for faster processing
2. Specify input shapefile from previous step
3. Specify exported WSS tables
   a. Component Table
   b. Chorizon Table
   c. Muaggatt Table
   d. Chorizon Texture Table
4. Join raw soils shapefile to WSS lookup tables [Add Join]
5. Verify individual field names (Names must follow !FieldName! format or syntax error will occur (*field names specified in background*)

Total Clay – Representative	1/3 bar Bulk Density
Total Sand – Representative	1/3 bar Moisture Content
Total Organic Matter – Representative	15 bar Moisture Content
Ksat	Soil Type
Water Table - Initial	

6. Join G-A parameter lookup table [Add Join]
7. Calculate G-A parameter fields from lookup table [Calculate Field]
   a. Suction
   b. Hydraulic Conductivity
   c. Porosity
8. Remove table joins [Remove Join]

e. ***WSS Data Fill***

This tool fills the empty soil parameters with a standard clay value. The soil type field is set as aClay for assumed clay soil type. All soil parameters match standard clay values. Urban soils are not given soil parameters within the WSS system. These soils are assumed to be compacted due to grading and development activities and act as clay soils in relation to hydrologic factors.

i. Pseudocode

1. Specify soil shapefile
2. Shapes that include Soil Types equal to Zero or Null are selected [Select Layer by Attribute]
3. Assume that areas with no Soil Type are Clay
   a. Soil Type name computed to aClay [Field Calculator]
   b. Compute remaining Green-Ampt parameters in accordance with standard Clay values [Field Calculator]
4. Selection of Null shapes removed [Remove Selection]

f. LULC Imp ManN

This tool uses a lookup table and landuse layer to specify impervious and roughness coefficients based upon land cover. The user specifies the land use layer, lookup table, lookup table field, corresponding shapefile field, and the output folder. The lookup table and landuse layer must have a column that match to transfer the data from one to the other.

i. Pseudocode

1. Specify landuse shapefile
2. Impervious attribute field created [Add Field]
3. Manning's n attribute field created [Add Field]
4. Specify Manning's n/Impervious lookup table file path
5. Specify Landuse ID attribute shapefile for use with lookup table
6. Specify corresponding Landuse ID lookup table attribute field [Join Table]
7. Tool calculates the related Manning's n and Impervious values based on the input landuse shapefile landcover attribute field [Field Calculator]
8. Specify output file location [Feature Class to Shapefile]

5. Model Parameters (GIS Process)

a. Drop Null Segments

This tool uses the MGIS pipe layer to remove null (zero length) pipe segments from the input pipe file. Zero length shapes can occur during digitization of the raw dataset and may cause issues during model creation and simulation analysis. The tool also calculates the length of all pipes and checks against a user specified field. All lengths with a variance greater than 20 feet are flagged for review by the user.

i. Pseudocode

1. Calculate all Link lengths [Calculate Geometry]
2. Select Links with null length and assign them the calculated length [Select by Attribute and Calculate Field]
3. Compare Calculated link length vs recorded link length [Calculate Field]
4. Tag with a note if greater than 20% off [Select by Attribute & Calculate Field]
5. For flagged pipes, fill in length to match measured length [Calculate Field]
6. Select and delete pipes less than 0.1' [Select by Attribute & Delete Features]
7. Add a name field based on the FacilityID field [Calculate Field]
8. End with 'Length' field, 'Name' field, and 'Comment' field calling out 20% variance

b. Node Data Merge

This tool merges the inlets and manhole layers to create a single node layer for model creation. The layer maintains all of the individual data for each layer type.

i. Pseudocode

1. Compile all nodes into a single shapefile [Merge]
2. End with a shapefile containing all node features

c. Assign Nodes

This tool utilizes spatial selection to name upstream and downstream nodes for pipes based upon a search radius specified by the user. The tool utilizes the previously merged manhole and inlet layer file to perform the analysis.

i. Pseudocode

1. Pull first (last for downstream nodes) vertex of pipe [Feature Vertices to Points]
2. Spatial join first vertex (last for downstream nodes) to nearest node respectively [Spatial Join]
3. Calculate name of the nearest node into the first (last for downstream nodes) vertex of pipe table [Calculate Field]
4. Join first (last for downstream nodes) vertex node table back to the working link table and assign the calculated name to a temporary US name [Join]
5. Repeat process for DS node (see above)
6. Tag with a note if the US or DS nodes are missing [Select by Attribute and Calculate Field]
7. End with 'Node_From' and 'Node_To' with missing nodes flagged

d. Assign Roughness

This tool calculates pipe roughness coefficients based upon the pipe material field in the MGIS pipe layer. The tool uses a pipe lookup table to reference the corresponding roughness values to each material.

i. Pseudocode

1. Recalculate all blank and null material types with 'Unknown' [Select by Attribute and Calculate Field]
2. Join known Manning's "n" table to pipe material field [Join]
3. End with 'UsManningsN' and 'DsManningsN'

e. Clean Depth

This tool takes a user input to insert assumed pipe sizes for pipes that have null diameters. The default assumed pipe size is set to 2 feet (24 inches).

i. Pseudocode

1. Create field 'UsMaxDepth' and set it equal to the PIPESIZE_I field converted to feet [Calculate Field]
2. Select all 0 depth pipes and assign them a user input assumed value [Calculate Field]
3. Comment on all assumed depths [Calculate Field]
4. Assign 'DsMaxDepth' field the same values as the 'UsMaxDepth' [Calculate Field]
5. End with 'UsMaxDepth' and 'DsMaxDepth' fields, comment on assumed depths

f. Fill in Null Invert with DEM Offset

This tool updates pipes with missing invert values based upon a user specified pipe cover value. The default pipe cover value is 1 foot. The diameter of the pipe is added to the specified cover value to calculate the assumed pipe inverts.

i. Pseudocode

1. Pull first (last for downstream invert) vertex of pipe [Feature Vertices to Points]

2. Pull elevation data from desired surface [Add Surface Information]
3. Subtract a desired cover and the existing pipe depth from the elevation [Calculate Field]
4. Join new elevations to the pipe shapefile [Join Field]
5. Tag with a note if inverts are missing [Select by Attribute and Delete Features]
6. Replace missing elevations with the calculated DEM depth [Calculate Field]
7. Repeat process for downstream inverts (*see above*)
8. End with 'UsInvert' and 'DsInvert' field

g. Find Bends within Pipes

This tool performs spatial analysis of the pipes layer to determine the presence of bends/blind junctions within individual pipe segments. Any segments with bends are specified to have an internal loss coefficient of 0.5. The bend location is assumed to be in the middle of the pipe and input into the attribute table for the pipe layer.

i. Pseudocode

1. Calculate the central point and centroid x- and y-coordinates for all pipes [Calculate Geometry Attributes]
2. Select all pipes where central point and centroid do not match for either the x- or y-coordinates [Select by Attribute]
3. Add the field 'BendLossCoef' and assign a value of 0.5 [Calculate Field]
4. Add the field 'BendLocation' and assign a value of 0.5 [Calculate Field]

APPENDIX A DETAILED INPUT DATA MAPPING STANDARDS

EDINA

Manhole Dataset: DManhole – 9,070 shapes

Input Raw Attribute Name	Description	Data Type	Output MGIS Standard Attribute Name
FacilityID	Edina Manhole ID Name-Number	Text	MH_ORID
AncillaryRole		Short	*not utilized*
Enabled		Short	*not utilized*
SubType	Structure Subtype Number ID		*not utilized*
AccessDiameter	Manhole Access Diameter		*not utilized*
AccessType	Access Type and Material	Text	*not utilized*
Depth	Structure Height	Double	MH_HT
InteriorDrop	Inlet to Outlet Pipe Vertical Drop, *No Data*		*not utilized*
BarrelMaterial	Structure Barrel Material #5 of 5	Text	MH_CMNT2
StepMaterial	Structure Step Material	Text	*not utilized*
BarrelDiameter	Structure Diameter	Double	MH_WID, MH_LNG
BenchMaterial	Structure Bench Material	Text	*not utilized*
ChannelMaterial	Structure Channel Material	Text	*not utilized*
RingMaterial	Structure Ring Material, #3 of 5	Text	MH_CMNT2
AccessMaterial	Structure Access Material, #2 of 5	Text	MH_CMNT2
FrameMaterial	Structure Frame Material, #1 of 5	Text	MH_CMNT2
ConeMaterial	Structure Cone Material, #4 of 5	Text	MH_CMNT2
BaseMaterial	Structure Base Material	Text	*not utilized*
MH_ID	Old Manhole ID	Long	*not utilized*
MH_B_OTTOM	Invert Elevation, #1 of 2, Main Dataset, 2,132 entries	Double	MH_IELEV
GROUND_EL_	Rim Elevation, #1 of 2, Main Dataset, 2,024 entries	Double	MH_RELEV
MH_BOTTOM_	Invert Elevation #2 of 2, Partial Dataset, 32 entries	Double	MH_IELEV
GROUN_EL_D	Rim Elevation #2 of 2, Partial Dataset, 397 entries	Double	MH_RELEV
MH_TXT	Previous Manhole ID, #1 of 2	Text	MH_CMNT
SOURCETHM	As-Built Information Source	Text	MH_ABDOC
SUMP	Presence of a Sump in Structure	Text	*not utilized*
SUMP_INV	Sump Elevation	Double	MH_SUMP
YEAR_INST	Year Installed	Text	*not utilized*
RECON_YR	Year Reconstructed	Text	*not utilized*
ASB_NUM	As-Built Number	Text	*not utilized*
Condition	Condition Rating	Text	*not utilized*
ConditionDate	Condition Date	Date	MH_CDATE
SubTypeMH	Manhole Type	Text	MH_CMNT
AccessLength	Manhole Access Opening Length	Double	*not utilized*
AccessWidth	Manhole Access Opening Width	Double	*not utilized*
SPCD	SPCD	Text	*not utilized*
Verified	Structure Data Quality Level	Text	*not utilized*
created_user	Manhole Data Created By	Text	MH_DASRC
created_date	Manhole Data Created Date	Date	not utilized
last_edited_user	Last Edited By	Text	MH_DATAN
last_edited_date	Last Edited Date	Date	MH_DAMOD
UntiCost	Unit Cost	Text	*not utilized*
ReplacementValue	Cost to replace structure	Double	*not utilized*
Owner	Owner of structure	Text	MH_OWNT, MH_MAINT
Notes	General notes on structure, #2 of 2	Text	MH_CMNT

Inlet Dataset: DCatchBasin – 3,588 shapes

Input Raw Attribute Name	Description	Data Type	Output MGIS Standard Attribute Name
FacilityID	Edina Inlet ID Name-Number	Text	IN_ORID
AncillaryRole	*No Data*	Text	*not utilized*
AdministrativeArea	*No Data*	Text	*not utilized*
LegacyID	*No Data*	Text	*not utilized*
Location	*No Data*	Text	*not utilized*
OperationalArea	*No Data*	Text	*not utilized*
SubBasin	*No Data*	Text	*not utilized*
Rotation	*No Data*	Double	*not utilized*
LifeCycleStatus	Inlet Structure Status	Text	IN_STAT
SubType	*No Data*	Text	*not utilized*
WarrantyDate	*No Data*	Date	*not utilized*
InstallContractor	*No Data*	Text	*not utilized*
WaterType	*No Data*	Text	*not utilized*
Elevation	*No Data*	Double	*not utilized*
BelowGrade	Depth below surface, *No Data*	Double	*not utilized*
Manufacturer	Inlet Structure Manufacturer, *No Data*	Text	*not utilized*
Measurement1	*No Data*	Double	*not utilized*
Measurement2	*No Data*	Double	*not utilized*
Depth	*No Data*	Double	*not utilized*
ID	ID Number, *No Data*	Long	*not utilized*
MH_ID	Old Manhole ID numbers	Long	*not utilized*
NODE_TYPE	Inlet Type (CB, drain)	Text	IN_CMNT
PREFIX	Previous Compiled Node Type and MH ID	Text	*not utilized*
MH_B_OTTOM	Invert Elevation (#1 of 10)	Double	IN_IELEV
GROUND_EL_	Rim Elevation (#1 of 2)	Double	IN_RELEV
MH_BOTTOM_	Invert Elevation (#2 of 10)	Double	IN_IELEV
GROUN_EL_D	Rim Elevation (#2 of 2)	Double	IN_RELEV
MH_TXT	Old Manhole Structure Name	Text	IN_CMNT2
DISTANCE2	Height of Structure, Partial Dataset	Double	*not utilized*
COMMENTS2	Connecting Pipe Notes	Text	IN_CMNT2
ZOOY_SURCH	Node Surcharges in 100Y event	Double	*not utilized*
Z0Y_SURCHA	Node Surcharges in 10Y event	Double	*not utilized*
ZY_SURCHAR	Node Surcharges in 1Y event	Double	*not utilized*
SOURCETHM	As-Built File name	Text	IN_ABDOC
CREATED_BY	GIS feature created by	Text	IN_DATAT
RIM_VER	Rim Elevation Verified	Text	*not utilized*
TYPE_VER	Inlet Type Verified	Text	*not utilized*
TR	Top of Rim Elevation	Text	IN_CMNT
SUMP_INV	Sump Elevation	Double	IN_SUMP
YEAR_INST	Year Installed, *No Data*	Text	*not utilized*
RECON_YR	Reconstruction Year	Text	*not utilized*
ASB_NUM	As-Built Number, *No Data*	Text	*not utilized*
Condition	Inlet Condition, *No Data*	Text	*not utilized*
ConditionDate	Inlet Condition Date, *No Data*	Date	*not utilized*
INV_S	South Pipe Invert Elevation (#3 of 10)	Text	IN_IELEV
INV_N	North Pipe Invert Elevation (#4 of 10)	Text	IN_IELEV
INV_E	East Pipe Invert Elevation (#5 of 10)	Text	IN_IELEV
INV_W	West Pipe Invert Elevation (#6 of 10)	Text	IN_IELEV
INV_NW	North-West Pipe Invert Elevation (#7 of 10)	Text	IN_IELEV
INV_NE	North-East Pipe Invert Elevation (#8 of 10)	Text	IN_IELEV
INV_SE	South-East Pipe Invert Elevation (#9 of 10)	Text	IN_IELEV
INV_SW	South-West Pipe Invert Elevation (#10 of 10)	Text	IN_IELEV
created_user	Inlet Data Created By	Text	IN_DASRC
created_date	Inlet Data Created Date	Date	*not utilized*
last_edited_user	Last Edited By	Text	IN_DATAN
last_edited_date	Last Edited Date	Date	IN_DAMOD
InstallDate	Installation Date, *No Data*	Date	*not utilized*

<u>Pipe Dataset:</u> DGravityMain – 9,831 shapes

Raw Attribute Name	Description	Data Type	MGIS Standard Attribute Name
FacilityID	Edina Pipe ID Name-Number	Text	PIPE_ORID
SubType	Pipe Type (DCollector)	Text	*not utilized*
RecordedLength	Pipe Length, Partial Dataset	Double	*not utilized*
Material	Pipe Material	Text	PIPE_MAT
UpstreamInvert	Pipe Upstream Invert	Double	PIPE_IELVU
DownstreamInvert	Pipe Downstream Invert	Double	PIPE_IELVD
Slope	Pipe Slope (%)	Double	PIPE_SLOPE
DepthUpstream	Depth to Pipe at Upstream End	Double	PIPE_DEP
DepthDownstream	Depth to Pipe at Downstream End	Double	*not utilized*
PIPE_ID	Old Pipe ID System	Long	*not utilized*
PIPE_LEN	Pipe Length	Double	PIPE_LNG
US_MH_ID	Upstream Manhole ID	Long	PIPE_FROM
DS_MH_ID	Downstream Manhole ID	Long	PIPE_TO
PIPETYPE	Pipe Material and Shape	Text	PIPE_CMNT
PIPESIZE	Pipe Diameter	Double	PIPE_DIA
DS_MH_TXT	Downstream Manhole ID – Old	Text	*not utilized*
US_MH_TXT	Upstream Manhole ID – Old	Text	*not utilized*
SOURCETHM	As-Built Document/File	Text	PIPEABDOC
LENGTH_FEE	Fee Length	Double	*not utilized*
CREATED_BY	Object Created By	Text	PIPE_DATAT
PIPESIZE_I	Pipe Diameter – Inches	Text	PIPE_CMNT
UPSTR_VER	Upstream Verified	Text	*not utilized*
DSTR_VER	Downstream Verified	Text	*not utilized*
PIPE_VER	Pipe Verified	Text	*not utilized*
RECON_YR	Reconstructed Year	Text	*not utilized*
Condition	*No Data*	Text	*not utilized*
ConditionDate	*No Data*	Date	*not utilized*
ASB_Path	As-Built Path	Text	*not utilized*
ASB_Folder	As-Built Folder	Text	*not utilized*
ASB_Num	As-Built File Number	Text	*not utilized*
Asbuilt	Compiled As-Built Path, Folder, File	Text	PIPEABLINK
created_user	GIS created by	Text	PIPE_DASRC
created_date	GIS created date	Date	*not utilized*
last_edited_user	Last Edited By	Text	PIPE_DATAN
last_edited_date	Last Edited Date	Date	PIPE_DAMOD
UnitCost	Unit Cost, *No Data*	Double	*not utilized*
ReplacementValue	Replacement Value, *No Data*	Double	*not utilized*
Owner	Owner of Pipe	Text	PIPE_OWNN
Notes	General Notes on Pipe Information	Text	PIPE_CMNT2
LifeCycleStatus	Status of Pipe	Text	PIPE_STAT
Plansheet	*No Data*	Text	*not utilized*
OldASBNumber	Old As-Built Number and Data	Text	*not utilized*
LiningType	Lining Type	Text	PIPE_CMNT2
InstallDate	Install Year	Text	*not utilized*
Old_ASB_Folder	Old As-Built Folder	Text	*not utilized*
Old_Asbuilts	Old Compiled As-Builts Folder, File Path	Text	*not utilized*

TURBID

Manhole Dataset: StormManhole – 29 shapes

Raw Attribute Name	Description	Data Type	MGIS Standard Attribute Name
FACILITY ID	Carver County Manhole ID , Partial Dataset	Text	*not utilized*
INSTALLDAT	Installation Date	Date	MH_IDATE
HIGHELEV	Highest Elevation	Double	*not utilized*
INVERTELEV	Structure Invert Elevation	Double	MH_IELEV
INVERT	Invert Data, *No Data*	Double	*not utilized*
RIMELEV	Structure Rim Elevation, (#1 of 2)	Double	MH_RELEV
CVTYPE	Control Valve Type, *No Data*	Text	*not utilized*
WALLMAT	Structure Wall Material, *No Data*	Text	*not utilized*
MHTYPE	Manhole Type, Partial Dataset	Text	*not utilized*
CONDITION	Structure Condition, *No Data*	Text	*not utilized*
LOCDESC	General Location, *No Data*	Text	*not utilized*
CUTDEPTH	*No Data*	Double	*not utilized*
FLOWDIR	*No Data*	Text	*not utilized*
LINED	*No Data*	Text	*not utilized*
GPSDATE	*No Data*	Date	*not utilized*
ENABLED	Enabled (from model software)	Long	*not utilized*
ACTIVEFLAG	Active Flag (from model software)	Long	*not utilized*
OWNEDBY	Structure Owned By	Long	*not utilized*
MAINTBY	Structure Maintained By	Long	*not utilized*
SUMFLOW	*No Data*	Double	*not utilized*
LASTUPDATE	Data Last Updated Date	Date	MH_DAMOD
LASTEDITOR	Data Last Updated By	Text	MH_DATAN
PROJECT_NU	Project Number, *No Data*	Text	*not utilized*
PROJECT__1	*No Data*	Text	*not utilized*
PROJECT__2	*No Data*	Text	*not utilized*
OWNERSHIP	*No Data*	Text	*not utilized*
CAST_TYPE	Casting Type	Text	*not utilized*
SUMP	*No Data*	Text	*not utilized*
SUMP_DEPTH	*No Data*	Double	*not utilized*
OVERFLOW	*No Data*	Text	*not utilized*
WATERSHED	*No Data*	Text	*not utilized*
NOTES	*No Data*	Text	*not utilized*
Receiving_	*No Data*	Text	*not utilized*
created_us	Created By User	Text	*not utilized*
created_ds	Created Date	Date	*not utilized*
last_edite	Last Edited By	Text	*not utilized*
last_edi_1	Last Edited Date	Date	*not utilized*
ID_prefix	Structure ID Prefix	Text	*not utilized*
MAPKEY	Map Key ID	Text	*not utilized*
STORM_STRU	Storm Structure ID	Text	*not utilized*
MS4_ID	*No Data*	Text	*not utilized*
TYPE	Structure Type	Text	*not utilized*
SIZE	Structure Diameter	Text	*not utilized*
RIM_ELEV	Structure Rim Elevation (#2 of 2)	Text	MH_RELEV
INVERT_ELE	Structure Invert Elevation (#2 of 2)	Text	MH_IELEV
PROJ_NUM	Project Number, Partial Dataset	Text	*not utilized*
SHEET	Planset Sheet Number	Text	*not utilized*
BLOCK	CAD Block Type	Text	*not utilized*
LAYER	CAD Layer	Text	*not utilized*
ANGLE	Rotation Angle	Double	*not utilized*
X_COORD	X Coordinate	Double	*not utilized*
Y_COORD	Y Coordinate	Double	*not utilized*
MATERIAL	Structure Material	Text	*not utilized*
LOCATION	General Location, Partial Dataset	Text	MH_LOC
INSTALL_DA	Installation Date, Partial Dataset	Text	*not utilized*
MS4	*No Data*	Text	*not utilized*
MS4_SPCD_T	*No Data*	Text	*not utilized*

Raw Attribute Name	Description	Data Type	MGIS Standard Attribute Name
MS4_STRUC	*No Data*	Text	*not utilized*
STRUCTURAL	*No Data*	Text	*not utilized*
MS4_OUTFAL	*No Data*	Text	*not utilized*
LEVEL_OF_A	Level of Accuracy	Text	*not utilized*
OWNER	Structure Owner Type	Text	MH_OWNT
STATUS	Structure Status	Text	*not utilized*
COMMENTS	*No Data*	Text	*not utilized*
MH_NUM	*No Data*	Text	*not utilized*
ORIG_FID	*No Data*	Long	*not utilized*
INSTALL__1	Install Date	Date	*not utilized*
City_ID	*No Data*	Text	*not utilized*
Plan_ID	*No Data*	Text	*not utilized*
BMP_Type	*No Data*	Text	*not utilized*
Diameter	*No Data*	Text	*not utilized*
Casting_Si	*No Data*	Text	*not utilized*
Casting_Ty	Casting Type (Number)	Text	*not utilized*
Cone_Top_S	*No Data*	Text	*not utilized*
Project	*No Data*	Double	*not utilized*
Rim_Elevat	*No Data*	Double	*not utilized*
Rim_Adjust	*No Data*	Text	*not utilized*
Consultant	*No Data*	Text	*not utilized*
Inlet_Outl	*No Data*	Text	*not utilized*
Pond_Basin	*No Data*	Text	*not utilized*
Original_C	*No Data*	Text	*not utilized*
House_Numb	*No Data*	Text	*not utilized*
Street_Nam	*No Data*	Text	*not utilized*
AVGACCURAC	*No Data*	Double	*not utilized*
WORSTACCUR	*No Data*	Double	*not utilized*
PCDDEVICE	*No Data*	Text	*not utilized*
PCDID	*No Data*	Long	*not utilized*
ESRIGNSS_R	*No Data*	Text	*not utilized*
ESRIGNSS_H	*No Data*	Double	*not utilized*
ESRIGNSS_V	*No Data*	Double	*not utilized*
ESRIGNSS_L	*No Data*	Double	*not utilized*
ESRIGNSS_1	*No Data*	Double	*not utilized*
ESRIGNSS_A	*No Data*	Double	*not utilized*
ESRIGNSS_P	*No Data*	Double	*not utilized*
ESRIGNSS_2	*No Data*	Double	*not utilized*
ESRIGNSS_3	*No Data*	Double	*not utilized*
ESRIGNSS_F	*No Data*	Long	*not utilized*
ESRIGNSS_C	*No Data*	Double	*not utilized*
ESRIGNSS_S	*No Data*	Long	*not utilized*
ESRIGNSS_N	*No Data*	Long	*not utilized*
ESRIGNSS_4	*No Data*	Date	*not utilized*
ESRIGNSS_5	*No Data*	Double	*not utilized*
ESRIGNSS_6	*No Data*	Double	*not utilized*
ESRIGNSS_7	*No Data*	Long	*not utilized*
ESRIGNSS_8	*No Data*	Double	*not utilized*
CARTEID	Old Structure ID	Text	*not utilized*
TEMPID	Temporary Structure ID	Long	*not utilized*
X	Structure X Coordinate	Long	*not utilized*
Y	Structure Y Coordinate	Long	*not utilized*
CarverCo_I	Carver County Manhole ID, Partial Dataset	Text	*not utilized*
POINT_X	Structure X Coordinate	Double	*not utilized*
POINT_Y	Structure Y Coordinate	Double	*not utilized*
CountyMain	Does County Maintain?	Text	*not utilized*
ID	Carver County Manhole ID, Full Dataset	Text	MH_ORID
Installed	Installation Date	Date	*not utilized*
Replaced	Replace/Modification Date	Date	*not utilized*
Retired	Retired/Removal Date, *No Data*	Date	*not utilized*
RouteID	*No Data*	Text	*not utilized*

Raw Attribute Name	Description	Data Type	MGIS Standard Attribute Name
Measure	*No Data*	Double	*not utilized*
RoadID	*No Data*	Text	*not utilized*
Estimated_	*No Data*	Double	*not utilized*
VerticalDa	*No Data*	Text	*not utilized*
BMP	*No Data*	Text	*not utilized*

Inlet Dataset – Turbid

StormInlets – 287 shapes

This dataset includes the inlets from the Laketown Township Storm Sewer map package. No inlets are located within the Turbid subwatershed area.

Raw Attribute Name	Description	Data Type	MGIS Standard Attribute Name
FACILITYID	Carver County Inlet ID, Partial Dataset	Text	*not utilized*
INSTALLDAT	Installation Date, *No Data*	Date	*not utilized*
INLETTYPE	Inlet Type	Text	*not utilized*
ACCESSDIAM	Access Diameter, *No Data*	Double	*not utilized*
INVERTELEV	Invert Elevation, Partial Dataset	Double	IN_IELEV
ACCESSMAT	Access Material, *No Data*	Text	*not utilized*
ACCESSTYPE	Access Type, *No Data*	Text	*not utilized*
ENABLED	Enabled (from model software)	Long	*not utilized*
ACTIVEFLAG	Active Flag (from model software)	Long	*not utilized*
OWNEDBY	Structure Owned By	Long	IN_OWNN
MAINTBY	Structure Maintained By	Long	IN_MAINN
LASTUPDATE	Data Last Updated Date	Date	IN_DAMOD
LASTEDITOR	Data Last Updated By	Text	IN_DATAN
AncillaryR	*No Data*	Long	*not utilized*
CASTTYPE	Structure Casting Type, *No Data*	Text	*not utilized*
TOPCAST	Structure Rim Elevation, Partial Dataset, (#1 of 2)	Double	IN_RELEV
PROJECT_NU	Project Number, *No Data*	Text	*not utilized*
PROJECT__1	*No Data*	Text	*not utilized*
PROJECT__2	*No Data*	Text	*not utilized*
OVERFLOW	*No Data*	Text	*not utilized*
WATERSHED	*No Data*	Text	*not utilized*
SUMP	*No Data*	Text	*not utilized*
OWNERSHIP	*No Data*	Text	*not utilized*
Receiving_	*No Data*	Text	*not utilized*
created_us	Created By User	Text	*not utilized*
created_da	Created Date	Date	*not utilized*
last_edite	Last Edited By	Text	*not utilized*
last_edi_1	Last Edited Date	Date	*not utilized*
GPSDATE	*No Data*	Date	*not utilized*
AVGACCURAC	*No Data*	Double	*not utilized*
WORSTACCUR	*No Data*	Double	*not utilized*
LOCDESC	*No Data*	Text	*not utilized*
CULV_NUM	*No Data*	Text	*not utilized*
ORIG_FID	*No Data*	Long	*not utilized*
CARTEID	Carver County Inlet ID, Partial Dataset	Text	*not utilized*
TEMPID	Carver County Inlet ID, Partial Dataset	Long	*not utilized*
QUADRANT	Location Quadrant, Partial Dataset	Text	*not utilized*
PCDDEVICE	*No Data*	Text	*not utilized*
PCDID	*No Data*	Long	*not utilized*
RIMELEV	*No Data*	Double	*not utilized*
MAPKEY	Map Key ID	Text	*not utilized*
City_ID	City Structure ID, Partial Dataset	Text	IN_CMNT
Plan_ID	*No Data*	Text	*not utilized*
MS4	*No Data*	Text	*not utilized*
BMP_Type	*No Data*	Text	*not utilized*
MS4_Creati	*No Data*	Text	*not utilized*
Type_	*No Data*	Text	*not utilized*
Material	*No Data*	Text	*not utilized*
Diameter	*No Data*	Text	*not utilized*
Casting_Si	*No Data*	Text	*not utilized*

Kimley»Horn

Raw Attribute Name	Description	Data Type	MGIS Standard Attribute Name
Casting_Ty	*No Data*	Text	*not utilized*
Cone_Top_S	*No Data*	Text	*not utilized*
Project	*No Data*	Double	*not utilized*
Layer	*No Data*	Text	*not utilized*
Rim_Elevat	Inlet Rim Elevation, Partial Dataset, (#2 of 2)	Double	IN_RELEV
Rim_Adjust	*No Data*	Text	*not utilized*
Consultant	*No Data*	Text	*not utilized*
Status	*No Data*	Text	*not utilized*
Owner	Inlet Owner	Text	IN_OWNN
House_Numb	*No Data*	Text	*not utilized*
Street_Nam	*No Data*	Text	*not utilized*
STORM_STRU	*No Data*	Text	*not utilized*
MS4_ID	*No Data*	Text	*not utilized*
RIM_ELEV	*No Data*	Text	*not utilized*
PROJ_NUM	*No Data*	Text	*not utilized*
X_COORD	*No Data*	Double	*not utilized*
Y_COORD	*No Data*	Double	*not utilized*
LOCATION	*No Data*	Text	*not utilized*
LEVEL_OF_A	*No Data*	Text	*not utilized*
COMMENTS	*No Data*	Text	*not utilized*
INSTALL_DA	*No Data*	Date	*not utilized*
X	X Coordinate of Point	Long	*not utilized*
Y	Y Coordinate of Point	Long	*not utilized*
CarverCo_I	Inlet Structure ID, full dataset	Text	IN_ORID
POINT_X	X Coordinate of Point	Double	*not utilized*
POINT_Y	Y Coordinate of Point	Double	*not utilized*
CountyMain	Does County Maintain?	Text	*not utilized*
NeedsInspe	Inspection Required?	Text	*not utilized*
InspCommen	Inspection Comment, *No Data*	Text	*not utilized*
InsideMS4A	Is inlet located in MS4 area?, *No data*	Text	*not utilized*
Inspection	Inspection performed?, *No Data*	Text	*not utilized*
ID	Inlet Structure ID, full dataset	Text	*not utilized*
Installed	Date of Installation	Date	IN_IDATE
Replaced	Date of Replacement/Modification	Date	IN_MDATE
Retired	Date of Removal, *No Data*	Date	*not utilized*
RouteID	Route ID, *No Data*	Text	*not utilized*
Measure	*No Data*	Double	*not utilized*
RoadID	County Road ID	Text	IN_LOC
InletShape	*No Data*	Text	*not utilized*
GrateType	*No Data*	Text	*not utilized*
Manufactur	*No Data*	Text	*not utilized*
Length	Inlet Length, *No Data*	Double	*not utilized*
Width	Inlet Width, *No Data*	Double	*not utilized*
VerticalDa	Vertical Datum, *No Data*	Text	*not utilized*
Notes	*No Data*	Text	*not utilized*
HighPriori	*No Data*	Text	*not utilized*
Source	*No Data*	Text	*not utilized*
LI_Date	Inspection Date	Date	*not utilized*
LI_Weather	Inspection Weather	Text	*not utilized*
LI_DaysRai	Inspection Previous Days of Rain	Text	*not utilized*
LI_RainAmo	Inspection Previous Days Rain Depth	Text	*not utilized*
LI_Materia	Inlet Material	Text	IN_MAT
LI_Conditi	Inspection Inlet Condition Rating	Text	*not utilized*
LI_Sedimen	Inspection Sediment Found Rating	Text	*not utilized*
LI_Scour	Inspection Scour Found Rating	Text	*not utilized*
LI_Erosion	Inspection Erosion Found Rating	Text	*not utilized*

Raw Attribute Name	Description	Data Type	MGIS Standard Attribute Name
LI_Sedim_1	Inspection Sediment #1	Text	*not utilized*
LI_Sedim_2	Inspection Sediment Depth	Text	*not utilized*
LI_Dischar	Inspection Discharge Condition	Text	*not utilized*
LI_Standin	Inspection Standing Water Observed	Text	IN_HOLDS
LI_Clogged	Inspection Inlet Clogged	Text	*not utilized*
LI_Overloa	Inspection Inlet Overflowing	Text	*not utilized*
LI_Immedia	Inspection Immediate Maintenance	Text	*not utilized*
LI_Working	Inspection Inlet Functioning	Text	*not utilized*
LI_Illicit	Inspection Illicit Discharge Occurring	Text	*not utilized*
LI_ConcDet	Inspection Concrete Replacement	Text	*not utilized*
LI_Grout	Inspection Grout Replacement	Text	*not utilized*
LI_OdorSew	Inspection Odor Sewage	Text	*not utilized*
LI_OdorRan	Inspection Odor	Text	*not utilized*
LI_OdorPet	Inspection Odor Pet	Text	*not utilized*
LI_OdorSul	Inspection Odor Sulfur	Text	*not utilized*
LI_OdorOth	Inspection Odor Other	Text	*not utilized*
LI_AppearO	Inspection Appearance #1	Text	*not utilized*
LI_AppearC	Inspection Appearance #2	Text	*not utilized*
LI_AppearS	Inspection Appearance #3	Text	*not utilized*
LI_Appea_1	Inspection Appearance #4	Text	*not utilized*
LI_Appea_2	Inspection Appearance #5	Text	*not utilized*
Estimated_	*No Data*	Double	*not utilized*
SymbolRota	*No Data*	Long	*not utilized*
BMP	*No Data*	Text	*not utilized*

Pipe Dataset #1 – Turbid

StormCulverts – 335 shapes

This dataset includes the culverts from the Laketown Township Storm Sewer map package.

Raw Attribute Name	Description	Data Type	MGIS Standard Attribute Name
Source	Data Source (GPS, Unknown)	Text	*not utilized*
Type	Pipe Shape	Text	PIPE_SHP
DiameterSi	Pipe Diameter (inches)	Text	PIPE_CMNT
Material	Pipe Material	Text	PIPE_MAT
Notes	Location Notes	Text	PIPE_CMNT
FlowDirect	Pipe flowing direction	Text	PIPE_CMNT
FacilityTy	Type of Crossing	Text	PIPE_CMNT
End1Direct	Pipe End #1 Direction	Text	PIPE_CMNT2
End1Type	Pipe End #1 Type	Text	PIPE_CMNT2
End2Direct	Pipe End #2 Direction	Text	PIPE_CMNT2
End2Type	Pipe End #2 Type	Text	PIPE_CMNT2
created_us	Created by user	Text	*not utilized*
created_da	Created date	Date	*not utilized*
last_edite	Shape last edited by	Text	PIPE_STAT
last_edi_1	Date of Last Edit	Date	PIPE_SDATE
Installed	Installed Date	Date	PIPE_IDATE
Replaced	Replacement/Modification Date	Date	PIPE_MDATE
Retired	Date of Retirement/Removal, *No Data*	Date	*not utilized*
RoadID	County Road ID	Text	PIPE_RDID
RouteID	County Route ID, *No Data*	Text	*not utilized*
FromMeasur	*No Data*	Double	*not utilized*
ToMeasure	*No Data*	Double	*not utilized*
ID	Pipe ID	Text	PIPE_ORID
Diameter	Pipe Diameter, general	Long	PIPE_DIA
Pavement	Type of Pavement over Pipe	Text	PIPE_CVG
Inspection	*No Data*	Long	*not utilized*
Inspecti_1	*No Data*	Date	*not utilized*
Street	County Road Name	Text	PIPE_LOC
Length	Pipe Length	Double	PIPE_LNG
LengthAccu	Accuracy of Pipe Length measurement	Text	*not utilized*
Slope	Pipe Slope	Double	PIPE_SLOPE
Manufactur	*No Data*	Text	*not utilized*
LiningMeth	Method of Lining Pipe	Text	*not utilized*
UpstreamIn	Upstream Invert Elevation	Double	PIPE_IELVU
Downstream	Downstream Invert Elevation	Double	PIPE_IELVD
VerticalDa	Vertical Datum, *No Data*	Text	PIPE_VDAT
LI_Date	*Unknown*	Date	*not utilized*
LI_Utility	*Unknown*	Text	*not utilized*
LI_BarrelC	*Unknown*	Text	*not utilized*
LI_BarrelA	*Unknown*	Text	*not utilized*
LI_BarrelE	*Unknown*	Text	*not utilized*
LI_BarrelS	*Unknown*	Text	*not utilized*
LI_BarrelM	*Unknown*	Text	*not utilized*
LI_Barre_1	*Unknown*	Text	*not utilized*
LI_BarrelR	*Unknown*	Text	*not utilized*
LI_Barre_2	*Unknown*	Text	*not utilized*
LI_Dischar	*Unknown*	Text	*not utilized*
LI_Percent	*Unknown*	Text	*not utilized*
LI_RateInv	*Unknown*	Text	*not utilized*
LI_RatePro	*Unknown*	Text	*not utilized*
LI_RateEmb	*Unknown*	Text	*not utilized*
LI_Disch_1	*Unknown*	Text	*not utilized*
LI_Perce_1	*Unknown*	Text	*not utilized*
LI_RateI_1	*Unknown*	Text	*not utilized*
LI_RateP_1	*Unknown*	Text	*not utilized*
LI_RateE_1	*Unknown*	Text	*not utilized*

Raw Attribute Name	Description	Data Type	MGIS Standard Attribute Name
Estimated_	*No Data*	Double	*not utilized*

Pipe Dataset #2– Turbid

pipes – 1 shape

This dataset is from the MnDOT database and includes a single feature.

Raw Attribute Name	Description	Data Type	MGIS Standard Attribute Name
HYD_PIPE_I	MnDOT Pipe ID Name-Number	Long	ORID
HYD_PIPE_N	Pipe ID	Text	*not utilized*
HYD_PIPE_S	Pipe Status	Text	PIPE_STAT
HYD_PIPE_C	Pipe Type	Text	*not utilized*
OWNER_NAME	Pipe Owner Name	Text	PIPE_OWNN
ROUTE_NAME	Road ID	Text	*not utilized*
PERPEN_OFF	Perpendicular Offset	Double	*not utilized*
OFFSET_FRO	Offset Distance	Double	*not utilized*
MMS_STATIO	*No Data*	Text	*not utilized*
LOCAL_NAME	*No Data*	Text	*not utilized*
MMS_ROADWA	Crossing Type (centerline)	Text	*not utilized*
HYD_PIPESH	Pipe Shape	Text	PIPE_SHP
HYD_MATERI	Pipe Material	Text	PIPE_MAT
HYD_CURR_W	Pipe Width	Double	PIPE_CMNT
HYD_CURR_H	Pipe Height	Double	*not utilized*
HYD_PIPE_1	Pipe Shape	Text	*not utilized*
HYD_MATE_1	Pipe Material	Text	*not utilized*
HYD_PIPE_W	Pipe Diameter	Double	PIPE_DIA
HYD_PIPE_H	Pipe Height	Double	PIPE_HT
HYD_PIPE_L	Pipe Length	Double	PIPE_LNG
HYD_UPSTRE	Upstream Size	Long	*not utilized*
HYD_PIPE_T	*No Data*	Text	*not utilized*
HYD_PIPE_2	*No Data*	Text	*not utilized*
HYD_PIPE_3	Pipe Outfall Direction	Text	*not utilized*
HYD_PIPE_4	*No Data*	Text	*not utilized*
HYD_LINER_	Pipe Liner	Long	*not utilized*
COMMENT_ST	*No Data*	Text	*not utilized*
HYD_INV_IN	*No Data*	Text	*not utilized*
MMS_YEAR_T	*No Data*	Double	*not utilized*
MMS_YEAR_1	*No Data*	Long	*not utilized*
HYD_REP_PR	*No Data*	Text	*not utilized*
HYD_REP__1	*No Data*	Text	*not utilized*
HYD_REP_NO	*No Data*	Text	*not utilized*
HYD_REG_NO	*No Data*	Text	*not utilized*
HYD_MS4_AR	Is the pipe located within an MS4 area?	Text	*not utilized*
HYD_OUTFAL	Is the pipe an outfall?	Text	*not utilized*
MMS_SP_NUM	*No Data*	Text	*not utilized*
HYD_YEAR_B	*No Data*	Long	*not utilized*
DATE_ACTIV	Date of Installation	Date	PIPE_IDATE
DATE_RETIR	*No Data*	Date	*not utilized*
MMS_JUR_OW	*No Data*	Text	*not utilized*
MMS_MAINT_	Pipe Maintenance Name	Text	PIPE_MAINN
MMS_CONST_	Pipe Construction Notes	Text	PIPE_CMNT2
COUNTY_NAM	General Location	Text	PIPE_LOC
MMS_STATE_	Ownership Name - Type	Text	PIPE_OWNT
MMS_JUR__1	*No Data*	Text	*not utilized*
MMS_AGREEM	*No Data*	Text	*not utilized*
HYD_UP_ELE	Upstream Pipe Invert Elevation	Double	PIPE_IELVU
HYD_DN_ELE	Downstream Pipe Invert Elevation	Double	PIPE_IELVD
HYD_LONGIT	Longitude Coordinate	Double	*not utilized*
HYD_LATITU	Latitude Coordinate	Double	*not utilized*
HYD_LONG_1	Longitude Coordinate	Double	*not utilized*
HYD_LATI_1	Latitude Coordinate	Double	*not utilized*
HYD_GEOM_L	Geometric Length	Double	*not utilized*
HYD_UP_V_A	*No Data*	Double	*not utilized*
HYD_UP_H_A	*No Data*	Double	*not utilized*

HYD_UP_XY_	Horizontal Accuracy	Text	*not utilized*
HYD_UP_E_1	*No Data*	Text	*not utilized*
HYD_DN_V_A	*No Data*	Double	*not utilized*
HYD_DN_H_A	*No Data*	Double	*not utilized*
HYD_DN_XY_	Horizontal Accuracy	Text	*not utilized*
HYD_DN_E_1	*No Data*	Text	*not utilized*
EXT_ASSET_	Asset ID	Text	*not utilized*
MMS_OFFSET	*No Data*	Text	*not utilized*
MMS_TRAFFI	*No Data*	Text	*not utilized*
USER_UPDAT	Updated in GIS by	Text	*not utilized*
DATE_UPDAT	Date Updated in GIS	Date	*not utilized*
HYD_INSPEC	Inspection Number	Long	*not utilized*
HYD_INSP_T	Pipe Type	Text	*not utilized*
INSP_STATU	*No Data*	Text	*not utilized*
HYD_INSP_S	*No Data*	Text	*not utilized*
HYD_INSP_D	Pipe Inspection Date	Date	PIPE_SDATE
HYD_INSP_N	Inspector Name	Text	*not utilized*
HYD_INSP_C	Pipe Inspection Condition	Text	PIPE_COND
HYD_INSP_M	Inspection Method (Visual)	Text	*not utilized*
HYD_INSP_1	Inspection Type	Text	*not utilized*
HYD_INSP_2	*No Data*	Text	*not utilized*
HYD_INSP_3	*No Data*	Text	*not utilized*
HYD_INSP_R	*No Data*	Text	*not utilized*
HYD_INSP_4	*No Data*	Text	*not utilized*
HYD_INSP_I	*No Data*	Text	*not utilized*
HYD_INSP_A	*No Data*	Text	*not utilized*
HYD_INSP_E	*No Data*	Text	*not utilized*
HYD_INSP_W	*No Data*	Text	*not utilized*
HYD_INSP_P	*No Data*	Text	*not utilized*
HYD_INSP_5	*No Data*	Text	*not utilized*
HYD_INSP_6	*No Data*	Text	*not utilized*
HYD_INSP_7	*No Data*	Text	*not utilized*
HYD_INSP_8	*No Data*	Text	*not utilized*
HYD_INSP_H	*No Data*	Text	*not utilized*
HYD_INSP_9	*No Data*	Text	*not utilized*
HYD_INS_10	*No Data*	Text	*not utilized*
HYD_INS_11	*No Data*	Text	*not utilized*
HYD_INSP_J	*No Data*	Text	*not utilized*
HYD_INS_12	*No Data*	Text	*not utilized*
HYD_INS_13	*No Data*	Text	*not utilized*
HYD_INS_14	*No Data*	Text	*not utilized*
HYD_INS_15	*No Data*	Text	*not utilized*
HYD_INS_16	*No Data*	Text	*not utilized*
HYD_INS_17	*No Data*	Text	*not utilized*
HYD_INS_18	*No Data*	Text	*not utilized*
HYD_INS_19	*No Data*	Text	*not utilized*
HYD_INS_20	*No Data*	Text	*not utilized*
INSP_COMME	*No Data*	Text	*not utilized*
PERIODIC_M	*No Data*	Long	*not utilized*
INSP_USER_	Inspector Name	Text	*not utilized*
INSP_DATE_	Inspection/Condition Date	Date	PIPE_CDATE
CC_ROUTE_N	County/City Route Name	Text	PIPE_RDID
FROM_RP_OF	Horizontal Offset	Text	*not utilized*
HYD_INS_21	*No Data*	Text	*not utilized*
CC_SPATI_1	*No Data*	Double	*not utilized*

APPENDIX B. METROGIS STORMWATER GEODATA TRANSFER STANDARD

Public Comments Received: April 2020 – September 2021

Metro Stormwater Geodata Project

Draft Stormwater Geodata Transfer Standard

Introduction and context. On Friday, April 17, 2020, the first release of the Metro Stormwater Geodata Project (MSWGP) draft Stormwater Geodata Transfer Standard and accompanying materials was published out to the statewide stakeholder community. The publication of the first draft of the standard represented the result of two years of consistent, focus, creativity, attention to detail of the MSWGP Steering Team members.

This material was released to the public with the specific purpose of enabling stakeholders to review the material, assess its relationship and fitness for their stormwater GIS data needs, to test and review a set of sample data and to provide feedback, suggestions, revisions and improvements to the draft data standard for its on-going improvement.

The draft release included the following materials:

- *The draft Stormwater Geodata Transfer Standard (v. 0.5) in both Word and Excel Spreadsheet format;*
- *The draft Inlet, Outlet and Pond Inspection Schema (v. 0.2) in both Word and Excel Spreadsheet format;*
- *A spreadsheet listing the way the draft standard aligned with known asset management needs;*
- *A sample dataset of stormwater system data in the v. 0.5 format for reviewers to download and test;*

These materials were published from the MSWGP's page on the MetroGIS web site which is hosted and maintained by the Metropolitan Council, available here: https://metrogis.org/projects/stormsewers.aspx

Public Review Period 1 (April 2020 – December 2020). Once the initial draft standard was developed and available, it was published for a round of public/stakeholder review. The first review period was intended to be a fixed 90-day period (from April 17, 2020 through mid-July of 2020), however with the impact and changing priorities brought on by the COVID-19 outbreak, the formal public release period was extended out through December 31, 2020.

Public Review Period 2 (July 2021 – September 2021). Once comments were collected from the first public review period, the MSWGP Steering Team convened for an on-line meeting during March 2021 to review these and modify the standard to reflect them. This modified version of the standard was again published for a sixty (60) day review period from July through September 2021.

On-going public input. The MSWGP Steering Team will welcome and continue to accept, review, and document recommendations, input, suggestions, and improvements from the stakeholder community as the standard continues to evolve as it is hopefully utilized by the professional community.

Purpose of this document. This document is an organized collection of the comments received by the stakeholder community during the two public review periods on the draft stormwater standard material. The MSWGP Steering Team has used the comments received input to shape and improve the content and form of the draft standard. The Steering Team membership is grateful to the members of the professional community who took time to download and review the materials and to provide their comments, suggestions, feedback, insights and input. The next version of the standard will be better for their contributions.

Summary of the themes and concepts from the stakeholder input:
Recurring themes and concepts which emerged from the comments received include the following:

- *Addition of a glossary for clearer definitions of stormwater terminology;*
- *Additional of examples of fixtures and features to explain them to GIS professionals who are generally not stormwater experts;*

- *Addition of terms and expansion of values in the domains provided in the draft standard*
- *Future inclusion and integration and inclusion of agricultural drainage systems and data;*
- *Consideration of the ability to accommodate non-structural stormwater elements*
- *Strengthen the ability to accommodate asset management activity with GIS data;*
- *Concern for the costs of data development or transition to using a standard of this type;*

The following pages contain the comments received during the two public stakeholder review periods as conducted by the MSWGP Steering Team. These comments have already been incorporated into the current draft (v. 0.6) of the proposed standard.

Molly Churchich
Ramsey County Public Works

<u>In the Draft Inspections Schemas v. 0.2 document on page 16:</u>
You could ***better define <u>outlet versus outfall</u>*****.** County outfalls are non-traditionally defined because outlet could leave a system but technically be defined as an outfall due to agreement ownership. Generally, Ramsey County owns the catch basin and leads of the storm sewer while the cities and township own the storm mains and manholes. Outfalls outside county right-of-way are the responsibility of the city and outfalls inside the county right-of-way are the responsibility of the county, unless explicitly stated in the agreement. Depending on the project, ponds and associated elements are assigned to different parties.

<u>In the Draft Inspections Schemas v. 0.2 document on page 40:</u>
Pond inspection does not have fields for ***capacity gauging and sediment sampling results*****.**

<u>In the Draft Stormwater Geodata Standard, v.0.5 document on page 17:</u>
Could there be ***multiple fields for pipe maintenance agreements***?
We often have multiple agreements for multi-partner projects.

<u>In the Draft Stormwater Geodata Standard, v.0.5 document on page 25</u>
Do people use the CTU ID TXT field? We've always identified the County Road Number associated with the road.

<u>In the Draft Stormwater Geodata Standard, v.0.5 document on page 99</u>
We won't use outlet tide chambers; this does not apply to our infrastructure.

<u>In the Stormwater Geodata Standard v. 0.5 Domains:</u>
Pipe diameters: are the units of ***pipe diameter in inches or feet?***

Currently, Ramsey County has the following storm sewer infrastructure inventoried:

INFILTRATION BASINS

Types:	Biofiltration basin	Filtration basin
	Filtration trench	Infiltration basin
	Infiltration trench	Other
	Permeable pavement	Stormwater reuse
	Tree trench (Subtypes: CCLRT Type 1; CCLRT Type 2; None)	

TREE TRENCH
Types: *(types and subtypes are linked in* **INFILTRATION BASINS***)*

OUTFALLS

Types:	Pipe	Ditch
	Lake	Pond
	Wetland	Channel
	Curbcut	Culvert
	Other	

STORM INLETS

Types:	Catch basin	Manhole
	Catch basin manhole	

SPECIAL STRUCTURES

Types:	Access manhole	Berm
	Berm weir	Bit_channel
	Box culvert	Channel
	Control manhole	Dam
	Deep manhole	Diversion box
	Diversion manhole	Diversion MH *(duplicate of diversion manhole?)*
	Diversion weir	Drop inlet
	Drop structure	Energy dissipater
	First flush diversion	Flapgate
	Floatable skimmer	Flume
	Gabions	Headwall
	Inlet manhole	Junction manhole
	Keepfill line	Land bridge
	Lined channel	Lock_dam
	Manhole	Multi-outfall MH
	Ob_well	Other
	Outfall baffle	Outlet control
	Pump	Riprap still basin
	Riprap channel	Sediment sump
	Siphon	Splitter manhole
	Stabil_mat	Stilling well
	Sump	Timber weir
	Trash weir	Triangular weir
	Turtle barrier	Ultra urban
	Valve vault	Weir

OUTLETS

Types:	Assess	Emergency overflow
	Primary	Secondary
	Compound	Concrete pipe
	Culvert	Horiz. Pipe
	Horizontal pipe	Lift station
	Pipe	Riprap berm
	Submerged outlet	Submerged pipe
	Trash rack	Vert pipe
	Vertical pipe	Weir
	Weir orifice	Weir_channel

Subtypes:	Berm
	Berm riprap
	Channel
	?

AERATORS LIFTSTATIONS PUMPS

Types:	Aerator	Compressor
	Control panel	Keepfill pipe
	Lift station	Obs well
	Pump	Well

We have some cleaning up to do of the locally stored data, but the intention is to get it all migrated to the network and available to others. The main constraint preventing this is time- it's incredibly time consuming to go through each of these features.

Where would Tree Trenches fall in the standard? We currently are symbolizing them with both a point and line feature. If they are incorporated in the ***line feature of Pipes*** in the standard, their subtype would be slotted, as this best describes their composition. But as Mike Goodnature pointed out, ***they are technically a BMP***, so perhaps would be suited for the Best Management Practice category.

The problem with identifying them as a point feature, is that placing the point midline of the feature is deceiving. Some of these trenches exceed 500 feet and I want to make sure inspectors inspect the entire facility. I'm concerned about placing the Tree Trench inventory into a database, such as pipes, because it would get lost in the inspection schedule.

Pipes are not mandated to be inspected on any regularity but are required to be mapped. Tree trenches are required to be inspected annually per the MS4 permit guidelines.

Ramsey County are in the process of consolidating condition ratings for all of its stormwater assets. Previously, we had used both text and numeric ratings for stormwater outfalls and inlets. Our new proposed rating scale is numeric 5-1 and U for unknown.

5 New
4 Good
3 Fair
2 Poor
1 Extremely Poor/Replace
U Unknown

The County's system is opposite of how the MSWGP rates conditions, as theirs generally follows MnDOT's scale. I didn't see any other comments of condition rating on the public comment period results. I just wanted to mention it if others use a different condition scale.

Lanya Ross
Metropolitan Council - Water Supply Planning

Overall, I was reviewing the document to see how the resulting data could be useful to help in groundwater modeling or other analyses of infiltration/recharge. I saw what I needed; whether this can be implemented remains to be seen, but I appreciate the goal of attempting this.

In the Draft Stormwater Geodata Standard, v.0.5 document on page 27:
Why is there no elevation data for the channels?

In the Draft Stormwater Geodata Standard, v.0.5 document on page 69:
How is the example provided in the Pollution Control Structure Type different than that provided in the Hydraulic Control Structure description?

In the Draft Stormwater Geodata Standard, v.0.5 document on page 100
How would you describe the Outlet Type for an underground structure, as an example?

In the Draft Stormwater Geodata Standard, v.0.5 document on page 101
In the Outlet Height or Mean Depth, does height refer to elevation or length?

In the Draft Stormwater Geodata Standard, v.0.5 document on page 138
Does the definition of structure include landscaped areas (For example: land graded in a way to capture water, even if no physical, constructed structure is present)? I assume so, but not entirely clear.

In the Draft Stormwater Geodata Standard, v.0.5 document on page 139
Some elevation data for BMPs could be useful to support modeling (defining head and flow)

Devon Savage
Swift County

We perform GIS work for Swift County in west central Minnesota, giving a more rural perspective to this project. Being a large farming community, our area has many drainage ditch systems that include open ditches and tile lines to move water. **Is it the intent of the standard to place ditches and tile lines into the "channels" and "pipes" layers?**

Would private ditches, tile, and lift station information be beneficial to collect? We only have the systems maintained by the county and the open ditches and tile lines are together in one layer. I think this project will be helpful for rural areas by **gaining access to the culvert and drainage data that the DNR/BWSR possess** since we have some systems that are on or near protected land. Having the ability to access a vast amount of drainage information in one location would be valuable when working with those entities on projects as well.

Duane Anderson
City of Woodbury

Like many in this business, we think it's a good idea to **document date/time-oriented information on our assets** whether they're related to Stormwater, Sanitary Sewer, or Water Main.

Unfortunately, that sets one up to either continually add date/time fields to accommodate the latest event, or one accepts that the only date/time information available is the last event. When the City of Woodbury opted to go with Beehive as its asset management package, we ran headlong into this concept and have since "come to Jesus" on **the more flexible concept of 'top level events,' i.e. a related table to accommodate events.**

Ben West
City of Inver Grove Heights

Over the last three years the City of Inver Grove Heights GIS Team has conducted a comprehensive database restructure – with a focus on key City infrastructure (Water, Storm, Sanitary). This was done with key contributions from our Engineering department, Public Works, and the help of an outside consultant (Bolton and Menk). This restructure focused on what our City staff view as key components to the different City assets while also **trying to improve: structure, logical groupings of assets, and overall completeness of data stored** (both adding fields and removing vestigial fields).

The type of guidance from a document such as the Stormwater Data Standard would have been an invaluable tool to use in that process and would have saved the City significant time (and money) in the reorganization of our GIS infrastructure. If nothing else, it would have served to provide helpful way posts to help guide internal discussions on the topic.

In part because we have so recently undergone our own data reorganization, in addition to providing feedback to MetroGIS, we as a City wanted to compare our data choices to the proposed recommendations found within the Stormwater Data Standard – and provide comments where possible. This process was done with our GIS staff and a Senior Engineering Technician – all who were the primary participants in the City's data reorganization.

P_BASN.6 – Basin Name
Have this **differentiated between dry or wet** depending the majority seasonal type of wet most of the time or dry most of the time. It might make sense to not include culvert here or rename it as something else;

P_BASN.10 – Basin Design Volume
Does this encapsulate the live or the dead volume? Our engineers have defined this as an important differentiation and asked that both be included in our information.

P_BASN.12 – Basin Design Flood Stage Elevation
Is this the critical water level? You already have the overflow elevation defined, so this is something different? There are almost too many different terms being used in storm water for the same thing. It would be helpful to have this defined with qualifiers, i.e. Elevation resulting from a 100 Year Storm or elevation resulting from back to back 100-year storms.

P_BASN.29 – Basin Maintenance Agreement Number
Type of maintenance agreement is more important to us than the actual maintenance agreement number.

Note: *Discuss adding a field for Basin Maintenance Agreement Type and establishing a set of domains for agreement types;*

P_BASN.40 – Basin Date Data Modified

When we've redone the schema for features, we have found it's easier to keep the standard ESRI naming conventions rather than creating a new one. However, I realize not every participating entity is using ESRI.

Additional values/attributes to consider adding or making use of:

- Dry/Wet Pond
- Low Floor Elevation
- Natural Overflow Elevation
- Drain Tile Present (Y/N)
- Landlocked basin (Y/N)
- DNR Pond (Y/N)

L_PIPE.12 – Pipe Depth

Where on the pipe are you going to measure this?
If the pipe is 15 feet below surface on one end and 6 feet below surface on the other which value is entered?

Note: *Discuss renaming as 'average depth of pipe' or establishing depth at the beginning/end of pipe. (More specifics are needed)*

L_PIPE.12 – Pipe Depth

This will have to be field determined and would not be useful for maintenance at the city level.

L_PIPE.22 – Pipe General Location

Too difficult to enter in Lat and Long for a line to make that useful. Too much inconsistency with what address would be used across length of pipe.

L_PIPE.30 – Pipe Condition

*Mislabeled, should be **L_PIPE.29***

Additional pipe attributes to consider:

- Seepage collar (Y/N)
- Restrained (Y/N)

Channels:

Our channel/overland flow feature class was not part of our major redesign of features (this is a comparatively minor component of our storm water system). However, it does need to be revised and we will be leaning heavily on the MetroGIS final standard to rebuild the schema for this feature class.

Artificial Path:

We do not currently have Artificial Paths, but this is something we are highly interested in as a City and will be leaning heavily on the MetroGIS final standard to build the schema for this feature class.

Artificial Point:

We do not currently have Artificial Points, but this is something we are highly interested in as a City and will be leaning heavily on the MetroGIS final standard to build the schema for this feature class.

Additional BMP, Hydraulic Control and Pollution Control attributes to consider

- High water elevation – High water elevation the structure controls to
- Normal water elevation – Normal water elevation the structure controls to
- Sump (Y/N) – Sump present in the structure (very valuable to know this!)
- Sump Depth – Depth of sump
- Control structure both: fixture could be both a hydraulic and pollution control fixture
- Value (Y/N) – Valve present in the structure
- Weir (Y/N) – Weir present in the structure
- Weir High Water – What is the high-water level of the weir
- Weir Low Water – What is the low-water level of the weir

P_IN.3 through P_IN12

We understand separating yes/no for all the 3-12 field options, however, we as a management entity, would still find it valuable to retain a "type" field;

P_OUT.10 – Outlet Type

Would prefer to have flapgate, ditch underground in the Type field

Additional P_OUT attributes to consider

- Apron Material (Material of apron)
- Riser (Y/N)
- Submerged (Y/N)
- Trash Guard (Y/N)
- Erosion Control Method *(Denotes what type of erosion control method (if any) has been installed with the outlet: e.g. riprap or cabled concrete.)*
- System Flow *(Potential to maintain all of our aprons in one Feature Class and then designate in a field if those aprons are inlets or outlets)*

P_MH.6 – Manhole Control
We place these in the control structure Feature Class. No matter if they're a manhole or something else. We don't see value in having it in our system twice.

P_MH.7 – Manhole Trap
We place these in the Pollution Control structures Feature Class. No matter if they're a manhole or something else. We don't see value in having it in our system twice;

P_MH.8 – Manhole Split
We would place these in the control structure Feature Class. No matter if they're a manhole or something else. We don't see value in having it in our system twice;

P_MH.40 – Manhole Ownership Name
Ensure "Private" in included in this Ownership field

Additional Manhole attributes to consider:

- Manhole type (establish a domain of values)
- Manhole diameter (diameter of manhole)
- Restrained cover (Y/N)
- In Street (denotes if manhole is in the street or not)

P_LS.3 – Lift Station Type
Maintain a LS type called "Emergency Lift Station" for temporary/emergency pumping stations

Additional Lift Station attributes to consider

- High alarm level (level where alarm sounds)
- Low alarm level (level where alarm sounds)
- Wet well diameter
- Pump gallons per minute
- Total dynamic head of the lift station
- Emergency pump station suction size
- Emergency pump station discharge size
- Generator back up present (Y/N)

BMPs:
We will not have a separate BMP feature class; we view this term (BMP) as being too nebulous as it too broadly encompasses features. Technically the pollution control structures are BMPs, Hydraulic Control Structures are BMPs, as well as encompassing education or other outreach or training to the public or staff. Internally, as a whole we find the term BMP to be poorly understood despite years of recurring education within the City.

Our path forward as a city is going to be encompassing these features within the specific structures/assets they most closely resemble - most notable including a dry ponds field within our Ponds Feature Class - or Basins as referred to in this document).

We also view the area for many of these features as being just as important as the location – i.e. we want to know the total square footage of permeable pavement in the City.

When viewing asset data, we as a City, prefer to view the associated data on the polygon and will move forward with that as our standard. Any points needed will be solely artificial points instead of as a BMP or Basin as point - we would consider adding a more comprehensive list of point types within the artificial points feature class for clarity; but want to avoid duplication of data as much as possible.

Monitoring Components

We do not currently have any representative assets of this feature type.
We would consider this standard monitor format if the City ever acquired any of this asset type.

Jon Røstum
Chief Strategist, Powel Environment, Oslo, Norway

In Norway we have worked on a related project on documentation tool of nature-based storm water solutions as a part of a national research program in Norway. I am especially interested in how far you have come ***to develop a standard for documentation and asset management of different blue-, green- and grey-stormwater solutions such as green roofs, swales and infiltration systems.***

Kim Soulliere
City of Golden, Colorado
Did your group discuss MS4 requirements such as the ***number of BMPs and which construction site they serve?*** We are having trouble modeling the issue of one BMP serving several sites, causing a one-to-many relationship. Another piece we are challenged by is the one-to-many in translating the GIS model to Cartegraph where data collection takes place.

Kellie Thom
Minnesota Department of Transportation

- Pipe Width – should be the interior width;
- Pipe Equivalent Diameter – should match MnDOT specs;
- Pipe Length – Add disclaimer that entities might measure length differently (including or not including end sections);
- Pipe Condition – I asked that the inspection information not be included as we all inspect our features differently;
- Pipe Consequence of Failure Rating, Probability of Failure rating, Pipe Criticality to the system – These should not be included in the standard as how do we measure;
- Channels – open flume would be our most similar but not something we'd typically collect unless it was constructed. Most cities have a network of both designed and natural features which they depict how everything works together. I do not have enough experience to comment;
- Artificial Paths – Again used to create a water flow network by most cities but not something we use so cannot comment on;
- Basin Components – these include both our ponds and basins. Again, same comments about condition and failure rating and criticality;

- Hydraulic control Structures - same comments about condition and failure rating and criticality;

- Pollution Control Structures – The types were hard to pin down and I think need to be re-visited. Again, same comments about condition and failure rating and criticality;

- Artificial Points – Not something we use and cannot comment on;

- Inlets and Outlets – MnDOT does it by type not if it is an inlet or outlet like most cities and counties do. This will be the hardest for us to get our data into for sharing as it is something we do not check. For end sections we do have upstream and downstream but for structures it will be hard. Same comments about condition and failure rating and criticality;

- Manhole – this is another difference between us and others. Manholes are not inlets or outlets so would be separated out. Same comments about condition and failure rating and criticality;

- Lift Stations – These currently fall under special features for MnDOT and would not be able to fill out most of the information that is asked for. Same comments about condition and failure rating and criticality;

- Best Management Components – To me this is a repeat of the basins for some and we would not be using this;

- Monitoring – We do not collect this information so cannot comment;

- Basins – polygons – same comments as before;

- BMP – polygons – same comments as before;

Lisa Sayler
Minnesota Department of Transportation
Hydraulic Engineering

Thank you for the opportunity to review the standard. A lot of thought and effort have been put into it. The documentation is well done for adding clarify to the standard and having the sample data set is very helpful for starting to understand how the data works together.

As with any collaborative product, there will be parts of the standard that MnDOT will be able to meet for transferring data to other agencies, and other parts of the standard will be infeasible for MnDOT provide data. I've included some specific comments and suggestions in the attached document.

My primary concern overall is that regulatory agencies may have the expectation that MnDOT will have data in this format to transfer and there will be an expectation that the owner does have this data for the data attribute fields listed available. The documentation is very careful to repeat multiple times that this is a data transfer standard and not a requirement for individual agencies, but if this is adopted as a statewide standard, regulatory agencies may choose to require.

Another concern is the potential cost to develop data conversion tools so that we can convert our data to transfer. I think it would be helpful to address data conversion in the discussion, especially if there may be any tools or resources planned to be available. At a minimum, this discussion may be helpful for us to lobby within the agency to commit resources to develop the conversion tools.

Overall Concerns with the Standard

Mandatory vs Optional/Available:

We have concerns on potential impacts of adoption of this as a statewide data standard. The documentation is very careful to repeat multiple times that this is a data transfer standard and not a requirement for individual agencies. The data definitions are clear on what data is mandatory vs. not. However, once adopted there may be agencies that we work with or get permits from that try to require some of the parts of the standard that it may be difficult and costly for MnDOT to conform to.

The data field included in the standard are extensive and it is unlikely that MnDOT would either have all of them or be able to fully populate them. Also, because of the attribute definitions/domains, there will not be a direct conversion for some of the data that MnDOT does collect.

Data Conversion Costs

MnDOT has an "in place" database for storm drain features and inspections that it has been using for over 20 years. It will take resources and expertise from MnDOT beyond what our unit has available to develop the necessary "cross-walk" and processes to transfer are data into this standard (if requested) and to be able to use other agencies data. There will be some data fields where it may not be able to transfer data because definitions/schema don't match exactly.

I recommend some content be added to the Overview, Context and FAQ section on what resources may be necessary to export/import data from the standard and if there are/will be any tools developed. If potential grant money becomes available as suggested in EQP State Water Plan, would be nice if could be directed to conversion development as well as data digitization as suggested.

Inlet, Outlet, Pond Inspection Schemas

I have concerns about including the inspection schema as part of an overall package for a standard. This would be very difficult to use as a transfer standard because of the different ways that agencies describe potential condition/problems. A lot of inspection data that MnDOT collects could not be transferred because we use Yes/No flag ratings that don't transfer to the domains in the standard.

With regards to adopting this as the data standard, MnDOT already has an inspection schema that does not match this, and it would require a lot of time, training and expense to change as well as making historical data much less useful. If this is approved as a standard, then there may be requirements and expectations on the part of other regulatory agencies that everyone they regulate must provide data in this format.

If this is intended to be used as a data transfer standard as well as an inspection data collection standard, need to plan for data fields where agency does not collect and store data by have null or unknown as options.

- Recommend against including a suggested condition rating – many agencies may have their own or be using PACP – difficult to translate between rating codes and gets confusing since may have different scheme for numbers;

- As applicable, domains/attribute fields should be options for None and Unknown. If this is used to transfer data, agency may not have collected that data, or may not have collected it in a way to allow transfer;

- What should be input for rainfall amounts if unknown – field should not default to zero, null should be allowed

Stormwater Standard - Components

Component Overlap – multiple records for individual features required?

Is it intended that an agency's stormwater feature needs to have a record for each component type that it might be part of? It is common that stormwater ponds and infiltration features will be both basins and BMPs. Less common but possible is that an inlet may have a sump/SAFL baffle and so also be a pollution control structure. If an agency only tracks these as one type of feature, do they needed to be included in both data sets, or is this only for when the data owner tracks them separately (appears in sample data set there are different IDs when a pond vs a BMP). Recommend more explanation on how to include where matches multiple component definitions.

Component Definitions

I think it would be helpful to add some more discussion on what defines whether a feature is a BMP vs a Pollution Control Structure. I think the domain list is helpful, but it would also be helpful to have a descriptive comparison. I also think it would be helpful to go into more detail in this overall description of components of where different types of underground detention/retention/filtration structures fit into rather than making people search through the domains.

Are stormwater tunnels pipes? If so, recommend that tunnel be added as a pipe type. Otherwise, need to define how/where they are included. Also, would be helpful to address in general component definition at beginning of documentation.

Component types common data

Federated ID – Not sure how this ensures a unique ID if only prefix only based on location/CTU where located. Other agencies/entities will be supplying data and have their own way of naming but could have a convention – such as just a number – which matches another agency with features within same CTU unit. Unlikely but possible that MnDOT *feature*_ORID will match a local agency *feature*_ORID for different features when they are in the same jurisdiction.

Ownership Name/Maintenance Authority Name

AgencyOwnName domain should include MnDOT/Minnesota Department of Transportation rather than lumping in with State of Minnesota, seems likely that there are other state agencies that also own or are responsible for maintenance of stormwater features that should be included specifically. Some of the sample data uses MnDOT for attribute data that standard shows used AgencyOwnName.

Data Producer/Source Name is listed as attribute name twice for each component. One based on using AgencyOwnName and the other a text field without domain. Having the same attribute name is confusing and the definitions are not real clear as to what is the difference between the two fields.

Consequences of Failure, Probability of Failure and Criticality to the System. The rating domain for these fields is very subjective and not well defined. Will be difficult for those that do rate these attributes to be able to combine data from other agencies that may use a different definition.

Pipe Components Field Definitions

Pipe Diameter – what is expectation if the fixture is not circular – null, 0?

Pipe Equivalent – in order to get consistency, recommend more precise definition. Suggest following MnDOT standard plates since many agencies use. MnDOT standard plate definition for equivalent diameter (if that is intention) as: EQUIVALENT DIAMETER EQUALS DIAMETER OF CIRCULAR PIPE WITH APPROXIMATELY EQUIVALENT CROSS-SECTION AREA. Figure 1 definition for Pipe Equivalent Diameter is what MnDOT Standard Plates call out as Span.
Why is ***pipe height*** the inside, and ***pipe width*** the outside? More consistent to see both as inside dimension and then add pipe thickness as attribute. For utility conflict, probably want to be able to get both outside width/height. For hydraulic modelling, want to be able to get shape, inside width, inside height in order to figure out hydraulic properties.

Pipe Type – because domain values so specific, may lose some data in transfer. For instance, we may not always know if drain tile is perforated or not because may be lumped together. Given the list of attribute values, would need to transfer as other type. I don't know if this is national standard or not but may have been better to have perforated as own attribute field where values are perforated, nonperforated or unknown.

Pipe_Mat domain should consider additional value and/or more description. Most **Corrugated Metal** pipe used is **Galvanized** – which is preferred? For asset management purposes, important to know if metal pipe has Aluminized or Polymeric Coatings.

Vertical accuracy value included for structures but not for pipes – this seems inconsistent.

Basin Components Field Definitions

Basin Type – confusing to include Culvert (centroid) as a basin type. A general definition of a culvert is an open-ended pipe that conveys water from one side of an embankment to another. Is this meant to be used for underground storage consisting of pipe segments?

Hydraulic Structure Components Field Definitions

Hydraulic Control Structure Type – not clear why Deck Drain listed under HCS when it also a data field in inlets. Confusing to me, needs for description to understand when a deck drain is a HCS and is it either an inlet or HCS, or is it both. With Detention and Retention tanks listed as HCS, does this mean underground storage? If so, would be helpful to include that in the overall description.

Pollution Control Structure Components Field Definitions

Pollution Control Structure Type – Definition includes example types and description for hydraulic control structure

Outlet Components Field Definitions

Outlet Type: Since outlet type includes culvert, is it expectation that there will be an outlet created for every culvert?

John Gulliver, Ph. D, PE
Department of Civil, Environmentla and Geo-Engineering
University of Minnesota

I have some comments on the draft standard allocation of BMPs, and your question to the users about whether they should be listed as points, lines or polygons:

Here are the practices that I feel should be a line:

- bioretention-rain garden (most of the time)
- filtration bench/shelf (no underdrain)
- filtration bench/shelf (with underdrain)
- filtration swale (no underdrain)
- filtration swale/shelf (with underdrain)
- infiltration trench,
- tree box,
- permeable pavement road
- planter
- porous paver road
- porous concrete road

Here are the practices that I feel should be a polygon:

- amended-composted soils
- dry pond
- filtration basin (no underdrain)
- filtration basin (with underdrain)
- green roof
- iron enhanced filter
- infiltration basin
- sand filter
- stormwater pond/wet pond
- offline basin
- permeable pavement parking lot
- porous paver parking lot
- porous concrete parking lot

APPENDIX C – MODEL BUILD TECHNICAL REPORT

2D Pilot Model Build

Model Build Report

Prepared by:

Kimley-Horn

Prepared for:

MINNEHAHA CREEK
WATERSHED DISTRICT
QUALITY OF WATER, QUALITY OF LIFE

Date:

April 2023

Kimley»Horn

Kimley»Horn

Table of Contents

LIST OF FIGURES

Document History

Date	Version	Description of Change
December 2022	1.0	Initial Draft
January 2023	2.0	Revised Draft
February 2023	3.0	Revised Draft
April 2023	4.0	Revised Draft
April 2023	FinalClean	Revised-Final with MCWD final comments addressed

Definitions

- ArcGIS – a desktop and cloud solution provided by Esri for GIS analysis, storage, data management, and data processing
- DEM – Digital Elevation Model, represents ground surface in a grid (raster) format. Elevations are assigned to each individual grid cell
- GIS – Geographic Information System
- ICM – InfoWorks ICM software package developed by Innovyze to perform 1D and 2D hydrologic/hydraulic simulation modeling
- ICPR – Interconnected Channel and Pond Routing (ICPR) software package version 4 developed by Streamline Technologies to perform 1D and 2D hydrologic/hydraulic simulation modeling
- MetroGIS (MGIS) – a GIS format designed for use by Twin Cities Metropolitan-area municipalities for the standardization of infrastructure data
- Geodatabase (GDB) – GIS file and data format that allows for standardization and template creation
- File Storage – cloud or physical file storage location utilized as a central repository for raw, input, and output datasets
- Shapefile – Spatial data file format that includes attribute data for individual shapes. May be in a point, line, polygon format and includes the file extension ".shp".
- Simulation – Collection of input parameters from various hydrologic and hydraulic processes as well as tolerances that culminate in the calculation of the flow of water over a defined period.
- Scenario – Situation that incorporates changes to the input parameters that represents a real-world condition.
- Lidar – Light Detection and Ranging. A portion of the remote sensing information that is gathered via aerial methods that includes numerous points of data that can be classified into types for ground elevation modeling.
- Master database (ICM) – File extension .icmm that includes all model information.
- Model group(s) (ICM) – Individual file/object folders within a master database that contain objects
- Refinement Elements – Breakpoints and Breaklines that are used to refine the 2D mesh

1 INTRODUCTION

The Minnehaha Creek Watershed District's (MCWD) current modeling tools are outdated and do not provide the required granularity and features necessary for the District to effectively characterize and quantify the impacts of climate change.. Therefore, District staff identified the need to develop a new modeling tool that has greater granularity that can better evaluate a range of scenarios towards informing decisions relating to climate adaptation strategies, programmatic policies, and specific projects. MCWD began the process to select a better tool/model by completing a cursory assessment of the full range of two-dimension modeling software systems currently available. This screening-level assessment, along with vendor information sessions and consultation with agency experts, led the District to narrow their focus to ICPR and ICM. Both were selected to be built within two distinct subwatershed areas (parts of City of Victoria and City of Edina) for the pilot model build analysis, giving the District an opportunity to comprehensively compare the two software packages. The District chose to pursue a pilot model build, ahead of the full watershed-wide build, to mitigate for the relational and technical risk that is often associated with large-scale, high-resolution models, such as selecting the right software for the intended use.

This memorandum provides an overview of input datasets, model build process, and challenges that were uncovered during the model build process for each software package. The information gathered during this portion of the project will be critical to the understanding of the benefits and challenges each modeling platform presents and ultimately for selection of a future watershed-wide modeling platform. Upon selection of a modeling platform, this information will also inform future implementation of the watershed-wide model build.

The specific model version used for this pilot model process were:

- ICM version 2023.2.0 with an unlimited license; and
- ICPR version 4.07.08 with an expert license.

2 MODEL INPUT DATASETS

The following subsections are formatted in the following way: Background Information, ICM import and defaults, ICPR4 import and defaults, and takeaways. Additionally, both software packages allow for user creation of new features directly within the software using the hand delineation tools and user inputs of parameter data.

2.1 Data Import Processes

2.1.1 ICM

ICM allows for import of data using one of three pathways depending on data type and desired use within the software. The main pathway utilizes the Open Data Import Centre (ODIC). The ODIC allows for import of data in the following formats: MapInfo TAB, GeoPlan Layer, CSV, Tab Separated Data, Access Database, Oracle, SQL Server, Raw Shape File, and XML. The ODIC allows for configuration files to be saved and loaded to set the import fields and default values. The ODIC also allows for import of spatial and lookup table data. Figure 1 shows the ODIC dialog box, the various inputs, and settings that can be applied to the input. The MGIS data was imported through the ODIC by individual file specification along with the appropriate configuration file for each data type.

The second data import pathway is utilized for import of the Digital Elevation Model (DEM). The DEM is imported directly into a Model Group as a Ground Model grid InfoWorks object. The ground model grid import allows for specification of horizontal and vertical unit type (feet, meter), cell size, and clipping boundary. Other unique spatial objects or simulation controls can also be directly imported into a model group. Appropriately defining the model groups within each master folder allows for consistency with model updates and efficiency when reviewing results. Model groups can hold a single data type or multiple data types depending on the folder structure that is required. For the pilot model build, master groups for Edina and Turbid-Lundsten subwatersheds were created with model group folders in each to hold to respective model data types and entries. Model group data can be referenced from outside of the master group during simulation runs (e.g., Edina rainfall data can be referenced into a Turbid-Lundsten simulation run).

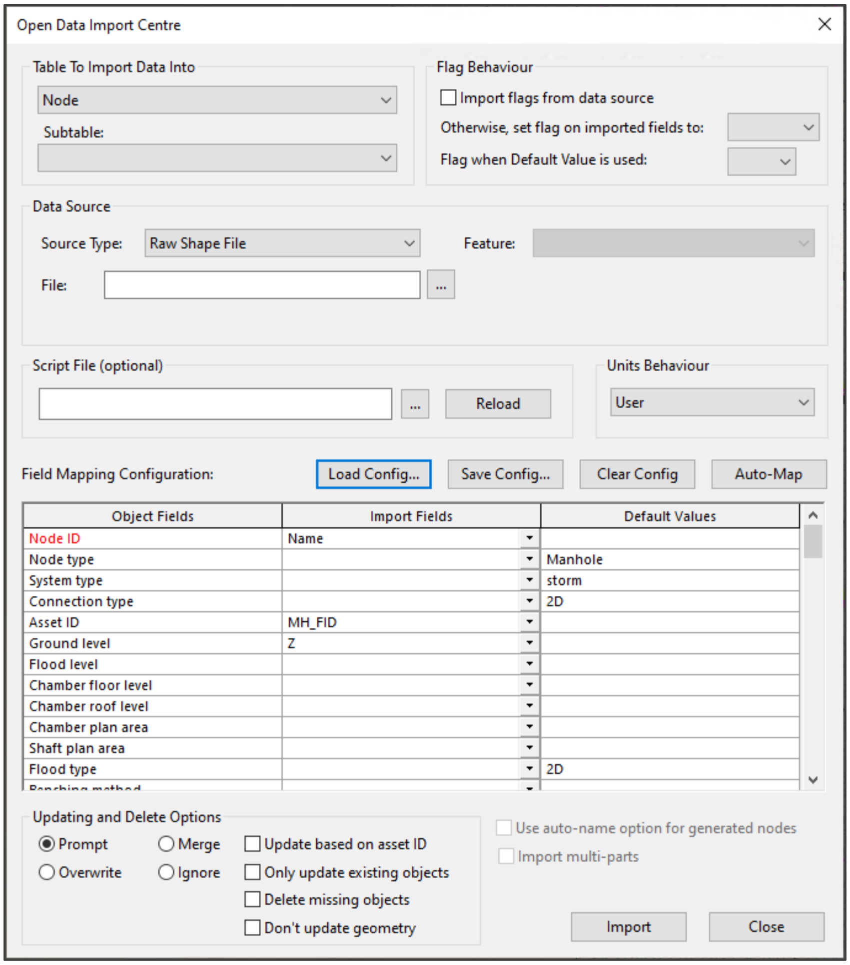


Figure 1. Open Data Import Centre Dialog Box

The third data import pathway is utilized for referencing outside data through the GIS Layer control manager. The GIS Layer control allows for the import of background reference files, aerial imagery, and any other desired shapefile import. The raw shapefiles can be in a different projection than the model, but it is recommended that they are the same projection for faster processing and viewing speeds. Shapefiles that are loaded in through the GIS layer control can be selected and attribute fields displayed directly within ICM for reference. The GIS layer control is used to view data and not to be included within the model simulation calculations. This can be helpful to reference in different background aerial imagery layers, verification of shapefile import, and result analysis based upon highlighted areas.

2.1.2 ICPR

ICPR allows for the importing of data from two primary sources and accepts multiple formats. The primary method of importing data is through the menu tab, using CSV files in the GWIS format. Data can also be imported from the data tree in graphic view, data can be imported using CSV files or shapefiles. It is important to note that any data imported using shapefiles will only include the element shape, placement, name, and upstream/downstream connections (if relevant). Importing pipe network data through shapefiles will result in the pipes missing invert, size, material, length, and loss coefficient data. This data would then have to be entered manually.

ICPR does not allow manual mapping of data fields from imported files. All data fields need to be named in the ICPR standard GWIS format before importing the data. Data was imported into the model using CSV files produced from the MGIS data for all 1D hydraulic elements including junctions, pipes, and outfalls. The model boundary, soils, and LULC data were imported using shape files. The DEM was imported from a raster.

2.2 Surface Datasets

2.2.1 Model Boundary

The model boundary files for the subwatersheds were supplied in layer format within a geodatabase. The layers were exported to individual shapefiles. The shapefiles did not have additional attribute data. ICM designates the 2D mesh and flow area as a 2D Zone and ICPR designates them as an Overland Flow Region.

ICM uses the model boundary for the 2D Zone input and assigns a vertical wall type to the boundary by default. The vertical wall does not allow water to leave the 2D Zone anywhere. The boundary type can be set to vertical wall, critical condition, supercritical condition, dry, or normal condition. The selected boundary type applies to the entirety of the boundary. The 2D Zone condition can be changed by using 2D boundary objects along a section of the 2D Zone boundary. The 2D Zone boundary can be adjusted within an individual scenario in ICM.

ICPR uses the model boundary for the overland flow region and takes a shapefile as an input. ICPR treats the model boundary as a vertical wall. The model boundary for ICPR was simplified and expanded to encompass a larger area. The simplified boundary was used to reduce the small mesh elements along the boundary of the model area. The expanded area was used to allow the groundwater flow to transition in and out of the original model area. The model boundary cannot be adjusted to incorporate different edge conditions without the additional incorporation of boundary stage lines or boundary stage points as discussed in Section 2.5.3.2.

The model boundary is slightly more flexible in ICM with the ability to assign different boundary conditions directly within the model boundary parameters where ICPR requires additional 2D features be created to vary the overland flow region boundary condition. Both models allow for the model boundary condition to be varied across its length using boundary stage lines and/or boundary stage points. The boundary stage lines can be applied to a particular portion of the model boundary and the boundary condition can be varied depending on the desired simulation scenario. It is recommended that model boundaries contain as few vertices as possible to represent the outline of the desired area. Vertices and shapefiles can be simplified by the user within GIS through manual and automated processes. This reduces mesh building and triangulation errors that can occur when multiple boundary points are spaced closed together.

2.2.2 Digital Elevation Model (DEM)

The digital elevation model (DEM) was built from MnTOPO lidar data collected in 2010 and 2011. The lidar data was collected using the UTM Zone 15 horizontal datum and the NAVD88 vertical datum. The horizontal and vertical units are in meters. The mean post (lidar point) spacing for the lidar collected was set at a maximum of 1.5 meters (4.92 feet). The lidar was resampled into a raster format for import to the models. The raster cell spacing was set at 0.5 meters (1.64 feet) for the import. For comparison, three cell spacing scenarios were developed to demonstrate future storage needs. The smaller the cell size, the greater the number of cells to cover an area. Assuming a total watershed area of 178 square miles and a 0.5-meter cell spacing, the overall DEM file would include approximately 6 billion cells. Generally, there is an inverse squared relationship between cell spacing and number of cells (e.g. reduction in cell spacing by ½ equates to a 4-fold increase in number of cells). The DEM raster cell size cannot be varied across the model area. Data presented in Table 1 illustrates how the cell spacing relates to the file size and number of cells for the surface in the Edina subwatershed model.

Table 1. DEM Cell Spacing vs. File Size vs Number of Cells

Cell Spacing (meters)	File Size (KB)	Number of Cells (million)
0.5	94,857	32.8
1.0	22,229	8.2
2.0	6,363	2.0

It is important to note that the 2D mesh grid is set to a lower resolution than the underlying DEM, the methodology for the mesh grid is discussed further in Section 2.5.2. The limiting factors in reducing the DEM resolution are the corresponding increase in required storage space, the resulting slowness during viewing a larger raster file in GIS and in the modeling software packages, and significantly increased simulation run times. There is also a diminishing return due to the 2D grid methodology used by both software packages to set the grid element elevations.

ICM imports the DEM as a ground model grid. There is a second option to import a ground model tin format instead. The ground model grid import allows the user to set a name, units for ground elevation and x,y coordinates, base cell size, and clipping the import to a polygon. Multiple ground model grids can be imported to a single master database. An individual ground model can be added and viewed in a single or multiple GeoPlan viewers. The ground model symbology can be adjusted to be transparent, shown as contours, or opaque. The color ramp can also be adjusted to specific colors or to be based upon only the area shown in the GeoPlan viewer.

ICPR imports the DEM into the surface manager menu. Vertical units are assumed to be feet, and the cell size is equivalent to that of the imported DEM. Once imported, the DEM can be viewed, the opacity can be edited, and the color scheme can be based on the entire surface, or the portion of the surface shown in the graphic view. Multiple surfaces can be included within the surface manager and be applied to different scenarios. The surface manager also holds the initial water table surface and confining top layer surface for use with the groundwater module.

The Edina subwatershed includes two bridges that are shown as a berm or dam in the lidar data. The bridge crossings of Minnehaha Creek were removed from the lidar points during the lidar preprocessing work but the relatively short span of the bridges result in triangulation issues during the DEM creation. Figure 2 shows the crossing of Minnehaha Creek at Wooddale Avenue S along with the “missing” lidar point area where the bridge elevation data was removed. Lidar points are classified by return number and different types of rasters can be created by using different selections of the return numbers. The lidar obstructions created by these bridges (or the lack of lidar points) were removed through terrain edits within GIS. Removal of the bridges was necessary to more accurately simulate flow along Minnehaha Creek. Additional cleanup of the bridge crossing locations were required to accurately simulate flow through these areas within ICM and ICPR. The updated terrain file was included in both the ICM and ICPR model builds.

Figure 2. Bridge Lidar Triangulation Area

During the watershed-wide model build process, crossings of Minnehaha Creek, tributaries, and major lakes by bridges should be reviewed to determine the required data needed to accurately model significant crossings. In areas where the creek is completely spanned by a bridge and the flood waters do not reach the low member of the bridge, then modifying the underlying terrain and removing any inconsistencies would be a reasonable approach. If a bridge crossing has piers, sizeable abutments in the floodplain, and/or is likely to be impacted by the flood waters, then the bridge data should be included in the model. If as-built information is not available, bridge data may need to be surveyed to be included in the modeling packages.

The required bridge information includes upstream and downstream cross-sectional data of the creek, upstream and downstream bridge cross-sectional information and the bridge deck profile. This data should include any additional obstructions in the creek and floodplain that would inhibit the flow of water downstream, as-built data for the bridge deck, upstream and downstream faces of the bridge, assuming that the cross-sectional data for the creek is included in the as-built data. A surveyed reference point may be required to spatially place the bridge depending on the robustness of the as-built dataset.

Due to the horizontal datum being set to UTM, ICM defaults to meters for elevation and sizes after each import. While the model is functional using the UTM projection in ICM, it creates nuisances that if not caught and can cause larger issues down the road with inconsistencies between units of different model parameters. Therefore, if this software is selected the project team strongly recommends that a model spatial projection of Minnesota State Plane – South be used to reliably and repeatably import data to the modeling software, which is based in feet and inches instead of meters and millimeters.

2.2.3 Land Use/Land Cover (LULC)

Manning's n roughness values are derived from the associated land use/land cover (LULC) layer. LULC was taken from the Twin Cities Metropolitan Area Land Cover Classification dataset. The dataset is generated by the University of Minnesota at a 1-meter resolution using high-resolution multispectral National Agriculture Imagery Program data including leaf-on imagery, spring leaf-off imagery, lidar data, multispectral derived indices, National Wetland Inventory, lidar building footprints, and other thematic data (2015). This LULC dataset does not break out road sections individually.

ICM imports the LULC data in two parts. The first part is the Roughness Zone, and the second part is the Roughness Definition. The zone is used to delineate the boundary of each landuse type. The definition is used to reference the roughness parameters for each LULC zone. A single roughness definition may be applied to multiple roughness zones. Each roughness definition may have up to three roughness parameters with unique phase-in depths. This is important to modeling areas that experience minor inundation followed by more extreme inundation. Varying the Manning's n values based on flow depth accurately models the reduction in roughness that is experienced at deeper flow depths. A single roughness definition can be applied directly within the roughness zone. An overall roughness value can also be applied to the whole 2D Zone or to areas without a Roughness Zone. All areas should be incorporated within a roughness zone from the input landuse file, although small gaps may occur during editing by the modeler. These gaps would be filled automatically by the underlying application of an overall roughness value. The gaps can also be removed through GIS processes prior to importing the GIS shapefile to ICM. The LULC delineations should be individual shapes, not multipart shapes within a shapefile.

ICPR imports the LULC data from a shapefile, then creates a raster from this data. Manning's n roughness values are assigned to the raster through a user-defined input table. ICPR uses deep and shallow manning's n roughness values based on user defined depth ranges. ICPR can also apply one roughness value to the entire 2D mesh which can be beneficial during initial model build processes or smaller model areas that are generally covered by consistent landcover.

Both software packages treat roughness zones and roughness definitions as separate entities, and both allow for depth varied roughness values. ICM has a more robust depth varied system, allowing three values as opposed to ICPR's two-value system. ICPR converts the LULC data to a raster while ICM LULC data remains in polygon format. To edit the ICPR LULC delineations, the data must be reimported and converted to a new raster while the ICM LULC shapes can be edited directly within the software. Building footprints can also be incorporated within both software packages. Building footprints can be used as obstructions to block overland flow paths. Within ICM, the obstruction can also be varied to allow flow through at a user-defined inundation depth. Increased roughness values within a building footprint as part of the LULC delineation is an alternative way to model the building obstructions. Within ICPR, buildings can be modeled as extrusions or exclusion areas depending on the desired effect to the ability for water to flow. Extrusions may be used when a building may collapse during an extreme flood event and allow flow through the area above a defined elevation. Exclusions remove the area completely from the 2D overland flow region.

2.3 Subsurface Datasets

2.3.1 Soils

The main Green-Ampt Parameters include suction, conductivity, and deficit (porosity). The values of these inputs range for each soil type and can be manually edited as part of a calibration process to reduce or increase the amount of surface runoff.

Similar to the LULC data, ICM takes the soil data in two parts, the Infiltration Zone and the Infiltration Surface. The infiltration zone contains the spatial delineation for each soil type and the infiltration surface contains the soil parameters for the individual soil types. ICM utilizes the following three soil parameters: suction, saturated hydraulic conductivity, and deficit. The moisture deficit value is set to the porosity value of the soil. This correlates to dry soil and allows for maximum amount of infiltration to occur in the simulation. As rainfall is infiltrated the saturation of the soil and effective infiltration rates vary within the model space. As rainfall recedes, the soil becomes unsaturated at a rate that is calculated through the saturated hydraulic conductivity parameter. All of these values can be adjusted to more accurately simulate in place conditions. The soil areas must be imported as separate features within the shapefile. ICM does not allow for multipart features to represent the delineation of multiple soil areas with the same soil parameters.

ICPR takes soil data the same way it takes LULC data. The first part is a shapefile import that is converted to a raster in ICPR, and soils data is entered into a table that gets paired with the raster file. ICPR can use Green-Ampt, Curve Number, or Vertical Layer methodology to model infiltration, this model build utilizes Green-Ampt methodology. ICPR takes 9 soil parameters: vertical saturated hydraulic conductivity (ft/day), saturated moisture content (decimal), field moisture content (decimal), initial moisture content (decimal), wilting moisture content (decimal), residual moisture content (decimal), pore size index (decimal), bubble pressure (in), and depth to water table (ft).

ICM and ICPR both treat soil zones and soils values as separate entities, but they handle them differently. ICM uses an infiltration surface to define individual soil properties while ICPR stores soil properties in a table that is linked to the soil zones before running the simulation. ICPR takes all relevant NRCS soil parameters for calculating Green-Ampt infiltration while ICM uses suction, conductivity, and deficit. These extra parameters allow soils in ICPR to recover more accurately in multi-event rainfall simulations. Similar to the LULC data, ICPR creates a raster of the soil type delineation. To edit the delineations of the soil layer in ICPR, the soil layer must be edited outside of ICPR and reimported to create a new raster. ICM soil data remains in polygon format and can be edited directly within the software. ICM allows for individual infiltration surface delineations to be modeled with different hydrologic methodology and input parameters. This is useful when the modeler desires to eliminate infiltration over impervious surfaces or has other predefined soils data.

2.3.2 Groundwater

ICM does not allow for import and use of groundwater data within the modeling software. One potential way to mimic groundwater levels is through the manipulation of the Green-Ampt parameters to simulate various soil conditions. Increasing or reducing the initial moisture content within the soil parameters would mimic wet and dry conditions at the beginning of the simulation.

ICPR can model two-dimensional groundwater flow using a triangular mesh similar to the two-dimensional overland flow mesh. The groundwater mesh and the surface water mesh can interact with each other through recharge, infiltration, seepage, and leakage. The model build incorporated recharge, infiltration, seepage. The leakage portion was not included as this portion of the groundwater model relates to the loss of groundwater through the confining (bedrock) layer. Groundwater modeling in ICPR requires multiple inputs to set initial conditions and soil parameters. Surfaces representing the ground surface (same as overland flow region), initial water table, and confining layer are required for developing the scenario. Single elevations can be specified in place of a surface for each initial condition input. Soil parameters must be specified for fillable porosity and conductivity zones. Typically, the zones for the soil parameter zones match the Green-Ampt soil infiltration zones.

The initial groundwater table was set based upon the average depth below ground surface at the groundwater monitoring wells for the entire model area. The corresponding initial water table surface was created by offsetting the ground surface by the average depth. The confining layer surface was created by clipping the countywide bedrock elevation raster contained within the county geologic atlas datasets. The fillable porosity parameter was assumed to be 0.3 for areas below the surface and set to be 1.0 for areas above ground. This dimensionless parameter correlates the available porosity within the soil layer to the location and is given as a percentage of the total available volume (0.3 = 30% void space). Conductivity was conservatively set equal to vertical saturated hydraulic conductivity from existing Green-Ampt data. Typically, measured horizontal hydraulic conductivity is greater than the vertical hydraulic conductivity. Multiple groundwater regions can be delineated, and they will interact along any face that is wet in the overland flow region. ICPR recommends breaking the groundwater regions at creeks and lakes to reduce the overall size of each groundwater region and increase computational efficiency.

ICM does not allow for groundwater modeling in a 2D simulation while ICPR supports combined surface water and groundwater 2D model and surface water only 2D model setups.

2.4 Infrastructure Datasets

2.4.1 Junctions

Junctions are used within the software packages as end points for conduits, connection points to the 2D overland region, and discharge locations. The junctions are taken as point features. All junctions from the input datasets were included in the model build. There are no limitations for the number of junctions included in either modeling software with the software license that was used. Lower license levels of a software package may have limitations on input and model datasets.

The 1D junctions within ICM can be used to model a variety of situations and interactions between the 1D system and 2D region. The junctions can be set to set as one of multiple different flood types as well. For the model build, the junctions were set to 2D as the flood type. The 2D flood type methodology uses a weir equation to calculate flow from the 2D mesh into the junction. The weir length is taken as the circumference of the junction which is calculated based on the diameter of the largest pipe that is connected to the junction. The size of the junction can also be manually edited by the modeler. Interaction between the junction and 2D mesh is set to depth (by default). This parameter can be changed under the 1D-2D linkage basis parameter to elevation to minimize oscillations within the calculations during the simulation. If there is a large discrepancy between rim elevation and ground elevation or if it is desired to model an in-place condition then using the elevation setting can produce the desired effect. The other main flood type for inlets is set to Inlet 2D. Inlet 2D allows for additional inlet parameters to be set based upon user input. A head-discharge table, flow efficiency relationship, custom equation, or HEC-22 data may be entered to increase the level of detail within the inlets in the model.

Junctions in ICPR can be set to one of multiple options to simulate conditions at the junction. Junctions can be setup to include stage-area, time-stage, or stage-volume data. The junction may also be setup as a 1D Node Interface element as part of the overland flow region. Junctions are part of the 1D network and the 1D Node Interface is setup as part of the 2D overland flow region. The 1D node interface forms a connection between the 1D network and the 2D overland flow region allowing water to pass between the two systems. These junctions have no area, and their elevation is assumed to be the same as the DEM at the insertion point. 1D node interface elements default to assigning a starting water elevation equal to the ground level. This default is appropriate for 1D node interfaces that represent outlets of culverts or pipe systems into the overland flow region but is not correct when modeling storm sewer inlets. The user can set the 1D node interface elements to start with a water elevation equal to the invert through import settings and/or through manual editing of elements. Time-stage nodes were used to represent outfalls which are further described below. Stage/Area Nodes connect to pipes and can have an assigned initial depth and stage/area relationship to represent storage at the node. When no initial depth is assigned the lowest invert from a connecting pipe is used. The Stage/Area Nodes in the model build did not have an initial depth or stage/area relationship.

The main difference between ICM and ICPR is that ICM utilizes the node rim elevation as the default setting and ICPR utilizes the DEM to set the rim elevation for each junction. ICM also allows for additional detail to be added for inlet capacity or known inlet rating curves to be specified by the user. The starting water elevation needs to be set within ICPR for all 1D node interface elements or the software will introduce additional water to the simulation and become unstable. The specification of the starting water elevation needs to be completed prior to data import or nodes will have to be individually adjusted within the model which can become time consuming.

2.4.2 Pipes

All pipes were imported to the model and are utilized to convey flow underground through the 1D storm sewer system. The pipe dataset has the greatest number of data gaps that were filled through various processes prior to import to each model and post-import to each model. Pipes with missing diameters were set to 12.1 inches, missing invert data was set with a user-defined DEM offset, and missing pipe material data was filled with an unknown-type place holder with the associated Manning's n set to 0.016. Furthermore, numerous pipes contained data but were shown to be incorrect when included in the software packages (invert elevations that differed by 80+ feet or were missing a number [80.76 versus 880.76] for invert elevations). This erroneous data appeared to either have duplicate or missing numbers in elevation when compared with surrounding pipes and the DEM. Filling the invert data with a DEM offset for the main trunkline storm sewer system caused issues with oscillations when the models were built. The DEM offset was overwritten for various pipes within the system through linear interpolation of upstream and downstream inverts of neighboring pipes to allow the system to function properly and allow drawdown of ponding locations. The DEM offset automation may need to be reviewed during the watershed-wide build process to determine the overall applicability to the full dataset or to targeted areas.

ICM utilizes pipes as the conduit input. The junctions (inlets, manholes, outfalls) must be imported prior to the import of the pipe layer to allow for snapping of the upstream and downstream ends of the pipe to the associated nodes. Any pipes with updated sizes, post-import, were changed to have a suffix of .2 for differentiation. The pipes were reviewed against the original dataset. This process was revised and included in the challenges section of this memo.

ICPR also utilizes pipes as the conduit input. Junctions can be imported before or after importing the pipe layer because the pipes are not snapped to nodes based on their proximity. Pipes are connected to their relevant junctions based on "From Node" and "To Node" name fields in the pipe attribute table. Some pipes needed to be manually assigned node names even after pipe data was processed in GIS. This process is more difficult in ICPR than in ICM because the property table for the pipe link needs to be manually edited as opposed to snapping pipes to nodes in ICM. Scaling this to a watershed wide build, the process would increase the time needed to manually edit pipe links but would not increase the difficulty of the process.

Both software packages needed additional manual processing to finalize the pipe import process and successfully run the models after the import was completed. Some pipes included upstream or downstream node names that did not match the nodes. They appeared to be from a previous naming convention. Due to the presence of erroneous data in these attribute columns, the preprocessing in GIS did not reassign new upstream and downstream node names for these pipes.

2.4.3 Outfalls

Depending on the robustness of the infrastructure dataset, outfalls may need to be imported separately to complete the 1D portion of the model build process. The Turbid-Lundsten subwatershed did not have outfalls as a separate input dataset and no additional import was required. The Edina subwatershed did have a separate outfall shapefile that was imported into the models. The outfall file was needed to form the connection at the outlet of pipe runs to the 2D mesh.

ICM treats outfalls as nodes with either the node type set to Outfall 2D or Outfall. The Outfall 2D allows for connection back to the 2D mesh while Outfall allows for free discharge from the end of the pipe and out of the model. The Outfall is meant for areas where the model is clipped and no tailwater condition is assumed. If a tailwater condition is assumed, then a level line can be applied with an appropriate level for the duration of the simulation to mimic the downstream conditions.

ICPR treats outfalls from the overland flow region as nodes with node type set to Time/Stage. A Time/Stage node with no table of values attached represents a free outfall with no tailwater condition assumed. A tailwater condition can be modeled by adding a table of time/stage values to the node. For outfalls connecting back to the 2D mesh, a 1D Node Interface connects pipes back to the 2D mesh.

Both ICM and ICPR allow for free outfall conditions, tailwater conditions for outfalls, and outfalls that connect back to the 2D mesh.

2.5 Model Build Datasets

2.5.1 Rainfall

The models were initially built and tested using the MSE-3 distribution and a rainfall depth of 7.4 inches. This rainfall distribution is the standard design rainfall distribution for the region for a 24-hour rainfall event. A second rainfall file was used to simulate the 100-year, 10-day rainfall event. This rainfall event uses a nested Atlas-14 distribution and has a rainfall depth of 10.1 inches. The 10-day rainfall event was used to match the inflow hydrograph taken from the watershed-wide XPSWMM model. The 10-day rainfall event has been assumed to be the critical duration event for Minnehaha Creek. The critical duration event for a watershed depends on the size and flow pattern of the watershed. Typically, a larger watershed will have a longer critical duration event. Additional recorded rainfall events were incorporated to the models during additional model refinement processes.

ICM takes in rainfall data as a time series dataset. The data can be entered by a user or imported by a CSV file. The timestep for the rainfall data can be changed to match the required timestep. The rainfall data is entered using inches per hour units. Once a rainfall file is utilized in a simulation run, the rainfall data cannot be edited.

ICPR has 18 non-dimensional rainfall distributions built into the software that only require a rainfall depth and storm duration to be specified. These distributions do not include MSE-3 so they are not relevant for this model build. Custom rainfall data can be added to ICPR in a variety of formats and storms can be applied globally or in local rainfall zones. Custom rainfall data can be input from a historic rainfall event, a dimensionless rainfall distribution, or a constant rainfall rate. Rainfall depth is measured in inches in ICPR. Rainfall files must come in a txt file format with tab delimiting, this is usually done by saving a CSV file as a txt file then moving the folder containing both files into the Resources>Rainfall directory in the ICPR file structure. Sample formats for custom rainfall files from the ICPR Help System are included below to show the differences for each. Rainfall data can be edited in its source file at any time a simulation is not running. Figure 3 details the rainfall information from the ICPR help menu.

ICM uses rainfall intensity as the input for the hyetograph while ICPR uses rainfall depth as the unit for the rainfall data. ICPR takes a wider variety of formats for custom rainfall data and allows for data editing after a simulation run. ICM does not allow dimensionless rainfall hyetographs as input while ICPR does.

Kimley»Horn

Historical Rainfall Event top

An example of an historical rainfall file in English units is shown below. This file is set up in absolute time (e.g. the year, month, day and hour are specified). If you prefer to work in relative time, then set all year, month and day values to zero and use cumulative hours from the onset of the simulation. The time values correspond to the beginning of a rainfall packet. For example, beginning at year 2012, month 4, day 7, and hour 4.0, 1.125 inches of rain falls evenly over the next 60 minutes (the rainfall packet time increment). Entries are not required for zero rainfall packets. The last record must contain the word "END" in uppercase.

File Type
Rainfall Packet Time Increment

```
0
60
2012   4   3    23.000  0.001
2012   4   6    6.000   0.002
2012   4   7    2.000   0.033
2012   4   7    3.000   0.911
2012   4   7    4.000   1.125
2012   4   7    5.000   0.566
2012   4   7    6.000   0.093
2012   4   18   16.000  0.035
2012   4   18   17.000  0.013
2012   4   18   18.000  0.006
2012   4   18   23.000  0.001
2012   4   19   9.000   0.015
2012   4   19   11.000  0.043
2012   4   19   16.000  0.192
2012   4   20   23.000  0.004
2012   4   21   0.000   0.002
2012   4   21   12.000  0.001
2012   4   21   13.000  0.001
2012   4   21   15.000  0.010
2012   4   21   17.000  0.012
2012   4   21   18.000  0.003
2012   4   21   19.000  0.005
2012   4   21   22.000  0.007
2012   4   21   23.000  0.010
2012   4   22   0.000   0.007
2012   4   22   1.000   0.050
2012   4   22   2.000   0.082
2012   4   22   3.000   0.194
2012   4   22   4.000   0.010
2012   4   22   8.000   0.010
2012   4   22   9.000   0.001
2012   4   22   11.000  0.003
END
```

Year Month Day Hour Rainfall Amount

Dimensionless Rainfall Distribution top

An example of a dimensionless mass curve (English units) is shown below. The file type is set to 2 (or 3 for a metric units), the storm duration to 24 hours and the total rainfall amount to 10.6 inches. *Non-zero values of storm duration and rainfall amount in the simulation control form (global rainfall) override the storm duration and rainfall amount in the data file.* Or, if you are using multiple rainfall zones instead of global rainfall, then the storm duration and the total rainfall in the text file are multiplied by the non-dimensional distribution to obtain the temporal distribution of rainfall for the simulation.

These are followed by dimensionless time-rainfall pairs. The dimensionless time is equal to the cumulative time divided by the storm duration. And, the dimensionless rainfall is the cumulative rainfall divided by the total rainfall amount.

File Type
Storm Duration
Total Rainfall

```
2
24.0
10.6
0       0
0.0417  0.00046
0.0833  0.00178
0.125   0.00451
0.1667  0.0089
0.2083  0.02026
0.25    0.03573
0.2917  0.06157
0.3333  0.09602
0.375   0.14664
0.4167  0.21059
0.4583  0.29448
0.5     0.4392
0.5417  0.64992
0.5833  0.74509
0.625   0.82
0.6667  0.87693
0.7083  0.91918
0.75    0.95158
0.7917  0.97342
0.8333  0.98623
0.875   0.99406
0.9167  0.99717
0.9583  0.99905
1       1
END
```

Dimensionless Time
Dimensionless Rainfall

Constant Rainfall Rate top

It is possible to simulate a constant rainfall rate using a non-dimensional rainfall distribution. For example, a custom hydrograph was created for a constant rate of 7.5 inches over 24 hours. The following text file is placed in the rainfall resources folder.

*Constant.txt - Notepad

File Edit Format View Help

```
2
24.0
180
0 0
1 1
END
```

Ln 9, Col 1 | 100% | Windows (CRLF) | UTF-8

Figure 3. ICPR Rainfall Data Entry

2.5.2 2D Mesh

The 2D Mesh is a critical piece to accurately simulate inundation and flow direction. Multiple mesh parameters can be set to manipulate the cell size and orientation. Through the development of the mesh in both software packages, different mesh development pathways were tested.

In ICM, the maximum triangle mesh area was set to 1,000 square feet, minimum mesh element area to 200 square feet, and minimum angle to 30°. The mesh was built using the terrain sensitive meshing feature along with a maximum height variation set to 3.28 feet. Adjusting the height variation will increase or decrease the rate at which new triangles are created during the mesh development. ICM aggregates small triangles to create a single element that is above the minimum mesh element size during the mesh creation process. This feature adjusts the mesh layout and spacing within the previously user-defined parameters to introduce additional detail into the mesh in areas with high rates of elevation change. Breaklines and refinement regions can be added to a mesh to enforce hydraulically significant features within the elevation data. A breakline is a polyline that aligns the cell edges with the polyline alignment. Refinement regions are polygons that change the mesh spacing parameters to either introduce additional detail into the model or reduce detail by aggregating cells. The ICM model included a single breakline along the centerline of Minnehaha Creek created manually by the model user. This breakline was the same between ICM and ICPR. Additional discussion on mesh refinement and the effect on runtimes is included in the scenario analysis and calibration memos. Within both software packages, each mesh element is assumed to be at a single elevation that is assigned from the DEM by sampling the ground model and taking the average of the sample point elevations.

The 2D overland flow mesh can be created using terrain-sensitive meshing or through the placement of breakpoints. When using the groundwater module using breakpoints to create the mesh is recommended. The overland flow breakpoint layout must be transferred to the groundwater mesh to eliminate continuity issues that result in model crashes and negative aquifer errors during simulation runs. The overland flow breakpoints were placed in a triangular pattern with 100-foot spacing to create the base overland flow mesh. The groundwater mesh was then created using 200-foot triangular spacing to align the overland and groundwater meshes. The 2:1 ratio is recommended based upon the honeycomb creation of both meshes and transfer of water between the meshes. Water flows only along the edges of the triangular mesh and the orientation of triangle edges must follow the direction of flow. Breaklines were added along principal flow paths to align the overland triangular mesh with the direction of flow. The overland flow breaklines were transferred to the groundwater mesh to align the meshes to each other. The terrain-sensitive meshing option is not recommended for use with combined overland and groundwater models. After placement of the breakpoints and breaklines, the mesh must be preprocessed. The preprocessing allows for the review of short triangle edges and mesh build errors. Triangle edges less than five feet should be removed through the adjustment of breakpoint location and breakline alignment. There is a search tool within the ICPR graphical viewer to find short edges but the refinement elements must be hand edited to remove the short edges. Discrepancies between the overland flow and groundwater mesh refinement elements can cause model crashes and model errors during simulation runs.

ICM and ICPR can build their triangular mesh using similar methods, except that ICPR does not include a maximum height variation parameter. The ability to specify the maximum height variation in ICM allows for a larger range between minimum and maximum mesh size to better capture flat and hilly areas within the same overall parameter and less manual user input to refine the mesh later. While ICPR can use terrain sensitive meshing, it is recommended to use breakpoints to generate the base mesh and breaklines to refine the mesh further. While the creation of the base mesh through breakpoints is done using an internal ICPR tool, the refinement of the mesh further must be completed through user edits. ICPR requires that the overland and groundwater meshes be refined in essentially the same manner and encounters routing issues when the internal mesh creation tools are used. ICM and ICPR were able to run all simulations at the original 2D mesh range of 200-1,000 square-feet. ICM was able to reduce the minimum cell size to 20 square-feet and successfully complete the simulations. ICPR was refined through hand edits to reduce cell size and was able to complete the simulations. Both models benefit from the use of 1D objects such as pond volume and river control areas that remove portions of the overland flow model from the 2D calculation by using the 1D solver.

Both software packages encounter issues during the simulation when there are extremely short mesh cell sides present. Cell face lengths less than 5 feet should be adjusted to increase the length. Typically, the minimum length of a cell face is proportional to the maximum depth that a cell may experience by a factor of 10 (e.g. 1 foot of depth = minimum of 10 feet of cell face length). This is a general rule of thumb and the larger the ratio between cell face length and maximum inundation depth in the cell, the more efficiently and stably a model will perform a simulation. During the mesh development, average and minimum element sizes can be reviewed through log files. The removal and/or adjustment of these small areas and lengths is highly recommended to improve simulation run times and accuracy of results. As a reduction in cell size is achieved, a similar reduction in time step must also occur for the models to perform simulations accurately and completely. Both software packages incorporate variable time steps within model runs. ICPR allows for specification of the range of time steps when using the Fireball solver whereas ICM will reduce the 2D timestep to complete the simulation in a stable manner. Both software packages will perform multiple calculations at a time step if needed to determine the flow and stage between 2D cells. When multiple iterations are needed to perform the calculation, overall model run times increase, sometimes significantly.

2.5.3 Boundary Conditions

2.5.3.1 Inflow Conditions

There were no inflow boundary conditions specified for the Turbid-Lundsten subwatershed model as this area is at the top of the watershed and no offsite flows enter the model area. A single inflow boundary condition was specified manually for the Edina subwatershed model at the upstream (west) end of Minnehaha Creek, where the creek enters the model area. The inflow boundary condition was taken from the watershed-wide XPSWMM model as an inflow hydrograph flow rate from the 100-year, 10-day storm event (Base Flood Elevation run). Using a flow hydrograph to introduce the creek flow produced better results compared to using a stage hydrograph to introduce flow. This was the case using both the base lidar for the channel mesh development and using the refined channel data for the mesh development.

ICM uses a line source to introduce the flow from the flow hydrograph into the model area. The line source is applied at the edge of the model along the channel cross-sectional area for flow to enter the model. A line source can be applied within the model area. Also, a point source can be used to introduce flow at a single point in the model area.

ICPR uses a line source to introduce flow from the flow hydrograph into the model area. The line source was applied inside of the model area due to the expanded size of the model boundary within ICPR. A point source within the model could have been used to introduce the flow at a single point within the model area, however, the line source option was used to maintain consistency between software packages and inflow points.

ICM and ICPR allow for external and internal boundary conditions to be specified for inflow to the models. The boundary conditions can be specified as either point or line inflow to mimic different types of inflow conditions. Upstream boundary conditions should be applied through external line features and be applied as flow hydrographs. Downstream boundary conditions should be applied through modifications to the 2D boundary and applied as stage hydrographs. Other boundary condition setups may be required for unique situations. During the creation of the inflow lines, small discrepancies in the alignment of the line can result in tiny 2D mesh elements. These small elements can increase simulation run times dramatically for both software packages. It will be important to review the minimum mesh size and remove tiny 2D mesh elements for the future watershed-wide build.

2.5.3.2 Outflow Conditions

The outflow boundary condition for the Turbid-Lundsten model area is free discharge at the downstream end of the MnDOT pipe that crosses Highway-5. There are multiple locations where pipes discharge from the Edina subwatershed and all of the pipe discharges were set to free discharge. The only user-specified outflow boundary condition is along Minnehaha Creek. The boundary condition was set to either the FEMA base flood elevation (BFE) or to free discharge depending on the scenario being modeled. The FEMA 100-year flood BFE level at the edge of the model is at an elevation of 861.

ICM uses level lines to introduce stage data. The level line is applied at the 2D Mesh boundary and overrides the previous 2D zone boundary type for the portion of the 2D zone that is colinear with the level line. For the simulation, the level line elevation was set equal to the BFE of 861 and held constant throughout the simulation time frame.

ICPR uses the same line and point elements to define outflow locations that it uses for inflow. Multiple stage boundary condition lines were used along the model boundary to allow runoff to flow out of the model. Minnehaha Creek boundary was set to 861 and all pipe discharge locations from both subwatershed models were set to free discharge.

ICM and ICPR allow for outflow boundary conditions in similar ways to be specified along the boundary of the mesh.

3 MODEL BUILD CHALLENGES

Challenges listed below are unique to each software package and should be considered in the evaluation matrix and the software decision.

3.1 ICM

If the District decides to move forward with ICM as the software for the full watershed-wide build, the following model build challenges should be considered and addressed:

Coordinates

Units are recommended to be changed from UTM Zone 15N projection to one that is based in the units of feet. ICM wants to revert to meters as the default units due to the underlying UTM projection. This causes issues when importing data through the ODIC as inches will be imported as millimeters and elevations as meters instead of feet. The imported data can be converted back to feet and inches through data manipulation within the internal ICM tables. The conversion marks all changed values with an "updated" flag and makes the model updating tricky to manage and track. Also, to export the results back to GIS, the overall model units must be switched back to meters to align with the underlying spatial projection of UTM. While this occurrence isn't a fatal flaw within the model build and simulation run process, the necessity for a streamlined and user-friendly process is key for long term success of the watershed-wide model build.

Mesh Size

Determining proper mesh size will be critically important to successfully implement the watershed-wide model. The mesh element elevation is calculated by taking the average elevation of multiple sample points. In areas where large variations in elevation occur in a relatively short distance, multiple mesh elements are required to accurately simulate the change in topography. Though the size of the mesh elements must be carefully adjusted as the size of the element decreases, the number of computations at each time step that the software must complete increases. The reduction in element size will also increase time for post-processing results and increase size of storage requirements. There are multiple ways that ICM allows for mitigation of this challenge. By using the terrain-sensitive mesh generation technique, a larger range between minimum and maximum element sizes can be specified. Determining the correct size of mesh will be important to developing results at a scale that is desirable for the final use.

1D Datasets

All pipe and node parameters are read directly from the pipe/node data, no information is taken from the DEM during the import process. As a result of this fact, the pipe outlet nodes must either have an elevation from as-built/survey or be recalculated based upon the associated DEM.

Following the pipe import process, pipes were discovered that the scripting process missed the conversion of diameter data with the " suffix for inches in the pipe size to be solely numbers (from 30" to 30). This process was remedied short-term by parsing the data column with the " inputs and reloading the data into the model. Th date. The pipe data should be parsed to remove inch (") data prior to incorporating with the preprocessing tools.

When GIS data has duplicate pipes (i.e., pipes that start and end at the same exact points), neither pipe is imported into ICM. This is due to conflict with placement and no hierarchy being placed on the pipes during import. The missing pipe following import occurred once during the Edina subwatershed model build and did not occur during the Turbid-Lundsten subwatershed model build. The missing pipe was found by using the GIS Layer Manager to bring in the pipe data as a background file and verifying that all pipes were imported. This is a quick process but a necessary one to verify the automation.

Overland Flooding

An issue with the representation of the overland flooding results within ICM was discovered during the initial analysis runs. The representation was reviewed with the staff at Innovyze and modifications to future releases of ICM will include changes to how the representation is shown. The underlying results are accurate but the triangulation between large mesh elements can be overwritten during the visual representation process and remove areas of inundation. Typically, these areas are located along the edges of the inundation and are visually apparent due to their rectangular nature. The short-term solution is to either reduce the mesh size in areas with large changes in elevation or view the results within the 2D model (triangles), not within the flood map representation (internal raster). Following review and discussion with Innovyze on the issue, it was determined to not be significant since the results are computing correctly and can still be viewed within the 2D model viewer. A results raster can also be created outside of ICM through geoprocessing tools in GIS.

<u>1D-2D Interface</u>

The ICM model encountered some model instability issues during the initial testing. These instabilities caused the simulation to crash within the initial 5% of the run time. The instabilities were most commonly due to 1D-2D connection elevation variances at the end of pipe runs. ICM creates a note during the validation process when there is a discrepancy between the downstream invert in a pipe and the 1D-2D node elevation but can still run the simulation. There are three main causes for this issue to occur during the model-build process and the resulting simulation runs.

1. A pipe discharges below the water level of a creek or pond. This can be due to Lidar's inability to penetrate water, resulting in a falsely high bottom elevation
2. Lack of data within the pipe dataset. This leads to third issue.
3. Pipe invert data being filled through the automated process. Pipes with inverts that do not have data are automatically filled with a DEM offset from the user input parameter. This new downstream invert is then set below the DEM and will need to be adjusted during the model-build and verification process.

3.2 ICPR

In the event the District selects ICPR for the full model builds, the following model build challenges should be considered and addressed:

<u>Coordinates</u>

All component data should be projected into the desired coordinate system and units before importing the data into ICPR. This reprojection was completed during the data processing automation. Failure to do this will result in elements of the model being misplaced. Units cannot be changed within ICPR, so any data with units not converted beforehand will need to have their data manually edited in ICPR after they've been imported. ICPR needs all 1D model elements to be imported as .csv files to maintain all of their input data shapefiles will only import location and connectivity data.

<u>1D Datasets</u>

ICPR determines connectivity in the 1D network based on data within the pipe so when data entry errors are present or name data is missing, ICPR will not be able to connect pipes to nodes regardless of spatial relationship. When these errors occur, the modeler must manually define the names of upstream and downstream connections for each pipe.

Following the pipe import process, pipes were discovered that the scripting process missed the conversion of diameter data with the " suffix for inches in the pipe size to be solely numbers (from 30" to 30). This process was remedied short-term by parsing the data column with the " inputs and reloading the data into the model. Preprocessing the pipe data to consolidate the pipe size attributes will also aid the model develop process to highlight areas that require additional information to fill the gaps created through a lack of pipe size data.

All pipe and parameters are read directly from the pipe data, no information is taken from the DEM during the import process. As a result of this fact, the pipe outlet nodes must either have an elevation from as-built/survey or be recalculated based upon the associated DEM. Node elevations can be manually specified but ICPR will automatically adjust them to the DEM if they are not manually specified.

When GIS data has duplicate pipes (i.e., pipes that start and end at the same exact points), both pipes are imported into ICPR. This causes a fatal error when the model tries to run. This error can be solved by deleting the duplicate pipes from ICPR. The missing pipe following import occurred once during the Edina subwatershed model build and did not occur during the Turbid-Lundsten subwatershed model build.

ICPR allows for creation of 1D nodes and 1D interfaces, these entities are separate types that cannot be swapped out. The 1D nodes live within the hydraulic network and are full 1D entities. The 1D interfaces are 2D features that connect the 1D pipe network and the overland flow region. To swap a junction from a 1D node to a 1D interface, the junction must be deleted from one dataset and created in the other by hand. 1D interfaces assume that the starting water surface elevation is at the ground elevation. This assumption is accurate for culvert inlets/outlets as they are typically dry at the start of a simulation. This assumption is not accurate for surface inlets (catchbasin) as this condition will assume that the manhole/structure is completely full of water at the start of the simulation. The starting elevation for a 1D interface must be specified to be at or below the connecting pipe invert to remove this issue.

Boundary Conditions

The ICPR model encountered instability when boundary conditions were not applied directly to the model boundary, when nodes were left in the model that did not attach to any pipes, and when inlets are placed very close to stage boundary conditions (less than 10 feet in Edina). The combination of these errors results in the model terminating at the first major rainfall (120 hours into the simulation). Fixing the boundary condition to conform exactly to the model boundary and removing pipe inlets close to the downstream stage boundary condition stopped errors from crashing the model. Further cleaning up the model to remove unconnected nodes and altering the boundary condition to ramp up with the rainfall event greatly improved runtime.

Groundwater Model

A fully functioning overland flow model must be created prior to creation of the groundwater model. All edits to the overland flow model must be transferred into the groundwater model, including breakpoints, breaklines, and refinement areas. The groundwater model uses a matrix solver to complete the calculations for groundwater levels and flow. Due to the matrix solver being used, the size of the individual groundwater meshes begins to reach a practical limit around 12,000 groundwater cells within a single groundwater mesh. Multiple groundwater meshes can be use within a single model but the interface line between groundwater regions must be wet (e.g., a lake, pond or creek) to allow flow across the boundary. At a minimum, groundwater mesh elements should be the same size as the overland flow elements. However, the model creator recommends groundwater mesh elements be set at a 2:1 ratio due to the groundwater mesh creation methodology and the interaction between the overland flow and groundwater meshes. For example, a model with surface base mesh size set at 500 square-feet would have a 1,000 square-foot groundwater base mesh at a factor of 2x. Multiple groundwater regions can be created and interact with a single overland flow region.

Model Instability

The 2D flow methodology of ICPR that only allows flow along the triangle faces of the overland flow region significantly impacts the model run times and stability when the faces are not aligned with the direction of flow. The issues become increasingly problematic when triangle faces are misaligned in areas of significant flow (ie. creek flow). Aligning the triangle faces with principal flow paths is accomplished through the creation of breaklines. The breaklines can be created within ICPR or through external GIS applications. For the pilot model build, the breaklines were created within ICPR. When considering a watershed wide build, the recommended approach is to create breaklines in GIS for the. Creating the breaklines within GIS allows for multiple users to create breakline shapefiles that can be joined into a single large file for incorporation within ICPR.

All breaklines created within the overland flow region should be transferred (copied) to the associated groundwater flow region for the area. Breaklines should also be snapped to vertices of other breaklines to reduce the occurrence of short triangle faces that need to be fixed during the model build process. A model can be run with short cell faces but there is a high likelihood that the simulation will crash or errors will occur during the simulation run that force the model to stop the simulation.

4 PILOT MODEL CALIBRATION AND VALIDATION

Since the outset of the project, the team had discussed calibration and validation of the model builds as a critical step towards evaluating each model’s ability to meet the Districts defined goals for the updated watershed-wide model. These two important steps in the evaluation process are discussed separately in the Calibration and Model Scenario Analysis Memorandums, respectively.

APPENDIX D – MODEL CALIBRATION REPORT

2D Pilot Model Build
Model Calibration Report

Prepared by:

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Prepared for:

MINNEHAHA CREEK
WATERSHED DISTRICT
QUALITY OF WATER, QUALITY OF LIFE

Date:

April 2023

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Document History

Date	Version	Description of Change
March 2023	1.0	Initial Draft
April 2023	2.0	Revised Draft
April 19, 2023	3.0	Final

Definitions

- ArcGIS – a desktop and cloud solution provided by Esri for GIS analysis, storage, data management, and data processing
- Calibration - the process of checking a measuring instrument to a referenced standard. For the purpose of this project, the instruments are the ICM and ICPR models and the referenced standard is a measured watershed response condition. The process involves running the model to produce results that can be compared to known, measured, watershed responses and then adjusting the model physical structure and/or input parameters to a point where the model results are accurate when compared to one or more measured responses.
- DEM – Digital Elevation Model, represents ground surface in a grid (raster) format. Elevations are assigned to each individual grid cell
- GIS – Geographic Information System
- ICM – InfoWorks ICM software package developed by Innovyze to perform 1D and 2D hydrologic/hydraulic simulation modeling
- ICPR – Interconnected Channel and Pond Routing (ICPR) software package version 4 developed by Streamline Technologies to perform 1D and 2D hydrologic/hydraulic simulation modeling
- Shapefile – Spatial data file format that includes attribute data for individual shapes. May be in a point, line, polygon format and includes the file extension ".shp".
- Validation - process that provides assurance that a system (i.e., model) consistently provides results within the acceptable criteria. For the purpose of this study, validation refers to comparing the calibrated model results to other generally accepted model results or other watershed response conditions that do not have supporting measured data.

1 INTRODUCTION

The Minnehaha Creek Watershed District (MCWD or District) began the process to select a model platform for their upcoming watershed-wide build by completing a cursory assessment of the full range of two-dimension (2D) modeling software systems currently available. This screening-level assessment, along with vendor information sessions and consultation with agency experts, led the District to narrow their focus to ICPR and ICM. The District chose to pursue a pilot model build effort focusing on these two models in advance of the full watershed-wide build.

Previous memorandums prepared throughout the course of this pilot model build project have described the processes to prepare data and build the models and have demonstrated the need to develop a new modeling tool that has greater granularity to answer more specific questions, such as characterizing and quantifying the impacts of climate change. The District desires a model that can evaluate both low water and high-water conditions, along with the ability to evaluate event-based storms and longer-duration runs, to inform decisions relating to climate adaptation strategies, programmatic policies, and specific project impacts. In addition, the District desires to have a higher level of confidence that the results of a selected model will be consistent with (within some level of accuracy) the measured and monitored responses observed in the watershed. An important factor in gaining that confidence comes from having a model that can be calibrated to a known watershed response, or better yet, multiple known responses. The focus of this memorandum is on the calibration process for both models within the Edina geography and how the calibration process completed during this pilot model build can inform the expectations for calibration needs and model build efforts for the watershed wide model build. The models constructed for the Turbid-Lundsten corridor were not addressed during this calibration effort.

This memorandum provides an overview of input datasets, model build process, parameter manipulation, and challenges that were uncovered during the calibration process for each software package. The results of the calibration process have demonstrated that both models can be calibrated to within generally accepted calibration tolerances. The information obtained through the calibration process provides additional critical insight and data into the benefits and challenges each modeling platform presents relative to meeting the District's goals for selecting a watershed-wide modeling platform. The specific model versions used for this pilot model process were:

- ICM version 2023.2.0 with an unlimited license; and
- ICPR version 4.07.08 with an expert license.

2 CALIBRATION OBJECTIVES

The primary goal of calibrating the pilot study models is to further inform the model selection criteria and evaluation matrix. Characterizing each model's ability to replicate measured results and meet the defined calibration tolerance targets is a foundational step that builds confidence in their abilities to simulate future events and scenarios. Furthermore, determining the ease of use in terms of calibration and model adjustment is critical to the sustained usefulness of the model.

Recognizing that hydrologic and hydraulic models are mathematical representations of the physical environment, obtaining a calibrated model is highly dependent on the quality of the data the mathematical expressions use to produce model results. Because it is not possible to obtain all information and data on the actual physical environment, assumptions must be made to complete the model build process. These assumptions represent the physical conditions and qualities within the model and are defined as parameters that are defined and adjusted by the modeler. Changing the parameters allows for manipulation of the results until an acceptable output result is reached. Model calibration almost always requires the adjustment of one or more parameters to align the modeled outputs with the recorded/measured conditions.

Model validation is the process of backchecking the final calibrated model(s) against additional historical records (or other best available data). Typically, the information used in the validation process differs in intensity, timing, and/or length from the calibration events. For example, if the calibration was performed to monitored smaller rainfall depth storms, the validation events can be longer duration, high intensity, or seasonally different event. In general, the more diverse or wide ranging the intended uses of the model are, the more numerous and wide-ranging the validation events should be. In most cases, the reality is that validation process uses the best available data which may be from monitored events, other accepted models, or even photographs showing observed high-water levels for a known event.

2.1 Calibration Metrics and Tolerances

Before the calibration process was started, the project team evaluated potential calibration metrics and corresponding calibration tolerances to help guide when the calibration process reached an acceptable level of accuracy. Primary and secondary metrics are shown in **Table 1** and the calibration tolerances for each primary metric are shown in **Table 2**. The primary metrics of stage, R-squared, standard deviation, and continuity error are numerical results that can be pulled directly from the model or calculated from model outputs. Secondary metrics are essentially graphical observation of hydrograph plots. They represent visual observations of how well the model hydrograph matches the monitoring results. For this pilot study, observations include a visual comparison of how well the peak modeled elevation matches the peak monitoring elevation or the accepted/published flood elevation data for both models and how much the response changes for the ICPR model with and without the groundwater mesh in the model.

Table 1. Calibration Metrics

Category	Metric
Primary	R – Squared (Stage)
	Standard Deviation (Stage)
	Continuity Error (Volume)
	Stage Difference (Average, Peak)
Secondary	Groundwater Influence
	Flood Inundation Levels (Peak Stage)

The metrics listed in **Table 1** are further defined as follows:

- R – Squared represents the proportion of the variance between a modeled and measured value. High R-squared values represent a higher level of confidence in the results mimicking the observed system. For the model results in this pilot study, R-squared value is based on the model stage results.
- Standard Deviation relates to the differences in the stage (in feet) between the recorded monitoring data and model simulation results. The smaller the standard deviation value, the closer the simulated results are to the recorded data. A high standard deviation indicates the model results are more spread out compared to the recorded data.
- Continuity Error (Volume) is the total error that occurs within the simulation process due to non-convergence and estimation within the equations used to calculate stage and flow within a model. The continuity error is a measure of the total volume and due to computational processes in a model, takes the form of either additional volume that is introduced to the model area or a reduction of volume.
- Stage Difference. Stage corresponds to a measured water level in the pond, storage area, creek, or river. For the model results in this pilot study, stage is expressed in feet of elevation in the NAVD 88 vertical datum. The average metric is the average difference calculated over the full model run time and indicates whether the data overall are higher (positive result) or lower (negative result) than the average stage. We want to see both a lower standard deviation and a lower average stage difference. The peak value is the difference in the peak elevation for the full run time, where the peak model result may occur at a different time than the recorded peak.

The primary metrics are gaged against industry standard tolerances for calibration and validation of hydrologic and hydraulic models. The tolerances allow for comparison between modeled events and the corresponding recorded event data. Tolerances are used to determine the level of fitness to the recorded data. The tolerances that correspond to level of fitness for a calibrated model will shift depending on the length of the simulation, severity of the storm, and size of model. Generally, the longer duration, low-intensity storm events will require a higher level of fitness to be rated higher (i.e., Very Good) than a short-duration, high-intensity storm event. **Table 2** outlines the sliding scale of fitness that was applied to the modeled results for the long duration events. A search for comparable tolerances for short-duration events did not yield usable information. Using the long-duration tolerances for the short-duration events provides a conservative fitness rating for the short-duration events.

Table 2. Primary Metric Calibration Tolerances for Long-Duration Events

Metric	Rating	Tolerance Level	Description
R - Squared	Poor	0.60	A higher RSQ signifies that as the recorded data increases in value, the simulation data also increases in value, and increases at a similar magnitude.
	Fair	0.70	
	Good	0.80	
	Very Good	0.90	
Standard Deviation	Poor	2.0 ft	The smaller the standard deviation value, the closer the simulated results are to the recorded data on average. If the simulated data fit the recorded data stage hydrograph perfect, the resulting standard deviation would be 0.0.
	Fair	0.5 ft	
	Good	0.1 ft	
	Very Good	<0.1 ft	
Continuity Error	Poor	> 5%	Lower continuity error totals indicate model stability, smaller volume addition/loss, and improved simulation times.
	Fair	2% – 5%	
	Good	1% – 2%	
	Very Good	< 1%	
Stage Difference	Metrics are reported as Average and Peak.		As the stage difference reduces to a value of 0.0 feet, the recorded and modeled hydrographs become aligned to a greater degree. Both metrics are to be evaluated in combination with the other factors, with more emphasis on having a smaller average stage difference and lower standard deviation to represent a tighter overall fit between modeled and recorded data.

3 CALIBRATION PROCESS

Success of a calibration effort is largely based on the availability of known results (i.e., recorded data) as a basis for model adjustments. The larger and more robust recorded datasets allow for a tighter calibration effort to be completed. The recorded data availability for the Edina subwatershed includes groundwater stage-time series data, Mill Pond outlet stage-time series data, Mill Pond outlet flow-time series data, 56th Street stage-time series data, and 5-minute (and select 1-minute) interval rainfall data for 2021 and 2022. Typically, model calibration is done using relatively small rainfall events as these are more common and a sufficient period of recorded data is available from which to base the calibration on.

The recorded data was used to create inflow hydrographs at the upstream limits of Minnehaha Creek in the pilot model and rainfall hyetographs for the various storm events. The storm events included a July 2022 event (6 days), a Sept 2021 event (1.6 days), and the Summer 2021 event (77 days). Other published or accepted model results were reviewed and used as additional validation runs, including the city of Edina localized flood inundation mapping from the city's XPSWMM model and the FEMA Base Flood Elevations (BFEs). These results are discussed within the subsequent scenario analysis technical memorandum.

3.1 Approach

The same general process was followed while calibrating both models. An overview of the calibration approach is provided below:

Step 1: Evaluate Base Model Performance

Calibration starts with understanding the correlation between the recorded data and the modeled results. The selected calibration events are run through the base model. Generally, discrepancies in runoff and discharge volumes have different origins than a discrepancy in high water levels. Understanding the basis of where the discrepancy is coming from is the first step to an efficient model calibration and validation process. The calibration datasets are needed to compare the pilot study model runs against recorded data. These datasets for river calibration need to include rainfall, downstream stage, and upstream inflow hydrographs. Additional stage and flow datasets throughout the study reach are beneficial to determine calibration quality and variability at multiple points along the river or creek reach.

Step 2: Adjust Physical Components

Incorporating better base physical watershed data (surface and infrastructure) should be the first consideration during the calibration process. Large discrepancies observed in step one is a strong indication that physical improvements to the model are likely needed. Updates to any surface feature, such as refined channel geometry, requires additional review of breaklines and mesh refinement to verify that they continue to represent the features that are hydraulically important within the model area. A shift in a channel thalweg that is not adjusted for correctly can remove the expected detail due to incorrect breakline placement based upon the new surface data. When breaklines and mesh refinements are done correctly, they can also reduce continuity errors within the model runs and reduce model run times by reducing convergence error occurrence.

Step 3: Revaluate the Physically Adjusted Model's Performance

Once physical updates have been made to the model, a rerun of the simulation should be performed to determine the effect of better data on the modeled results. The physical updates can change the watershed response in many ways. Areas of inundation may appear or be reduced, and flow rates and flow paths can change drastically. The modeled results should be compared to the recorded data to determine the effect of the physical model updates and whether bias or performance issues still exists.

Step 4: Model Parameter Adjustment

If additional calibration is required, the next phase is to review the scale at which the calibration adjustments need to be made. If the modeled results match the curve of the recorded hydrograph but are off vertically, then an adjustment of the roughness values may be required to better match the recorded data. If the modeled results don't match the gaged hydrograph or are off by multiple feet, then a review of hydrologic parameters may also be required to better match the gaged data. There is a subset of model parameters that are typically utilized during calibration, which include:

- Hydraulic Parameters: Channel and Overland Roughness (Manning's n), Land-use delineations, Porous Polygons (Building Footprint Representation);
- Hydrologic Parameters: Initial Moisture Content, Hydraulic Conductivity (maximum and minimum), Pore Storage Volume (ICPR Only), Impervious Percentage;
- Groundwater Parameters (ICPR Only): Fillable Porosity, Hydraulic Conductivity, Leakage Conductivity.

Calibration of a model based on input parameters is typically accomplished through multiple iterations to gauge the effectiveness of the changes to the desired model output. It is not recommended to adjust multiple parameters during a single calibration run due to the general lack of knowledge during the result review process of which parameter facilitated the corresponding change in results. Changes to the soil parameters should be taken with caution as changing the hydrologic parameters may be adjusting for hydraulic differences that are not being represented within the model correctly. For example, if the depressional storage areas in the model are not being represented due to lack of detail in the elevation dataset or the 2D mesh, then adjustment of the infiltration parameters to include more infiltration will have a similar result in detaining runoff from the downstream system. However, when the storm event changes, the amount of infiltration that occurs will vary and may not represent the localized depressional storage that the parameter was originally adjusted to represent, and the calibration will be inaccurate. Adjustment of the infiltration parameters needs to be done with caution and an understanding of the overall system response.

Step 5: Documentation

All physical and parameter adjustments within the final model version should be documented to provide a clear picture of: (1) where the model initially struggled to meet recorded data; (2) what adjustments were made to bring the modeled results closer to measured; (3) what limitations or bias remains; and (4) recommendations for additional calibration efforts in the future.

4 CALIBRATION RESULTS AND DISCUSSION

The calibration of both software packages starts with an evaluation of the base model's performance against the measured data. Discussion in the next three subsections details the refinement and additional updates that were completed to achieve models calibrated to within the desired tolerance ranges.

4.1 Base Model Evaluation

The base model development used the infrastructure and spatial data that was created as part of the automated data development process. These datasets included pipe, structure, outlet, land use, soils, and elevation information. The automated data development processes used standard values for their outputs and included data gap filling for the infrastructure datasets. A single breakline was incorporated into both ICM and ICPR along the channel bottom of Minnehaha Creek to align the adjacent cells with the flow direction. Initial water surface elevations in the ponds and wetlands in the northern portion of the Edina Subwatershed were set based on aerial imagery and MnDNR data, where available.

The 77-day calibration event was run through the base model for ICPR and ICM. The modeled results for ICM and ICPR reflected results that were substantially higher than the gaged data as illustrated in **Figure 1**. ICM was able to simulate the increases and decreases of flow and stage within the creek but at a higher elevation while ICPR experienced extreme amounts of continuity error and was not able to represent the general hydrograph curve.

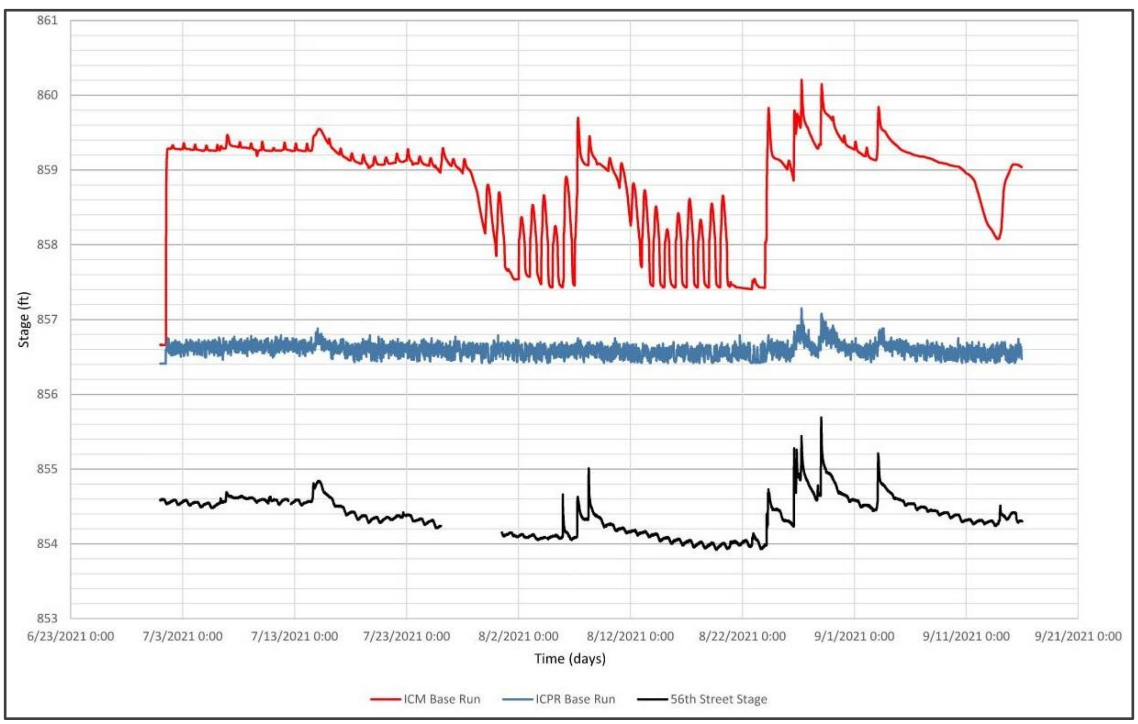

Figure 1. Base Model Comparison

The differences between the modeled and measured results within ICM and ICPR indicated that physical corrections to both models were possibly needed since there wasn't a practical way to reach the measured results through parameter adjustments. **Figure 2** shows the relationship between the ICPR mesh elevations and the DEM elevation when the cell sizes are too large to represent the flow capacity of the creek channel. The ICPR model overestimates the size of the channel while underestimating the elevation of the corresponding node. In this case, the lack of resolution within the 2D mesh allowed for an overestimation of lower elevation channel flow capacity. The location of the creek section shown in the graph is represented as a red line that crosses the creek channel perpendicular. Each step along the ICPR line represents the corresponding elevation that ICPR uses to perform the calculations. The result of this overestimation is the lack of response within the stage hydrograph from ICPR during the base model run.

The base model development used the best available data that could be incorporated through an automated process. However, the lidar data that was used to develop the elevation dataset was originally taken in 2011. In addition, the process of gathering the lidar points does not allow for elevations below a water surface to be obtained. This means that areas that contain water are set at the elevation of the water surface at the time the lidar data was collected, not at the bottom of the channel or pond. The effect of this is that a channel or storage area may have more depth, and therefore more volume capacity, when compared to conditions represented in the lidar data. The result is often a higher inundation level than the known or measured elevation since the model does not have the actual storage capacity for the runoff volume. Knowing this limitation LiDAR, in combination with the modeled results, it was deemed necessary to reconstruct the geometry of the channel and floodplain using alternative datasets.

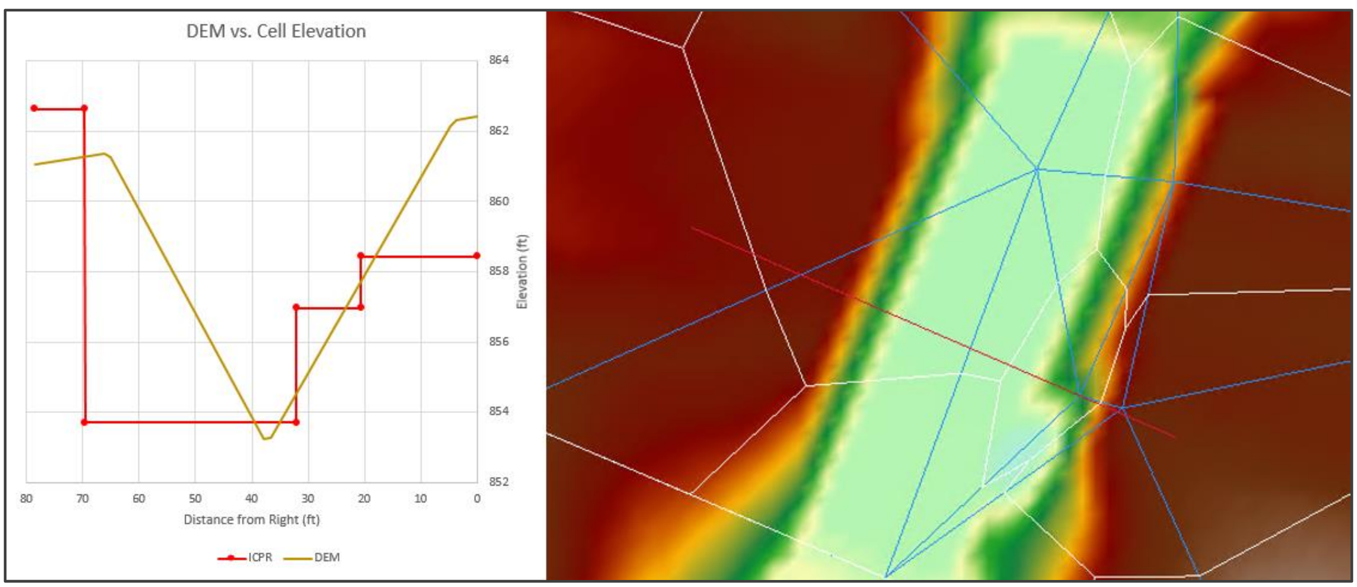

Figure 2. ICPR Mesh Comparison

Cross-sections for segments of the Creek were pulled from the District's current XP-SWMM model. Cross-section profiles were digitized as points across the channel, with the lowest elevation placed at the Creek centerline. These point profiles were repeated along the general length of the Creek as indicated by the XP-SWMM cross-section link.

For the Arden Park area geometry, the as-built elevation survey that was previously created as part of the District's work at Arden Park in the past 5 years was used to create the basis for the terrain. Elevations were captured both on land and at multiple transects across the creek. These elevation points were used to generate a TIN, which was combined in the TIN generated from XP-SWMM cross-sections. Some final clean-up of the combined cross-sectional and TIN surfaces was done to remove areas of incorrect triangulation during the meshing process. This final updated TIN was overlaid on the original lidar surface for the remainder of the Edina subwatershed model.

The impact of the modified terrain on the modeled results is described in the model specific calibration sections below.

4.2 ICM Calibration

Table 3 includes a summary of the primary metric results starting from the base model through progression of the calibration process. **Figure 3** provides a visual for the reported calibration event progression. Significant steps in the calibration process are summarized in the following paragraphs.

Table 3. ICM Long Term Run – Tolerance Results

ICM Long-Duration Event	R-Squared (Stage)		Standard Deviation (Stage)		Continuity Error (Volume)		Stage Difference (ft)	
	Value	Rating	Value (ft)	Rating	Value (%)	Rating	Avg.	Peak
Base	0.62	Fair	0.497	Fair	-0.04	Very Good	4.45	4.50
Terrain Modification	0.81	Good	0.113	Good	-0.01	Very Good	0.54	0.62
Mesh Refinement	0.78	Good	0.128	Good	-0.09	Very Good	-0.18	-0.04
Final	0.85	Good	0.138	Good	-0.07	Very Good	0.05	0.61

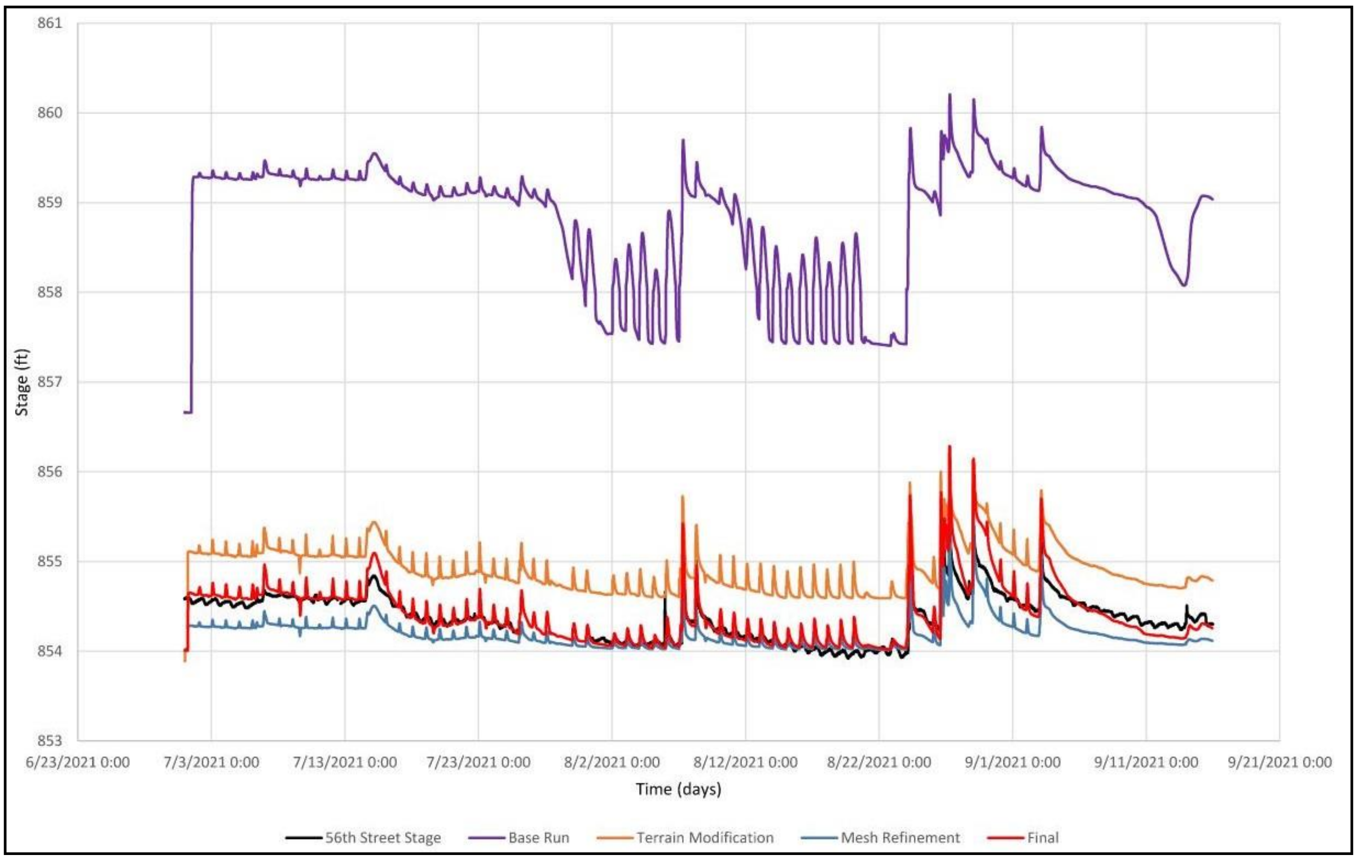

Figure 3. ICM Long Term Run – Calibration Steps

Terrain Modification: The modified-terrain version reduced the stage discrepancy to an average of 0.5 feet higher during the 77-day run, which was a substantial improvement from the base model that was 4.5 feet higher on average. The terrain modification also reduced the peak stage discrepancy between simulated and recorded data to 0.6 feet from 4.5 feet for the Base run. As part of the new terrain inclusion, a new breakline was delineated along the creek centerline to align the 2D mesh to flow downstream. The next step was to refine the mesh to increase the tolerance ratings shown in **Table 3**.

Mesh Refinement: The lowering of the minimum mesh element size was completed next as part of the ICM calibration process. The minimum mesh element size was reduced from 200 square feet to 20 square feet. The 20 square feet introduced excessive run times (30 hours). This was due to small mesh elements being located within the main channel bed of Minnehaha

Creek. The minimum mesh size was increased to 50 square feet. This increase continued to allow for additional detail along the banks of the creek and floodplain to be captured and represented more accurately while resulting in similar stage results along the section and reducing run times for the simulation to around 12 hours (similar to Base and Terrain Modification runs). The R-Squared results reduced slightly but remained within the good rating while the average and peak stage results decreased significantly.

Final: The final step of the ICM calibration process included the adjustment of Manning's n roughness values. The values were increased from the standard to the higher values for the land-use types. This was done to increase the stage results within the creek. The results from the final adjustment increased the baseflow to be in line with the recorded data to a closer degree as shown in **Table 3**. The R-Squared value increased while the average stage difference decreased. The peak stage difference did increase back to 0.6 feet similar to the Terrain Modification run. Through all the simulation runs, the continuity error for ICM remained at Very Good rating level. **Table 4** lists the revisions to input parameters that were adjusted as part of the calibration process within ICM and ICPR. Within ICM, only the shallow and deep Manning's n values were adjusted from the initial values to the final values in **Table 4** as part of the final calibration step.

Table 4. Revised Parameters (Initial vs. Final)

Landuse		Impervious[1]		Shallow Manning's n		Deep Manning's n	
Code	Description	Initial	Final	Initial	Final	Initial	Final
100	Agricultural	0.00	0.00	0.100	0.100	0.070	0.090
111	Farmstead	0.00	0.12	0.050	0.050	0.050	0.050
113	Single Family – Detached	0.10	0.25	0.050	0.065	0.030	0.050
114	Single Family – Attached	0.10	0.38	0.040	0.065	0.030	0.050
115	Multifamily	0.50	0.65	0.040	0.060	0.030	0.040
120	Retail/Commercial	0.85	0.85	0.030	0.045	0.030	0.030
130	Office	0.85	0.85	0.030	0.045	0.030	0.030
141	Mixed Use Residential	0.50	0.85	0.030	0.045	0.030	0.030
143	Mixed Use Commercial	0.50	0.85	0.030	0.045	0.030	0.030
151	Industrial	0.50	0.72	0.035	0.060	0.030	0.040
160	Institutional	0.00	0.30	0.040	0.065	0.030	0.050
170	Park/Open Space	0.00	0.00	0.080	0.100	0.050	0.080
173	Golf Course	0.00	0.00	0.060	0.090	0.040	0.060
210	Undeveloped	0.00	0.00	0.090	0.100	0.080	0.090
220	Open Water	1.00	1.00	0.030	0.045	0.030	0.030

1. ICPR model adjustment only.

4.3 ICPR Calibration

Table 5 includes a summary of the primary metric results starting from the base model through progression of the calibration process. **Figure 4** provides a visual for the reported calibration event progression. Significant steps in the calibration process are summarized in the following paragraphs.

Table 5. ICPR Long Term Run Calibration Results

ICPR Long-Duration Event	R-Squared (Stage)		Standard Deviation (Stage)		Continuity Error (Volume)		Stage Difference (ft)	
	Value	Rating	Value (ft)	Rating	Value (%)	Rating	Avg.	Peak
Base – GW	0.30	Poor	0.212	Good	-16.1	Poor	2.22	1.48
Terrain Modification	0.87	Good	0.130	Good	-7.69	Poor	-0.29	-0.47
Mesh Refinement	0.86	Good	0.094	Very Good	+3.36	Fair	-0.09	-0.42
Impervious	0.83	Good	0.106	Good	+1.24	Good	-0.29	-0.30
Final	0.83	Good	0.103	Good	+1.46	Good	-0.26	-0.18

Terrain Modification: The modified-terrain version reduced the stage results to an average of -0.29 feet lower than the Base Run model during the 77-day run, which was a substantial improvement to the base model that averaging 2.22 feet higher. The terrain modification version also increased in R-Squared value and rating while the continuity error remained extremely high and poor in rating. The continuity error was a key issue that helped drive the success of the overall calibration effort while reducing the uncertainty of the results with the continued reduction in continuity error. One additional note on the Terrain Modification version is that while the visual fit of the model results shown in Figure 4 are the best fit to the actual monitored data, the continuity error rating required additional work to move the calibration metrics into an acceptable range.

Mesh Refinement: Refining the mesh was the next step at calibrating the ICPR model. Breaklines were added to the creek and overbank areas, where most of the error was occurring. It is critical in ICPR for the triangular base mesh to be oriented so that the faces of the triangular mesh align with flow direction. To align the edges of the triangular mesh with the flow direction, multiple breaklines were used to contour the mesh to the flow direction. This contouring is illustrated in **Figure 5** as well as the general increase in mesh cell refinement. The left image shows the original 2D mesh with the single breakline along the thalweg of the creek. The right image shows the refined mesh with the breaklines shown in red. The refined mesh has more cells, and they are better positioned to transition flow from upstream to downstream and across the floodplain area. Breakpoints were added flowing the breakline delineation in the overbank areas to mitigate triangulation issues between the refined area in the creek and the original mesh density outside of the creek channel. The inclusion of additional breaklines and breakpoints reduced error by an additional 63% from the updated terrain version. The mesh refinement also reduced the average stage difference to -0.09 feet while the peak stage difference reduced slightly when compared to the Terrain Modification model run. Graphically, the stage results in the creek decreased at the gaging location when compared to the Terrain Modification model run. The next step was to increase flow to the creek within the subwatershed with an increase in impervious values.

Impervious: The next step to increase the impervious value included adjusting the impervious values from the standard values to the higher-end values. This was done to facilitate additional runoff from infiltrating and instead runoff to the creek. The increase in impervious values increased the average stage difference while lowering the peak stage difference to -0.30 from -0.42 feet. The reduction in peak stage difference is due to the flashy or direct runoff nature of the subwatershed to the creek during an intense rainfall event versus the increase in average stage difference is due to a reduction in baseflow entering the creek channel from the groundwater portion of the model. The difference was surprising and was noted in the following Constraints and Future Recommendations section of this memo. To increase the stage levels in the creek, the Manning's n roughness parameters were increased next. **Table 4** lists the increase in impervious levels within ICPR as part of this step within the calibration process from the initial values to the final values for each land use type.

Final: The final step from the calibration was to increase the Manning's n roughness values. This was done in a similar manner to the ICM calibration process. The standard Manning's n values were increased to the corresponding high values to simulate increased resistance to flow and a higher stage in areas of flow. By increasing the roughness values, the water should move at a slower rate within the channel and increase in stage. The change in elevation resulting from the adjusted n value was minor compared to the desired result while the overall stage results remained within the acceptable range for the calibration process. The R-Squared value remained the same from the Impervious model run but the average stage difference decreased slightly, and the peak stage difference reduced by 60% as shown in **Table 5**. **Table 4** lists the increase from initial to final values for the Manning's n parameter. The increase from initial to final values were the same for both the ICM and ICPR models.

As a follow-up to the discussion in the Terrain Modification section, while the numeric values and rating of the calibration metrics all fall within the acceptable range, the visual fit of the Final version results shown in Figure 4 is clearly not as good as the visual fit of the Terrain Modification curve. We expect that in a full model build process, the visual fit could and would be improved through additional calibration adjustments.

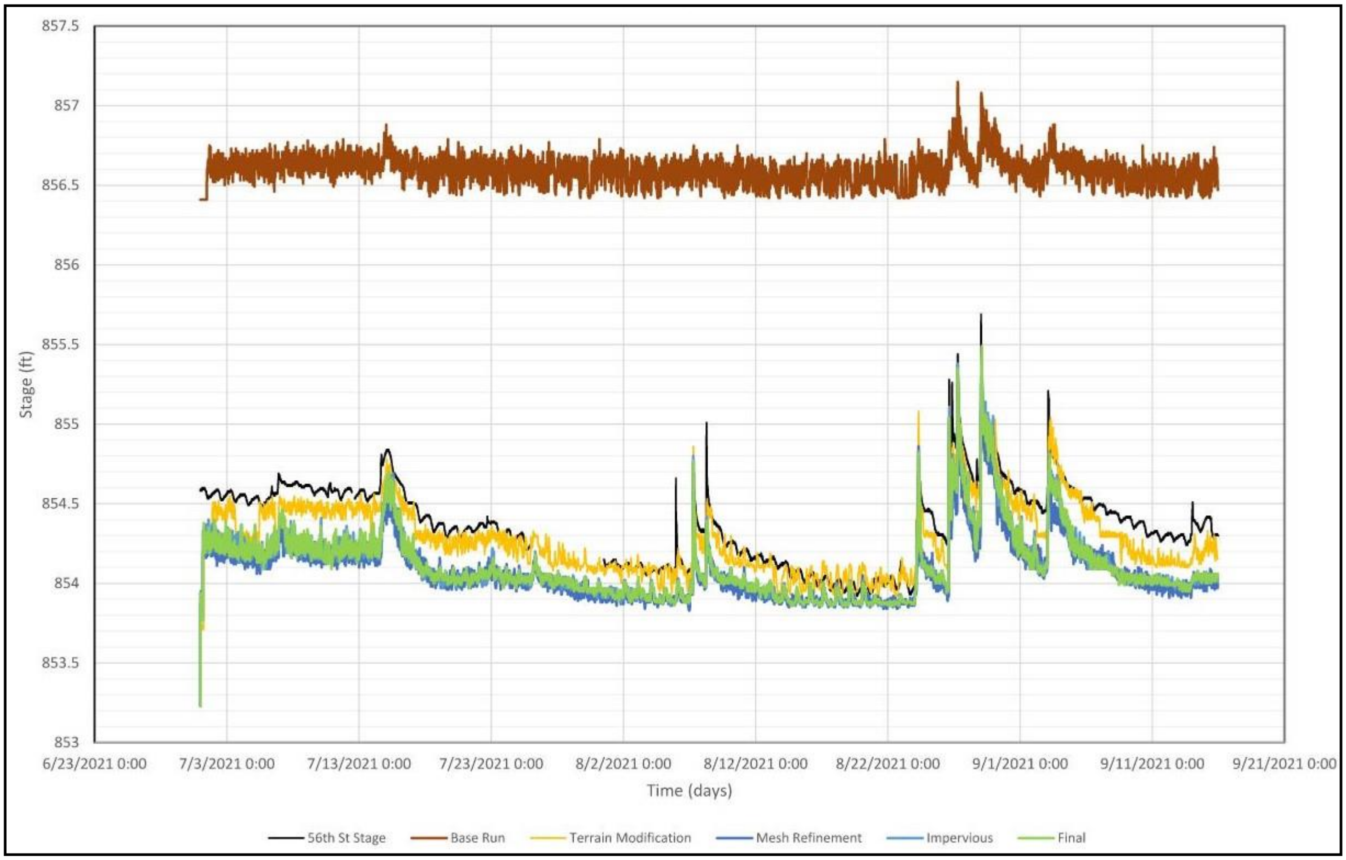

Figure 4. ICPR Long Term Event Calibration

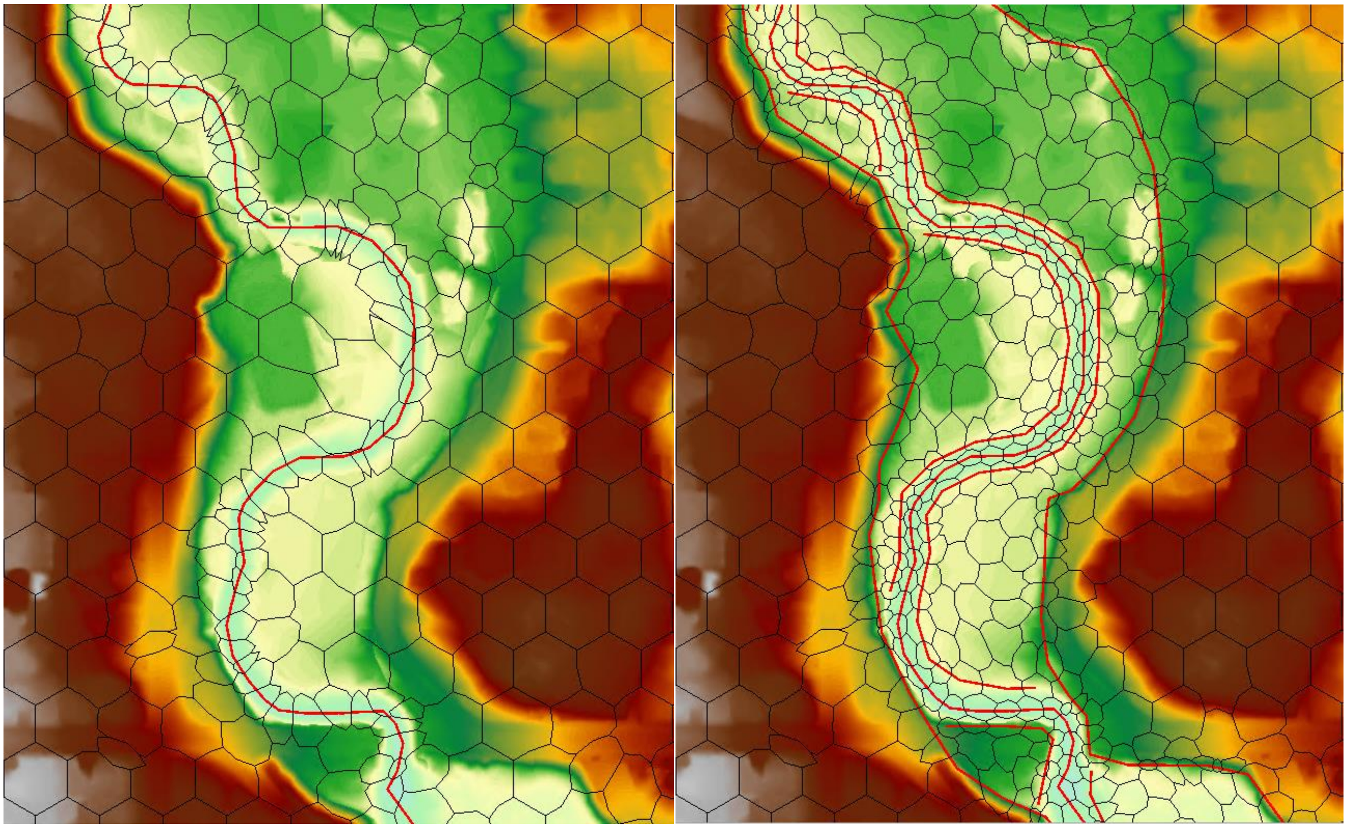

Figure 5. ICPR Mesh Refinement

4.3.1 ICPR Groundwater Component

ICPR's ability to model 2D groundwater mesh is a distinguishing feature from other 2D H&H models. To better understand the level of influence the groundwater component plays within the software, a non-groundwater version of the model was maintained to gauge the differences in results between the groundwater and non-groundwater versions. **Figure 6** illustrates the final differences between the groundwater and non-groundwater ICPR model versions. The largest discrepancy between the two versions is the two time periods during the month of August 2021 where the creek flow drops to zero in the non-groundwater version. The groundwater version demonstrates baseflow conditions within the creek during these periods of limited inflow upstream. The creek stage levels are also slightly higher with the groundwater version than the non-groundwater version. The groundwater component allows for transfer for infiltrated water back into the overland mesh during times of minimal flow in the creek.

During the calibration process, adjusting some parameters may have an adverse effect on the results than what was desired. This phenomenon was seen during the calibration of the ICPR model. Typically, increasing impervious values within the runoff portion of the model results in additional flow in the downstream receiving water body. There was a slight lowering of the downstream stage when the impervious values were increased within ICPR. This was theorized to be due to the groundwater module within ICPR. In a strictly 2D overland model, any water that is infiltrated into the ground is lost from the simulation. In ICPR with the groundwater module, the infiltrated water is allowed to accumulate and flow back into the overland system during times of low flow/stage within the creek. By increasing the impervious parameter in ICPR, the groundwater system was not able to recharge to the same degree as previously seen in earlier model runs. The resulting stage levels downstream were lower than previous iterations and had the opposite effect than anticipated.

The groundwater influence is greater during long-duration simulations than short-duration simulations. This is due to the relatively long time for groundwater to travel through an area versus surface water. The groundwater influence also becomes more pronounced during extended periods of wetness and drought. A high-groundwater table limits the amount of water that can be infiltrated during future rainfall events. A predefined groundwater initial water surface can be defined within ICPR to mimic high and low groundwater levels for short duration events. Additionally, the groundwater module can be used to calibrate a model further but also introduces additional dials to turn. Having a strong understanding of how a system work is key before beginning to calibrate a model, the groundwater system is typically very difficult to understand at a small scale but can be represented well at a large scale. This means that analyzing scenarios to determine the effects of groundwater at a parcel/site scale may not be appropriate given the quality and robustness of the groundwater data that the results are based on but determining effects at a regional or larger scale may be appropriate.

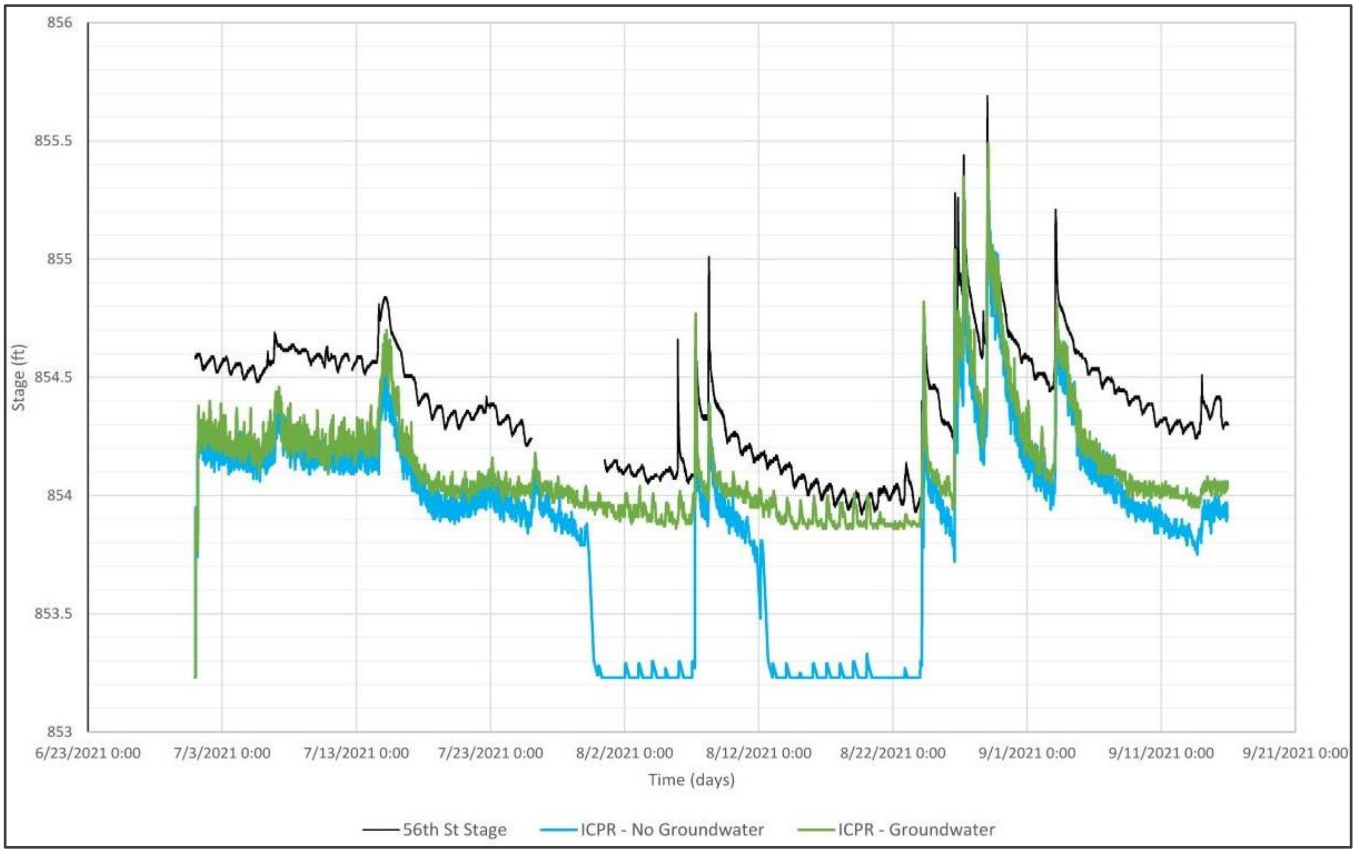

Figure 6. ICPR Groundwater Influence

5 COMPARISON AND CONCLUSIONS

As a core objective of the pilot model, it is important to compare the modeled results of ICM to ICPR and call attention to major differences. **Figure 7** shows the 77-day simulation for both calibrated models, **Figure 8** shows the September 2021 simulation results, and **Figure 9** shows the July 2022 simulation results. Both ICM and ICPR models shown on **Figures 7, 8, and 9** represent the final model versions that were developed through the calibration process. Throughout the calibration process, ICM remained generally above the recorded data at the 56th Street gage location. The baseflow followed the rising and falling sections of the hydrograph but the peaks during the individual rainfall events overestimated the increase in stage. This was seen in **Table 3** as the average stage difference reduced throughout the calibration process, but the peak stage results were overestimated continually. This trend continues in **Tables 5 and 6** where ICM continually overestimated the stage results in the short-term events as well. ICPR remained generally below the recorded data for the long- and short-term events as shown in **Tables 4, 5, and 6**.

ICM draws down at a slower rate after a peak stage than the recorded data and ICPR draws down much quicker than the recorded data. ICM also appears to drawdown at a consistent rate, where ICPR has a high degree of noise and doesn't seem to draw down in a natural manner. This noise, in contrast to ICM's smooth results, can make it difficult to interpret what is happening precisely.

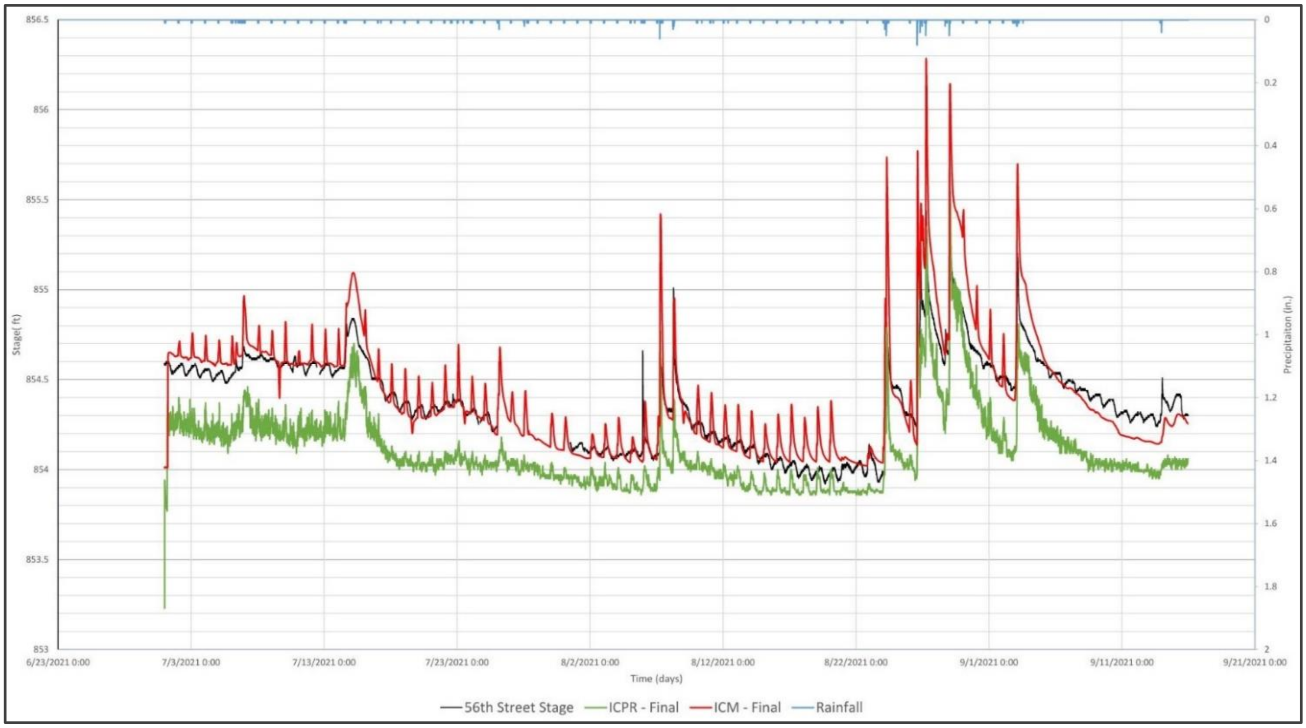

Figure 7. ICM – ICPR Long Term Stage Comparison

Table 6. September 2021 – Model Comparison

September 2021 Event	R-Squared (Stage)		Standard Deviation (Stage)		Continuity Error (Volume)		Stage Difference (ft)	
	Value	Rating	Value (ft)	Rating	Value (%)	Rating	Average	Peak
ICM – Final	0.680	Fair	0.351	Good	+0.06	Very Good	0.06	0.43
ICPR – Final	0.559	Poor	0.287	Good	-1.55	Good	-0.35	-0.43

Table 7. July 2022 – Model Comparison

July 2022 Event	R-Squared (Stage)		Standard Deviation (Stage)		Continuity Error (Volume)		Stage Difference (ft)	
	Value	Rating	Value (ft)	Rating	Value (%)	Rating	Average	Peak
ICM –Final	0.894	Good	0.168	Good	-0.01	Very Good	0.23	0.23
ICPR – Final	0.901	Very Good	0.106	Good	+0.77	Very Good	-0.15	-0.22

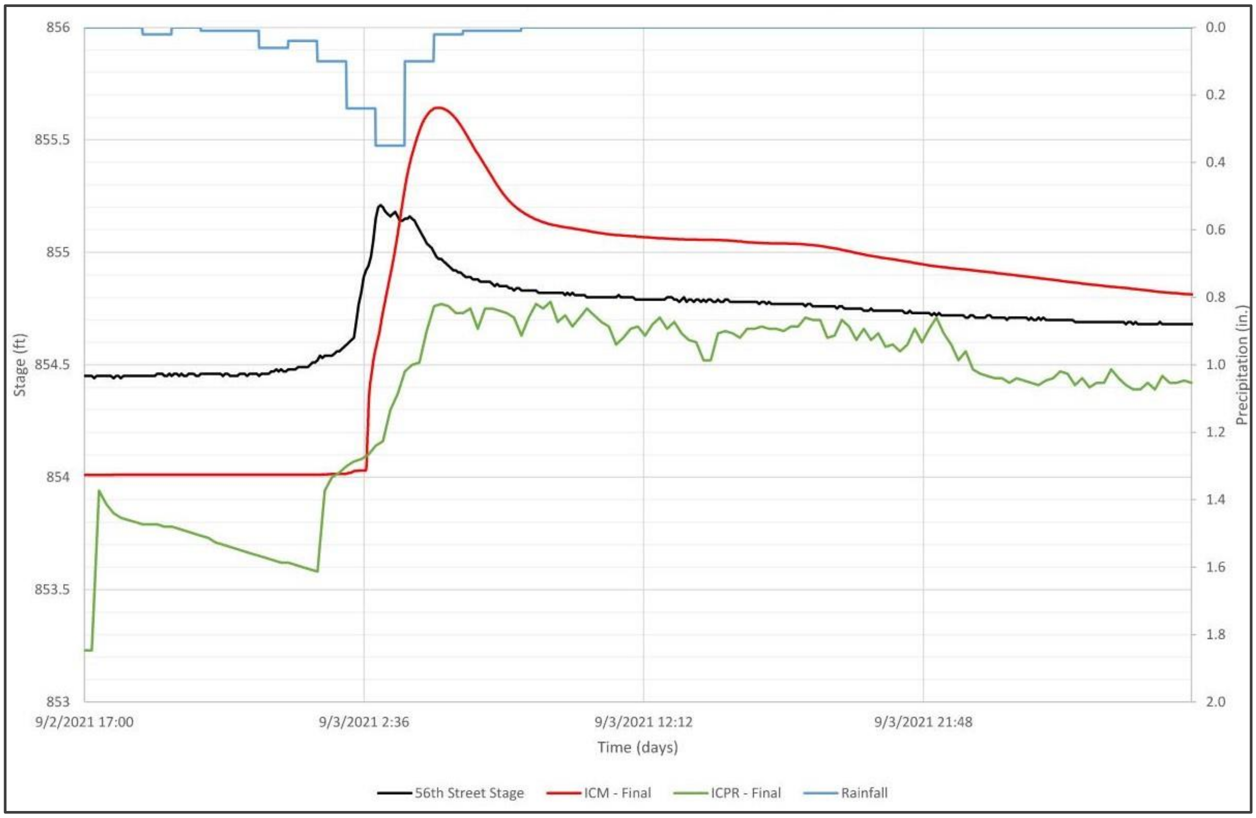

Figure 8. September 2021 Stage Comparison

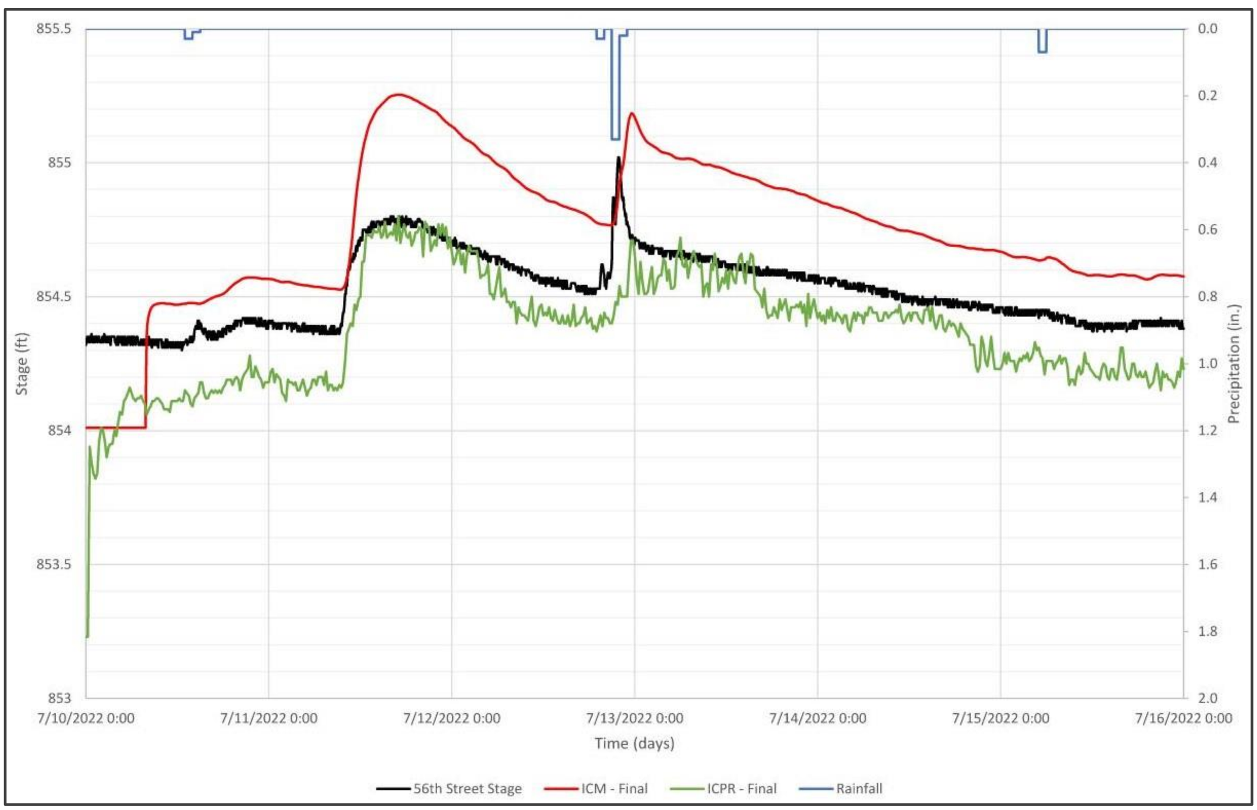

Figure 9. July 2022 Stage Comparison

6 CONSTRAINTS AND FUTURE RECOMMENDATIONS

Modeling constraints and in-depth understanding of the hydrologic and hydraulic system being modeled are uncovered during the calibration process. The effect of changing parameters and the magnitude of the changes is tracked to determine the best tools to perform the calibration. Through the pilot model's calibration efforts, four key constraints were observed and should be considered as the District scales to the watershed-wide build. These include:

1. Accuracy and Resolution of Terrain Data

   The largest constraint to developing a 1D-2D hydrologic/hydraulic model for extreme event analysis is the quality (or lack of) of the terrain information. Terrain files can be generated from survey data points, lidar files, contours, and a combination of all three. Each terrain data source has issues that are particular to the individual source.

Table 8. Strengths and Weaknesses of Elevation Data Sources

Terrain Source	Strength	Weakness
LiDAR	Very high resolution	Unable to penetrate and represent below water storage
Survey Data	Ability to direct and fill elevation gaps where needed	Collected by surveyor discretion; manually intensive
Contours	Fill storage gaps that LiDAR can't represent	Can miss critical hydraulic structures; often not readily digitized/accessible

   Understanding and using all three versions of terrain information will be key to developing large-scale accurate hydrologic and hydraulic models. The importance of this dataset was exemplified during the pilot model calibration when the inclusion of surveyed cross-sections and project as-built data greatly improved stage accuracy. During the watershed-wide model build process, it is critical that the best elevation information be used. This may require additional survey and elevation data to be obtained either through manual processes or partnership with individual agencies throughout the watershed to gather the required data. Channel and pond cross-sectional area will aid in the development of stage-area storage relationships for use with 1D objects or manipulations of the terrain surface to represent the storage within the 2D mesh.

2. Resolution of Monitoring Stations

   Additional monitoring station data will be critical to the future calibration of the watershed-wide model build. Increasing the density and accuracy of the recorded data will allow for greater accuracy of the calibration process. Adjusting parameters to meet a single comparison point is valuable to understanding the sensitivity of the model in general and match results at the single location but overestimation of input parameters may occur. When the overestimation of a parameter occurs to match a single calibration point, a change in storm intensity or length can lead to large discrepancies in the results. It's understood that the District is in the process of implementing its real-time sensor network that is designed to collect continuous water-level and flow from critical locations throughout the watershed. This data source will be extremely useful to aid in watershed-wide calibration.

3. Range of Calibration Events

   The bulk of the available monitoring data was collected during the 2021 and 2022 open water seasons. Typically, two years of data provides a range of creek flows and responses to varying rainfall events (small, medium, large events). However, both 2021 and 2022 were drier than normal years for MCWD. In fact, most of 2021 the watershed was under moderate drought designation, with an extreme drought designation reached in the fall of 2022. The precipitation events from 2021 and 2022 were minor events when compared to overall design storms in terms of rainfall depths and intensities Calibrating a model to either extreme (drought or flood) can pose unique challenges.

During extreme events, debris may enter the flow paths and clog inlets to storm sewer and culverts, the spatial variability of rainfall is typically much higher, deeper water typically flows much faster than shallow water.

For the watershed-wide build, there ideally will be access to monitoring data that spans a wider range of water-level conditions. This is clearly outside anyone's control, but longer periods of record should help yield a variety of conditions to reference.

4. Vertically Varied Parameters

   Within ICM, the Manning's n roughness coefficient can be varied up to three times depending on the depth within a cell. Within ICPR, the Manning's n roughness coefficient can be varied twice (shallow and deep). Both models allow for changes to the roughness values at each inundation level and changes to the inundation level breakpoints by roughness zone. The flexibility to adjust the parameter and level allows for a higher degree of calibration. Manning's n roughness values are reported as typical ranges that are applied to specific landuse categories. These ranges can be significant and should be reviewed for having representative values for the areas in the model. These are helpful when flow depth varies greatly during the simulation timeframe. As the depth of flow increases, the effects of friction on the flow velocity decreases. Developing the transition depths between low depth and high depth Manning's n values can further calibrate the model to various storm intensities and flood events.

   ICPR allows for soils layers (and associated infiltration parameters) to be varied vertically. The infiltration parameters are the same as the Green-Ampt parameters with the addition of layer thickness and cells per layer. The use of vertical layers for infiltration allows for specification of known variability as soil depth increases. This can be beneficial when a clay layer is known. The drawback to this approach is the relatively high input data requirement. Typically, soil borings are needed to verify soil depths and associated infiltration parameters to accurately model infiltration using vertically varied parameters. This may be beneficial for smaller areas of interest within the watershed-wide model build but may become inefficient when scaling to the full watershed-wide model build.

While the calibration process allows for additional confidence in the modeled results to be gained, the process is never truly finished. The calibration process can be reevaluated at any point for either model developed through the 2D Pilot Model Project if additional monitoring data is obtained.

APPENDIX E – SCENARIO MODELING REPORT

2D Pilot Model Build
Scenario Modeling Report

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MINNEHAHA CREEK
WATERSHED DISTRICT
QUALITY OF WATER, QUALITY OF LIFE

Date:

May 2023

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Document History

Date	Version	Description of Change
December 2022	1.0	Initial Draft
April 2023	2.0	Revised Draft
May 2023	3.0	Final Draft
May 2023	4.0	Revised Final Submittal

Definitions

- ArcGIS – a desktop and cloud solution provided by Esri for GIS analysis, storage, data management, and data processing
- DEM – Digital Elevation Model, represents ground surface in a grid (raster) format. Elevations are assigned to each individual grid cell
- GIS – Geographic Information System
- ICM – InfoWorks ICM software package developed by Innovyze to perform 1D and 2D hydrologic/hydraulic simulation modeling
- ICPR – Interconnected Channel and Pond Routing (ICPR) software package version 4 developed by Streamline Technologies to perform 1D and 2D hydrologic/hydraulic simulation modeling
- MetroGIS (MGIS) – a GIS format designed for use by Twin Cities Metropolitan-area municipalities for the standardization of infrastructure data
- MSE – Midwest and Southeast states, used in the NRCS Rainfall Distributions
- Geodatabase (GDB) – GIS file and data format that allows for standardization and template creation
- File Storage – cloud or physical file storage location utilized as a central repository for raw, input, and output datasets
- Shapefile – Spatial data file format that includes attribute data for individual shapes. May be in a point, line, polygon format and includes the file extension ".shp".
- Scenario – Updates to a model that represent a past or future condition to simulate conditions

1 INTRODUCTION

The Minnehaha Creek Watershed District's (MCWD or District) current modeling tools are dated and do not provide the granularity and features necessary for the District to effectively manage and adapt to climate change. District staff identified the need to develop a new modeling tool that has greater granularity that can characterize and quantify the impacts of climate change and evaluate a range of scenarios to shape climate adaptation strategies, programmatic policies, and specific projects.

The District chose to pursue the pilot model build ahead of the watershed-wide build, to mitigate for the relational and technical risk that is often associated with large-scale, high-resolution models such as selecting the right software for the intended use. The pilot model compares two modeling platforms, ICM and ICPR, which were chosen based on findings from an initial screening of available two-dimensional models. A key step within the project is conducting various scenario and model runs to help evaluate and understand the strengths and weaknesses of each platform.

This memorandum provides an overview of the selected model runs, results, and learnings. Three categories of model runs were conducted, each aimed at learning something different about the two platforms. The objective of each category is described below:

- **Rainfall Scenarios**: These runs look to compare the results of ICM and ICPR to identify where we see differences and whether observations seen during calibration hold consistent in other areas of the watershed and under a wider range of rainfall conditions.
- **Geospatial Scenarios**: These scenarios look to reveal the differences and challenges associated with (1) incorporating adjusted spatial data and (2) model functionality and performance.
- **ICPR Groundwater Sensitivity:** These runs look to examine the level of influence ICPR's 2D groundwater component has on surface water results.

Model run times were tracked during a majority of the scenario runs as a performance metric and is included within this memorandum. In addition, the range of scenario runs provide a comparison of the output capabilities of each model. The specific model version used for this scenario analysis were:

- ICM version 2023.2.0 with an unlimited license; and
- ICPR version 4.07.08 with an expert license.

2 RAINFALL SCENARIOS

Prior to completing the scenario analysis model runs, both models were calibrated as described in the Model Calibration Memorandum. Calibration focused on the simulated stage results within Minnehaha Creek, as this portion of the subwatershed had the most robust recorded dataset. The calibration was also performed against small, low-intensity storm events; the recorded datasets captured numerous small, low-intensity storm events but no major rainfall events were captured within the subwatershed. The simulations included within this section aim to compare the modeling results of ICM and ICPR across a wider range of typical and intense rainfall conditions. It's important to characterize where differences were observed, explain potential reasons those differences may exist, and evaluate whether consistent patterns or biases are noticed across all the simulations. To provide additional context to the results comparison, additional outputs from other accepted models and datasets were included for a subset of the simulations.

Five simulations were run to support the objective of rainfall scenarios, which include:

1. FEMA BFE: Compares ICM and ICPR results to FEMA Base Flood Elevation (BFE) results;
2. Localized Flood Mapping: Compares localized ICM and ICPR flood inundation results to City of Edina's model output;
3. Turbid-Lundsten Discharge Rates: Compares ICM and ICPR discharge rates across four event-based simulations;

4. 2014 Flood of record: Compare ICM and ICPR under an extreme event; and
5. Design Storms: Compare ICM and ICPR results under four event-based design storms.

2.1 FEMA BFE – Edina Subwatershed

Data provided in **Table 1** represents a comparison between the documented FEMA Base Flood Elevation (BFE) results and the calibrated ICM and ICPR modeled high-water levels along Minnehaha Creek within the Edina subwatershed area. Model results data is taken from the calibrated base model-build versions of both models and the FEMA BFE results are based on the data from the published Flood Insurance Study (FIS) that was completed in 2016. The Minnehaha Creek XPSWMM model was originally certified by FEMA in 2003 and then a major update was completed in 2012 per FEMA documentation.

Results in the "Elevation" columns of **Table 1** represent each model's results using the 100-year, 10-day event that was taken from the XPSWMM model for inflow conditions. The downstream boundary condition was set to mimic the stage elevation of the downstream BFE of 861. For ICM, the average difference in elevation at the BFE cross section lines is +1.0 feet with a standard deviation of 0.7 feet. For ICPR, the average difference in elevation at the BFE lines is +0.5 feet with a standard deviation of 0.9 feet. The average and standard deviation results were taken using only data from cross section represented as BFEs 872 through 862 in **Table 1.** Reported stage results at the upstream two and downstream cross-sections represents somewhat erroneous data for both models due to model boundary condition influences. It is generally not recommended to use simulation results that are close to boundary conditions due to potential for influences that overpower the actual simulated results. This can be seen in the results for both models near the model boundaries.

Table 1. Modeled Elevations Compared to FEMA Base Flood Elevations

FEMA Cross-Section (27053C-)	FEMA BFE (ft)	ICPR		ICM	
		Elevation (ft)	Delta (ft)	Elevation (ft)	Delta (ft)
1547	875[1]	878.1	+3.1	878.0	+3.0
1546	873[1]	876.6	+3.6	876.4	+3.4
1544	872	874.8	+2.8	874.0	+2.0
1581	871	871.0	0.0	871.8	+0.8
1545	869	869.1	+0.1	869.3	+0.3
1573	866	867.3	+1.3	867.5	+1.5
1542	865	865.9	+0.9	866.9	+1.9
1543	865	865.1	+0.1	866.3	+1.3
1541	864	864.4	+0.4	865.0	+1.0
1623	864	864.2	+0.2	864.6	+0.6
1574	863	862.5	-0.5	863.0	0.0
1459	862	862.0	+0.0	862.5	+1.5
1539	861[1]	865.0	+4.0	861.3	+0.3

1. Cross sectional results Impacted by boundary conditions

As shown in **Table 1**, the ICM model results are generally a bit higher than ICPR, except near the upstream and downstream boundary sections, while both models produce results slightly higher than the FEMA BFE results. This difference is likely a result of several factors, with the greatest influences being: a) not having calibrated the models to an extreme event; and b) differences in channel geometry between the FEMA model having a 1D cross section and the two pilot study models having variable mesh sizes. Additional refinement of input parameters may be beneficial during the watershed-wide build to more closely align the simulated results with the recorded data. Additional refinement may include finer delineation of changes in land cover in the overbank areas, modeling bridge crossings that impact the flow of water within the creek, and further refinement of the 2D mesh to enforce all hydraulically significant features. Another approach that may be beneficial in the watershed wide build would be to create a 1D channel section throughout the critical reaches of the creek.

Overall, the results illustrate a reasonable validation of the model results, especially when considering that the model was not calibrated to a larger event. Both models show a slightly higher than FEMA result, which may relate to a combination of the additional runoff volume generated by the models that is not captured in the FEMA model that simulates a flow value through the creek channel, and the variation of the channel geometry between the 2D models and what was used in the FEMA model.

2.2 City of Edina Localized Flooding Maps

Localized flood maps based on results from the City of Edina's previously calibrated XPSWMM model were used for comparison to the results produced by the calibrated ICM and ICPR models. In contrast to the BFE comparison in the previous section, this analysis looks to compare results within overland areas. The Edina XPSWMM model was calibrated based on data from a network of rain gauges and flow gauges that were installed throughout the Morningside Neighborhood. The Edina flood inundation boundaries for the 10-year and 100-year flood events were compared against the respective ICM and ICPR inundation results. Exhibits showing the modeled inundation (depths and boundaries), City of Edina flood extents, and FEMA Flood Zone data are included in Appendix A of this memorandum. High-water levels at four locations were taken from ICPR and ICM to compare results between the software packages and the City of Edina's flood data. **Table 2** lists the high-water levels as well as the corresponding inundation depth in parenthesis.

Table 2. Peak High-Water Elevation Comparison

Location	City of Edina Model		ICPR		ICM	
	10-year	100-year	10-year	100-year	10-year	100-year
Weber Pond	868.2	869.3	864.8 (1.2)	866.2 (2.6)	865.3 (3.1)	867.4 (5.2)
Townes Rd. – West (Pond/Wetland)	872.8	878.2	871.2 (3.4)	872.3 (4.5)	870.8 (3.2)	872.6 (5.0)
West 51st Street (Low Area)	876.6	878.5	877.9 (2.0)	879.3 (3.4)	880.5 (4.7)	881.6 (5.8)
Arden / 50th Street (Low Area)	886.2	886.4	883.5 (1.9)	884.9 (3.3)	884.4 (2.9)	885.8 (4.0)

When comparing the ICPR and ICM models, the ICM model consistently produced higher peak stage values than ICPR. The only location where ICPR produced higher results was the Townes Road – West area. This was due to a strong influence from the groundwater module in the area of the Townes Road – West. The groundwater module starting elevation was derived from the groundwater monitoring wells, the wells averaged a groundwater elevation approximately 6 feet below the existing ground. Directly east and south of Townes Road – West is a high area that ranges in maximum elevation between 910 and 920 feet. As the simulation begins, this area of mounded groundwater begins to flow to the low area that is Townes Road – West (ground elevation of 867 feet). This difference in groundwater level versus ground elevation allows for large amounts of groundwater to enter the overland flow mesh. This area also does not have a natural or piped outlet within the models.

When comparing the modeled results for ICPR and ICM to the City of Edina data, including a review of Exhibits 1A through 2B in the Appendix, the pond/wetland areas (Weber Pond and Townes Road) have lower peak elevations and smaller flood inundation limits while the low areas (West 51st and Arden/50th) match closer to the City of Edina data.

The ICM inundation results show ponding in many of the smaller areas scattered throughout the subwatershed for the 10-year and 100-year rainfall events, whereas the ICPR inundation results over-represent the extent of deeper inundation and under-represent shallow inundation. This is largely due to the relatively large cell size that ICPR was developed with due to the placement of breakpoints since the terrain-sensitive meshing tool within ICPR cannot be used when also including a groundwater mesh. **Figure 1** illustrates the differences in the mesh resolution of the final calibrated model versions for ICPR and ICM. The ICM mesh was based on the terrain sensitive meshing tool, while the ICPR mesh was based on the defined break lines and breakpoints. Areas of shallower inundation may be able to be better represented through additional breakline refinement and delineation of mesh refinement areas within the ICPR model. These updates would be done through user inputs and user created features. ICM shows extensive flooding in street areas where the City of Edina data shows no inundation (Intersection of Townes Road and W 48th Street and along Kellogg Avenue and Wooddale Avenue) within the 100-year results. The inundation extents within ICM underestimates some of the shallow ponding areas north and south of Branson Street. ICPR would require additional manual effort to achieve a similar resolution that was obtained in ICM through its automated build process. ICPR is reliant on breaklines and breakpoints for mesh creation when the groundwater module is used; Based on experiences during the pilot model build, this effort may not scale efficiently during the watershed-wide build process.

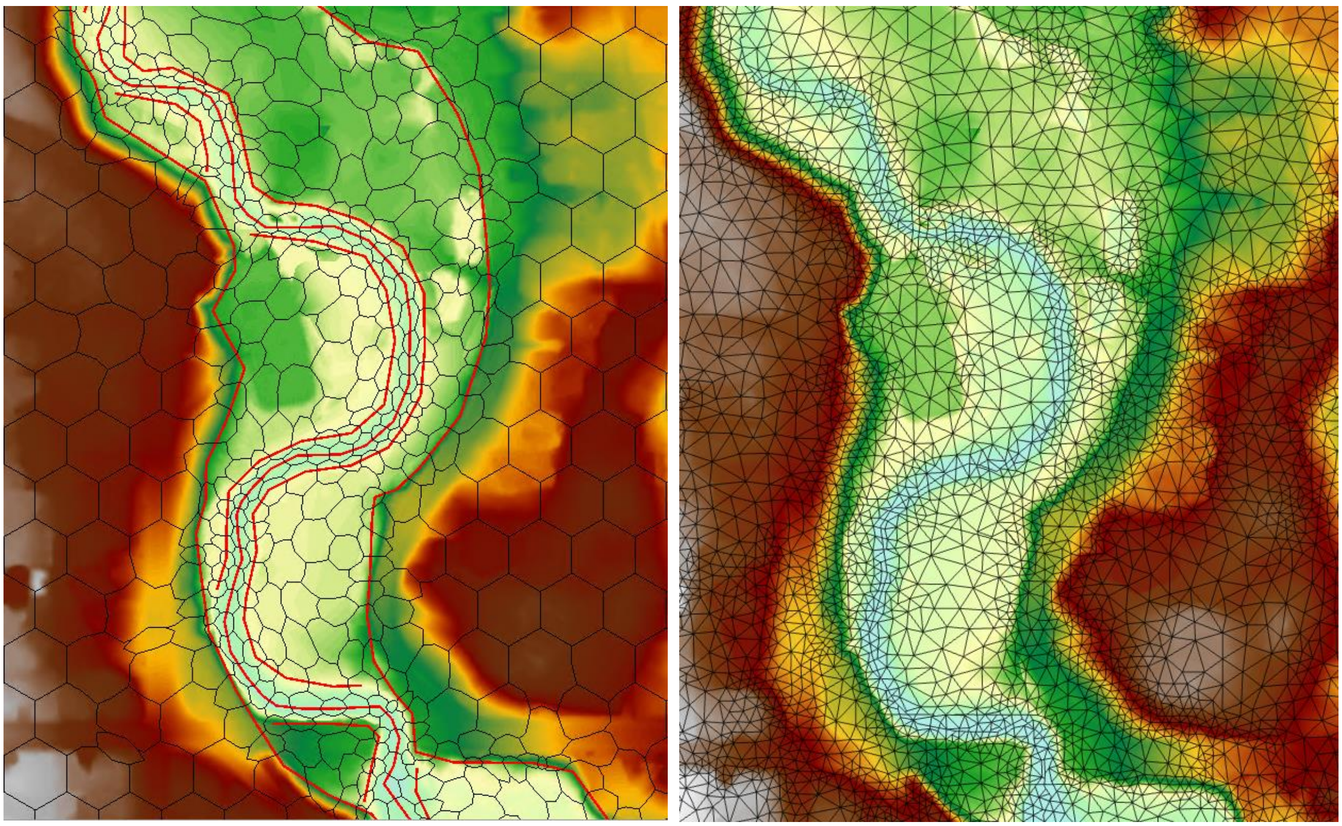


Figure 1. Mesh Development ICPR (left) vs. ICM (right)

The areas of major inundation within the model areas show higher inundation depths/elevations in the ICPR model versus the ICM model. As expected, the corresponding inundation extents are also higher within ICPR versus ICM. The inundation results appear to be more consistent through the Minnehaha Creek channel in ICM versus ICPR, likely a result of the increase in size of the mesh elements in ICPR. The larger mesh element size (i.e., lower resolution) relates to a poorer representation of the creek channel and loss in available cross-sectional area.

Changing the inundation depth cutoff from 0.25 feet to 0.10 feet increases the inundation boundary in ICM to more closely match the Edina localized flood mapping. The level of detail in the infrastructure dataset is assumed to be greater in the Edina (city) model than that of the pilot model builds considering that the intent was to build a model to a specific and very local flood inundation area and to build it manually by adding area-specific features (pipe, pumps, etc.) and making area-specific adjustments within the model to calibrate the model to a known response. Conversely, the 2D Pilot model builds were largely automated model builds using the baseline best available data and making manual additions and adjustments only where needed to reach the established calibration thresholds. An increase in level of refinement in both pilot models (e.g., breaklines along all roads) would allow for finer results and routing of overland flow. Increasing the detail within the infrastructure dataset (e.g., assigning real values for assumed pipe inverts and pipe sizes) would increase the level of accuracy when simulating low to mid-level intensity storm events.

Mesh refinement will be an important effort to the accuracy of model results during the full model build process. While mesh elements can be decreased in size to limit the amount of manual mesh refinement that is required, the trade-off will be model run times. Smaller cells result in shorter time steps increased run times. The key will be to find the right balance between the higher-resolution auto-generated mesh and the impact the higher resolution has on run times.

2.3 Turbid-Lundsten Discharge Rate

The Turbid-Lundsten subwatershed model area was run with the 2-year, 10-year, 100-year 24-hour and the 100-year 10-day rainfall events. The four rainfall events simulated are typical events that are analyzed as part of developing a proposed site or development plan. While this model didn't follow the same level of calibration process that the Edina models followed, scenario's run within the Turbid-Lundsten area offer an opportunity to evaluate if ICM and ICPR behave in a similar way within an undeveloped area that has different underlying features.

Table 3 shows the discharge rate from the model area through the existing 48-inch culvert under Highway 5 for each event for both models. While the District has monitoring data at the downstream end of the culvert under Highway 5 for short periods of 2014, 2015 and 2016, there is not corresponding detailed rainfall event data that can confirm which event(s) best matches the short periods of monitored flows for the outfall. However, daily precipitation totals were pulled for 2014-2016 from the Minnesota State Climatology Office (MSCO) website, using the Nearest Station Precipitation Data retrieval tool to use as the best available data for comparison.

Table 3. Peak Discharge Rate Comparison

Model	2-year, 24-hour (2.8 inch)	10-year, 24-hour (4.2 inch)	100-year, 24-hour (7.5 inch)	100-year, 10-day (7.5 inch)
ICPR	67.0	99.8	176.6	176.6
ICM	38.2	61.8	152.1	177.5

ICPR produced the same peak discharge rate for the 100-year, 24-hour and 100-year, 10-day events. This may relate to the interaction between 1D and 2D elements in ICPR that results in limiting flow when a pipe becomes surcharged. Based upon standard engineering practice pipe calculations, as a pipe becomes surcharged there is an increase in pressure and the flow continues to increase through the pipe as surcharge increases. When reviewing the flow hydrograph from ICPR for the 48-inch culvert, the flow increases to 176.6 cfs and then holds constant until the flow draws down below that level as shown in **Figure 2**. The hydrograph flatlines and does not allow a discharge rate above 176.6 cfs to occur in ICPR. We did not observe this flow cut-off within ICM for flows up to 190 cfs in the Turbid future development model runs.

When comparing discharge model results to the MSCO precipitation data, the first observation is that the overall subwatershed is very flashy when reviewing the model results and response of the system. The drawdown time in the 100-year, 24-hour run from the peak discharge of 152.1 cfs to approximately 2 cfs occurred within 24 hours for ICM and from 176.6 to 40 cfs in ICPR in 36 hours. The model run was not extended past 48 total hours for this validation run.

The first observation of monitored flows in early 2014 is that flows appear to have some level of baseflow on the order of 1-3 cfs. The frequency of recording flow values of once every one to two weeks was clearly not sufficient to capture the peak discharge for each of the rainfall events. However, the baseflow results are consistent with what the modeling shows for the tail of the hydrograph after 24-hours at a discharge on the order of 2 cfs. Overall, pilot model flows seem to be in the range of what could be expected for comparable depth events simulated in both models. More frequent monitoring points throughout a given event would be needed to better capture the flashy nature of this watershed.

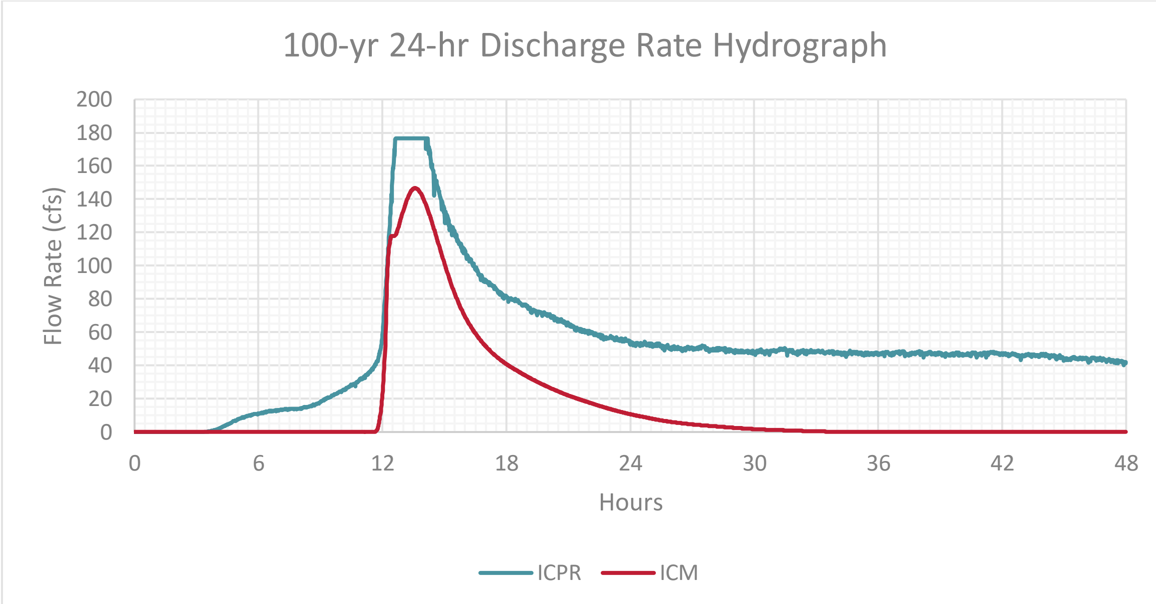


Figure 2. 100-year, 24-hour Discharge Rate – Turbid-Lundsten

2.4 2014 Flood of Record in Edina

The flood of record for the Edina subwatershed occurred over multiple days in the middle of June 2014. The timing of this storm points to the origin coming from a summer thunderstorm event. The event produced approximately 7.5 inches of rainfall over a 6-day (147 hour) period. Based upon the NOAA Atlas-14 point precipitation frequency estimates, this storm ranges between a 25- and 50-year rainfall event. Within the longer storm, three peak rainfall intensity periods occurred. The first peak reached an intensity of 0.57 inches per hour, the second peak reached 0.46 inches per hour, and the final peak reached 1.28 inches per hour. The first and third peak rainfall periods produced the greatest portion of the overall rainfall depth (1^{st} = 2.24 inches, 3^{rd} = 4.19 inches).

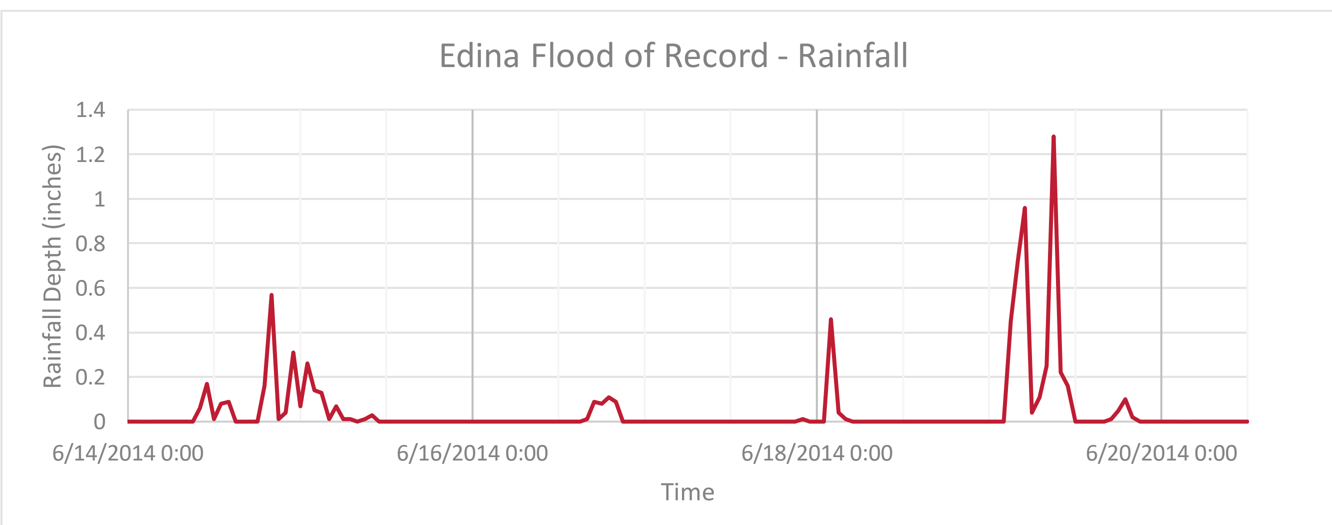


Figure 3. Rainfall Events and Depths During the 2014 Edina Flood of Record

Table 4 presents the peak high-water elevations and peak discharge rates at multiple locations along Minnehaha Creek for both pilot models. This scenario run did not include an upstream flow hydrograph boundary condition due to lack of flow data from 2014. Therefore, all flow and stage levels from the calibrated models within Minnehaha Creek are attributed to runoff from the rainfall event. ICM produced slightly higher peak elevations at all of the comparison locations but produced lower discharge rates compared to ICPR. This relates to the computational approach each model takes and highlights the need to look at multiple parameters when reviewing model results data. In addition, **Figures 4** and **5** illustrate the runoff hydrographs through the system at 54th Street for the ICPR and ICM pilot model runs, respectively.

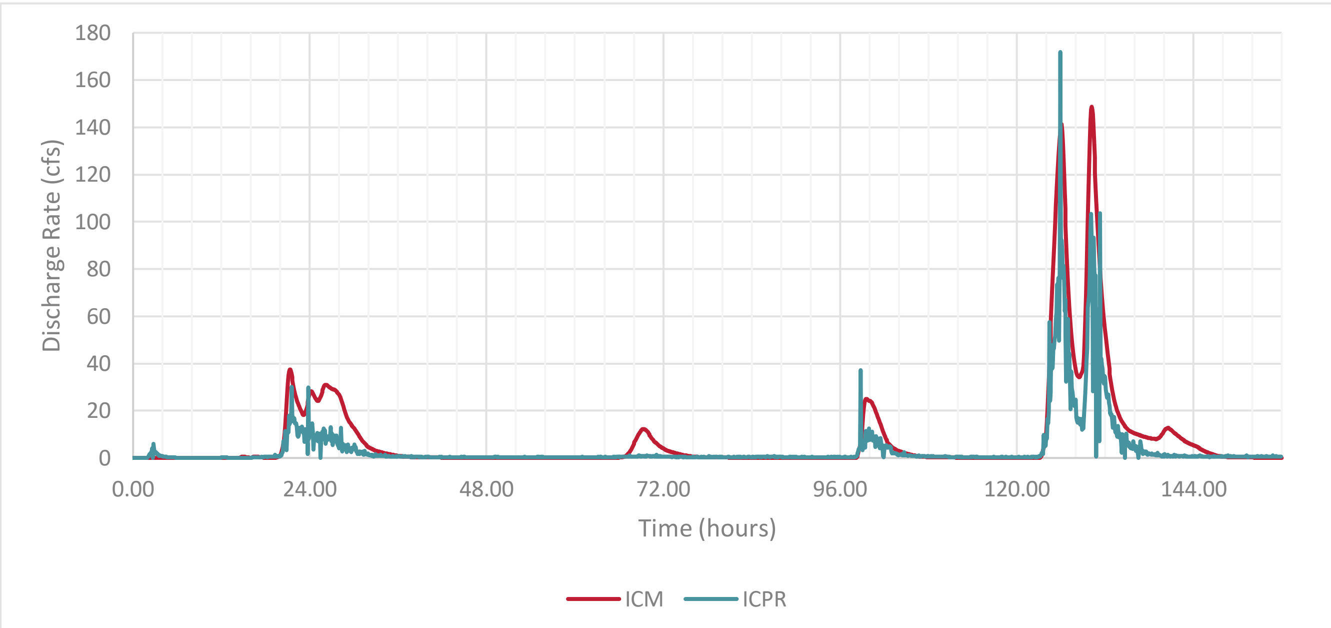


Figure 4. Discharge Rate Hydrograph at 54th Street

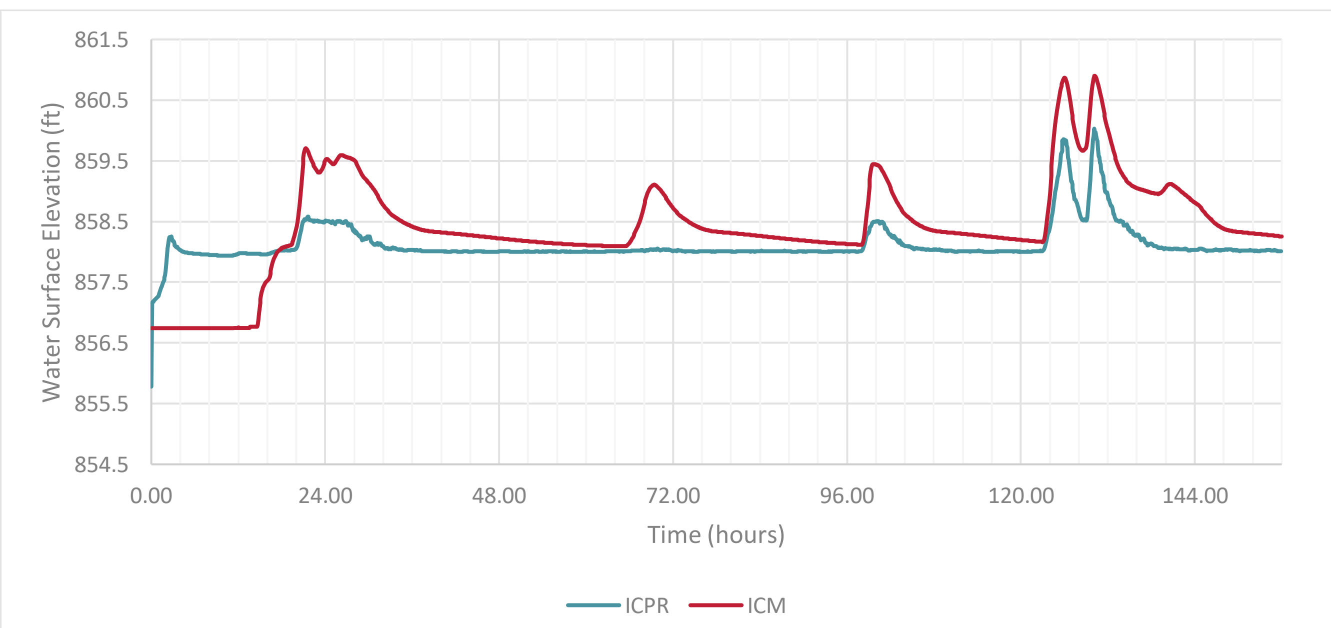


Figure 5. Water Surface Elevation Hydrograph at 54th Street

In the case of this model results comparison, the peak elevations are a much better point of comparison than the peak discharge rates. The peak discharge rates from ICPR were produced from single spikes in the discharge rates in an otherwise smooth plot, very similar to the noise shown in the calibration stage hydrographs for ICPR. This does not indicate that the model results for peak elevation are not reasonable, only that further exploration of the peak discharge spike shown in the result data may not represent actual conditions. As discussed in the calibration memorandum, additional refinement of the channel geometry in both models may substantially address the peak discharge difference between the two models.

Table 4. Flood of Record – Peak Elevation and Discharge Rate Comparison

Location	ICPR		ICM	
	Peak Elevation (ft)	Peak Discharge (cfs)	Peak Elevation (ft)	Peak Discharge (cfs)
Wooddale Ave	870.80	42.7	871.58	42.7
Arden Park	861.99	169.7	863.15	119.7
54th Street	860.06	291.3	860.89	148.7
56th Street	856.24	336.9	857.18	150.5

2.5 Atlas-14 24-hour Design Storms – Edina

The second scenario dataset uses the Atlas-14 rainfall depths applied over the MSE-3 rainfall distribution to create design storms. The Atlas-14 rainfall depths representing the 2-year, 10-year, and 100-year return periods that are associated with a 24-hour storm event were taken from the NOAA Atlas-14 Point Precipitation Frequency Data Server. The rainfall depths used for this scenario analysis were: 2-year – 2.86 inches, 10-year – 4.28 inches, and 100-year – 7.49 inches. The rainfall depths were then applied to the MSE Type 3 (MSE-3) dimensionless rainfall distribution curve.

Table 5 details the peak high-water level, peak discharge rate, and continuity error for each model. The peak high-water level and flow rates are taken from both models at the 56th Street crossing of Minnehaha Creek. ICM again produced slightly higher peak elevations during each of the simulated storm events than the ICPR model, with all differences for the three events on the order of one foot. The peak discharge rates in **Table 5** are similar to the trend discussed for data in **Table 4** that all ICPR peak discharges are higher than ICM. The continuity errors for both ICPR and ICM are within acceptable ranges, while ICPR continuity errors are consistently higher than ICM. Again, a reflection of the noise seen in the ICPR hydrograph plots.

Table 5. Atlas 14 - Peak Elevation, Discharge Rate and Continuity Comparison

Event (24-Hour)	Peak Elevation (ft)		Peak Discharge (cfs)		Continuity (%)	
	ICPR	ICM	ICPR	ICM	ICPR	ICM
2-yr	856.0	857.1	258.2	142.8	-1.420	0.038
10-yr	857.0	857.9	395.2	246.6	-1.620	0.020
100-yr	858.2	859.2	976.6	505.3	0.150	-0.001

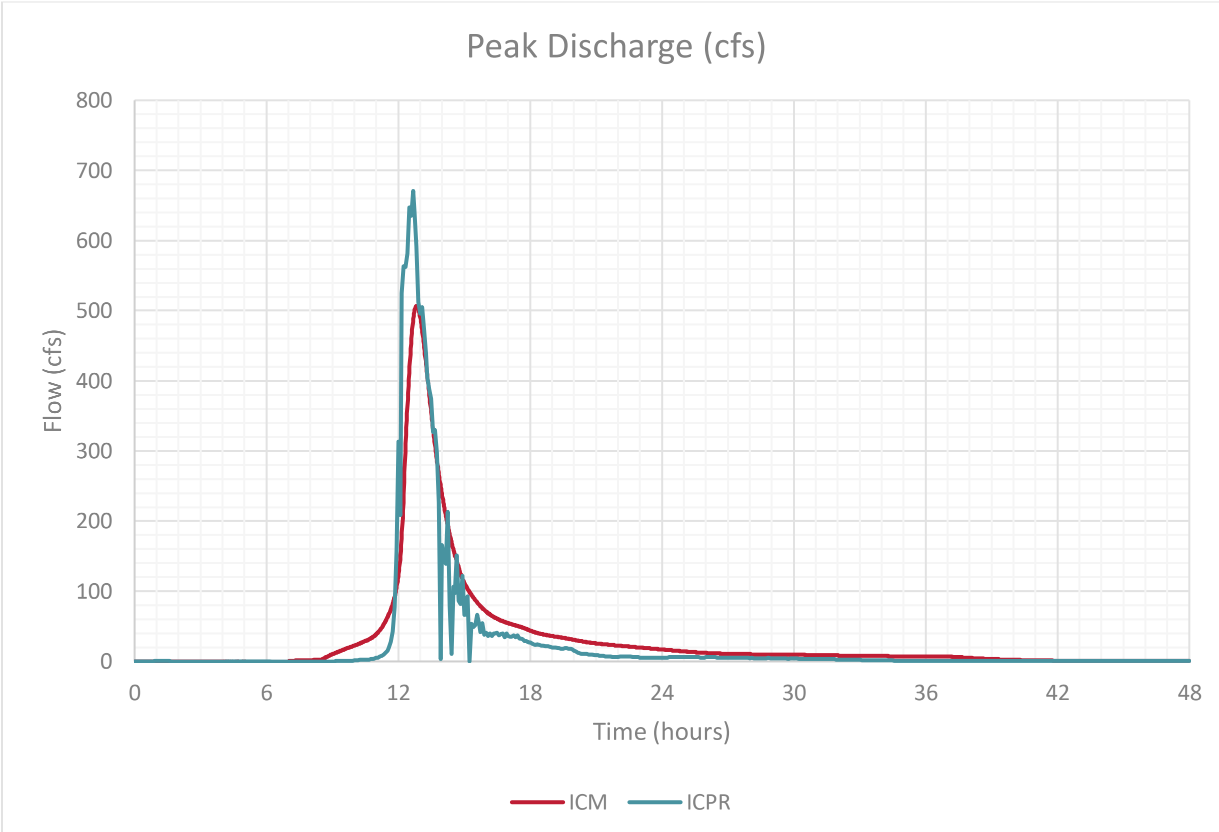


Figure 6. Peak Discharge Hydrograph – Exported Results

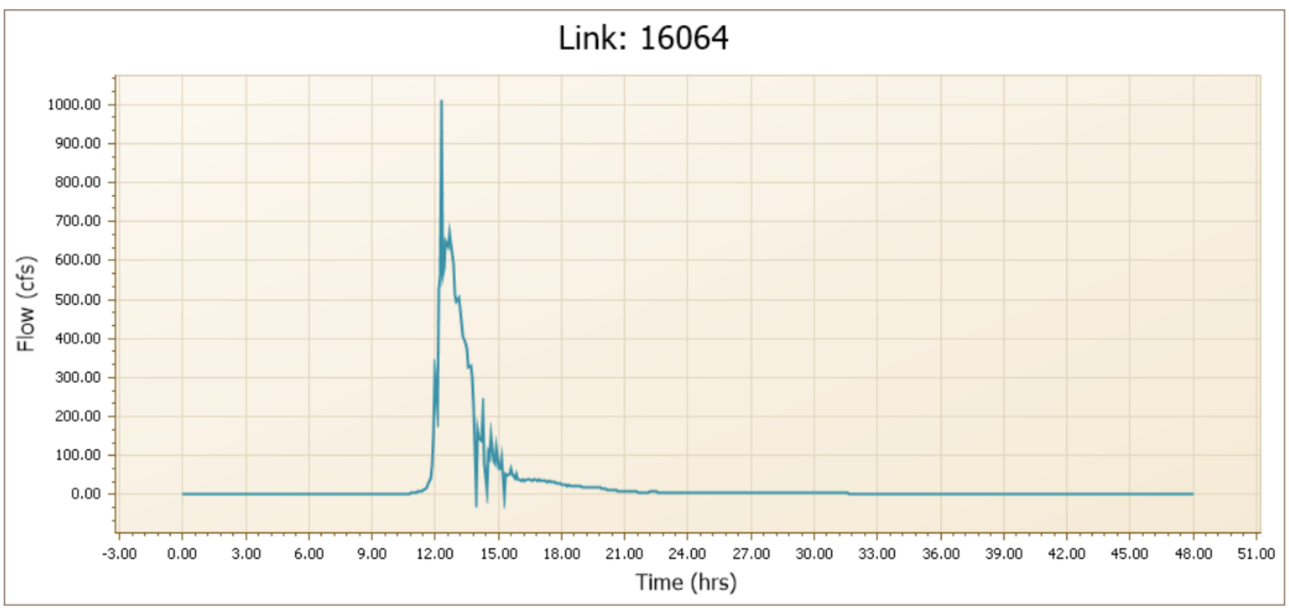


Figure 7. ICPR Peak Discharge Results – Internal Hydrograph

One important takeaway from the working through the data export process within ICPR, is that we observed different peak discharge rates at a given node when viewing data within the model compared to the data that was exported from the model to be presented or plotted in Excel, for example. As shown in the internal hydrograph in **Figure 7**, the peak discharge rate is on the order of 1,000 cfs, which was not shown in the exported results. In an effort to better capture the peak discharge rate in the exported results, the ICPR model was rerun with the surface hydraulic timestep being reduced from 5 minutes to 15 seconds. The rerun of the ICPR model with the smaller timestep also did not capture the simulated peak discharge rate shown visually within the model, in the exported data. The rerun of ICPR did result in an increase in model run time from 24 minutes to 303 minutes, with no other model parameters adjusted between the two model runs. The variability in results seen within the visual software interface compared to the exported results could lead to inconsistencies in reported results depending on where the model user pulls the data from. At a minimum, we would recommend a standard process to use the values taken from a consistent approach, based on the model users best professional judgement of viewing the hydrograph and reviewing the exported data. There are likely other model creation factors that could narrow the gap between the visual result and the exported data, such as a 1D channel, which we have mentioned previously as an option to reduce some of the noise in the high-water level results.

2.6 Summary

The five rainfall scenario simulations confirm that using a model that was only calibrated to relatively small events is difficult to draw precise conclusions on the validation of the models to larger events due to the wide variations in the rainfall event intensity, duration and antecedent conditions, for example.

ICM generally produced higher peak elevations than ICPR, which was also observed during the calibration process. This trend is not a result of the model computational process; instead, the trend relates much more to where we stopped the model adjustments during the calibration process and the lack of having a larger event to calibrate to. We are confident that the gap in peak elevations could be narrowed by additional adjustments in one or both model in additional calibration efforts and do not see this difference as a limitation or concern in either model. On the other hand, the peak discharge rates tend to be consistently higher for ICPR, which very much appears to relate to the computational processes within the pilot models. As we have discussed previously, ICPR shows much more variation in the peak discharge results with relatively high values shifting to lower values in subsequent time steps while ICM produces a much smoother hydrograph. As discussed in the calibration memorandum, this tends to present itself in a higher continuity error values for ICRP, with both models producing errors within the established calibration tolerance limits.

3 GEOSPATIAL SCENARIOS

The following sections detail two complex scenarios that looked at altering the geospatial data within the original calibrated models. These scenarios are represented of the processes and challenges the District will encounter as it looks to assess future impacts of climate and development activity. This subset of scenarios looks to reveal the differences and challenges associated with: 1) incorporating adjusted spatial data; and 2) model functionality and performance. The two selected scenarios include:

1. Pre-settlement vs. Future Development: Assesses the impacts of regional land-use change.
2. Morningside Flood Reduction Project: Assesses a localized change to pipe infrastructure.

The following sub-sections outline the datasets that were used to setup the scenarios, the results from each model, and a summary of the learnings.

3.1 Pre-Settlement vs. Future Development – Turbid-Lundsten

This scenario dataset includes pre-settlement and future development landuse for the Turbid-Lundsten subwatershed. The pre-settlement landuse file was broken out by vegetation and wetland area. The wetland areas are associated with a storage volume based upon the overall size of the wetland delineation. The wetland area delineations were also used to modify the terrain file by lowering each area with a wetland boundary by 2.5 feet to represent the pre-settlement conditions across the subwatershed. The future development scenario included the updated landuse delineations assuming residential and commercial buildout within the subwatershed according to the City of Victoria – West Growth Area projections from May 2018. Future development terrain was modified to represent future water quality ponding throughout the subwatershed to meet the current development requirements. Breaklines were added to the future development scenario in ICM and ICPR to enforce the storage areas within the 2D mesh. The 2-year, 10-year, and 100-year 24-hour rainfall events and the 100-year 10-day rainfall event were simulated for the pre-settlement and future development scenarios. These events were modeled using the MSE-3 rainfall distribution applied directly to the model area.

Table 6 provides the pre-settlement, existing conditions and future development peak discharge rates and volume passing through the 48-inch culvert at Highway 5 from the Turbid-Lundsten subwatershed. The ICPR peak discharge rate was limited by the pipe capacity similar to the results discussed in **Section 2.3** and **Table 3**. The peak discharge in future development conditions was restricted to 176.6 cfs. The discharge rates were lower in pre-development conditions when compared to the existing conditions model results (**Section 2.3**). The future development discharge rates are similar to the existing conditions rates in ICM and ICPR, respectively.

Results in **Table 6** point towards an expected increase in overall peak discharge rates due to development within the subwatershed from pre-settlement to existing conditions. In addition, future development and associated pond creation/routing mitigate for the increase in discharge volumes and peak rates throughout the subwatershed relative to the existing conditions. It should be noted that the Turbid-Lundsten model was not calibrated, and results show a wide separation between the two modeling platforms. The difference between models is more pronounced as runoff volumes are compared (**Table 6)**. Without a calibrated model, and sufficient monitoring data, it's difficult to discern whether one model is over or under predicting, or a combination of both. This highlights the importance of calibration beyond the baseline model build. As you may recall, a large separation existed been ICPR and ICM results within the Edina base model build. But upon calibration, scenario outputs (peak discharge/elevations) were quite similar to one another. Therefore, watershed-wide model calibration to both events and baseflow conditions will be critical and monitoring data will be needed within each major subwatershed.

Table 6. Pre-Settlement to Future Development – Discharge Rate and Volume Comparison

Model / Scenario	2-year, 24-hour (2.8 inch)	10-year, 24-hour (4.2 inch)	100-year, 24-hour (7.5 inch)	100-year, 10-day (10.3 inch)
DISCHARGE RATE AT HIGHWAY-5 OUTLET (cfs)				
ICPR				
Pre-Settlement	19.8	32.7	73.7	90.7
Existing	67.0	99.8	176.6	176.6
Future Development	72.6	104.6	176.6	176.6
ICM				
Pre-Settlement	20.3	49.9	111.6	142.6
Existing	38.2	61.8	152.1	177.5
Future Development	28.9	58.8	168.6	190.3
DISCHARGE VOLUME AT HIGHWAY-5 OUTLET (acre-feet)				
ICPR				
Pre-Settlement	37.6	54.7	88.4	335.2
Existing	118.9	154.0	202.9	871.5
Future Development	149.2	164.8	191.4	1,272.7
ICM				
Pre-Settlement	3.6	15.0	51.7	66.0
Existing	5.6	20.2	60.5	70.2
Future Development	7.8	23.2	64.1	79.2

ICPR and ICM are similar in effort required to update landuse and swap out DEM files for various scenario runs. Depending on extent of pipe updates required for a scenario, the effort to update varies between software packages. Small updates require similar levels of effort through hand edits to the pipe/node data within the models. Larger updates will require use of the import tools for each software. ICM allows for multiple options when importing including overwrite, prompt, merge, and ignore when duplicate features are encountered during import. ICPR requires that the import dataset is clipped to only include the new/updated features. This allows for efficient updates and removal of previously created features. Additionally, 1D pond objects could be used within both models to test pond sizing and routing without the need for additional terrain and mesh element refinements. Modifying a single ponding feature to a 1D object would be a very simple and quick process, while for multiple locations the process would be more time consuming to manually enter each 1D object.

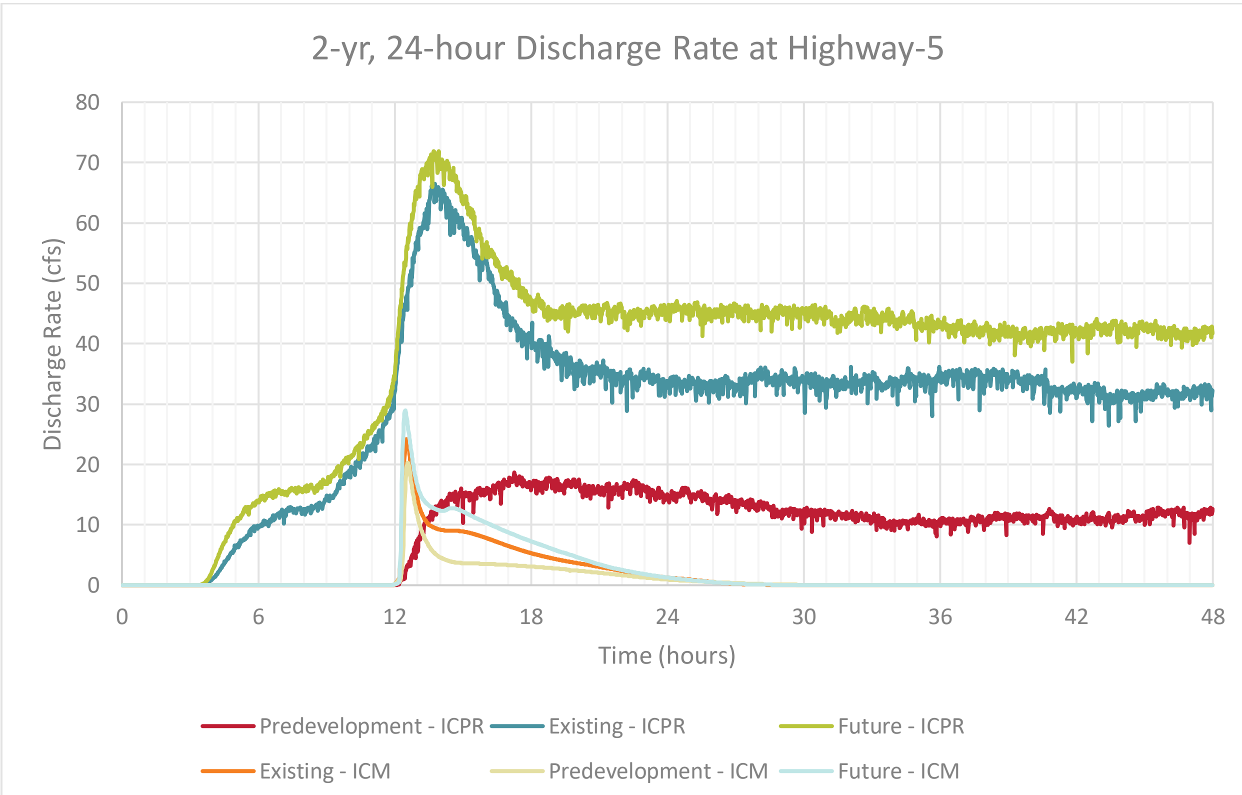


Figure 8. Discharge Rate Hydrographs – 2-year, 24-hour

3.2 Morningside Neighborhood Flood Reduction Project – Edina

The final scenario dataset includes the proposed improvements to the Morningside Neighborhood as part of the regional flood reduction project. The flood reduction project includes upsizing existing storm sewer, rerouting trunklines to maximize existing and proposed storage areas, and constructing a stormwater pump station and forcemain. Weber Pond will also be increased in size to further minimize the impacts from localized flooding in the neighborhood. The proposed conditions were simulated using the 2-year, 10-year, and 100-year 24-hour design storm events. The Morningside model updates included multiple trunk storm sewer updates (taken from a GIS file provided by the District), updated DEM and mesh refinement within both models, and the inclusion of the proposed pump from Weber Pond to allow drawdown and high-water level management. The pump curve was developed from the previous Basis of Design report supplied by the City of Edina for the Morningside Flood Risk Reduction Infrastructure Design (May 2022).

Inclusion of the pump data was unique in each model. ICM specifies pumps as pump links and ICPR specifies pumps as a rating curve link. Both options allow for varying levels of data to be included as part of the pump station. Typically, pump and forcemain hydraulics are calculated outside of the software to develop a pump curve that relates the upstream and downstream head to flow rates while including losses from bends, friction, and others. This allows for the pump system within the model to be simplified to a single link that takes inflow at the inlet end of the pump system and outflow at the outlet point. Both models allow for pump on/off elevations to be specified along with selecting a node within the model for reference for each. ICM allows for logic and numerical arguments to be created and used to control the pump during a simulation independently of the pump curve (i.e., pump breaks 15 hours into simulation run).

Pond footprints were created within GIS and imported to the infiltration layer for ICM models. This was done to limit infiltration through the pond bottom and allow for specification of starting water elevations for pond features.

Table 7 presents model results for the high-water levels within Weber Pond as a result of the improvements to the Morningside neighborhood. ICPR produced higher peak results for the 2-year and 10-year rainfall events while ICM produced the highest peak result for the 100-year, 24-hour rainfall event. Both models produced comparable results for each of the three events with the difference between the two models being lower for the larger, 100-year, event run.

Table 7. Weber Pond – High-Water Level

Storm Event	ICPR	ICM	City of Edina Model
2-year, 24-hour	860.4	859.7	N/A
10-year, 24-hour	861.2	860.5	868.2
100-year, 24-hour	863.1	863.4	869.3

Both models produced stage results significantly lower than the documented Basis of Design report that used the City's previously constructed and calibrated XPSWMM model. These results raise the obvious question of why such a difference? There maybe a few possible factors that drive the differences including assumed/assigned pipe sizes used in the automated build process and mesh resolution. We believe the most significant factor is likely in the details of the infrastructure data for the automated model build. While calibration efforts focused on the recorded data at the creek, there was not corresponding calibration efforts focused on smaller localized ponding areas like Weber Pond for the pilot models. The automated model build includes an assumed 12-inch RCP pipe where no data was available in the initial infrastructure dataset in this area. Within the Weber Pond drainage area, the actual pipe sizes routed to Weber Pond may be larger than the assumed/assigned data used during the automated build process. Larger pipes would result in less restriction to the flow into Weber Pond and a higher peak.

Two main take-aways from this scenario simulation are that: 1) getting the most accurate base infrastructure data up front during the watershed-wide build will allow the automated model build to provide better results throughout the watershed instead of just at or near the calibration locations; and 2) depending on the desired use(s) of the model (i.e., creek evaluations versus localized areas such as Weber Pond), the level of calibration may need to vary.

4 ICPR GROUNDWATER SENSITIVITY

ICPR's 2D groundwater capabilities are a defining feature and a key difference from ICM. ICPR can simulate groundwater flow through the use of a second 2D mesh layer that is aligned to the 2D surface mesh allowing groundwater to enter the surface layer and contribute to surface flows. ICM on the other hand, has a standard infiltration function that removes the water that infiltrates from the system and the infiltrated volume does not contribute to runoff.

During the calibration process for the ICPR pilot model, model runs were conducted to show the influence the 2D groundwater component had on results, by running a scenario with and without the groundwater module activated. Through that exercise, it became clear that ICPR's groundwater component was responsible for keeping base flow within the channel in periods between storms. To further understand the influence of the groundwater module and its impact on results, three additional runs were conducted. The only change within each run was the starting groundwater level condition, which was:

1. Low: Constant elevation of 853 feet for the entire model area
2. High: Matching the terrain (e.g., water table is at the ground surface level)
3. Varied: 6-feet below the terrain. (the level used for all model build, calibration, validation and scenario analyses)

Results showed that the initial groundwater elevation assumption can have a significant impact for smaller storm event results when assessing high-water level results on ponding and low areas as shown in **Figure 9**. Groundwater level assumptions had a smaller impact on larger events results and on creek peak flow and stage results.

The resulting stage hydrographs are provided in **Appendix B**. Results are reported at Weber Pond and at the 56th Street crossing along Minnehaha Creek. The Morningside scenario model version was used to perform the sensitivity analysis. The influence in surface stage hydrograph levels varied depending on location (pond vs. creek) and storm intensity (2-yr vs. 10-yr vs. 100-yr). In relation to peak stage within Weber Pond, the High groundwater scenario produced extremely high stage results when compared to the Low and Varied groundwater scenarios for all of the simulated rainfall events. In part, this likely result from an additional volume of water being in the model at model start time. For an additional 6-feet of groundwater in a medium having 30% pore space, an additional 15 inches of water depth is available in the model, beyond what is produced in the rainfall-runoff process, and at least a portion of that available volume discharges into the surface features.

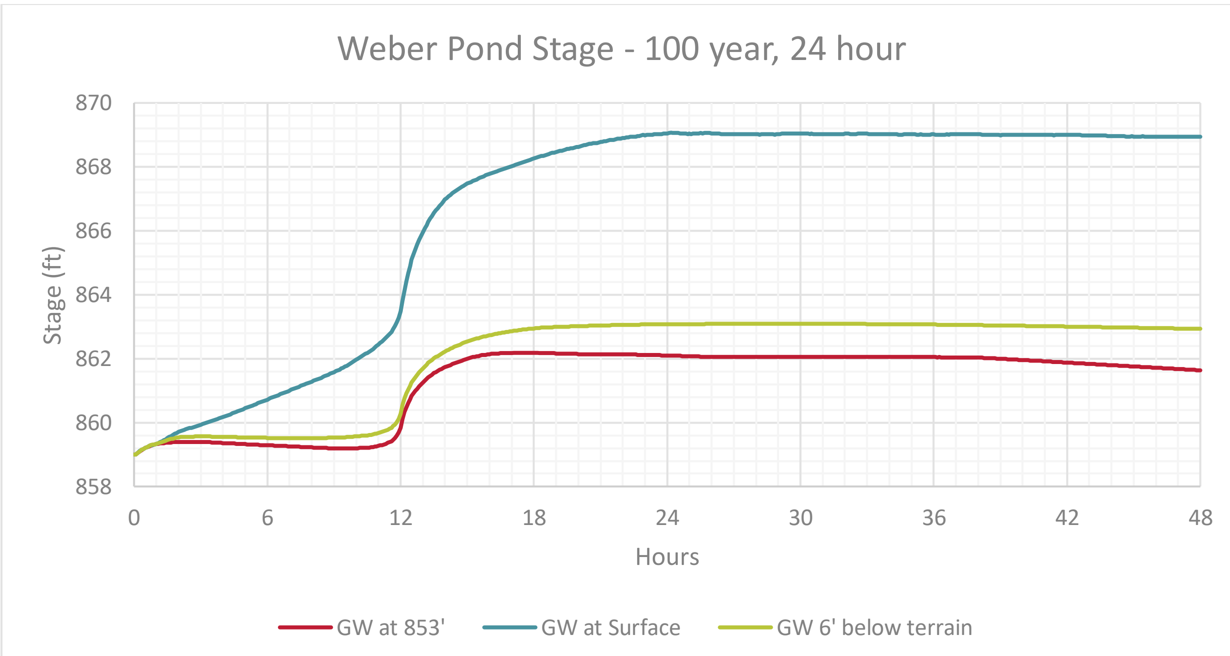


Figure 9. ICPR: Impact of Groundwater Initial Conditions on Weber Pond Stage

The 56th Street Stage results demonstrated a smaller influence from the High groundwater scenario across all storm events when compared to the Weber Pond stage results. The influence from the High groundwater scenario on the peak stage elevation also decreased as the intensity of the rainfall event increased.

At a minimum, the modeled differences in high-water level for both Weber Pond and 56th Street highlight the need for greater emphasis on having confidence in the groundwater elevations throughout the watershed if ICPR is the selected model for the watershed-wide build. Additional monitoring data for groundwater would clearly help to more accurately develop groundwater inputs for the watershed-wide model build process and subsequent simulation runs. Over long simulation time periods (e.g., the 77-day simulation in Calibration memorandum), the influence of groundwater is allowed to even out as the model "warms-up" at the beginning of the simulation time. This allows the ICPR model to more accurately simulate groundwater over long time periods and the influence of the starting groundwater elevation becomes increasingly minimal as the simulation time length increases. When reviewing and simulating shorter storm events, there is a larger impact of the results from the initial conditions.

5 MODEL RUN TIMES

The models were developed and run using various laptop setups to assess the overall usability and processing power needs and considerations. A computer with a good graphical processing unit (GPU) will be beneficial to reduce simulation run times for ICM. A computer with a fast CPU is beneficial for performing ICPR simulations and reduce overall run times. Both software developers have recommendations for desired computing power and overall computer setups to increase modeling efficiency.

The run times shown in **Table 8** provide a comparison of the calibrated models across selected events. This is not a true apples-to-apples comparison, as the models were constructed at much different resolutions and required different adjustment to reach acceptable calibration tolerances. For example, ICPR has 11,900 triangular elements in the Turbid model while ICM has 96,000 triangular elements for the same model area. Similar differences in resolution are present in the Edina models. Furthermore, the ICPR model includes the groundwater simulation which is essentially a second 2D grid with a second set of computations being completed for each time step. This added computational need is offset within this set of examples by differences in the cell numbers and corresponding mesh size (i.e., resolution).

Table 8. Summary of Scenario Model Run Times

Scenario	Storm Event	Simulation Length (hours)	Model Run Time (minutes)	
			ICM	ICPR
Edina Flood of Record	2014	156	54	65
Edina Atlas-14	2-yr, 24-hr	48	18	15
	10-yr, 24-hr	48	20	18
	100-yr, 24-hr	48	21 (14)	24
Turbid Pre-Settlement	100-yr, 24-hr	48	42	85
	100-yr, 10-day	360	223	290
Turbid Future Development	100-yr, 24-hr	48	46	74
	100-yr, 10-day	360	180	213
Edina Morningside	100-yr, 24-hr	48	25	22

To evaluate run times on a more representative apples-to-apples scenario, model resolution was adjusted to be comparable between the two models. Due to model build challenges and level of effort observed while constructing mesh in ICPR, it was deemed most efficient to bring the ICM model to a lower resolution (i.e., larger mesh size). The purpose of these runs was solely to evaluate run times, and the impact the resolution change had on results was not considered. A computer with NVIDIA Quadro T2000 with Max-Q Design GPU and an Intel Core i7-10850H CPU was utilized for the comparison. Results for a 100-year, 24-hour design storm event run are presented in **Table 9**.

Table 9. Model Run Times with Comparable Model Resolution

Subwatershed	Resolution	ICM		ICPR		
		Run Time (minutes)	# of 2D Elements	Run Time (minutes)		# of 2D Elements
				Overland Only	With Groundwater	
Turbid-Lundsten	Low	20	12,053	33	47	11,900
	High	42	92,931	78	106	50,842[1]
				169	N/A	105,498[2]

[1] ICPR high-resolution run developed from hand-delineation tools (breakpoint offset, breaklines)
[2] ICPR high-resolution run developed from automated build tool

The results indicate that longer run times will be experienced with ICPR. These run times will increase if the model is scaled watershed-wide and/or a greater resolution is desired. Modifications to the build of ICPR, such as "phased" groundwater regions, will be critical for watershed-wide scaling and may help workaround long run times. To further evaluate the model run time comparison, a sensitivity analysis was performed on the existing conditions Turbid-Lundsten watershed using the 100-year, 24-hour storm event and a 48-hour simulation length. This sensitivity analysis was completed at the end of the scenario analysis and following the previous calibration analysis. Thus, all improvements to both models (ICM and ICPR) were incorporated within the analysis as well. Seven scenarios were included within the sensitivity analysis as shown in the list below and detailed in **Table 9.**

ICM

1. Low-Resolution (12,053 2D elements), Automated Mesh Tool
2. High-Resolution (92,931 2D elements), Automated Mesh Tool

ICPR

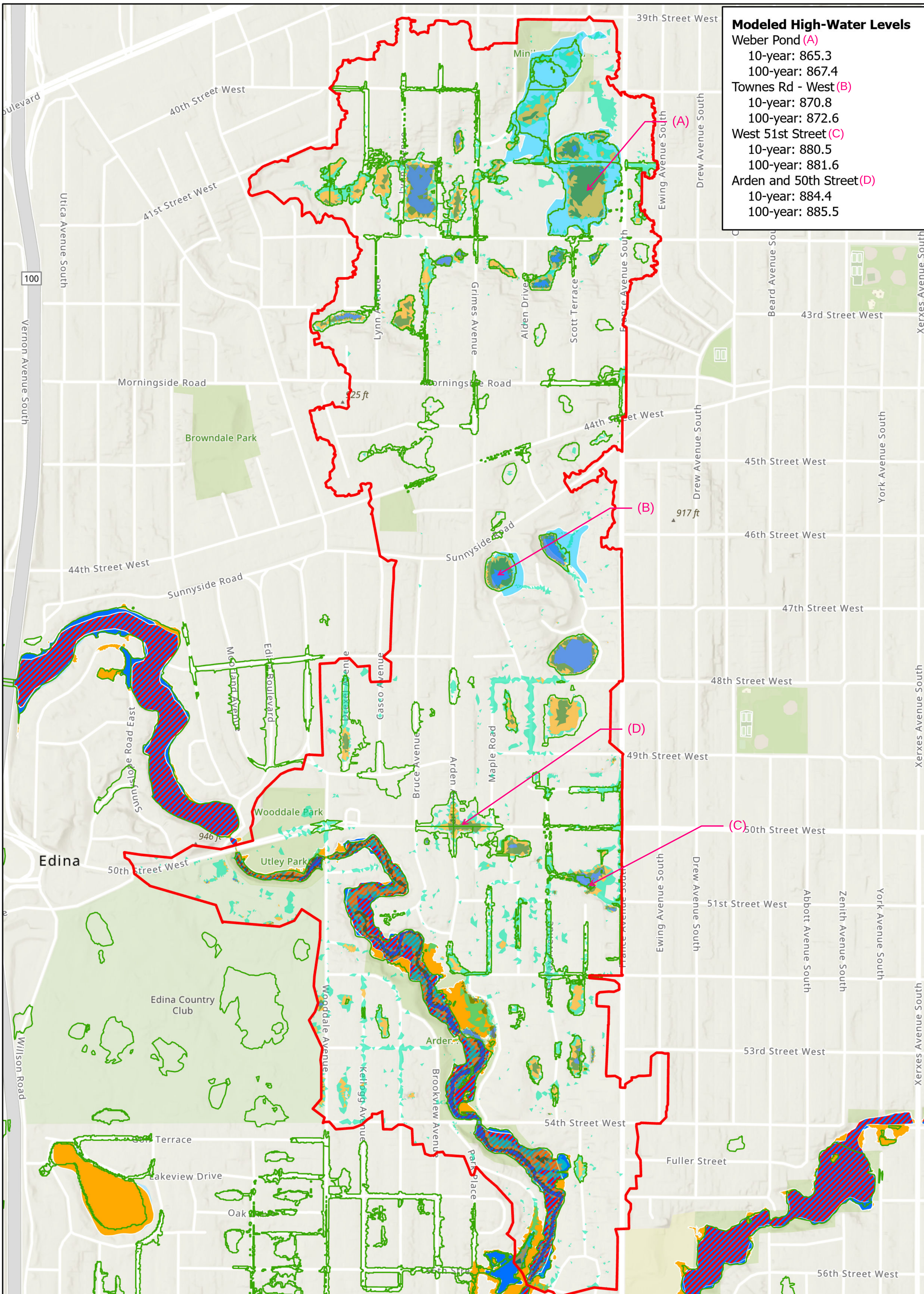
3. Low-Resolution (11,900 2D elements), Hand-Build Mesh, Overland Region Only
4. Low-Resolution (11,900 2D elements), Hand-Build Mesh, Overland and Groundwater Regions
5. High-Resolution (50,842 2D elements), Hand-Build Mesh, Overland Region Only
6. High-Resolution (50,842 2D elements), Hand-Build Mesh, Overland and Groundwater Regions
7. High-Resolution (105,498 2D elements), Automated Mesh Tool, Overland Region Only

ICM still reports faster run times across all scenarios. The groundwater region within ICPR increased run times additionally, although it should be noted that the previously discussed 18,000-20,000 groundwater mesh element limit was not reached in Scenario 6. If ICPR is scaled to the watershed wide build, the District could consider whether the groundwater module is needed for all scenario runs or whether its needed active through the entire watershed to help lower run-times.

Outside of the simulation processing time, ICM and ICPR both need to preprocess the mesh to parameterize each 2D mesh element with infiltration and roughness values for use during the model runs. ICM completes the preprocessing of the mesh quickly and will typically complete the preprocess build in under a minute to five minutes. ICPR completes the preprocessing in under 30 minutes for the low-resolution scenario and between two and five hours for the high-resolution scenario.

APPENDIX A

EDINA FLOOD MAPS



N

0 500 1,000 2,000 Feet

Kimley»Horn

MINNEHAHA CREEK WATERSHED DISTRICT — QUALITY OF WATER, QUALITY OF LIFE

Exhibit 1A

ICM - Flood Inundation Comparison

10-year, 24-hour Rainfall Event

04/26/2023

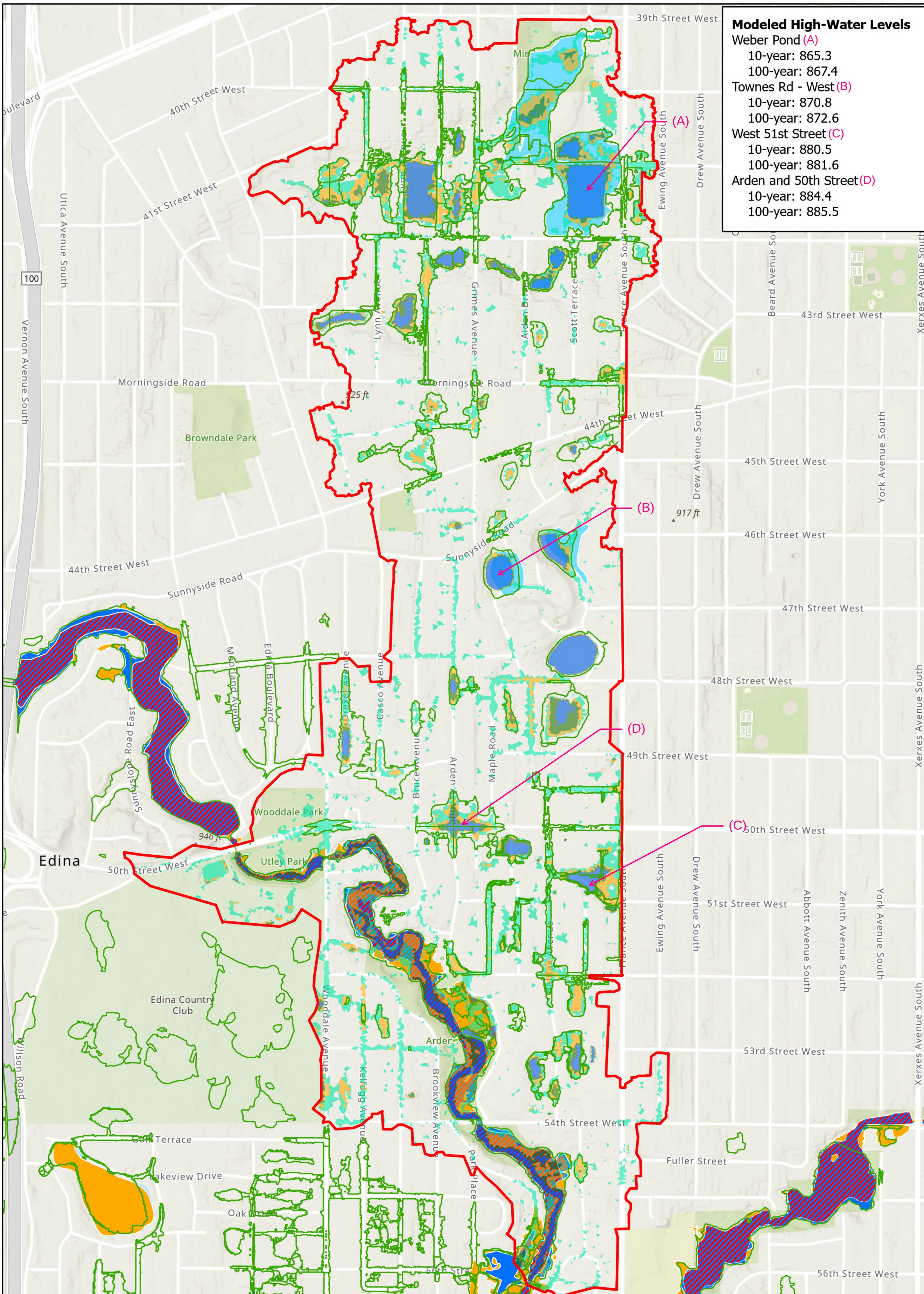
Legend

FEMA Flood Zone
- A,
- AE,
- AE, ADMINISTRATIVE FLOODWAY
- AE, FLOODWAY
- AH,
- AO,
- X, 0.2 PCT ANNUAL CHANCE FLOOD HAZARD

City of Edina Mapping Inundation 10-year

Edina Pilot Model Area

10-year Inundation (FT)
- Less than 0.25
- 0.251 - 1.00
- 1.01 - 2.00
- 2.01 - 3.00
- 3.01 - 10.00



N

0 500 1,000 2,000 Feet

Kimley»Horn

MINNEHAHA CREEK WATERSHED DISTRICT — QUALITY OF WATER, QUALITY OF LIFE

Exhibit 1B

ICM - Flood Inundation Comparison

100-year, 24-hour Rainfall Event

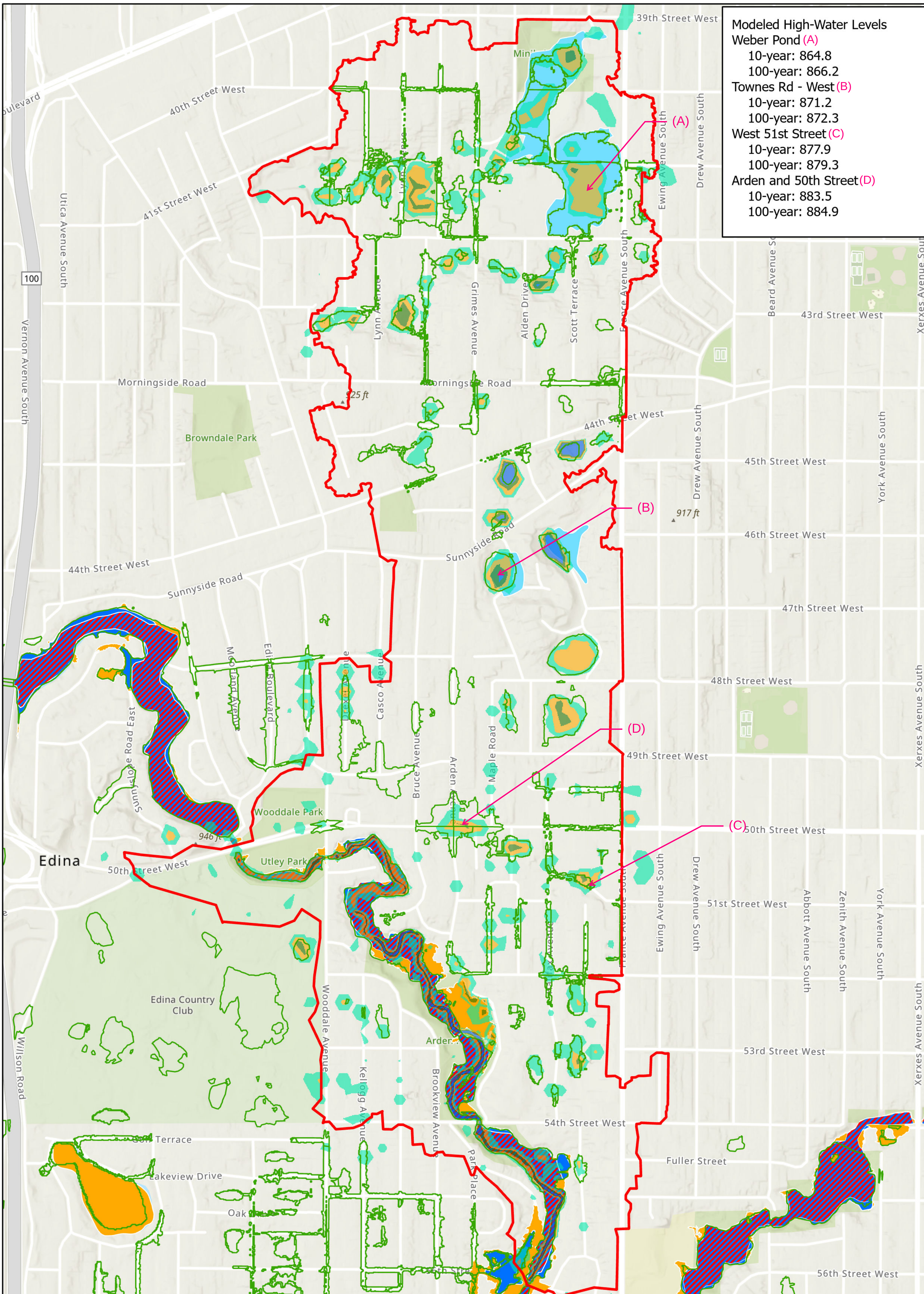
04/26/2023

Legend

FEMA Flood Zone
- A,
- AE,
- AE, ADMINISTRATIVE FLOODWAY
- AE, FLOODWAY
- AH,
- AO,
- X, 0.2 PCT ANNUAL CHANCE FLOOD HAZARD

- Edina Pilot Model Area
- City of Edina Mapping Inundation 100-year

100-year Inundation (FT)
- <0.25
- 0.251 - 1.000
- 1.001 - 2.000
- 2.001 - 3.000
- 3.001 - 10.000



N

0 500 1,000 2,000 Feet

Kimley»Horn

MINNEHAHA CREEK WATERSHED DISTRICT — QUALITY OF WATER QUALITY OF LIFE

Exhibit 2A

ICPR - Flood Inundation Comparison

10-year, 24-hour Rainfall Event

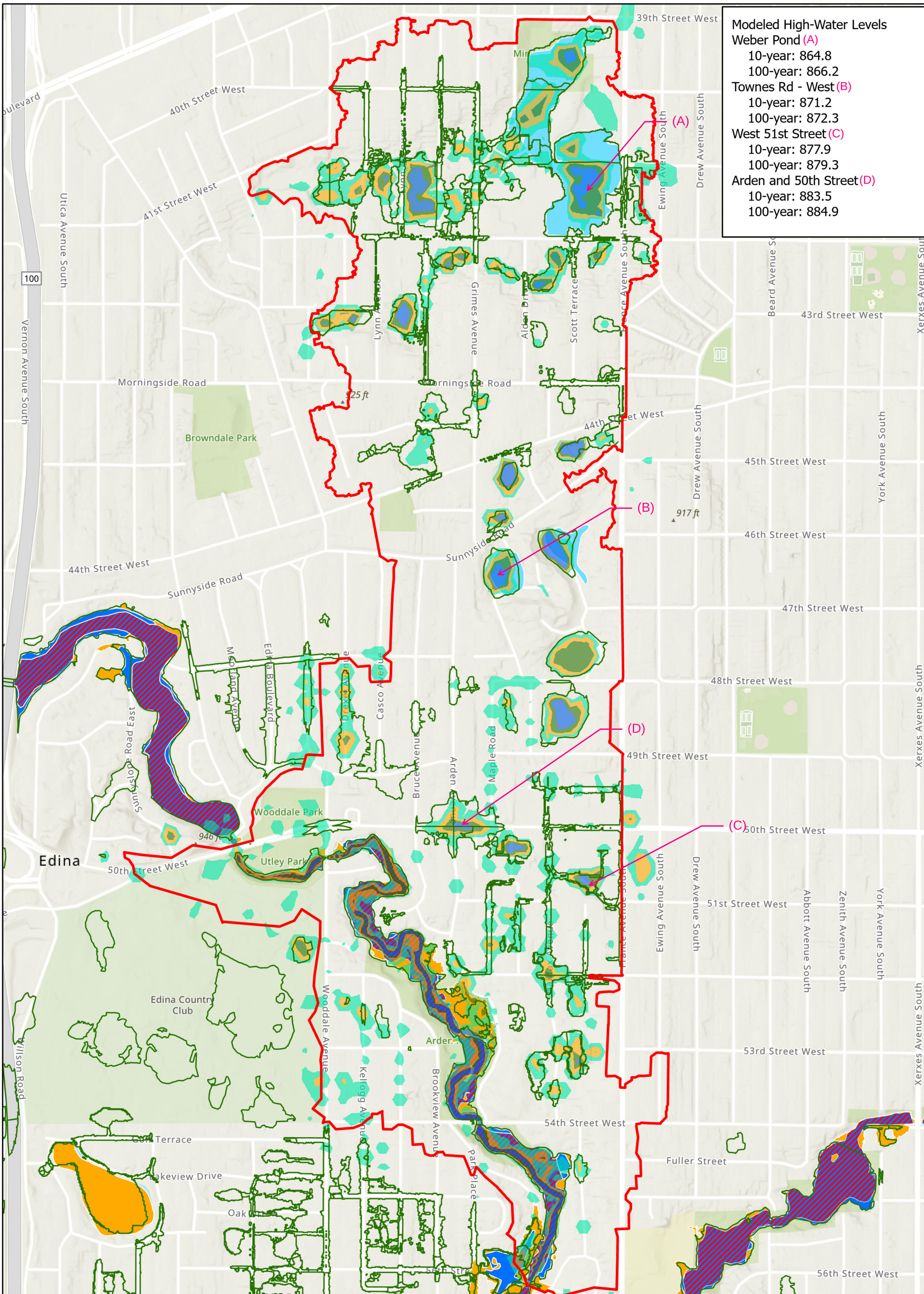
04/26/2023

Legend

FEMA Flood Zone
- A,
- AE,
- AE,ADMINISTRATIVE FLOODWAY
- AE,FLOODWAY
- AH,
- AO,
- X,0.2 PCT ANNUAL CHANCE FLOOD HAZARD

- Edina Pilot Model Area
- City of Edina Mapping Inundation 10-year

10-year Inundation (FT)
- <0.25
- 0.251 - 1.000
- 1.001 - 2.000
- 2.001 - 3.000
- 3.001 - 13.000



N

0 500 1,000 2,000 Feet

Kimley»Horn

MINNEHAHA CREEK WATERSHED DISTRICT — QUALITY OF WATER · QUALITY OF LIFE

Exhibit 2B

ICPR - Flood Inundation Comparison

100-year, 24-hour Rainfall Event

04/26/2023

Legend

FEMA Flood Zone
- A,
- AE,
- AE,ADMINISTRATIVE FLOODWAY
- AE,FLOODWAY
- AH,
- AO,
- X,0.2 PCT ANNUAL CHANCE FLOOD HAZARD

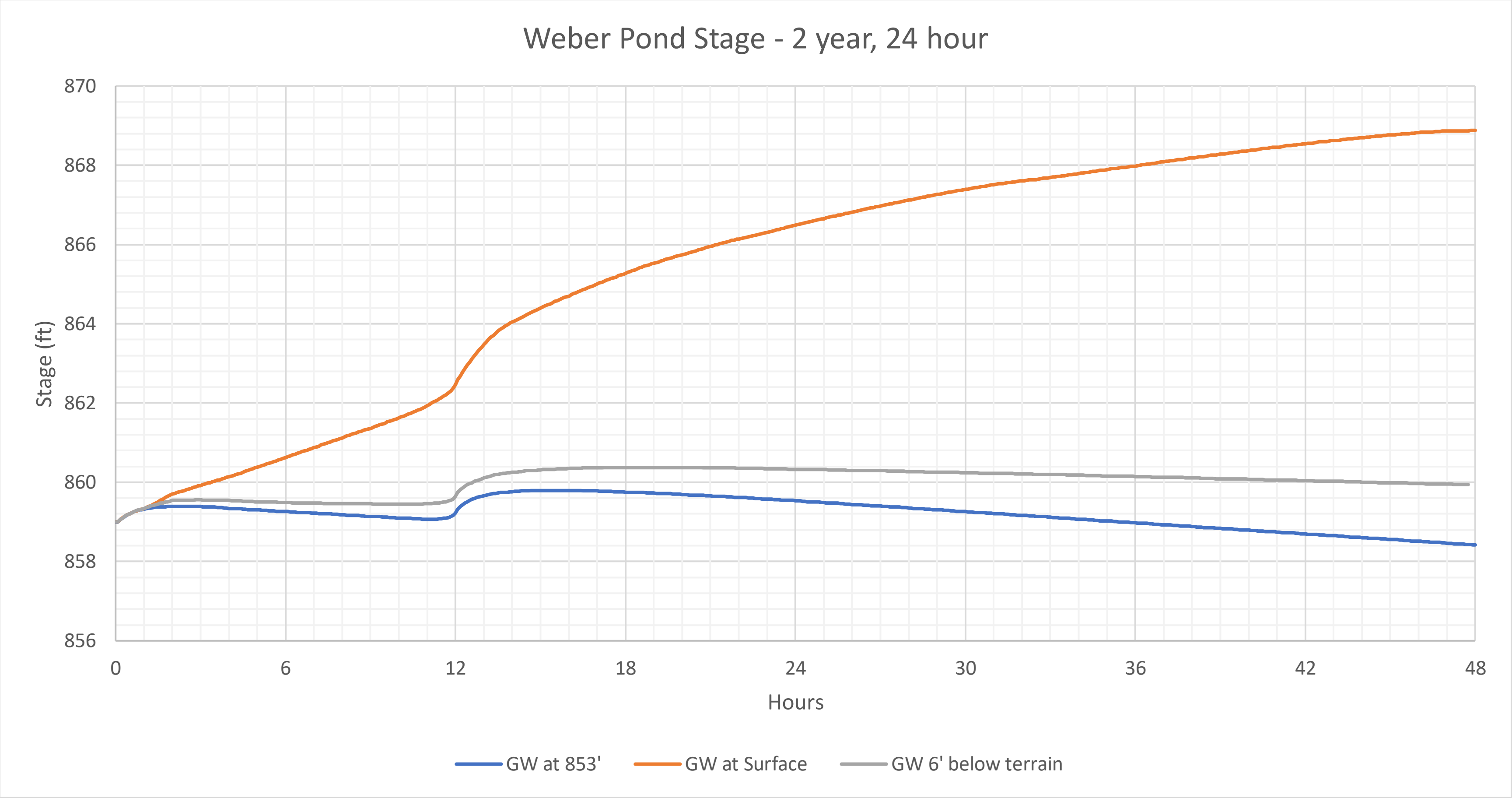
- Edina Pilot Model Area
- City of Edina Mapping Inundation 100-year

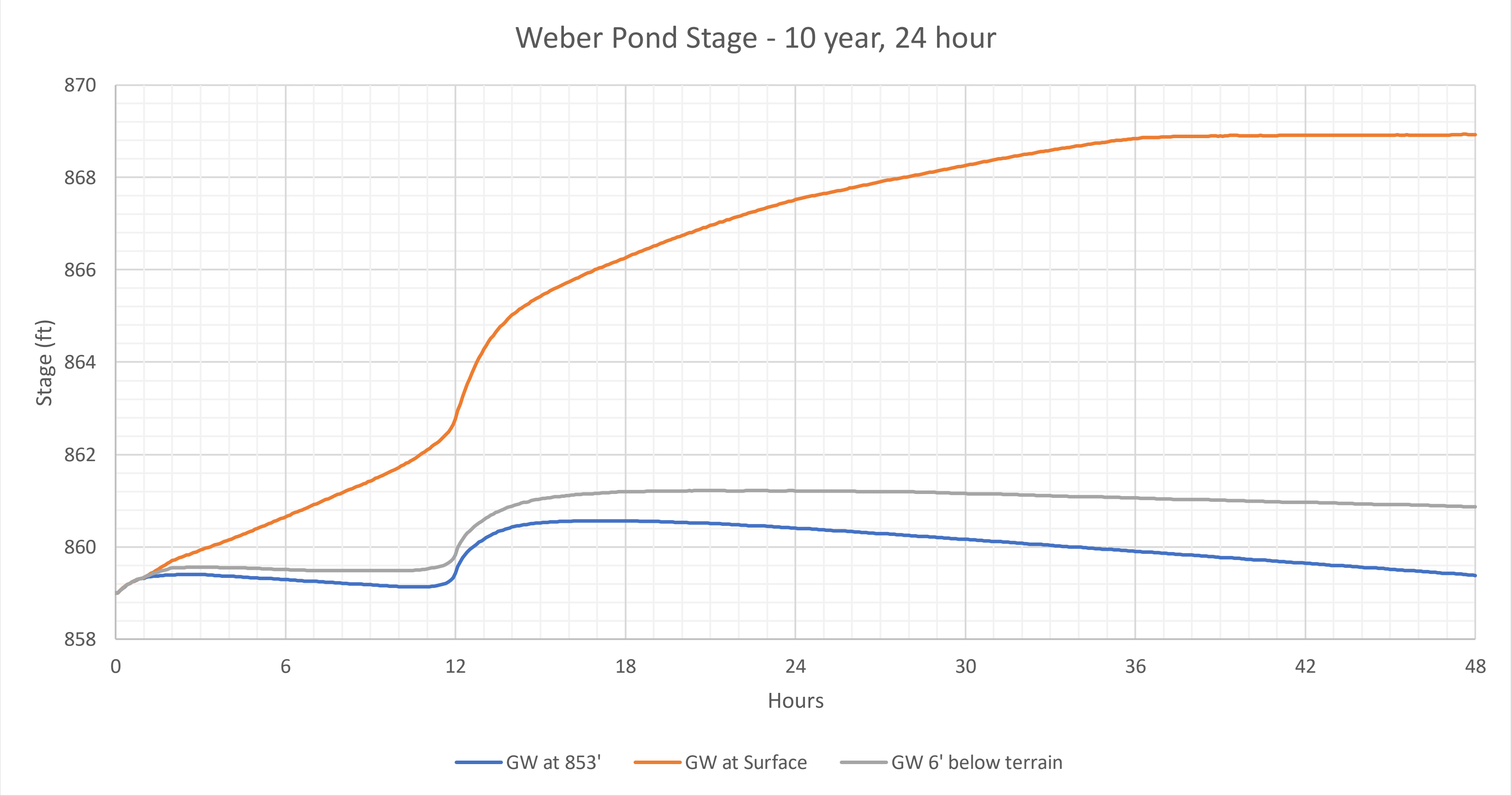
100-year Inundation (FT)
- <0.25
- 0.251 - 1.000
- 1.001 - 2.000
- 2.001 - 3.000
- 3.001 - 10.000

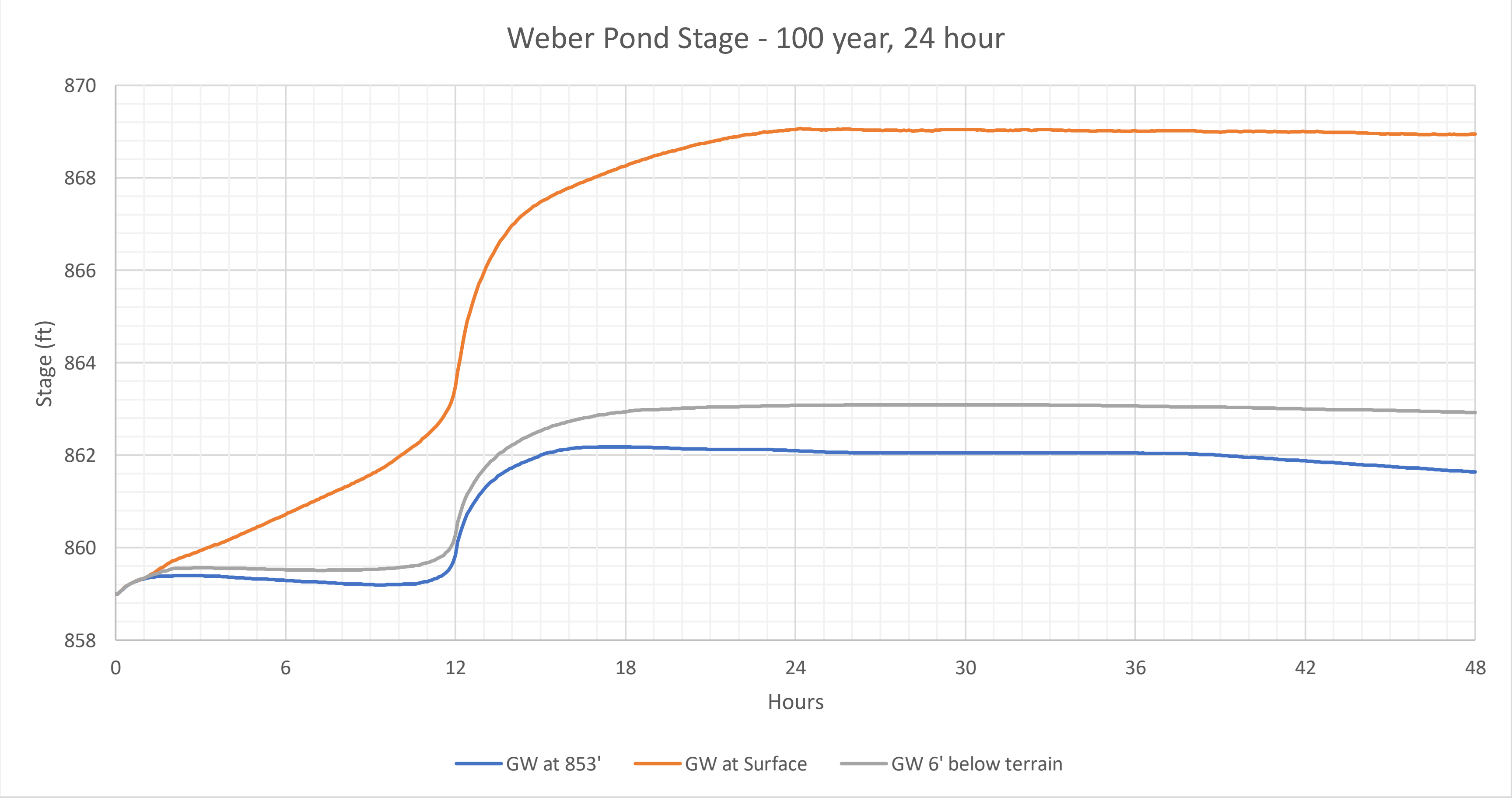
APPENDIX B

GROUNDWATER INFLUENCE EXHIBITS

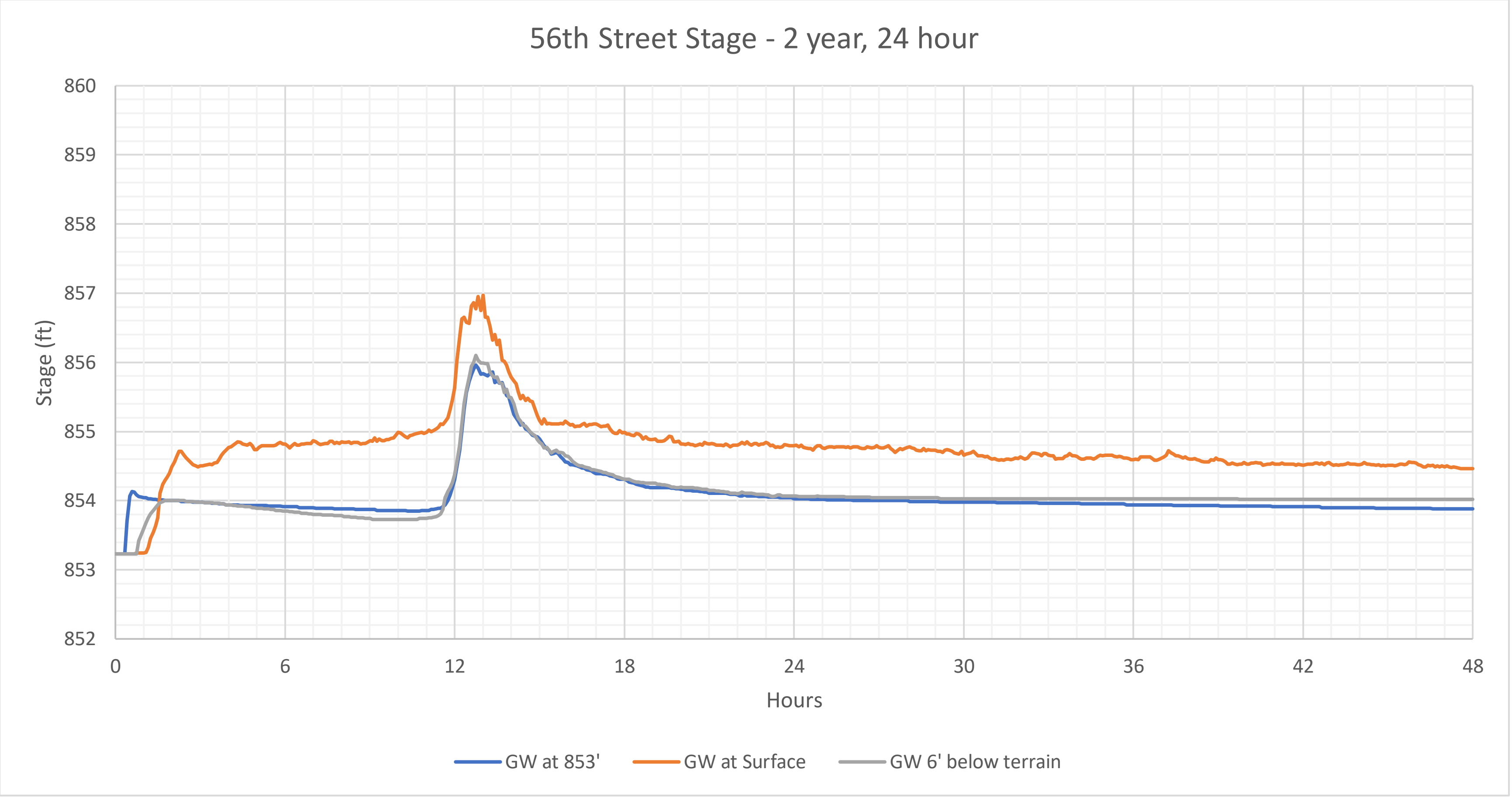
APPENDIX B – GROUNDWATER INFLUENCE

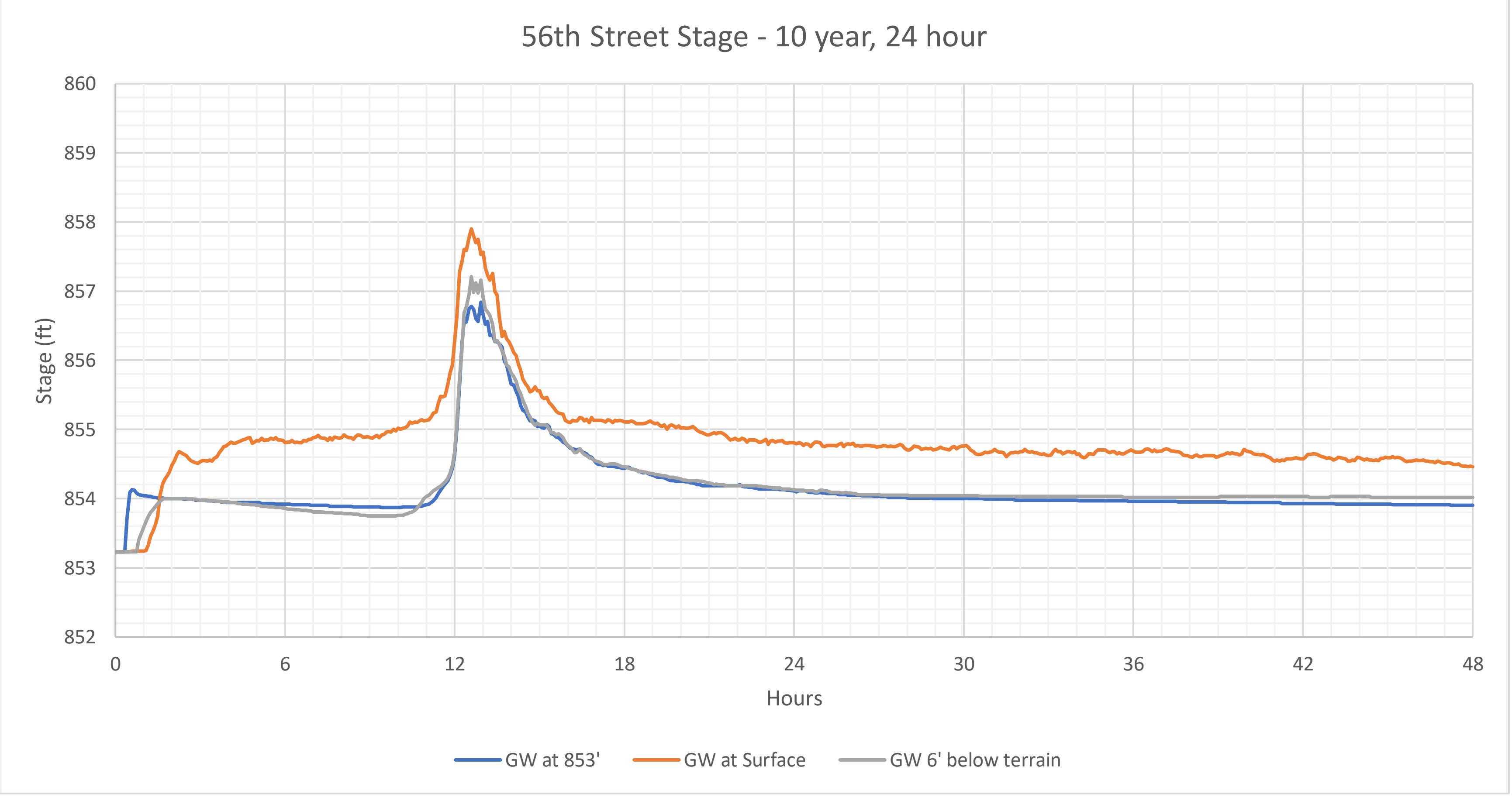






APPENDIX B – GROUNDWATER INFLUENCE





APPENDIX F – EVALUATION FRAMEWORK MEMORANDUM

MEMORANDUM

To: Kailey Cermak, Project Manager | Minnehaha Creek Watershed District

From: Ron Leaf, Project Manager | Kimley-Horn

Date: March 2022 (Revised May 2023)

Subject: 2D Pilot Model Build - Evaluation Framework Memo

BACKGROUND

The Minnehaha Creek Watershed District's (MCWD or District) current modeling tools are dated and do not provide the granularity and features necessary for the District to effectively manage and adapt to climate change. District staff identified the need to develop a new modeling tool that has greater granularity that can characterize and quantify the impacts of climate change and evaluate a range of scenarios to shape climate adaptation strategies, programmatic policies, and specific projects.

MCWD began the model selection process by conducting a cursory assessment of several two-dimensional modeling software packages. This screening-level assessment (included as an appendix), along with vendor information sessions and consultation with agency experts, led the District to narrow their focus to ICPR and ICM. Both software packages were selected for evaluation through two distinct subwatershed areas during the pilot model build analysis, giving the District an opportunity to comprehensively compare the two. The District chose to pursue a pilot model build, ahead of the full watershed-wide build, to mitigate for the relational and technical risk that is often associated with large-scale, high-resolution models such as selecting the right software for the intended use.

A key objective of the pilot model build project and the first task within the scope of work is to establish a clear, comprehensive evaluation framework that the District can ultimately use as a resource to:

1) Inform which of the two models is best suited to meet the District's current needs; and
2) Understand the operational considerations and challenges of scaling the model watershed-wide.

This memorandum outlines key components of the evaluation framework and how the information will be used by the District in support of making an informed decision on which modeling platform to advance to the watershed wide model build phase of their initiative.

FRAMEWORK OVERVIEW

The purpose of this portion of the memo is to describe how the framework was developed and to provide an overview of its structure. It was important that the evaluation framework serves the District for its current model evaluation process and can be re-used in the future as the District's modeling needs change and new tools need to be evaluated. To accomplish this, the project team concluded that the framework must evaluate models based on a combination of model use criteria and model operational criteria. This approach provides a broad view of each model's range of capabilities evaluated against the District's primary intended use cases.

The framework structure and definitions are as follows:

MCWD Model Uses

The first step in a model evaluation process is defining clear objectives since each software package provides unique features and capabilities. While the District relies on modeling for a variety of uses, the upcoming watershed-wide model's primary purpose is to serve climate adaptation planning work. It's important that emphasis gets placed on modeling features that directly support the District's primary use. Therefore, there are two categories within this section, which include:

1) *Primary Uses:* The primary model uses section lists what the MCWD has identified as priority needs and uses from the upcoming watershed-wide model. Emphasis will be placed on this category during model selection.

2) *Secondary Uses:* The secondary model uses section lists capabilities from which the District and its partners would benefit, although these metrics will not drive model selection.

Model Operations

The ability to efficiently build, run, and export data are also important considerations when developing a model. Having a thorough understanding of these operational-level metrics will shape how the District chooses to scale and maintain the upcoming watershed-wide model. The categories within this section include:

1) *Data Processing:* This category includes metrics related to how raw datasets are processed into model-build ready datasets. While this category is important to evaluate if either model has any significantly different level or format of data import needs, the end result of those differences would likely relate more to how much effort a user may need to expend during the pre-model build process to ready the data for import into the model. The other differentiator relates to how effectively the scripting process can process the raw datasets into a model-build ready format.
2) *Model Build Processes (Including Calibration and Validation):* This category is intended to assess the metrics that impact the ability of the automated model build scripts to create a functioning model. Important differences in the two models will relate to how well each accepts and connects the surface grid interaction with the subsurface conduit data through the automated processes. Two model maintenance metrics are included to differentiate between the ease of automated model updates and the more manual maintenance process for model version and security. Significant attention was placed on the calibration process and validation process during the pilot study.
3) *Model Function and Results (Scenario Analyses):* This category focuses on metrics relating to obtaining reliable and repeatable model results, comparing output capabilities of the two models and how well each model is suited to a range of scenario planning situations. This category is the most directly related to each model's ability to meet the District's primary modeling goals.
4) *Software Specifics:* This category captures a range of metrics that do not fit directly within any of the previous categories. In general, these are more administrative type considerations that are not likely to directly influence model selection. Instead, these metrics are more likely to inform the District on considerations that will impact costs of owning the model, watershed-wide scale-up issues and/or long-term maintenance and administration of the model. As the project and evaluation process progresses, additional categories may be carved out of this section.

EVALUATION PROCESS

Approach

The matrix metrics were intentionally established at the beginning of the project, so the project team would have a designated place to track observations and data points about each model. The general approach was to provide space for qualitative assessments, while also being able to record quantitative study results to provide an objective comparison of the two models. The final version of the matrix presents the following assessment information:

1) ICM/ICPR Evaluation Process Comments / Observations. Comments and observations included here represent a combination of the pilot modeling team input form the pilot study experiences and, in some areas, input directly from the model developer has been included.
2) Summary / Comparison. Based on the full body of comments from the pilot modeling team and comments provided by the model developers, this column includes a comparison of where the two models differ or a statement that both models are capable in this area and there is no apparent difference based on the scope and results of the pilot study.
3) Rating. The rating format assigns a 0-1-2 level for each Evaluation Factor based on the model's relative capability for that factor. A "0" rating defines the model as not capable or having only weak capabilities; a "1" rating defines the model as being proficient for that factor; and a "2" rating defines the model as having strong capabilities for that factor. Where one model rated higher than the other, that box has been highlighted either blue (for ICM) or green (for ICPR), to better emphasize where model differences were observed. Scores were not totaled only for the matrix as a whole and not for each category. The total score should be considered a data point that confirms both models have wide capabilities and should not be considered an absolute numerical ranking of each model.

A description of how each section of the matrix was populated and scored is provided below.

Model Use Metrics Assessment

The primary and secondary model uses represent two categories of metrics within this evaluation framework. These two categories of factors include some of the most common model capabilities the District currently uses and some additional model functions that the District see as the providing the greatest program related value in the future. The evaluation of these model use factors or metrics is designed to provide an overview of how the two models differ in their abilities as it relates to known upcoming uses. The lead ICM/ICPR modelers, in coordination with model Quality Control (QC) leads, populated these sections prior to commencement of the model build and then revisited each of the responses after completing each subsequent step in the model build and scenario analysis phases of work. These updates were intended to confirm whether the initial assessment is still accurate and to supplement observations based on the completed pilot study phase.

Operational Metrics Assessment

Similar to the Model Use metrics, a qualitative assessment of each of the operational metrics was initially completed by the respective ICM and ICPR modeling leads and GIS/Software experts during the initial phases of work to process data needed for model builds, build and calibrate the models and ultimately complete the scenario analyses. The goal with these factors is to define the specific capabilities of each model related to a given metric and draw attention to any unique or significant benefits or drawbacks.

Upon completion of distinct model build phases, the ICM and ICPR modeling leads and GIS/Software experts revisited the initial comments and observations.

MODEL EVALUATION

The original intent of the evaluation matrix process was to provide an objective comparison framework for the two models. The initial framework included a numeric rating process that was removed in favor of the current 0-1-2 rating format to provide a more representative direct assessment of the model capability for each factor. This approach supports the goal of the matrix being to inform the decision by the District, but not to produce a decision based purely on the final score.

At the outset of the pilot study, District staff were not anticipating that the evaluation process would reveal a clear and easy choice and desired a broad range of evaluation factors within the evaluation matrix to refer back to as the final assessment of both models took place. Each model will likely deliver on some primary uses better than the other and each model's overall capabilities comes with its own unique operational considerations and challenges. The District is prepared to prioritize selecting a model based on its ability to meet its primary uses, even if it means it will be operationally more difficult.

A summary of the findings from this evaluation process and insight on each model's ability to scale and deliver on the District's primary uses will be discussed in the final project report.

ATTACHMENTS

1. Evaluation Metric Descriptions
2. Evaluation Framework Matrix
3. Aquaveo Screening Study

EVALUATION METRIC DESCRIPTIONS

Primary Model Uses

1. *Produce channel and localized flood inundation maps*
    a. The ability to present the occurrence of flooding in a particular location within the model and through export of model result to GIS or other platforms for producing maps to illustrated flooding extents and/or depths.
2. *Run long-term back-to-back extreme wet or dry years to evaluate groundwater-surface water interactions*
    a. The does model have the ability to discern results related to impact of ground water table and antecedent moisture content on infiltration rates in existing and proposed stormwater features. Is there capability to assess ground water-surface water interaction during the model run.
3. *Evaluate impacts of current and alternative regulation/policies on surface water quantity*
    a. Review results and impacts to water levels in surface water features based on changes in landuse from development and changes in infiltration rules applied on a project scale or land area scale, for example.
4. *Quantify the impact of regional volume management strategies (Projects/BMPs)*
    a. Ability to extract additional results information at specific surface water features throughout the watershed based on applying a combined developed condition with volume control requirements applied.

Secondary Model Uses

5. *Short-term channel and localized flood forecasting (all seasons, consider snowmelt)*
    a. Ability to use future projections of rainfall and snowmelt conditions to efficiently predict flow and runoff results throughout the watershed and within creek channels.
6. *Characterize water quality changes / impacts*
    a. Ability to determine impacts of additional development on water quality parameters and the presence and movement of contaminants through the watershed.
7. *Provide boundary conditions for other models*
    a. Set and/or extract boundary conditions at edges of subwatershed-scale model boundaries to benefit partner model development.
8. *Establish updated FEMA certified flood maps*
    a. Determine the impacts to riverine flooding conditions based upon proposed/future modifications to the watershed and have the model results accepted by FEMA as the official basis for base flood elevation inundation mapping.

Data Processing

9. *Accepted file formats of input datasets*
    a. Diversity of import dataset types and formats.
10. *Repeatability of data process to model build ready data*
    a. Is the process of data preparation repeatable? And easily repeatable?
    b. Scale of preprocessing effort to efficiently build a baseline model of a subwatershed or the entire watershed build out.

11. *Manual processing effort to get model input data ready for model import. Infrastructure data and geospatial data.*
    a. Additional manual processing effort for import of standard infrastructure and surface features (e.g., gravity pipes, landuse delineations, inlets)
12. *Manual data processing feedback loops. Ability to export manually adjusted data to external geodatabase.*
    a. Import/export of manual data changes for future tracking and to reduce of duplication of effort and potential for missing updated data.

Model Build Processes

13. *Model node limitations (scale capabilities*)
    a. Is there a model node limit, actual or practical? Is there a large change in process to build the model when adding additional nodes/links within model?
14. *Default hydrology method and processing.*
    a. *What is or are the available default hydrology methods and are the applicable to District needs and uses.*
15. *Watershed-wide construction considerations. Single watershed wide model versus multiple smaller model areas.*
    a. Ability to efficiently develop the baseline watershed-wide model and does the model format allow for variations and detail between single area and watershed-wide builds.
16. *Ability to carve out smaller sections of the model.*
    a. Ability to efficiently increase model level of detail in areas where finer results are required. Does the finer model build area/version allow for automated update to the base model.
17. *Model resolution required to support primary uses*
    a. Baseline model resolution in terms of 2D grid sizes to support the primary uses. Is the mesh a constant or does it allow for variable mesh size to capture greater detail in areas of interest such as where steep grades are present.
18. *2D overland mesh methodology*
    a. What is the mesh creation methodology and what is the resulting need for additional hand edits to the mesh for baseline model development.
19. *1D-2D Connection Points.*
    a. *What is the models approach and options for connecting the 2D surface mesh with the 1D features such as pipes and inlets to the pipes.*
20. *Pump system functions/capabilities*
    a. Ability to model existing and proposed pump stations and forcemains within the watershed.
21. *Method/approach to calibration*
    a. Steps to review model results and multiple scenarios in terms of adjusting inputs/parameters for calibration to one or more known events/observed results.
    b. Steps to review baseline model build results with respect to observed events and results. Specifically, the ability to relate model results to other previously calibrated models and calibrated results.

Model Function and Results

22. *Ease and Options for BMP Evaluation*
    a. Input process for proposed BMPs, any unique parameters and simulating the resulting effects of the modifications.
23. *Ease of Land-Use Change Scenarios*
    a. Effort and process to swap out land-use delineations or parameters in a given area.
24. *Model runtime (common processing system)*
    a. Overall model run times on common computer comparison.

25. *Results quality and output format*
    a. Quality of results data, broadness of results in model and in exports.
    b. Exported results resolution and assessment of consistency of exported results (i.e., exported data the same as viewed in the model)?
26. *Export process and format*
    a. The ease of exporting results for use in outside programs and analysis.
    b. The default format for exporting results, and any additional options for exporting results.

Software Specifics

27. *Sharing model versions*
    a. Formats for sharing models or portions of a model.
    b. Issues in sharing models, sending to others (internally and externally).
28. *Local versus network – processing ease*
    a. Options for performing model simulation runs on a local device or network and the change in model run times and model saving considerations.
29. *License type and cost*
    a. License cost, types, features.
30. *Model maintenance (version management, security, technical support)*
    a. How does model maintenance work? Is the software updated often? New features in the works? Is the technical support provided easily accessible and responsive? Are there any unique security issues related to model storage and sharing.
31. *User Community*
    a. Size and extent of users across the region/country.

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EVALUATION FRAMEWORK MATRIX

MCWD 2D PILOT MODEL BUILD
EVALUATION FRAMEWORK MATRIX
31-Jul-23

Evaluation Category	Line ID	Evaluation Factor / Description	Evaluation Process Comments / Observations		Summary / Comparison	Rating (0 - not capable or weak; 1 - proficient; 2 - strong)	
			ICM	ICPR		ICM	ICPR
MCWD Primary Model Uses	1	Produce channel and localized flood inundation maps	Capabilities to view flood animation results within the model (inundation depth, velocity). Fully feasible to produce results and maps to depict out of bank and localized inundation areas within the model or through export to other tools. 2D results elements (points, line, polygons) can also be used to review flooding and simulation results along and within common locations over multiple model simulations.	Capabilities to view flood animation results within the model (inundation depth, velocity). Feasible to produce results and maps to depict out of bank and localized inundation areas within the model or through export to other tools.	Both models fully capable to produce inundation mapping.	2	2
	2	Run long-term back to back extreme wet or dry years to evaluate groundwater-surface water interactions	Not feasible. Model does not account for two-way surface water/groundwater interaction. Can mimic antecedent condtions through soil moisture at the beginning of the simulation. Uses Green-Ampt parameters to mimic antecedant soil mositure at beginning of simulation.	Model can dynamically model groundwater via 2D network or simpler methods, and multiple scenarios are possible.	ICPR tracks horizontal groundwater movement and ICM does not. ICM simulations are based on a starting GW condition and do not vary throughout a long-term simulation, like ICPR.	0	2
	3	Evaluate impacts of current and alternative regulation/policies on surface water quantity	Options to spatially update land-use through hand edits or re-import of land-use delineations. Land-use delineations and parameters can be varied by scenario to allow for additional flexibility.	Able to manipulate through land use map layers via spatial update, or via tabular property update, for entire study area on the fly.	Both models fully capable and have wide capabilities	2	2
	4	Quantify impact of regional volume management strategies on surface water quantity (projects/BMPS)	Use the 2D results elements to review infiltration rates and volumes for proposed regional BMPs or specific policies.	Somewhat limited in ability to quantify smaller BMP impacts en masse, but smaller elements can be implemented manually. ICPR can interact on multiple model scales within a single model.	Both models fully capable and have wide capabilities	2	2
MCWD Secondary Model Uses	5	Short-term channel and localized flood forecasting (consider snowmelt)	Feasible	Feasible; snow melt can be further varied via baseflow input parameters, likely manual edit within the software.	Both models fully capable and have wide capabilities. ICM refers to a different snowmelt analysis than what is current practice in MN.	2	2
	6	Characterize water quality changes/impacts	Not directly evaluated during pilot study. Software developer input and model documentation refers to multiple functions and capabilities to model multiple parameters, including sediment, salt, coliforms, phosphorus and many others.	Not directly evaluated during pilot study. Software developer input and model documentation refers to 1D water quality modeling in ICPR4 Pro, and plans to release a new water quality module in late 2023.	ICM has capabilities to model TP and other parameters of interest to the Distrct. ICPR does not currently have any capabilities to track nutrients or pollutants.	1	0
	7	Provide boundary conditions for other models	Feasible to export and use stage and flow hydrographs at any location.	Feasible to export and use stage and flow hydrographs at any location.	Both models fully capable.	1	1
	8	Establish updated FEMA certified flood maps	Not currently approved nationally by FEMA. Has been locally approved in selected locations. Developer is actively seeking national approval from FEMA.	Not currently approved nationally by FEMA. Has been locally approved in selected locations.	Neither is nationally accepted currently. Both have examples of being accepted regionally/locally. ICM may likely be accepted sooner as they are actively seeking	0	0
Data Processing	9	Accepted file formats of input datasets	Shapefiles, Geodatabases, CAD, Text	Shapefiles, CAD (.dxf), CSV tables	Both models fully capable and have wide capabilities.	2	2
	10	Repeatability of data process to model build ready data	Use of MGIS and Configuration files for consistent import of infrastructure data.	Use of MGIS and Configuration files for consistent import of infrastructure data.	Both models equally capable/functional.	1	1
	11	Manual processing effort to get model input data ready for model import. Infrastructure data and geospatial data.	Manual effort required for the following cleanup steps: US/DS node name for pipe, artifically high pipes due to DEM fill of invert. Non-snapping of nodes to DEM in model space, node elevations needs to be pre-defined for pipe outlets to match the pipe invert.	Manual effort required for US/DS nodes on some pipes missed, DEM invert revisions, repeat pipe names. 1D connections for catchbasin (inlets) starting elevation need to be overwritten and assigned pipe invert elevation or additional water introduced to system at beginning of simulation. Nodes cannot be easily swapped out for 1D connections (live in separate buckets: 1D object vs. 2D feature)	For 1D infrastructure elements - no signifcant difference. For 2D elements ICPR takes additonal effort to set groundwater layer for functionality ICM does not have.	1	1
	12	Manual data processing feedback loops. Ability to export manually adjusted data to external geodatabase.	Allows for export of pipe/junction parameters along with flags to denote original value or updated value in export attribute table.	ICPR has a "difference" tool that can compare and report on additions, deletions, and changes between scenarios for 1D input data.	Both models equally capable/functional.	2	2
Model Build Processes (Including Calibration and Validation)	13	Model node limitations (scale capabilities)	There are no limits to the number of nodes (unlimited license).	No limits, may have practical limit when compared to run times. Groundwater mesh practical limit around 18,000 nodes due to matrix solver. Can get around this by creating multiple groundwater areas.	No significant differences in cabilities. ICPR has some recommended approaches related to addition of the 2D groundwater mesh.	2	2
	14	Default hydrology method and processing	Green-Ampt, Horton, Constant Rate, Fixed Rate	SCS Curve Number, Green-Ampt, Vertical Layers Green-Ampt	No significant difference. Both have options for varied methods.	1	1
	15	Watershed-wide construction considerations.	Ability to introduce various levels of detail through scenario manager. Feasible to build a single overall watershed-wide model with multiple scenarios with additional data recommended. Also feasible to build several subwatershed-specific models.	Ability to incorporate various levels of detail through model build. Feasible to build single model for entire watershed possible while considering the developer's recommended practical limits on the groundwater mesh size. Ability to scale groundwater module watershed-wide, but may reduce resolution. Multiple smaller models would allow for higher resoultion in groundwater mesh. Combined SW and GW mesh will require additoinal attention and careful construction of watershed wide build.	No significant difference for surface water. Groundwater capability for ICPR requires additional effort and adjustment/calibration iterations to get it built well and running efficiently for single model or for multiple smaller models.	2	1
	16	Ability to carve out smaller sections of the model.	Capability to create new sub-model to allow multiple scenario runs of smaller areas. Cannot push sub-model edits back to full model. Changes to base model are automatically updated in sub-model.	Capability to create a separate model to allow multiple scenario runs of smaller areas. Cannot push model edits back to full model.	Both have a scenario manager function/option that allows for separate/discrete model areas to be created and saved. ICM retains connection of sub-models to base model.	2	1
	17	Model resolution required to support primary uses	Automated variable mesh generation tool allows for development of mesh with sufficient detail to meet primary use needs (exception of groundwater).	Automated variable mesh resolution results in flexibility when only overland flow module is being used. To couple overland flow and groundwater, the mesh must be manually created using breakpoint offsets. Breaklines must be transferred from overland flow to groundwater mesh.	Both models equally capable/functional.	1	1
	18	2D overland mesh methodology	Triangular elements represent the average elevation within the element. Breaklines, void areas and walls can also be included in the mesh development to simulate hydraulically signficiant features.	Three elements; triangles represent links, hexagons represent storage/land use parameters, diamonds connect hexagon edges. Breaklines must be enforced along flow paths to allow water to move freely. Breakpoints are recommeded. All overland mesh breaklines must be transferred to the groundwater region to ensure alignement between meshes.	Both require edits for breakline refinement of 2D mesh. ICPR requires more breaklines to define accurate flowpaths. ICPR requires additional refinement of GW mesh.	2	1
	19	1D-2D Connection Points	1D connections are specified through the standard node input. Using either the 2D, Gully 2D, or Inlet 2D flood type allows user input of inlet capacity. Can modify/swap inlet types and parameters after creation, also allowed for removal of inlet capacity (manhole).	1D connections utilize the mesh elevation data to determine starting WSEL. User must specify alternate starting elevation when modeling 1D connection to storm sewer (e.g., catchbasin). 1D connections allow direct connection between overland flow region and 1D hydraulics, do not allow for inlet capacity limitation. To model inlet capacity, weir link required between 1D connection and stage/area node (manhole).	Both models equally capable/functional.	1	1
	20	Pump system functions/capabilities	Pumps can be included as part of the development. Additional user input to include pump curve and others needed to effectively model pump. Mulitple pump types available. Allows for specific pump information and is fairly intuitive for users familiar with pump system modeling.	Pumps can be included as part of the development. Additional user input to include pump curve and others needed to effectively model pump. Mulitple pump types available. Input and review of results required to accurately inform pump curve selection.	ICM may be slightly easier to use for pump systems, but the vast majority of pum ps ceanrios will be essenatilly the same.	1	1
	21	Method/approach to calibration	Calibration was achieved through the adjustment of surface roughness changes and breakline delineation. No adjustments were required to reduce error during calibration.	Calibration was achieved through the adjustments of surface roughness changes, breakline delineation, breakpoint addition, and impervious value increases. Adjustments to the breakline placement were required to reduce model error to acceptable ranges. The groundwater mesh region required an additional step to add breaklines to the GW region that matched the SW region. Adjustment of breaklines in one region must be transferred to other region.	No significant difference in surface water only. ICM produced a lower error than ICPR with comparable calibration effort. ICPR requires additional adjustments and setps to achiev accepteble calibration related to added groundwater surface.	1	1
Model Function and Results (Scenario Analyses)	22	Ease and options for BMP evaluation	BMP evalulation can be achieved through 1D element creation or 2D mesh manipulation depending on underlying level of data for BMPs.	BMP evaluation can be achieved through 1D element creation or 2D mesh manipulation depending on underlying level of data for BMPs.	Both models equally capable/functional.	1	1
	23	Ease of land-use change scenarios	Ability to change delineations and roughness values within scenario manager.	Straightforward via land use map layer or underlying data table manipulation.	Both models equally capable/functional.	1	1
	24	Model runtime (common processing system)	Design storm runs for both watersheds take less than 5 minutes to run. 100 year, 10-day event (30 day simulation) takes 2 hours to complete run. ICM generally runs fast but the modeler should review the 2D time step during the simulation run for issues. 1D hydraulic time step can have an affect on overall simulation run time.	Model run times are affected by overall stability of model and the use of 1D elements for lake/pond areas and creek channel areas. Varying the Fireball timestep parameters can achieve small reductions in model run times. When groundwater is actively passing water back to overland module, the simulation slows down. Increasing groundwater timestep allows for faster processing.	ICM is faster at comparble resolution sometimes signficantly faster.	2	1
	25	Results quality and output format	Extensive results data review can be completed within the software. Most (if not all) results that vary with time can be reviewed on table or graph format (e.g., stage, velocity, infiltration rate, saturation). Easy to review changes to parameters and affect on output. E.g. changes in effective infiltration rate, flow direction from individual cells	Standard results can be viewed within the software (stage, flow arrow, depth to groundwater). Cannot easily view individual cell outputs outside of standard outputs. Output reports can be saved (2D Node Selection) for duplication over various scenarios.	ICM has better visual results (less noise) and more stable hydrographs for the more automated 2D build under this pilot study. ICPR stability may improve by going to 1D channels and ponds, for example.	2	1
	26	Export process and format	Ability to export individual timestep results and maximum results. Graphs and tables available for export. Use of selection lists to export key data/monitoring locations. MapInfo MIF, MapInfo TAB, shapefile, ESRI geodatabase, CSV. The shapefile export includes the triangular mesh as a polygon shapefile.	Results from 1D network is exported from the report section of the model. Results for 2D inundation are exported from the Animation tab in the model Export reports can be saved to reuse in future. Text files, graphics, animations, DEMs from animations.	Both models equally capable/functional.	2	2
Software Specifics	27	Sharing model versions	Model files can be stored in a multiuser format assuming shared network location, or model can be packaged using a transportable database and sent to external user for modification.	Must keep track of versions when sharing model files. There is no multiuser format.	ICM transportable database is more portable from a file size transfer standpoint compared to copying a full folder for ICPR.	2	1
	28	Local versus network - processing ease	Can process locally on computer or on a cloud computer, can save results locally or on a server location. New verion has ability to be run on Innovyze server to give faster run times.	Can process locally on computer or on a cloud computer, can save results locally or on a server location	Both models equally capable/functional.	1	1
	29	License type and cost	Subscription; $18,000/yr for unlimited nodes and mesh elements (price may have changed with new subscription model from Autodesk). 2023 $54,000 for 3 year subscription. Flex option may also be considered for limited use approach.	Subscription, $2,400/yr/simultaneous user	ICPR lower annual license cost.	1	2
	30	Model maintenance (version management, security, techncial support)	Currently model version updated each year with new version. Innovyze seems to be very responsive to questions and solving problems that arise.	ICPR is updated periodically. Streamline Technologies has been very responsive to questions and solving problems that arise.	Both models equally capable and responsive technical suport.	1	1
	31	User Community	Over 450 consultants/utilities using ICM in the US based on developer records.	Used widely in Florida by consultants and utilities. Based on developer input, also currently working with roughly a dozen universites for research and teaching purposes.	Minnesota/Midwest starting to see some ICM uses. Nothing notable for ICPR in this area.	2	1
						44	39

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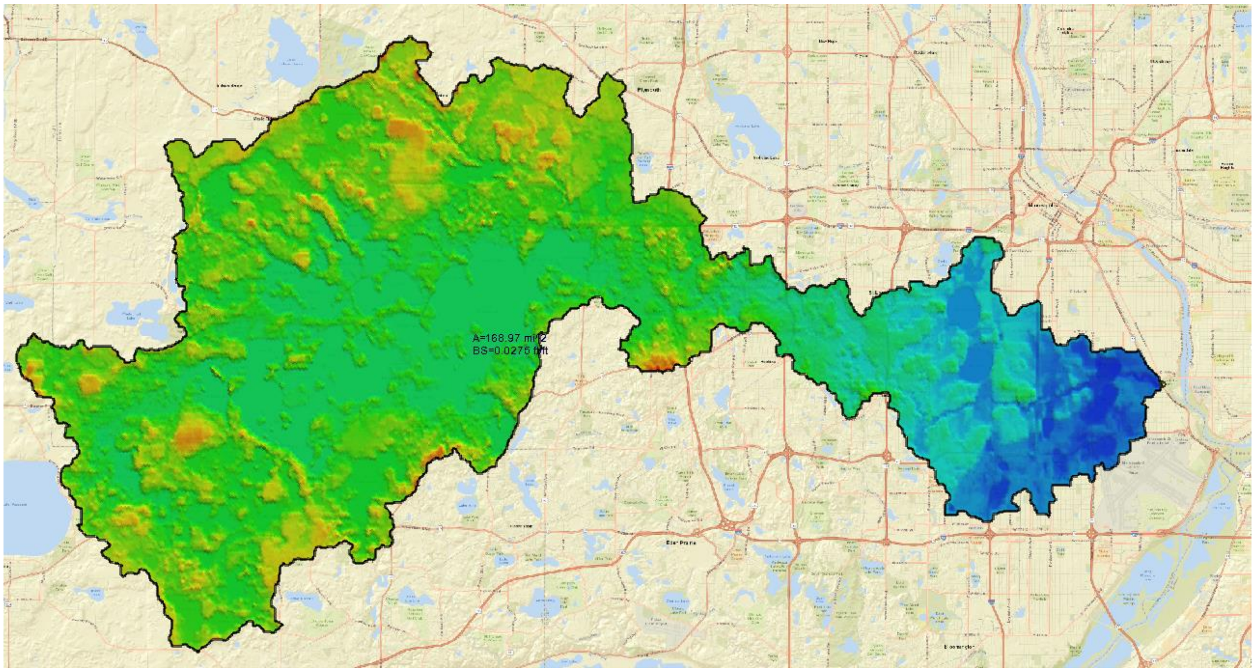
AQUAVEO SCREENING STUDY



1D/2D MODEL COMPARISON

Performed for Minnehaha Creek Watershed District

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Background and Description

Aquaveo was tasked with assessing the hydrologic and hydraulic modeling needs of the Minnehaha Creek Watershed District (District) and to provide a comparison of multiple numerical models. The purpose of this comparison is to provide the District with the information necessary for selecting a model to replace an existing XP-SWMM model of the Minnehaha Creek watershed. This legacy XP-SWMM model uses a lumped parameter sub-catchment representation of hydrology and rainfall/runoff processes. The District is looking to replace the model with a coupled 1D/2D hydrologic model that takes advantage of high-resolution elevation data. The model will be used to analyze urban flooding events and assess vulnerabilities.

The tasks that Aquaveo was assigned to complete are the following:

Task 1. Review the District's modeling needs assessment summary

Task 2. Prepare a comparison matrix of applicable model options.

Task 3. Prepare a short presentation summarizing findings and recommendations

Task 4. Provide project technical memorandum and finalized comparison matrix

Tasks 1 – 3 were completed prior to the preparation of this report. The document represents the deliverable for Task 4.

Model Comparison and Methods

The District's provided work order ("Aquaveo_modelreview_WorkOrder_Final.pdf") states that the model comparison must include the following models: TUFLOW, HEC-RAS (1D/2D), InfoWorks ICM, SRH-2D, xP2d/XP-SWMM, and MIKE FLOOD. The GSSHA and ICPR4 models were added to the list at the request of Aquaveo and the District. The criteria by which each model was evaluated are listed below:

- Model Input Formats
    - Shapefiles
    - Geodatabases
    - CAD
    - Text files
- Editing Model Inputs
    - Methods for editing inputs
    - Ease of editing inputs
    - Ease of modifying model scenarios and BMPs
- Model Output Format
- Groundwater Representation
    - Groundwater or Infiltration included
    - Method for representing groundwater or infiltration
    - Groundwater/Streamflow interaction

- Modeling Capabilities
    - Hydrology
    - Hydraulics
- Parallelization
    - Included
    - What method is used if included
- User Community
    - Publications
    - Model is well documented online
    - When was the last update of the model?
- Cost
    - Single cost or subscription
    - Cost of licensing method

The model comparison matrix is given in below.

Table 1. Model Comparison Matrix

Modeling Software	Model Input Format				Model Inputs			Model Output	Groundwater			Modeling Capabilities		Parallelization		User Community			Cost	
	Shapefiles	*Geodatabases*	*CAD*	*Text files*	*Method for editing*	*Ease of Modification*	*Ease of Implementing BMPs*	*Format*	*Included*	*Method*	*Surface water exchange?*	*Hydrology*	*Hydraulics*	*Allowed*	*Method*	*Publications*	*Well Documented*	*Last updated*	*Single or subscription*	*Cost for License*
Tuflow (classic, HPC)	Yes	Yes	Yes	Yes	Multiple Interfaces/ Programmatically	Some text editing, Easy with GIS software	BMPs and LIDs are not built-in. Roughness can be modified to represent land use change and hydrograph attenuation	Output depends on the interface selected, includes ASCII, XMDF	Infiltration and Groundwater	Green-Ampt, Horton	Once groundwater level reaches surface, no more infiltration is allowed.	Can specify rainfall and infiltration for basin areas	Yes, primarily a 1D (ESTRY)/2D hydraulic model	Yes	If purchasing TUFLOW HPC, must also purchase GPU option	47 in 2021 (Google Scholar)	Online manual, support, forum	Software released in 10/2020, manual released in 3/2018	Subscription	$6,000 plus annual fees
HEC-RAS 2D	Yes	No	Yes	Yes	HEC-RAS interface/ Programmatically with text files.	Depends on familiarity with HEC-RAS software. Some editing can be done using text files.	BMPs and LIDs are not built-in. Roughness can be modified to represent land use change and hydrograph attenuation	.dss, .tif file for 2D results	No	No	No	No, however, recent update (v6.0) allows for spatial precipitation and infiltration).	Yes, 1D and 2D, does not allow for piped networks.	Yes	Built-in OpenMP parallelization (cpu)	788 in 2021 (Google Scholar)	Online manual, large user community	Dec-20	Single	Free
InfoWorks ICMOne	Yes	Yes	Yes	Yes	InfoWorks ICMOne interface/ Ruby scripting	Depends on familiarity with InfoWorks interface	Multiple LID options and processes. Applied to polygons and subcatchments. Can be edited programmatically	MapInfo MIF, MapInfo TAB, Shapefile, ESRI geodatabase, CSV	Yes	Uses SWMM infiltration methods for subcatchments (i.e., GA, Horton)	Groundwater is not connected to surface water features. Performs soil moisture accounting.	Yes, 2D mesh based overland flow.	1D pipe hydraulics, 2D river hydraulics/dam breach analysis	Yes	Claims to be "multi-core and multi-processor aware." Can take advantage of GPU for 2D analysis	45 in 2021 (Google Scholar)	Online videos and tutorials. User manual appears to only be available to paying customers.	2021	Subscription	$30,000/yr for unlimited nodes and mesh elements
SRH-2D	Yes	No	Yes	Yes	SMS Interface/ programmatically	Depends on familiarity with SMS interface	BMPs and LIDs are not built-in. Roughness can be modified to represent land use change and hydrograph attenuation	ASCII, XMDF, text formats	No	No	No	No	Yes, 2D depth averaged St Venant	No	No	21 in 2021 (Google Scholar), endorsed and funded by FHWA	Aquaveo/FHWA provides training courses, tutorials, videos, and wiki page	2021	Single	$5,115 plus annual fees
xP2d/XPSWMM*	Yes	Yes	Yes	Yes	Inputs edited within XPSWMM software	Requires a familiarity of XPSWMM	Multiple LID options and processes. Applied to polygons and subcatchments	ASCII and text output	Infiltration and Groundwater	Green-Ampt, Horton	Once groundwater level reaches surface, no more infiltration is allowed.	Can specify rainfall and infiltration for basin areas	Yes, primarily a 1D/2D hydraulic model	Yes	Allows for GPU parallelization	31 in 2021 (Google Scholar)	Not well documented online	Couldn't find information online	No	No
MIKE FLOOD	Yes	Yes	Yes	Yes	Offers two interfaces/ programmatically	Requires a familiarity with DHI or ArcGIS software	BMPs and LIDs are not built-in. Roughness can be modified to represent land use change and hydrograph attenuation	Common raster formats and ASCII text files	Infiltration but groundwater is limited.	Not a super detailed soil moisture model.	Yes this is allowed.	Yes	Yes	Yes	Allows for GPU parallelization	89 in 2021 (Google Scholar)	some online information, however, not as accessible as some of the other software suites	2021	Subscription	$11,000/yr
GSSHA	Yes	No	Yes	Yes	WMS interface/ programmatically editing .prj file	Requires a familiarity of WMS.	LIDs and BMPs can be implemented by modifying infiltration parameters and roughness values.	ASCII, shapefiles	Yes	GA, Richard's	Yes	Yes, 2D grid overland flow, solves two-dimensional manning's equation.	1D pipe hydraulics, 1D river hydraulics	Yes	Built-in OpenMP parallelization (cpu)	27 in 2021 (Google Scholar)	Aquaveo provides tutorials, videos, training courses, GSSHAWiki page	2020	Single	Single - $6,500 plus annual fees
ICPR4 Expert	Yes	No	Yes (.dxf)	Yes	ICPR4 interface.	Requires a familiarity with the ICPR4 interface.	Multiple ponds, wetlands, infiltration, percolation, french drains available.	Textfiles, graphics, animations, DEMs from animations. Not much information online about output file formats.	Yes	2D Surficial aquifer groundwater flow	Yes, designed to model surface water body and surficial aquifer interactions.	Yes, 2D overland flow using the finite volume methods of the St. Venant equations. Spatially variable rainfall and evapotranspiration.	1D pipes and canals.	Yes	Not much information is offered online. Website states "ICPR4 includes parallel processing, so multiple cores is advantageous."	14 in 2021 (Google Scholar)	Limited online documentation. Help is provided through technical support and tutorials installed with the software.	Called Streamline Technologies and they said version 4.07.08 was released 2/9/2021	Subscription	$2,400/year/simultaneous user

* Notified by Innovyze that XP software would be discontinued

Conclusions and Recommendations

The model comparison matrix was completed according to previous knowledge of the model, online documentation, and speaking with company representatives. In this section, we will provide our conclusions from the study and our recommendations.

Based on our discussions with the District and information provided in the "Modeling Needs" document, it is apparent that the District is seeking a model that offers 2-dimensional overland flow and 1-dimensional piped stormwater network representation. This requirement eliminates some of the models compared in this study, such as HEC-RAS and SRH-2D as neither of those models offers the 1D piped network component. Additionally, we were notified by Innovyze that xP2d/XPSWMM would likely be discontinued sometime in the next few years. For that reason, it will be difficult to continue to find online support or documentation for the model.

Each of the remaining models (TUFLOW, InfoWorks ICMOne, MIKE FLOOD, GSSHA, and ICPR4) have their strengths and weaknesses. InfoWorks ICMOne appears to offer all the modeling capabilities the District needs, however, the cost of $30,000/yr may be the deciding factor. MIKE FLOOD also offers many of the components that are required by the District, however, the cost of $11,000/yr may be a factor. Additionally, MIKE FLOOD doesn't perform the groundwater/infiltration calculations that the other models do. GSSHA is much less expensive ($6,500 one-time cost plus annual fees) and provides the hydrologic and hydraulic components required, however, the user community for GSSHA is much smaller than for some of the other models. As a result, features such as the piped network and groundwater flow haven't been tested as extensively and may contain bugs. The ICPR4 model, developed by Streamline Technologies, offers the ability to simulation 2D overland flow, 2D groundwater flow, and 1D piped networks. The cost is also much more reasonable at $2,400/year. However, it's not clear whether ICPR4 offers GPU parallelization, and the online documentation is extremely limited! For these reasons, our recommendation is that the District considers InfoWorks ICMOne, the less expensive TUFLOW model, or the ICPR4 model (with discretion due to the lack of online documentation) to meet their modeling needs.

Attachment B

MINNEHAHA CREEK WATERSHED DISTRICT
QUALITY OF WATER QUALITY OF LIFE

To: Pilot Model Advisor Committee
From: Minnehaha Creek Watershed District
Date: August 30, 2023
Subject: MAC Overview and Feedback Synthesis

Introduction and Background

In 2003, the District built a watershed-wide XP-SWMM hydrologic and hydraulic (H&H) model that was considered state of the art at the time. It was designed to characterize the total volume and pollutant runoff from the landscape and understand the impact of runoff on receiving water bodies. Over the years, the District has used the XP-SWMM H&H model to estimate watershed pollutant loading, conduct creek flood forecasting, support floodplain management, and aid permitting assessments.

Between 2014 and 2019, the Minnehaha Creek Watershed experienced the wettest seven years on record. In response, policymakers, partner agencies, and District staff have been asking questions that demonstrate the limits of MCWD's XP-SWMM model to answer specific climate questions. The model does not contain the stormwater infrastructure resolution, groundwater capability, or topographic granularity needed to characterize how water is moving through the system, making it challenging to manage and adapt to climate change. During this time, the District developed its Climate Action Framework (CAF), which lays out a pathway to identify and implement high-impact solutions in collaboration with our partners. This pathway includes three key pillars:

Pillar 1: Understand and Predict- Utilize and expand technical capabilities in data collection, analysis, and tools to understand and predict the impacts of climate change at a watershed scale.

Pillar 2: Convene and Plan- Bring together local, regional, and state agencies to build consensus around the issues, align goals, form partnerships, leverage resources, and develop a coordinated strategy.

Pillar 3: Implement, Measure, and Adapt- Coordinate implementation actions with partners to make measurable progress towards goals. Implementation actions may include projects, policy changes, and operational improvements.

The need for an additional modeling tool that has greater surface granularity and capability of characterizing the interaction of surface water-groundwater was identified so that the District can characterize and quantify the impacts of climate change and evaluate a range of scenarios to shape climate adaptation strategies, programmatic policies, and specific projects.

Climate Model Selection Purpose and Process

MCWD began the model selection process by conducting a cursory assessment of two-dimension modeling software systems that could meet the needs of MCWD's Climate Action Framework. This screening-level assessment, along with vendor information sessions and consultation with agency experts, led the District to narrow its focus to ICPR and ICM. Both models were selected to be built and evaluated for two distinct subwatershed areas during the pilot model build analysis, giving the District an opportunity to comprehensively compare the two. The District chose to pursue a pilot model build, ahead of the full watershed-wide build, to mitigate for the relational and technical risk that is often associated with large-scale, high-resolution models such as selecting the right software for the intended use.

A key objective of the pilot model project is to understand the strengths, weaknesses, and observed differences of each model throughout the project to inform which model is best suited for the District to scale watershed-wide for climate adaptation planning. This information is documented within technical memorandums, each written after a project milestone. In addition, information learned through the project is summarized in an evaluation matrix, that was established at the onset of the project.

As the District nears the end of the pilot model, input was sought from a select group of technical experts to help improve clarity around which platform is selected to scale watershed-wide to support climate planning work. This document provides an overview of the model advisor committee members (MAC), the process ran, and a synthesis of the feedback the District received.

Other Potential Uses for the Climate Model

When the pilot model began, it was unclear whether one of the platforms would be able to serve both the District's upcoming climate needs (primary uses), while also replacing some or all of the day-to-day needs the current XP-SWMM model provides (secondary uses). With climate at the forefront, staff wanted to be mindful of these secondary needs since XP-SWMM will eventually be sunset and its functionality will need to be replaced. Unfortunately, no single modeling software exists that can do everything well. As staff weigh these tradeoffs in the coming months, expectations need to be clearly set for partners on whether (1) the climate model will replace any functionality of XP-SWMM and (2) when and how the District would look to sunset and replace XP-SWMM in the future.

MAC Overview and Purpose

Staff are utilizing the technical advisor group to stress test the results of the pilot model and bring more definition to the technical and relational risks associated with each model. The objectives of the advisor group were to (1) gauge if the District is considering and weighing each platform's abilities and limitations appropriately based on the District's intended uses and (2) better understand how a future with each model will shape and/or impact work with our partners and consultants. It was important to draw on expertise from a wide range of perspectives to effectively deliver on the objectives. The advisor group included representation from the groups shown in Table 1.

Table 1. Pilot Model Advisor Committee participants

Representation	Perspective
Barr Engineering	Experience building/using H&H models; unique experience with groundwater modeling (Metro Model-3)
Bolton & Menk	Experience building/using H&H models; Engineer for many municipalities within District
City of Edina	Municipal perspective; municipal climate planning experience
Hennepin County	Regional climate planning perspective

Met Council	Regional climate planning perspective
Stantec	Experience building/using H&H models; District Engineer
Virginia Tech University	Experience building and using H&H models; extensive experience using ICPR for climate planning studies

Input from this group was not intended to be ongoing but instead served as a discrete focus group and an opportunity for the District to receive additional feedback to inform upcoming decisions around model selection and model development. It's anticipated that a technical committee will be formed and utilized once the District kicks off the climate model build, which may be comprised of similar technical reviewers.

The process to gather input from the technical advisor group involved the following steps:

1. **Kickoff meeting:** District staff provided an overview of our climate planning needs and the pilot model project.
2. **Independent Review:** Technical memorandums and the model evaluation matrix generated through the pilot model project were provided to the team for review and background.
3. **Feedback:** Advisors submitted feedback based on a list of tailored question prompts that they were provided.
4. **Closeout Meeting and Synthesis Review**: District staff reviewed submitted feedback and developed a synthesis, highlighting key areas of consensus and unique perspective/insights, which is documented within this document. This information was shared through a closeout meeting and reviewed for accuracy.

MAC Question Prompts:

A list of question prompts was provided to the MAC to support their independent review of materials and direct their feedback (Appendix A). Not all questions were asked of each member in an effort to manage workload and target each member's specific area of expertise/perspective. The questions posed to the model advisory committee (MAC) were categorized into three categories that included:

- **Model Intended Use Categories:** Gauge if the District's primary model uses are aligned to support climate planning efforts
- **Technical Risks:** Gauge if MCWD is considering and weighing each platform's strengths and limitations appropriately based on the District's intended uses. Technical questions were also asked to inform the District's approach to data collection and watershed-wide construction.
- **Relational Risks:** Better understand how climate planning with each model will shape or impact our internal work and work with our partners and consultants in the near-term and how the model could be leveraged for work beyond climate planning.

MAC Feedback Overview

The synthesis structure will largely follow the structure of the MAC questionnaire (intended use, technical risk, and relational risk). The summary below highlights (1) areas of consensus, representing a sentiment that was mentioned across multiple responses and (2) unique insights that were of significance within a response but not observed across multiple responses.

Model Intended Use Categories

Areas of Consensus

- High value placed on localized flood issues and risk: There was wide mention that the District has correctly categorized the need to characterize channel and localized flood risk as a primary use of the upcoming climate model tool. Furthermore, it was expressed that this primary use will be valued the most by municipal partners.
- Primary and secondary use classification: There was generally wide support for how the District has prioritized model uses between primary and secondary categories with the following exceptions:
    - Two participants noted that long-term surface-water groundwater interactions should be considered a secondary use/need.
    - One noted that characterizing water quality seems to fall in-between primary and secondary as it seems more important than the other listed secondary uses but is rightfully below the listed primary uses.
    - The importance of providing boundary conditions was noted, to the degree that it may make sense to consider a primary use. However, the level of importance appears to be under the assumption that the climate model would replace MCWD's current XP-SWMM model and be the new source of boundary conditions.

Unique Insights

- Value of integrated groundwater: There was disagreement on the need to build a model that integrates surface water and groundwater to support the District's climate planning efforts. Viewpoints generally fell into two camps:
    - Not necessary: Some voiced that modeling together isn't necessary to characterize issues/inform management related to surface water flooding. It was noted that the difference in time scales suggests you could model them independently and use the separate models as boundary conditions.
    - Necessary: Others expressed that an integrated groundwater surface-water model is a critical feature, necessary for characterizing climate change impacts and system scale volume management.
- Uncertainty around the upcoming climate model's relationship to the District's current XPSWMM model: Each respondent's interpretation of how the upcoming climate model correlates to District's XPSWMM model was different. The District needs to be more explicit that as our understanding through the pilot model has grown, the upcoming climate model build is not intending to replace the need for XP-SWMM, and instead the climate model will be used as an additional tool to answer a new set of questions to guide climate adaptation work. This needs to be clearly expressed as the District continues to engage with stakeholders to manage relational risk and set accurate expectations.

- Grays Bay Dam: A few responses noted that the opportunity for this tool to evaluate dam operations should be considered, as the Dam plays a critical role in managing both flood and drought conditions.

Technical Risks

Areas of Consensus

- Channel Geometry Importance: Cross-sections are important to model construction and there are varying methods for "best practice" to guide spacing with the intended goal to capture hydraulically important areas of change within the channel (riffles/pools, constrictions/expansions)
- ICPR Technical Issues: There was consensus that the three issues identified during the pilot are valid and should be addressed (pipe surcharge, noisy hydrograph, and continuity errors). The responses to these issues varied slightly, however, the responses were close enough that they can be generalized as follows:
    - **Pipe surcharge:** This issue was vexing to most of the advisors. No solutions were identified, but it was clear this was an issue that needs to be resolved before selecting a model. It needs to be determined whether this is a flaw in ICPR's pipe hydraulic methodology.
    - **Continuity error:** We generally heard that there will be some level of continuity error on large scale models that will be difficult to reduce. It was noted by many that continuity errors are typically driven by the model build, not inherent to the modeling software, meaning this could be managed through mindful construction during the watershed-wide build.
    - **Noisy results**: Similar to continuity error, we heard that this noise is likely the result of the mesh/geometry construction and is not an inherent flaw of ICPR.

Unique Insights

- 1D Channels: Building the stream channel, particularly Minnehaha Creek, as a 1D conveyance should be considered and likely to lead to less continuity error/noise and support faster run-times.
- Future Data Collection Efforts: Recommendations for allocating data collection resources varied across responses. Recommendations acknowledged that initial collection efforts may best be informed once the build begins, while other data collection efforts may be influenced by known changes to the landscape. Some of these recommendations included:
    - Pockets of higher resolution and/or updated LiDAR
    - Improve accuracy within infrastructure datasets
    - Additional hydrogeologic data (ICPR only)
- Metro Model 3 should be referenced: A few spoke to how Metro Model 3 could be utilized to guide and/or support the District's efforts, but in a variety of ways:
    - Metro Model 3 results and understanding could be referenced during the groundwater zone build, for setting initial water table conditions, and calibration of ICPR.
    - Metro Model 3 results could be used to generate long-term trends/responses of water table to incorporate into deterministic groundwater scenarios for ICM.

- Uncertainty around model inputs to support groundwater modeling: A question was raised on whether the necessary inputs are available to build out and rely on ICPR's groundwater module.

Relational Risks

Areas of Consensus

- Conflicting results concern: It was noted by many that having multiple models with varying model results will cause confusion and frustration for partners. An example of flood elevations was referenced, in which FEMA flood elevations have been established from XPSWMM, the District's climate model produces flood inundation maps, and a city model may produce a third flood elevation. Frustration would likely occur if results were significantly different across these platforms.
- Alignment with municipal needs: ICPR is less likely to be used and/or built by municipalities and would not be well-suited to replace XP-SWMM for the District. Conversely, ICM's strengths are more closely aligned with municipalities' needs including 1) localized flooding, often driven by stormwater infrastructure limitations and 2) ICM's ability to integrate SWMM models.
- ICPR's lack of translation to other models: The inability to convert to or from other commonly used H&H models will be a potential barrier and may cause frustration among consultants and partners. This same sentiment was echoed when referring to the importance of a smooth import/export process of boundary conditions.

Unique Insights

- Limited regional use: Both models have limited community user support, which is an area of risk. The District should consider how model inputs can be as convertible as possible in the event a different model was desired/required down the road.
- ICM License Cost: A few noted that ICM's expensive licensing is likely to be a barrier in its adoption/use by cities and consultants. There was a suggestion that other less expensive models, such as PC-SWMM, are more likely to be supported for a replacement of the XP-SWMM model.

Matrix Analysis

In addition to submitting written feedback, a portion of the MAC group was asked to populate a scenario assessment matrix. The matrix provides an opportunity to characterize each model's capability to answer specific model questions based on the reviewer's understanding of the model. Responses were bucketed into "cannot run scenario", "able to run scenario", and "uniquely suited to run scenario", which District staff transformed into a numeric score of 0, 1 or 2. The results in these figures represent an average of the three submitted responses, based on the primary use categories.

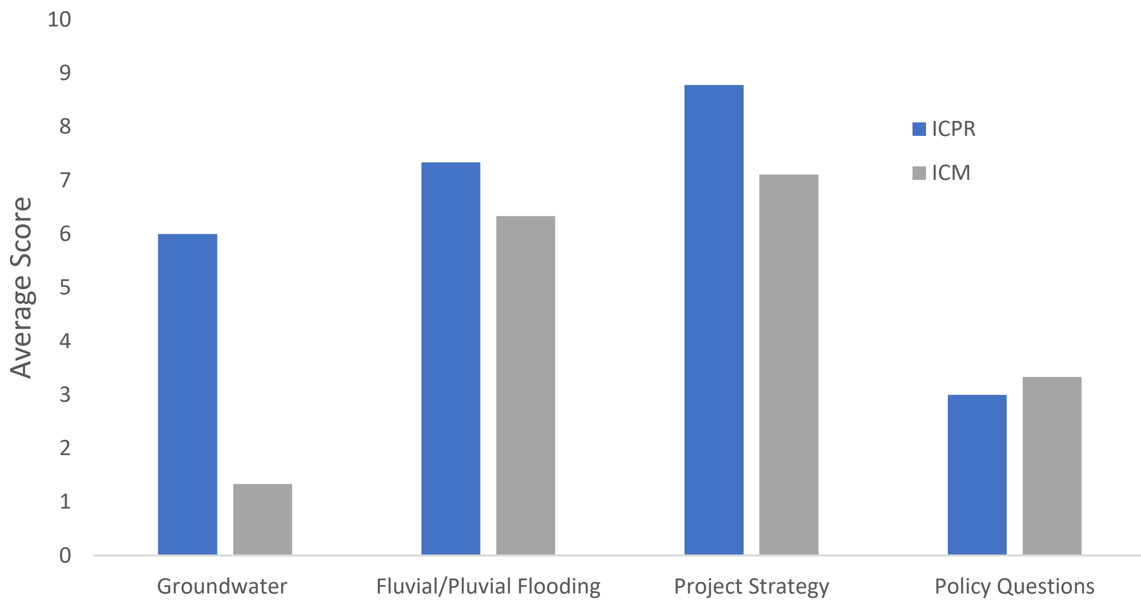

Figure 1. Average model capability grouped by scenario categories

The consolidated reviewer feedback indicates that ICPR may be better suited to support the primary model use questions. The area of greatest separation between the models in the assessment was that ICPR scored much higher in the groundwater/surface water interaction primary use section, however, many reviewers noted that reviewing ICPR's capacity to accurately represent groundwater is an important prerequisite for model selection.

There was less separation between the models for flooding assessment and project strategy evaluation, however, ICPR did rank higher for both of these categories based on reviewer feedback. This was driven by ICPR's capacity to characterize how infiltration will impact surface water conditions to support MCWD's project strategy development.

The only category where ICM was ranked higher than ICPR was in the policy questions category, however, it was only a fraction of a point greater than ICPR. Overall, this suggested that the models were equally capable of answering the policy questions.

Generally, ICPR and ICM are relatively equal with respect to project strategy assessment, standard flooding assessment, and policy evaluation, which suggests that both models can deliver on MCWD's needs. The major differentiator for the models is ICPR's capacity to integrate groundwater into runs to characterize how long-term trends across dry and wet years impact surface water conditions. With that being said, it will be important to confirm that the model can accurately represent groundwater storage and movement to ensure that the model will provide valid results under various scenarios.

Near-term Steps

Intended Uses and Relational Next Steps:

Municipal Partner Meeting: MCWD will host a meeting with partner communities this fall to begin discussing the model selection process to support the first pillar (understand and predict) of the Climate Action Framework. This meeting will serve as an important first opportunity to set clear expectations around the climate model's purpose and differentiate it from the District's day-to-day XP-SWMM model.

Technical Next Steps:

Clarify outstanding technical risks: Following the MAC feedback review, there are still a few outstanding technical questions that require answering. Staff have outlined two paths to strengthen our understanding of ICPR functionality:

- **Pipe Surcharge**: MCWD staff have reached out to the developers at ICPR to confirm that the pipe hydraulic methodology within the software does account for surcharged conditions. The developer has offered to look at the model build to evaluate why those conditions were experienced so we can avoid this technical issue during future runs if ICPR is selected.
- **Alternative Model Construction**: The District is continuing its relationship with Dr. Saksena from Virginia Tech to explore alternative ways to construct ICPR. The goal is to evaluate how alternative construction impacts run-time, results, and technical errors. This will confirm feedback heard from the MAC regarding ICPR's technical risks and provide insight into how the District should go about scaling ICPR if selected.
- **Groundwater Data Inputs**: In addition to the work mentioned above, the District and Dr. Saksena have talked through alternative ways to establish the initial water table. A stronger understanding of the water table within the District exists compared to what assumptions/settings were used within the pilot model. Datasets such as the Hennepin County Groundwater Atlas, Metro Model 3 outputs, and the District's shallow groundwater wells would help construct initial conditions in ICPR and allow for it to equilibrate much sooner to more accurately represent shallow groundwater. Furthermore, the District's shallow groundwater well network will be used to verify that ICPR's water table is responding similarly. With the help of Dr. Saksena, the District is looking to verify that the water table within the modified ICPR pilot model can reflect similar responses to the measured well data. Changes to the model and their impact on results and technical issues will be documented and can be shared with the MAC group.