



Title:	Adoption of 2D Model for 2027 Watershed Management Plan	
Resolution number:	26-077	
Prepared by:	Name: Brian Beck Phone: 952-471-8306 bbeck@minnehahacreek.org	
Recommended action:	Accept the final watershed-wide 2D model report documenting the development, calibration, and validation of the Upper and Lower Watershed models.	
Schedule:	October 31 st , 2026: Groundwater calibration finalized	
Budget considerations:	N/A	
Past Board action:	Res #: 24-012	Title: Awarding Contract for 2D Watershed Model for Climate Planning
	Res #: 22-038	Title: Authorization to Submit Proposal to LCCMR for Development of 2D Watershed Model

CLIMATE CONTEXT

Climate change is measurably changing the distribution, frequency, and intensity of rainfall in Minnesota. Between 2013 and 2019, the Minnehaha Creek Watershed District (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.

CLIMATE ACTION FRAMEWORK AND WATERSHED PLANNING

The District's 2017 Watershed Management Plan, adopted in January 2018, established an approach centered on Balanced Urban Ecology and the integration of land use and water resource planning. Its four goals address water quality, water quantity, ecological integrity, and thriving communities. The 2027 Plan will carry this direction forward, with an increased focus on developing a coordinated flood management strategy with communities across the watershed.

The Board adopted the Climate Action Framework in December 2022 to guide this work through three pillars: Understand & Predict; Convene & Plan; and Implement, Measure, & Adapt. The model is a primary investment in the

first pillar, providing a more detailed understanding of existing conditions and a means to evaluate future precipitation and land use scenarios. That information will support the second pillar by giving staff and partners a common basis for discussing vulnerabilities, management goals, and the tradeoffs of potential responses.

The 2027 Plan will translate these discussions into priorities, policies, and implementation responsibilities. As projects are implemented, maintaining the model and comparing its results with monitoring data will also support the third pillar by helping staff evaluate performance and refine future management decisions. In this way, the model supports an ongoing planning and evaluation process beyond the current Plan update.

2D WATERSHED MODEL BUILD

MCWD was awarded a \$738,000 Legislative-Citizen Commission on Minnesota Resources (LCCMR) grant in 2023 to support development of a watershed-wide 2D model for climate planning and related technical work. In February 2024, the Board authorized a contract with HDR to support the watershed-wide build. MCWD staff led development of the Upper Watershed Model, while HDR led development of the Lower Watershed Model. Staff and HDR worked together to represent storage and conveyance, prioritize data collection, and develop consistent methods across the two models.

The model build required additional work to address missing infrastructure information and characterize culverts, stream channels, and wetland storage. These features affect how much water the landscape can hold and how quickly water moves downstream. The additional data processing and model development work informed the scope adjustment brought to the Board in February 2026.

The build integrates stormwater infrastructure data from all communities within MCWD into a common dataset, providing a shared foundation for planning with cities across municipal boundaries. The model combines these data with terrain, soils, and water resource information to evaluate how water moves across the landscape, through stormwater pipes, and between surface water and shallow groundwater. Cities and their engineers can also use the standardized datasets in their own modeling tools.

The event-based model is available for the initial flood risk assessment. Groundwater calibration will continue with Streamline Technologies and Virginia Tech to support evaluation of longer wet and dry periods. Applications that depend on groundwater response will need to incorporate the calibration findings and remaining limitations documented in the model reports.

The Policy Planning Department will use the model with partner communities to assess current and future flood risk for the 2027 Plan. Staff will compare storage, infiltration, and infrastructure strategies to understand where they are effective and how they influence upstream and downstream conditions. These results will help align regional water resource priorities with city projects, land use plans, and investment decisions.

Recommendation and Next Steps

Staff recommend that the Board accept the Upper and Lower Watershed 2D Model Build Reports. Research and Monitoring staff will continue supporting the Policy Planning Department in applying the model, interpreting results, and maintaining the underlying datasets.

Supporting documents (list attachments):

- Upper Watershed 2D Model Build Report
- Lower Watershed 2D Model Build Report



RESOLUTION

Resolution number: 26-077

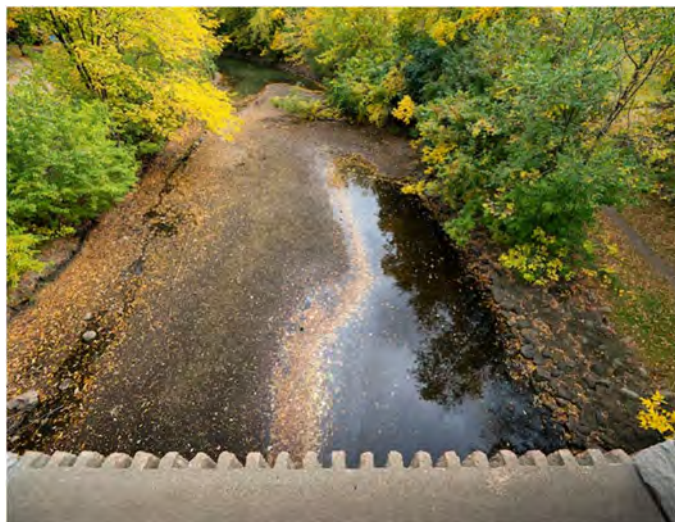
Title: Adoption of 2D Model for 2027 Watershed Management Plan

- WHEREAS, climate change is measurably changing the distribution, frequency, and intensity of rainfall in Minnesota; and
- WHEREAS, a key pillar in Minnehaha Creek Watershed District's (District) Climate action framework is to understand and predict the impacts of climate change using new data analytical and planning tools;
- WHEREAS, to support this strategy, the District has identified the need to develop a watershed-wide two-dimensional (2D) model that incorporates high-resolution stormwater infrastructure and land surface data to improve its ability to inform current and future water resource management decisions in the face of climate change;
- WHEREAS, in June 2022, the Board of Managers authorized staff to submit a proposal for \$738,000 to the Legislative-Citizen Commission on Minnesota Resources (LCCMR) to develop a watershed-wide model;
- WHEREAS, in August of 2022, the LCCMR recommended funding the project entitled "Leveraging Innovations in Data Analytics for Project Implementation" in the amount of \$738,000, and in May of 2023 the Minnesota legislature approved funding in that amount;
- WHEREAS, in February 2024 the Board of Managers approved a contract with HDR for the Development of a 2D watershed Model for climate planning in an amount not to exceed \$611,560;
- WHEREAS, Bolton and Menk, during the watershed-wide model input refinement process, identified significant gaps in the culvert dataset, which are critical for accurate model development;
- WHEREAS, MCWD staff led development of the Upper Watershed Model and HDR led development of the Lower Watershed Model, working collaboratively to establish consistent methods, address data gaps, and represent watershed storage and conveyance;
- WHEREAS, the model build integrates stormwater infrastructure data from all communities within MCWD with terrain, soils, and water resource information to support shared planning and evaluation of how water moves across the landscape, through stormwater pipes, and between surface water and shallow groundwater;
- WHEREAS, model construction methods, data, calibration work, assumptions, and limitations are documented in the Upper and Lower Watershed 2D Model Build Reports;
- NOW, THEREFORE, BE IT RESOLVED that the Minnehaha Creek Watershed District Board of Managers accepts the Upper and Lower Watershed 2D Model Build Reports as documentation of the watershed-wide model build and a technical basis for the District's climate planning work

Resolution Number 26-077 was moved by Manager _____, seconded by Manager _____. Motion to adopt the resolution ___ ayes, ___ nays, ___ abstentions. Date: 9/24/2026

Secretary Date: _____

DRAFT



Draft - Hydrologic and Hydraulic Modeling Report

Minnehaha Creek Lower Watershed
Model Build and Calibration

August 7, 2026



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Appendix E – Task 4 Script Documentation

Appendix F – Waterbody Screening and Prioritization for Additional Data Collection

Acronyms and Abbreviations

1D	one-dimensional
2D	two-dimensional
CAF	Climate Action Framework
cfs	cubic feet per second
CCV	channel control volumes
DCIA	Directly Connected Impervious Area
HEC-RAS	Hydrologic Engineering Center-River Analysis System
LiDAR	light detection and ranging
MCWD	Minnehaha Creek Watershed District
MGIS	unified geographic information system schema
MNDNR	Minnesota Department of Natural Resources
MNDOT	Minnesota Department of Transportation
MSP	Minneapolis-St. Paul
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe efficiency
OF	overland flow
PBIAS	percent bias
PCV	pond control volumes
R ²	coefficient of determination
SSURGO	Soil Survey Geographic Database
USGS	U.S. Geological Survey

1 Introduction

This report outlines the watershed model build and calibration for the Minnehaha Creek Lower Watershed. The watershed model was built using the StormWise (previously known as ICPR4) software and includes a two-dimensional (2D) surface mesh integrated with a 2D groundwater mesh. This documentation provides an overview of the watershed, describes data used and developed, explains model build decisions, describes each model element used to create the watershed model, and discusses calibration of the model to observed data. Detailed descriptions of data refinement and model build processes are appended to this report as separate technical memoranda.

1.1 Project Background

The Minnehaha Creek Watershed District (MCWD) experienced their wettest decade on record from 2010 to 2019 and severe drought in 2021 and 2022. The watershed, like much of the Midwest, is experiencing the extremes of flood and drought with increasing frequency, which directly impacts the water resources and the communities that depend on them. MCWD is proactive in developing a Climate Action Framework (CAF) to address the challenges of these shifting precipitation patterns. The CAF is built on three pillars: **Understand and Predict** vulnerabilities across the watershed, **Convene and Plan** with the MCWD's partners to develop a coordinated watershed adaptation strategy, and **Implement, Measure, and Adapt** projects and policies to the changing climatic conditions.

This watershed-wide model development is at the center of the CAF, enabling MCWD to effectively understand and predict water movement through a numerical tool capable of capturing the physical processes important to the watershed response to single rainfall events as well as extended simulation periods. The power of a model exists in its ability to explicitly understand the implications of change. Future applications of the model, beyond the scope of this project, will evaluate the impacts of future climate on flood risk and how projects, policies, and operational actions may alter those impacts.

HDR and MCWD (Project Team) are working collaboratively to develop a model through a shared understanding of model goals and shared decision-making process. HDR is developing the Lower Watershed model (downstream of Lake Minnetonka) while MCWD is developing the Upper Watershed model (Lake Minnetonka and upstream). At the completion of this preliminary model build, MCWD's Advisory Team reviewed the developed Lower Watershed model and provided suggestions to improve the final model build. The Advisory Team is comprised of a group of technical experts that included technical staff from the software developer, Streamline Technologies, and faculty specializing in watershed modeling, who use StormWise at Virginia Tech. Input from that review along with additional model enhancements were integrated into final Upper and Lower Watershed model builds, including calibration of the model to historical events.

1.2 Minnehaha Creek Watershed

The Minnehaha Creek Watershed drains 178 square miles within the western Twin Cities metropolitan area, as shown in Figure 1-1. The watershed is divided into two distinct subbasins, the Upper Watershed and the Lower Watershed. The Upper Watershed drains 104 square miles of rural and suburban land to Lake Minnetonka, a 22-square-mile waterbody. Lake Minnetonka outlets

through Gray's Bay Dam operated by the MCWD into Minnehaha Creek. The Lower Watershed begins at Gray's Bay Dam and drains approximately 52 square miles into Minnehaha Creek through the Minneapolis Chain of Lakes or directly by means of stormwater conveyances or overland flow. Minnehaha Creek passes over Minnehaha Falls and then flows into the Mississippi River (MCWD 2017).

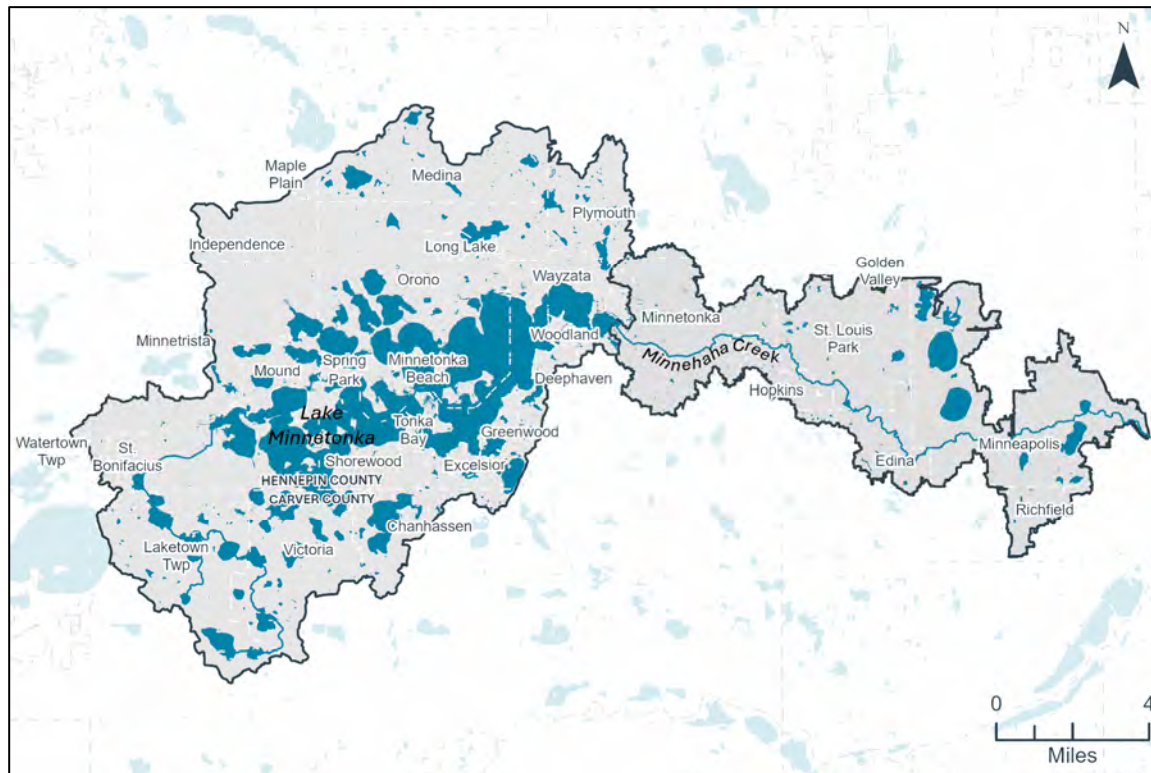


Figure 1-1. Minnehaha Creek Watershed

1.3 StormWise Software Selection

Prior to watershed-wide model development, MCWD completed a pilot 2D model build, comparing Infoworks ICM and StormWise software packages for function and applicability to represent the watershed response and meet MCWD's overall modeling goals (Kimley Horn 2023). Pilot models were created for two small subwatersheds of contrasting land use to represent the variability of land use and hydrologic dynamics of the watershed. Between the two platforms, StormWise aligned more closely with MCWD's climate planning needs. Both models have the capability to evaluate flood risk; however, StormWise is capable of integrating surface water and physically based groundwater methods into flood risk evaluations. This enables MCWD to evaluate the complex interactions between surface water and groundwater to more holistically understand flood and drought risk.

StormWise is a hydrologic and hydraulic modeling software that is commonly used for watershed and stormwater modeling in Florida, where interconnected ponds and groundwater interaction are important. In 2014, the software released the fully integrated one-dimensional/two-dimensional (1D/2D)-coupled surface water and groundwater components for the model with an emphasis on interaction between surficial groundwater and surface water bodies. For the Minnehaha Creek

watershed model, StormWise, version 4.08.03, expert license (2D capabilities enabled) was used for the build and simulation. The software includes:

- Link-Node (1D) approach to describe stormwater inlet-pipe-manhole systems, which can also be used to represent simplified subbasin runoff response and pond/channel routing.
- 2D overland flow (OF), using a flexible triangular mesh with automated mesh generation based on geometric inputs. The 2D OF can be used to represent infiltration and surface runoff instead of the conventional subbasin approach.
- 2D saturated horizontal flow in the surficial aquifer between the ground surface and a confining layer, as shown in Figure 1-2.
- 2D OF and link-node components can be simulated independently or coupled with groundwater.

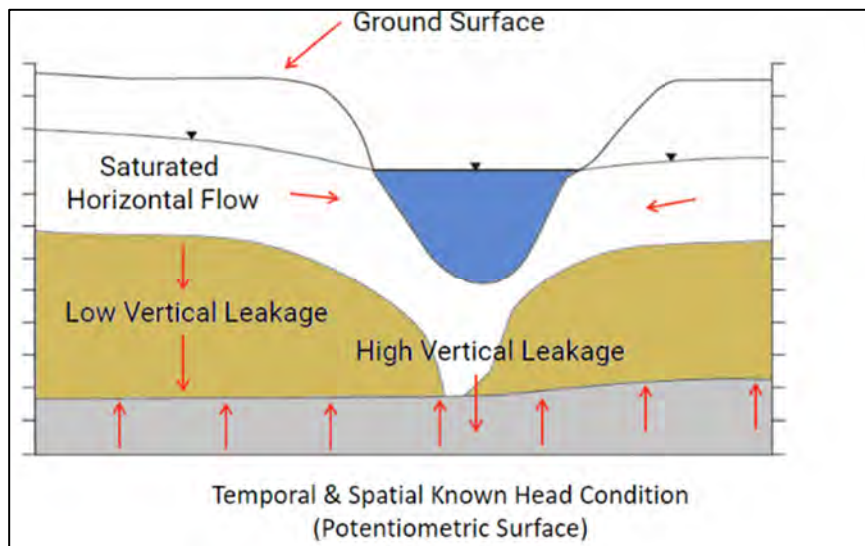


Figure 1-2. Saturated Horizontal Groundwater Flow (figure from Streamline 2024)

2 Watershed Model Build Decisions

The Minnehaha Creek Watershed was divided geographically between MCWD and HDR for the model build, but model build decision making was performed collaboratively. MCWD staff led the Upper Watershed model build and HDR staff led the Lower Watershed model build. This modeling report documents the specifics of the Lower Watershed model.

Modeling decisions were addressed through three methods: 1) workshop meetings at key model build stages, 2) emailed requests for input on model approach with recommendations from the modeling team that were reviewed and agreed upon by the group, and 3) additional unforeseen choices made along the way, which were discussed through bi-weekly meetings and verified with the larger group through detailed description and concurrence. Decisions are documented as part of this report, appended materials, and through summary notes of the model build workshops.

Alignment of the Project Team on directional decisions for the model build approach was completed through a series of five workshops. Workshop attendees included the Project Team and the Advisory Team.

Five workshops for this project consisted of the following:

1. **Goal Setting and Prioritization:** Develop a shared understanding of model objectives and key decision areas to guide the upcoming model build process.
2. **Surface Water Model Build:** Develop an approach to create the surface water components of the model through a discussion of the model domain and boundary conditions, 1D storm sewer integration, channel and storage area representation, and overland flow representation.
3. **Surface Water Overland Flow:** Weigh the benefits and limitations of overland flow approaches with respect to MCWD goals through detailed discussion.
4. **Groundwater Model Build:** Develop a shared understanding of groundwater specific goals, model domain and boundary conditions, and details of mesh generation and parameterization.
5. **Calibration and Validation:** Develop a shared understanding of the typical watershed response, data availability, and calibration/validation approaches with the intent to select events and performance metrics for calibration/validation efforts.

Workshop notes are included as part of Appendix A.

2.1 Phased Model Build Approach

Due to the level of detail of this model build, a phased approach was used. Model detail was incrementally added in four key phases to improve build efficiency and minimize chances of unforeseen errors. Figure 2-1 provides an overview of the geometric features of each phase. After each phase of model build, the model was simulated to test for potential issues, as described below.

- **Phase 1 Surface Mesh:** The first phase of model development focused on the 2D surface, or OF, mesh. The intent of this phase was to estimate the OF mesh resolution to confirm it aligns with the model intent. Model elements included in this phase included breakpoints, breaklines, 1D node interface points, and the existing ground surface. Issue identification targeted mesh generation inputs resulting in narrow triangles.
- **Phase 2 Control Volumes:** The second phase added channel control volumes (CCV) and pond control volumes (PCV). The intent of this phase was to include more detail within the OF region and to evaluate the quality of flow pattern representation within the watershed, which includes Minnehaha Creek, the connected chains of lakes, and a number of other smaller surface waterbodies.
- **Phase 3 Storm Sewer Network:** The third phase added the full storm sewer network as 1D model elements. This includes inlets, manholes, pipes, weirs, culverts, and other miscellaneous storm sewer inputs. This phase looked for connectivity and consistency of the storm sewer system and additional mesh refinement required to integrate these elements.

Potential errors of new narrow triangulation and missing storm sewer data were reviewed and resolved.

- **Phase 4 Groundwater:** The fourth phase was completed in two parts, adding vertical infiltration, and adding a horizontal groundwater model domain. These components were appended to the Phase 3 build. Here, the groundwater model domain was defined and split into computational regions, and the groundwater mesh was generated from a standard breakpoint pattern. Evaluation of the groundwater-only domain supported the troubleshooting of groundwater-only issues such as input surface (ground, bedrock, and water table) intersections and provided a resulting set of water table rasters used for final model initialization. Only the Phase 3 model with vertical infiltration was used for calibration to flood events. A completed four-phase model build was generated but not calibrated as part of this work; future efforts can use this generated model as a starting point for coupled surface water-groundwater calibration.

The following sections describe the complete model construction resulting from all four phases of model build, the decision workshops, input data and its pre-processing, and details of individual model element integration.

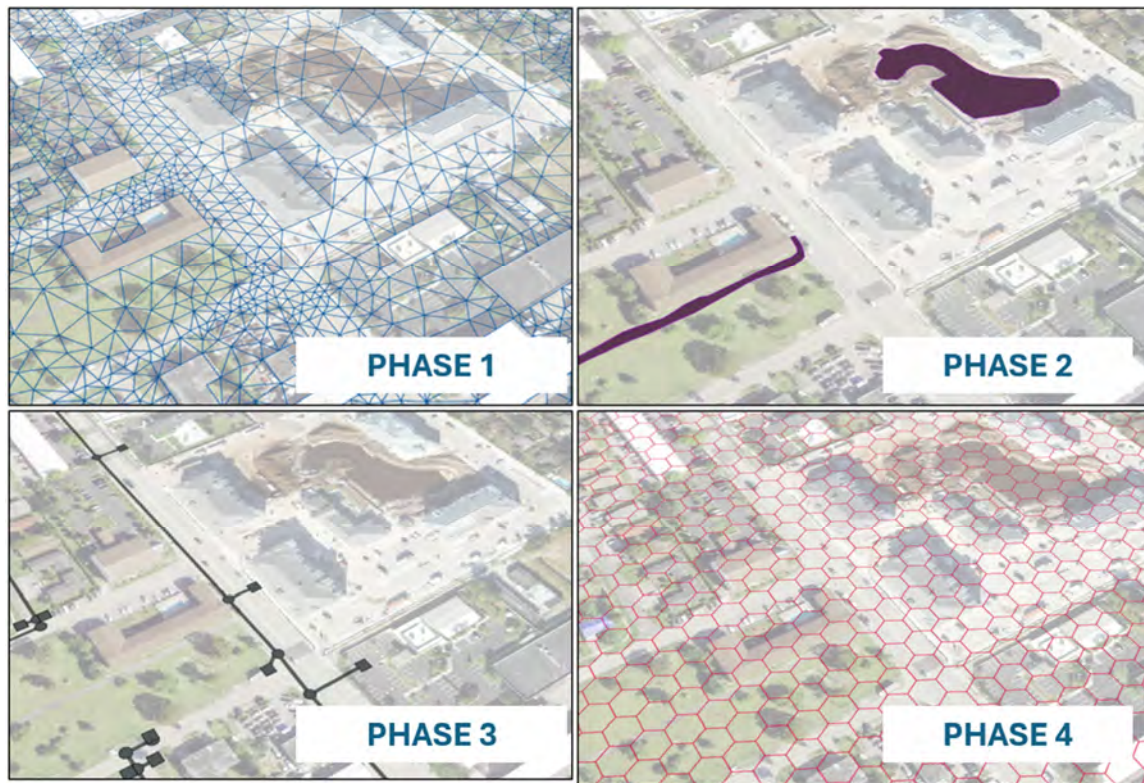


Figure 2-1. Phased Model Build Approach

2.2 Overview of Model Build Decisions

Overarching directional decisions were determined through the collaborative build workshops and follow-on technical discussions. This section provides an overview of these decisions for each modeling phase. The influences on the model build are described here and can be seen throughout the model build.

- **Phase 1 Surface Mesh:** MCWD has interest in identifying and understanding both local and regional flooding areas, to describe the groundwater/surface water interactions in a spatially meaningful way, and be capable of consistently evaluating policy and projects watershed wide. To meet MCWDs modeling objectives, 2D OF was used throughout the entire lower watershed in lieu of using mapped basins to generate infiltration and runoff. To support this intent, buildings were specifically included as mesh-generating elements, detailed breaklines were generated to support understanding of localized flow patterns, and due to the density of overland flow mesh geometry features and their influence on mesh element size and spacing, a systematic review of feature vertices was required to mitigate small triangles while retaining high level of model detail.
- **Phase 2 Control Volumes:** Surface storage is known to affect the watershed response in a meaningful way throughout the watershed; therefore, the built model needed to effectively capture the influence of these features. CCVs and PCVs can provide increased model efficiency and increased model accuracy. To support this intent, where applicable storage was explicitly represented by PCVs, bathymetric surfaces for many storage features were estimated to better reflect the below-normal water storage conditions, outlet control structures were surveyed to better describe water levels, and CCVs were used for the entire length of Minnehaha Creek.
- **Phase 3 Storm Sewer Network:** All or most of the storm sewer infrastructure data were included in the model to effectively describe localized flooding and future effects of modified storm sewer conveyance. To support this intent, the existing python scripts, which aggregate the municipal storm sewer data, were expanded to comprehensively check the datasets for redundancy, erroneous data, connectivity issues, and develop assumptions to fill all necessary attributes. These scripts could be used in the future for re-importing updated storm sewer data from municipalities. To develop a representative and efficient 2D mesh, 2D elements needed to align with localized flow pathways (e.g., in gutters) to reasonably characterize flow entering storm sewer inlets at a density sufficient to capture in-street flows versus out-of-street flows and inlets needed to be explicitly included in model development.
- **Phase 4 Groundwater:** Groundwater integration into this model build is critical to represent the dynamic nature of near surface groundwater movement and soil water storage relative to flood risk and long-term water balance. To meet this intent, the vertical layers method was selected to better estimate vertical and horizontal groundwater flow and continuous simulations will be used to effectively initialize the groundwater and soil water components.

2.3 Data Integration

Minnehaha Creek watershed overlays portions of more than 30 entities, including municipalities, counties, park boards, and park districts. Each of these entities as well as MCWD maintains their own stormwater infrastructure data. A critical component of a successful model build and future use of these data is to aggregate, store, and manipulate these data in a transparent, repeatable manner. Data provided from each of the project partners, previously surveyed by MCWD, or aggregated through this project, are integrated into a unified geographic information system schema or “MGIS Formatted” geodatabase. These data are then reviewed for gaps and inconsistencies followed by correction of these data, where applicable. Where automated inconsistencies and correction is not sufficient, manual overrides were identified and integrated at this stage. Stormwater infrastructure is then converted into a model ready format. Here additional non-infrastructure data are included into the complete package of model ready inputs. Figure 2-2 provides an overview of how and where various data sources enter the integration process. These steps are described in more detail throughout the report.

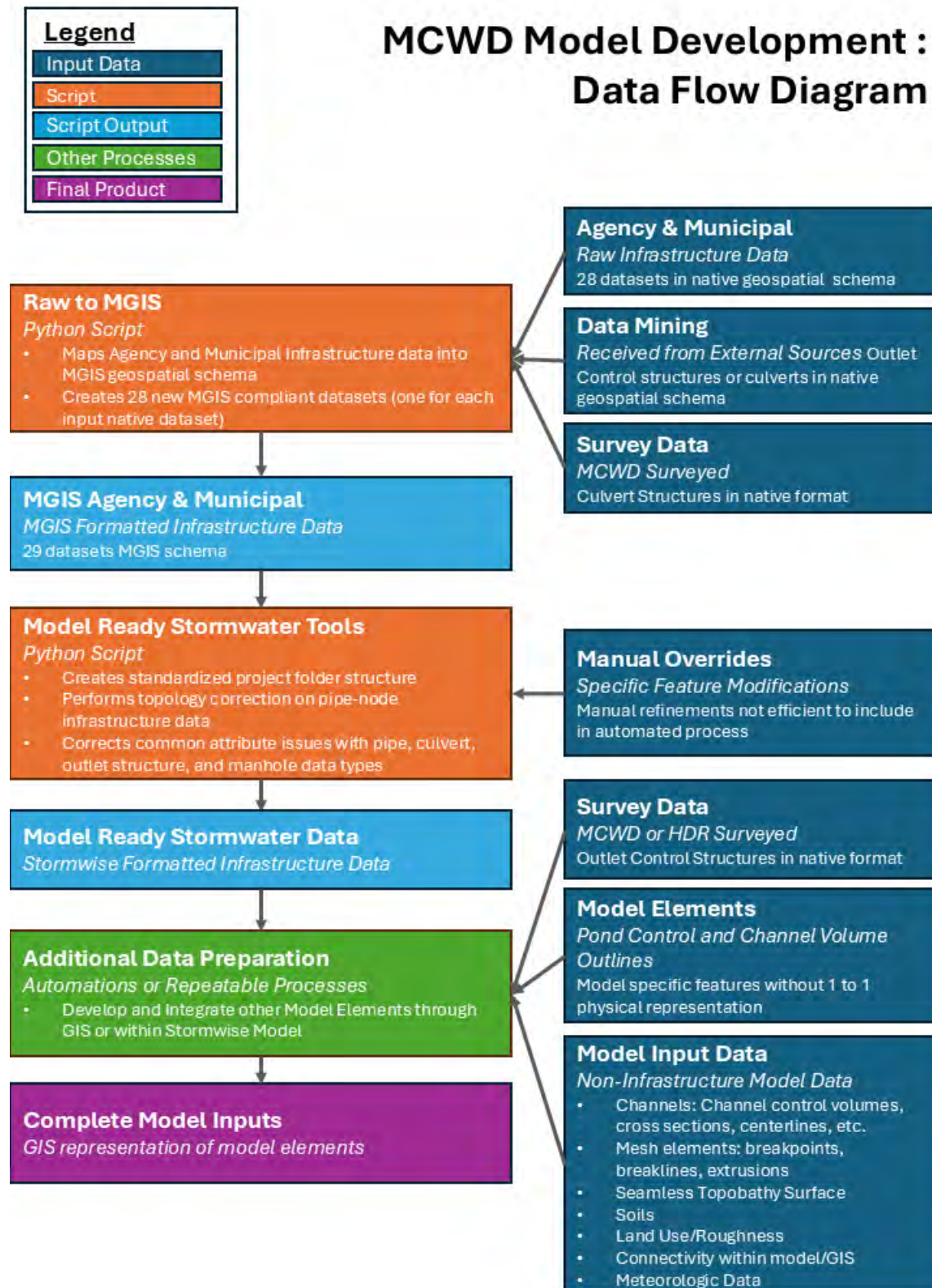


Figure 2-2. MCWD 2D Model Build Data Flow Diagram

3 Watershed Model Inputs

Development of the Lower Watershed model followed the four-phased approach that is described in Section 2.1. The following sections are arranged by model build phase with each section first discussing the data acquired and any preprocessing needed, while Section 4 provides a discussion of the model elements. Each build phase incrementally added detail to the previous phase often requiring iterative refinement to prior phase model features.

Refer to Appendix B for the Data Registry, which documents data sources and use in the model development. Appendix C (C-1 through C-13) provides details on how various elements were refined or developed as part of the model build. Note Appendix C is instructional and often requires the explanation found in this report for broader context.

3.1 Phase 1: Surface Mesh

Phase 1 required the input of a representative surface watershed boundary, seamless topographic-bathymetric ground surface, land cover, and mesh-generating elements (breaklines and break points).

3.1.1 Lower Watershed Boundary

MCWD provided two Lower Watershed lateral boundaries: the MCWD administrative boundary and a generalized estimate of the hydrologic watershed. It is important for the OF model domain to accurately represent the existing ground surface. Boundaries not in alignment with the topography could cause water ponding against the model domain or outflow inaccurately along the model edge. The Lower Watershed boundary was updated as part of this project. The general shape and extents remained the same, with 16 acres added to the Lower Watershed. The approach used ArcHydro processing to define boundaries that reflect the topography, which were manually reviewed with regard to the storm sewer network to determine which systems flow into or out of the watershed. The updated Lower Watershed Boundary vertices were coarsened to a minimum of 25-foot spacing to limit likelihood of small triangles as part of the OF mesh generation for use as a single OF region in the model.

Additional details of this process are provided in Appendix C-1, “Watershed Boundary Adjustment Process.”

3.1.2 Topography and Bathymetry

Topographic data for the model was generated from a combination of the best available (most recent) light detection and ranging (LiDAR) data, publicly available bathymetric data, survey data acquired by MCWD, and estimated bathymetry in critical waterbodies. Figure 3-1 shows the locations of bathymetric data development in the lower watershed.

- **LiDAR:** The most recent LiDAR data product for the region, collected in spring 2022, was processed at the original product resolution of 0.5 meter and is of U.S. Geological Survey (USGS) Quality Level 1 or better (USGS 2022). This is a high-quality dataset; however, LiDAR does not collect elevation data beneath the water surface and can have difficulty in densely vegetated areas.

- **Channel Bathymetry:** 2D models require a continuous surface for terrain development. To supplement the LiDAR surface, MCWD provided existing surveyed cross-sectional data of the Minnehaha Creek for use in bathymetry surface development. Survey data along the creek was used to construct a channel bathymetry surface through linear interpolation between cross sections. Bathymetric data was mosaicked with the LiDAR-based surface to create a new topographic surface that more accurately represents the channel bottom elevations.
- **Surface Waterbody Bathymetry:** StormWise model relies on accurate characterization of the stage-storage volume of potential water stored within the feature. Known bathymetry was mosaicked into the LiDAR surface for 190 features, including many of the largest waterbodies in the watershed. LiDAR classification of hydro-flattened waterbodies (2 acres or more) was used to identify 405 waterbodies within 1 mile of the watershed boundary (upper and lower). Empirical methods were used to estimate maximum waterbody depth and volume. Bathymetric contours were iteratively generated as interior buffers of the hydro-flattened waterbody at incremental depths to closely match the estimated depth-volume relationships. Interior buffers were converted to a depth raster which was subtracted from the hydro-flattened LiDAR surface to generate a continuous LiDAR-channel bathymetric surface.

Additional details of this process are provided in Appendix C-2, “Development of the Terrain Surface with Bathymetry,” and Appendix D, “Task 3b: Non-pipe Stormwater Feature Development Summary.”

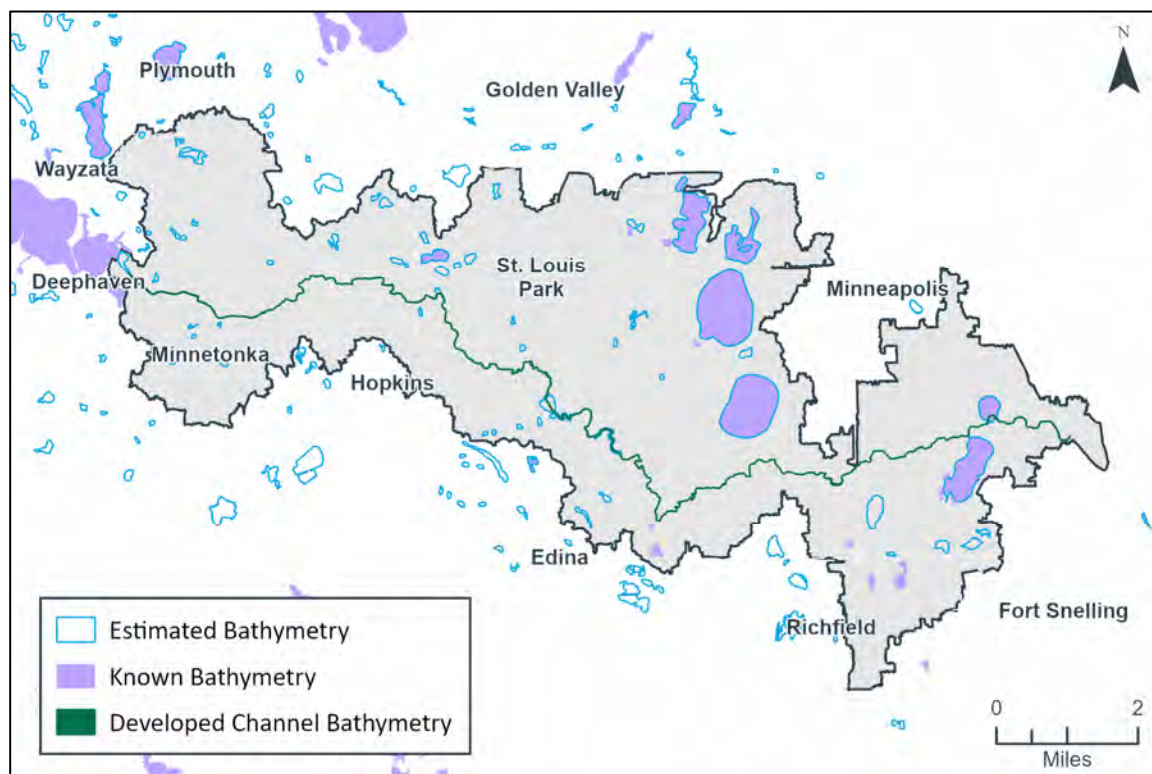


Figure 3-1. Lower Watershed Bathymetry Development

3.1.3 Land Cover

Land cover characteristics were used to describe roughness of overland flow (resistance to flow) and to define impervious surfaces for infiltration/direct runoff calculation. Through coordination with Moore Engineering, a blended land cover was selected to support future watershed planning efforts (Email Correspondence 3/16/2026). The blended land cover uses the following two primary products.

- Metropolitan Council Environmental Services (MCES) Generalized Land Use dataset (2020) is provided for the seven-county metro area and is developed through aerial photography, county-level parcel data, and field verification. It includes mixed-resolution polygons representing consistent land use areas. The coverage is updated every 5 to 7 years. This dataset provides added classification detail in developed areas. Therefore, the MCES (2020) product was selected to represent all areas identified as developed land cover.
- National Land Cover Dataset (NLCD 2024) provides national cover data classification at 30-meter resolution. It is based on satellite data and updated annually. In undeveloped spaces, NLCD provides additional classification detail that are not included in the MCES (2020) dataset. Therefore, where the MCES data (2020) identified undeveloped land use, the NLCD data (2024) was used.

Land cover in the lower watershed is predominantly developed (90+ percent) with a large portion made up of single-family residences (50+ percent), as shown in Table 3-1. The final blended land cover is shown in Figure 3-2. Additional details of the blending process are provided in Appendix C-3, “Land Cover Polygons Process.”

Table 3-1. Land Cover Distribution of Lower Watershed

Land Cover Description	Land Cover Zone	Area (acres)	% of Total Lower Watershed Area
Farmstead	111	0	0.0%
Seasonal/Vacation	112	0	0.0%
Single Family Detached	113	15606	51.7%
Single Family Attached	114	1120	3.7%
Multifamily	115	1151	3.8%
Manufactured Housing Park	116	0	0.0%
Retail and Other Commercial	120	1065	3.5%
Office	130	358	1.2%
Mixed Use Residential	141	111	0.4%
Mixed Use Industrial	142	167	0.6%
Mixed Use Commercial	143	35	0.1%
Industrial or Utility	151	553	1.8%
Institutional	160	1398	4.6%
Major Highway	201	1019	3.4%
Major Railway	202	48	0.2%
Airport or Airstrip	203	301	1.0%
Open Water	11	1499	5.0%
Developed, Open Space	21	2501	8.3%
Developed, Low Intensity	22	1486	4.9%
Developed, Medium Intensity	23	431	1.4%
Developed, High Intensity	24	57	0.2%

Land Cover Description	Land Cover Zone	Area (acres)	% of Total Lower Watershed Area
Barren Land (Rock/Sand/Clay)	31	0	0.0%
Deciduous Forest	41	279	0.9%
Evergreen Forest	42	19	0.1%
Mixed Forest	43	4	0.0%
Shrub/Scrub	52	0	0.0%
Herbaceous/Grasslands	71	2	0.0%
Hay/Pasture	81	7	0.0%
Cultivated Crops	82	0	0.0%
Woody Wetlands	90	127	0.4%
Emergent Herbaceous Wetlands	95	860	2.8%
Total		30204	100.0%

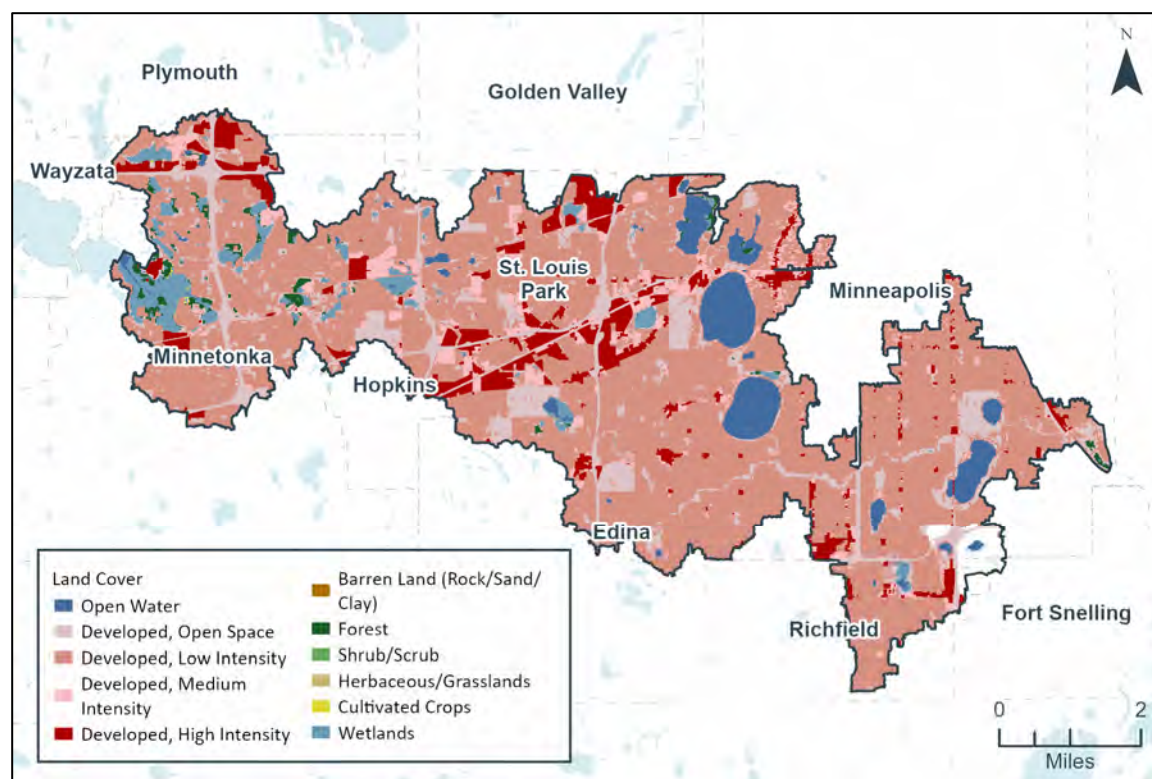


Figure 3-2. Lower Watershed Land Cover

3.1.4 Surface Roughness

StormWise implements a depth variable roughness approach that allows users to specify a shallow and deep flow roughness coefficient and a transition depth to change from shallow to deep flow. Shallow flows that experience more frictional surface roughness have a higher value than deeper flows over those same surfaces. Roughness coefficients were selected using literature values and through coordination with the Advisory Team. Table 3-2 shows the selected roughness values for the model build.

Table 3-2. Manning's Roughness Coefficients

Land Cover	Shallow Flow Depth ² (feet)	Shallow Flow n	Deep Flow n ¹
Open Water	0.1	0.038 ²	0.038
Developed, Open Space ³	0.1	0.15 ¹	0.04
Developed, Low Intensity ⁴	0.1	0.15 ¹	0.09
Developed, Medium Intensity ⁵	0.1	0.15 ¹	0.12
Developed, High Intensity ⁶	0.1	0.15 ¹	0.16
Barren Land (Rock/Sand/Clay)	0.1	0.05 ²	0.027
Forest ⁷	0.1	0.4 ²	0.19
Shrub/Scrub	0.1	0.4 ²	0.11
Herbaceous/Grasslands	0.1	0.24 ²	0.04
Cultivated Crops ⁸	0.1	0.17 ²	0.10
Wetlands ⁹	0.1	0.15 ¹	0.07

Source:

¹ HEC RAS Manual (USACE 2025)

² NEH: sheet flow (USDA 2008)

³ Developed, Open Space includes farmstead, major highway, major railway, and airport or airstrip

⁴ Developed, Low Intensity includes single family detached, single family attached, manufactured housing park, and institutional

⁵ Developed, Medium Intensity includes multi-family

⁶ Developed, High Intensity includes retail and other commercial, office, mixed use residential, mixed used industrial, mixed-use commercial, and industrial or utility

⁷ Forest includes deciduous forest, evergreen forest, mixed forest, and seasonal/vacation

⁸ Cultivated Crops includes hay/pasture

⁹ Wetlands include woody and emergent herbaceous wetlands

3.1.5 Impervious

StormWise requires impervious percent and directly connected impervious percent as model inputs. This input describes the amount of impervious surface on the land for which infiltration will not occur; instead rainfall is directly converted into runoff. Impervious area was determined for each land classification using the NLCD (2024) Impervious layer. This layer provides impervious percent estimates at a 30-meter resolution over the entire watershed. For each blended land cover description, an average impervious percent was determined watershed wide resulting in a single impervious percent value for each land cover description. These average impervious percent values were used as input to the model. Directly Connected Impervious Area (DCIA) are impervious areas that are connected to the stormwater drainage system, surface or subsurface, and are expected to respond faster and without infiltration losses.

Table 3-3 provides the model inputs; additional details of this process are provided in Appendix C-3, "Land Cover Polygons Process." Note that calibration resulted in adjustments to the impervious percent; these are discussed in more detail in Section 5.4.

Table 3-3. Impervious and DCIA Model Inputs

Land Cover Description	Impervious %	DCIA %
Farmstead	18	9
Seasonal/Vacation	4	2
Single Family Detached	29	18
Single Family Attached	49	30
Multifamily	60	38
Manufactured Housing Park	48	39
Retail and Other Commercial	75	75
Office	68	68
Mixed Use Residential	75	43
Mixed Use Industrial	69	69
Mixed Use Commercial	78	78
Industrial or Utility	65	65
Institutional	47	35
Major Highway	60	45
Major Railway	62	46
Airport or Airstrip	63	32
Open Water	0	0
Developed, Open Space	11	0
Developed, Low Intensity	34	33
Developed, Medium Intensity	62	60
Developed, High Intensity	86	80
Barren Land (Rock/Sand/Clay)	0	0
Deciduous Forest	0	0
Evergreen Forest	0	0
Mixed Forest	0	0
Shrub/Scrub	0	0
Herbaceous/Grasslands	0	0
Hay/Pasture	0	0
Cultivated Crops	0	0
Woody Wetlands	0	0
Emergent Herbaceous Wetlands	0	0

3.1.6 Breaklines

Breaklines are used to define mesh element edges and are often used to define flow paths and ridgelines across the model surface. Breaklines were created using an automated process for this model and focused on describing critical flow paths within the watershed. Geospatial tools were used to create draft breaklines based on a flow accumulation threshold of 5,000 square feet in developed areas and 50,000 square feet in undeveloped areas and the lower watershed west of US-169. Flow paths in the urban spaces were often curblines that required a smaller accumulation threshold to adequately describe. The less developed areas had more natural drainage features that could be represented with a higher threshold. These draft lines that were then modified to confirm parallel breaklines did not result in small triangles, minimize line vertices, and snap to other mesh elements, where necessary.

Additional details of this process are provided in Appendix C-4, “Surface Mesh.”

3.1.7 Breakpoints

Breakpoints are used to define mesh element vertices. These are typically generated on a regular grid pattern within StormWise to fill the space between other mesh generating elements. To better represent surface water-groundwater interactions and to improve inundation mapping along narrow channels, a denser breakpoint pattern was generated within CCVs and PCVs. Within CCVs, a 25-foot side length was used, and within PCVs, a 50-foot side length was used. A standard coarser breakpoint pattern was applied for the rest of the Lower Watershed area, as discussed in Section 4.1.

Additional details of this process are provided in Appendix C-4, “Surface Mesh.”

3.2 Phase 2: Control Volumes

Phase 2 required development of PCV model elements (boundary polygons, nodes, and connectivity), CCV model elements (boundary polygons, links, nodes, and cross sections), and rating curves for any creek or channel crossings that cannot be represented by a culvert. Pond and channel control volumes override the 2D mesh and simplify the hydraulics into a 1D representation. The Project Team intentionally located these features to maximize accuracy of the watershed response while improving model efficiency. PCVs were used to represent large frequently wet waterbodies, while CCVs were used for the entire length of the Minnehaha Creek channel from Gray’s Bay Dam to the Mississippi River as well as a few key tributaries.

3.2.1 Pond Control Volumes

PCVs are polygons that simplify computations in portions of the 2D OF area using a 1D approximation of storage and connectivity. These features can result in increased numerical efficiency and, where appropriately implemented, can improve model accuracy. PCVs were used in the model for many of the continuously wet waterbodies along with large wetland complexes. To represent these features in the model, a polygon outline (control volume) and a node (stage/area) are needed.

Polygons were created using closed contour lines that represented the approximate top-of-bank area of a waterbody. Where PCVs were adjacent to other PCVs or CCVs, their polygon edges were aligned and a 1D weir was added allowing water to exchange through the weir connection. These features were manually modified to contain pipe ends (inlet or outlet) that connect to the waterbody, and then these polygons were simplified to minimize the number of vertices. Stage/area nodes, a 1D model element, are associated with PCVs. Each stage/area node was placed within the PCV polygon and assigned to the corresponding PCV. Two hundred thirty-one PCVs were included in the Lower Watershed model, as shown in Figure 3-3.

Additional details of this process are provided in Appendix C-5, “Pond Control Volumes.”

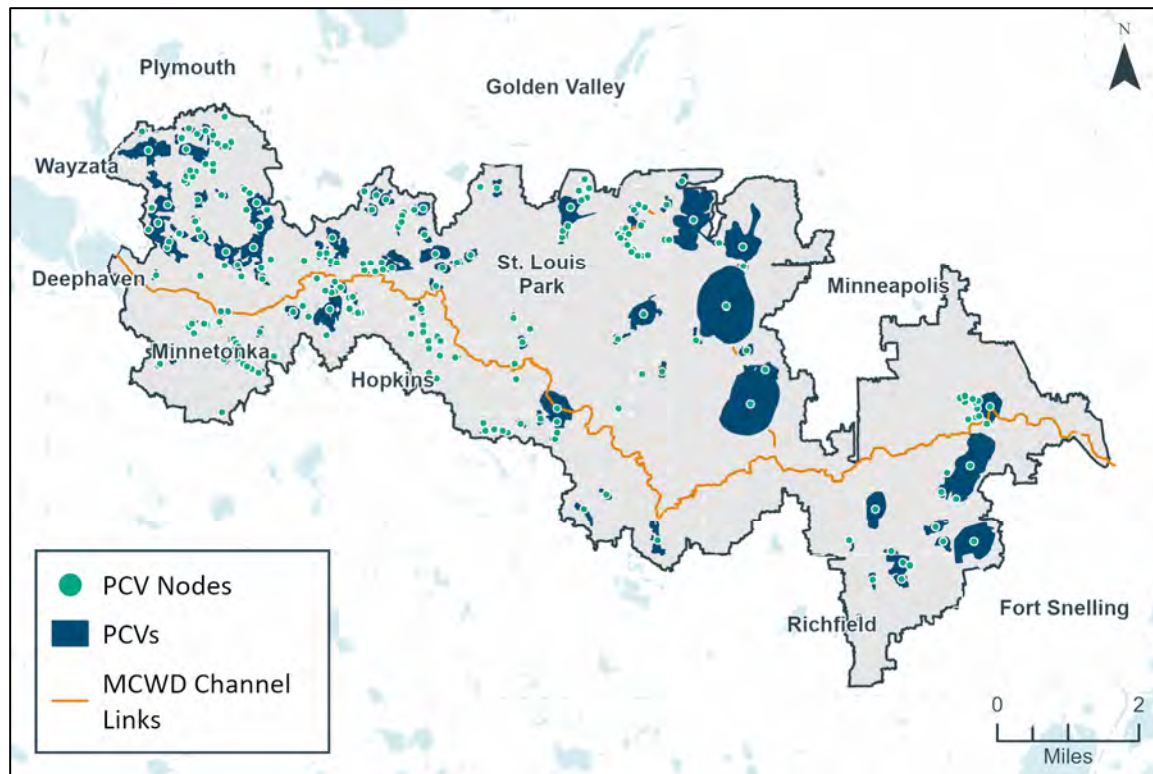


Figure 3-3. Pond and Channel Control Volumes

3.2.2 Channel Control Volumes

CCVs are used to define areas of linear water features such as channels, rivers, and streams that can be represented with a 1D channel link. For this watershed model, the entirety of Minnehaha Creek was included as a series of 1D channels, as well as a few of the smaller channel features, as shown in Figure 3-3. To represent CCVs in the model, the following are needed: channel links, cross sections, polygons outlining incremental channel areas (control volumes), a channel node (stage/area node).

Channel links are the 1D elements that represent open channel flow routing. The entirety of Minnehaha Creek in the Lower Watershed was included as channel links. Channel links estimate flow area in the creek using channel cross sections. Cross sections, placed at approximately 150-foot intervals, were co-located with survey channel data to most accurately reflect observed channel conveyance. Stage/area nodes were generated at the intersection of cross sections and channel links. CCVs represent the area of 1D flow and were developed using contours to estimate top of bank areas and aligned with the limits of the 1D channel cross sections. Approximately 800 channel links are included in this watershed model to represent the Minnehaha Creek and other smaller channel features. CCVs act as mesh-generating features, so vertices along the polygons were minimized and/or snapped to other mesh features.

Along with 1D channel links, the model requires OF channel features to define connectivity within the channel. These features are typically identical to the 1D channel link geometry. See Figure 3-3 for the location of CCVs.

Additional details of this process are provided in Appendix C-6, “Channel Control Volumes.”

3.2.3 Minnehaha Creek Crossings

More than 90 Minnehaha Creek crossings (bridge or culvert) or control structures (weirs) exist along the 22 stream miles in the Lower Watershed. In many cases, these crossings impact the natural flow through the creek by creating a restriction, causing increased upstream inundation, and attenuating flow peaks. Since StormWise does not have robust bridge hydraulic routines, the standard approach for including bridges is to develop geometric model inputs within the U.S. Army Corps of Engineers’ Hydrologic Engineering Center-River Analysis System (HEC-RAS) and export the results as a family of head-flow conditions. These rating curves are imported directly into StormWise.

HDR reviewed and categorized the stream crossings into three tiers. Tier 1 includes 15 structures that are anticipated to have a significant impact (deemed 1 foot or greater) to the creek’s peak water surface elevation in either the 100-year or 500-year annual chance flood events and were included in the StormWise 2D model. Incorporation of creek crossings used existing HEC-RAS models, generated new HEC-RAS models, used MCWD’s XPSWMM model, or used the storm sewer infrastructure datasets. The following structures are included and shown in Figure 3-4:

- 9 bridges included as HEC-RAS generated rating curves
- 6 culverts included as pipe links
- 2 weirs included as weir links

There are limited tributaries in the Lower Watershed. For the model build, a review of and development of tributary bridge rating curves was not performed. Minnehaha Creek crossings not explicitly included in the model as rating curves, culverts, or weir links are allowed to flow without additional restriction along the creek. Additional details of this process are provided in Appendix C-7, “Minnehaha Creek Crossing Data Summary.”

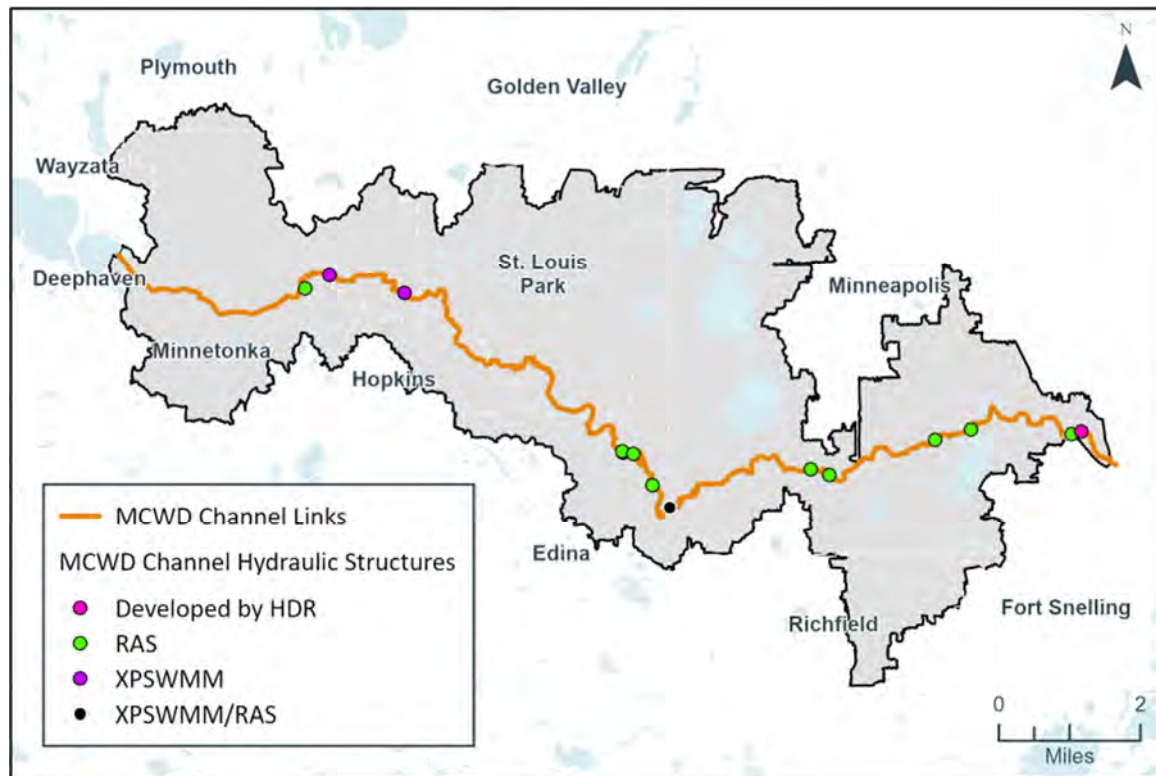


Figure 3-4. Tier 1 Minnehaha Creek Channel Crossings Included in Model Build

3.3 Phase 3: Storm Sewer Network

Phase 3 required the input of the storm sewer infrastructure, which includes primarily inlets, pipes, manholes, outlets, and culverts. These are part of the 1D “link-node” modules of the software and are connected to the 2D OF through 1D node interface points. These interface points are typically storm inlets and establish a new mesh-generating element, which requires refinement of the OF 2D mesh to integrate these features and detailed review to remove small triangle edges.

3.3.1 Storm Sewer Infrastructure

MCWD overlaps numerous municipalities, counties, and other entities that own storm sewer infrastructure. Approximately 30 different storm sewer infrastructure datasets were aggregated and processed for use in the whole watershed model build (Upper and Lower). Figure 3-5 shows the pipe network throughout the watershed, including the following infrastructure features:

- 49,500 storm sewer conduits ranging in size from 6 to 120 inches
- 3,100 culverts ranging in size from 6 to 120 inches
- 33,400 inlets
- 7,000 outlets
- 19,100 manholes

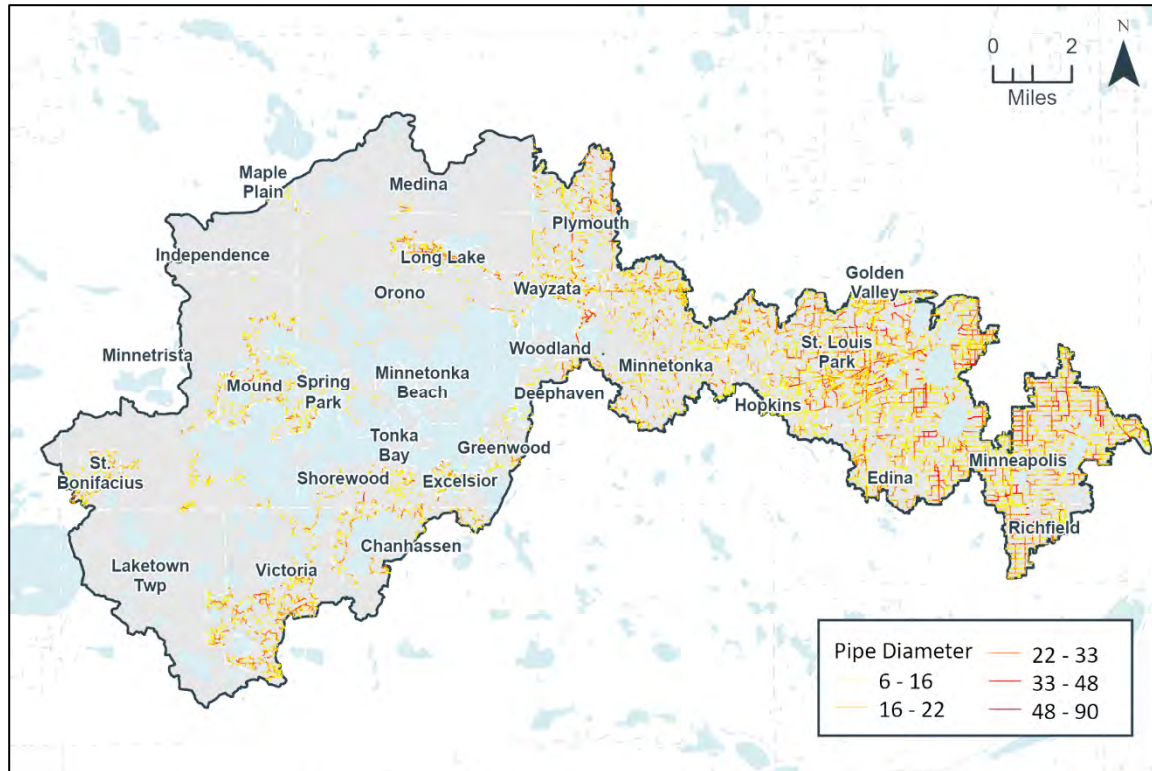


Figure 3-5. Watershed-wide storm sewer infrastructure

3.3.2 Storm Sewer Refinement

Major advancements were completed as part of the pilot project to aggregate, review, and refine these storm sewer datasets. Scripts developed for the MCWD watershed-wide model pilot study systematically re-formatted and consolidated storm sewer datasets from all constituent owners (state, county, city) into a unified geographic information system schema (MGIS) (Kimley Horn 2023). To support model development, data gaps and erroneous attributes were flagged and filled following a variety of methods depending on the gap type and available data. As part of this model build, the MCWD scripts were updated to fill gaps for all required missing attributes. The “Task 4 Script Documentation” Technical Memorandum describes modifications to the previously developed scripts and is included as Appendix E. Both an automated and manual approach were used to identify issues and address them. Where manual updates were completed, a tracking geodatabase was populated with the required updates, and this dataset was input into the scripts to perform the modifications in a systematic and repeatable manner.

3.3.2.1 Automated Procedures

Where automated procedures filled gaps in pipe and node features, a systematic review of municipal datasets was performed to determine appropriate default values for each attribute. Methods for filling data gaps varied by attribute and consisted of the following:

- **Node (inlets, manholes) rim elevation:** where rim elevations were more than 0.5 feet different compared to topographic surface elevations, rim elevations were replaced with the topographic surface elevation.

- **Node (inlets, manholes) invert elevation:** where node invert elevations were questionable (less than 700 feet, greater than 1,200 feet, or greater than the digital elevation model point elevation), invert elevations were set to null and filled in by subsequent steps of the script. Where nodes were connected to a pipe, pipe inverts were used to fill data gaps. Where pipe data were missing, the surface elevation minus and cover depth was used to fill these data. Typical cover depth over the conduit was assumed to be 4.0 feet, based on review of the municipal data sets, and included a typical 6-inch pipe thickness for the top of the pipe. Two passes were used to fill data gaps for structures: an initial pass to fill data gaps based on initially available data, and a second pass to fill data gaps, based on assumed pipe invert elevations.
- **Pipes (culverts, storm sewer) to/from nodes:** populated from connected nodes or a buffered snapping procedure (snapping pipe ends to nodes within 5 feet). Where unable to snap, manual review was performed.
- **Pipes (culverts, storm sewer) geometry (diameter, height, width, shape, material):** where pipes were connected to other pipes, the average of those geometric fields were used to fill any data gaps. Where connecting pipe data were also missing or if pipes were at the upstream end of the network (having no other connecting pipes upstream), default values were applied instead. A manual review of the municipal datasets was performed to determine typical pipe attributes. Typical pipe diameters, shapes, and materials were found to be generally consistent across municipalities within the watershed; therefore, default values of 15 inches (diameter), circular (shape), and reinforced concrete (material) were applied in cases where the data gap-filling procedure required default assumptions.
- **Pipes (culverts, storm sewer) length:** where the attributed length is greater than +/- 20 percent of the geometric feature length or if not populated, the geometric feature length was used.
- **Pipes (culverts, storm sewer) inverts:** uses the same process as node inverts.

Further detailed discussion of the associated attribute fields and approach used to fill data gaps in the storm sewer infrastructure data is provided in Appendix C-8, "Storm Infrastructure Assumptions."

3.3.2.2 Manual Procedures

Manual procedures were implemented where decisions required human input or where clear repeatable automated processes would be onerous to implement given the number of features required to address. Two primary methods were used: a random sampling process (where many features required review) and a manual one-by-one review of each feature in question.

Random sampling was implemented where widespread redundancies in storm sewer data were identified in source datasets to the MGIS data aggregation workflow. This analysis selected a statistically significant sample of each potentially redundant dataset to review for potential omission from the aggregated dataset. The results of the random sampling analysis indicated that Hennepin County and Carver County data may be omitted without substantial loss of relevant data. Minnesota Department of Transportation (MNDOT) data also exhibited a high degree of redundancy and were omitted; however, further review of these data is recommended for potential inclusion in specific regions of the watershed area.

Manual review was performed for culvert features identified as potentially redundant with storm sewer pipes in the overall storm pipe dataset. Where manual procedures were required, manual updates were tracked as features in a manual overrides geodatabase for inclusion into the script process. The script was then updated to read the manual overrides geodatabase and incorporate the manual updates to make them repeatable. Manual modifications were required where engineering judgement was needed to address a conflict such as pipe/node proximity conflicts, redundant datasets, or infrastructure around the model boundary.

Further detailed discussion of the random sampling analysis process and results is presented in Appendix C-9 “Storm Infrastructure Duplicative Dataset Evaluation Process.”

3.3.2.3 Automated Conversion to Model Ready

While StormWise allows several input dataset methods, for this model build, a .CSV input approach was implemented. A python script developed by MCWD ingested complete model-ready storm infrastructure geodatabase features as well as PCVs and CCVs. The script removed features completely contained within PCVs and CCVs, updated the pipe links to/from nodes to the appropriate control volume feature, and converted each feature class into a set of .CSV files for import into StormWise. The .CSV storm sewer inputs are provided as part of an electronic delivery package delivered along with this report.

3.3.3 Waterbody Outlet Survey Collection

Surface water storage in distributed waterbodies throughout the watershed has a significant impact on watershed response. Many of these features have limited information available to describe the outlet conditions and connectivity downstream. The Technical Memorandum, “Task 6: Waterbody Screening and Prioritization for Additional Data Collection,” describes the process to identify and prioritize survey data collection and is included as Appendix F.

A desktop analysis was performed on the largest 256 waterbodies watershed wide. Here the storm sewer infrastructure, LiDAR topography, and oblique aerial imagery was reviewed to identify potential gaps in data required to include outlet structures into the model. The desktop analysis resulted 155 features with data needs to support model development, as described below:

- Culverts/pipes (113): MCWD to survey
- Outlet structures (20): HDR to survey
- Lift Stations (4): Data request to owner
- Unknown (18): MCWD to field verify

Surveyed culverts/pipes were integrated as an independent data pathway into the stormsewer infrastructure scripts. Lift stations and more complex survey data were integrated directly into the model. Figure 3-6 shows locations of outlet control structures that were directly integrated into the model based on survey data, as-builts, or the current MCWD XPSWMM model.

3.3.4 Lift Stations

Municipal stormwater infrastructure datasets identified 42 lift stations within the lower watershed. Lifts stations are characterized by, at a minimum, maximum discharge capacity, off/on elevations, and upstream/downstream connectivity. Sufficient information or reasonable assumptions allowed

for the incorporation of 36 of the lift stations. Where stormwater models were provided (City of Edina and City of St. Louis Park), lift station characteristics were directly replicated. Where no lift station attributes were available, they were assumed: on/off elevations were offset up from the incoming pipe invert by 2.5 feet (on) and 1.5 feet (off), and maximum capacity was based on discharge pipe diameter and categorized as either 0.5, 3, or 9 cubic feet per second (cfs) for pipes less than 15 inches, between 15 and 42 inches, and greater than 42 inches, respectively. Of the lift stations identified, 36 had sufficient connectivity data for incorporation into the lower watershed model. Figure 3-6 shows the lift station locations.

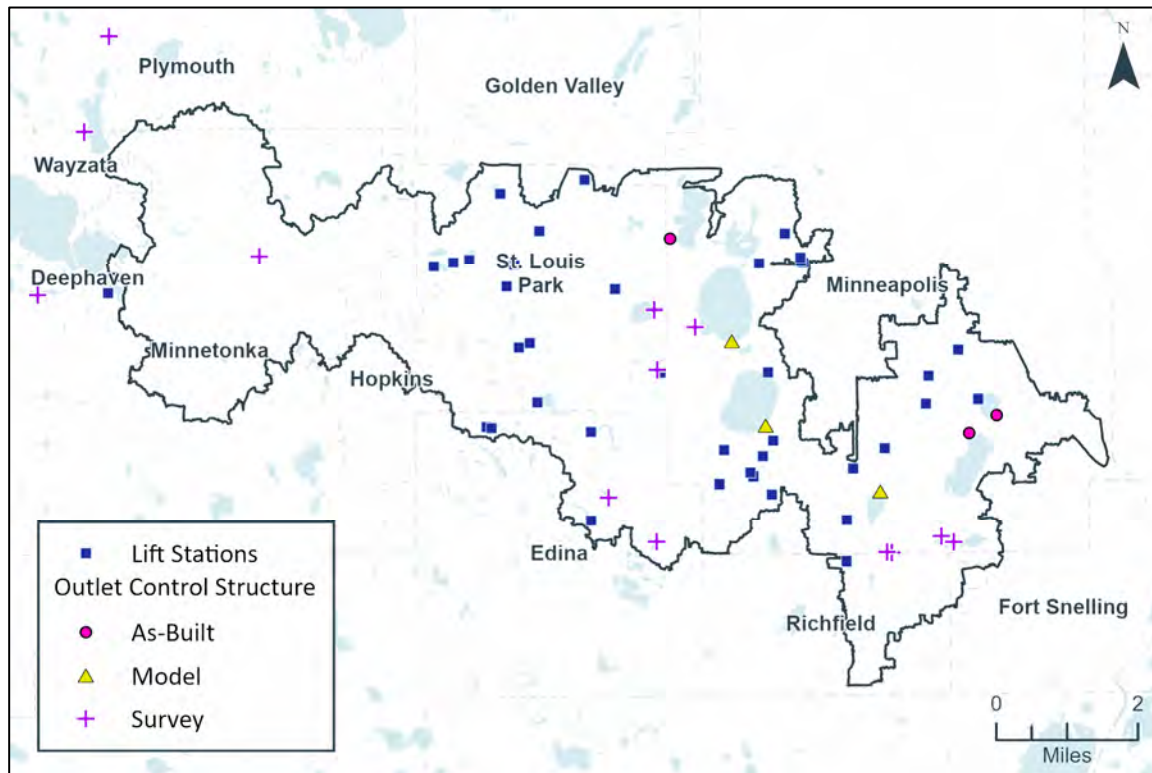


Figure 3-6. Lift Stations and Outlet Control Structures

3.4 Phase 4: Groundwater

Phase 4 required the input of a representative groundwater boundary, groundwater regions, soil spatial and vertical variability as well as parameters, a continuous confining layer, and mesh generating elements (break points).

3.4.1 Lateral Groundwater Boundary

Lateral groundwater boundaries were chosen to be different than, and typically outside of the surface water boundary. Lateral groundwater boundary extents were set to locations of known boundary conditions (head) to reduce the uncertainty of these inputs. Boundary points were defined at groundwater wells with available water table information, surface water bodies anticipated to be perennially wet, or artificial points used to keep the groundwater boundary outside of the surface water boundary. The groundwater boundary and points to generate it are shown in Figure 3-7.

Downstream of the Minnehaha Falls in the Mississippi River valley, a groundwater region without lateral boundary conditions was used as it is believed that the Minnehaha Creek confluence with the Mississippi River, represented at the OF region, was enough to dominate groundwater hydraulics. The Project Team made this decision for several reasons:

- Groundwater downstream of the falls is relatively independent of the groundwater upstream of the falls.
- Groundwater mesh detail at and downstream of this location required to capture the rapid variability in elevation change may limit the model's ability to simulate longer term conditions.
- StormWise requires a continuous thickness of unconfined material between the lower boundary (bedrock) and upper boundary surface. When the bedrock meets the surface this assumption is no longer valid.

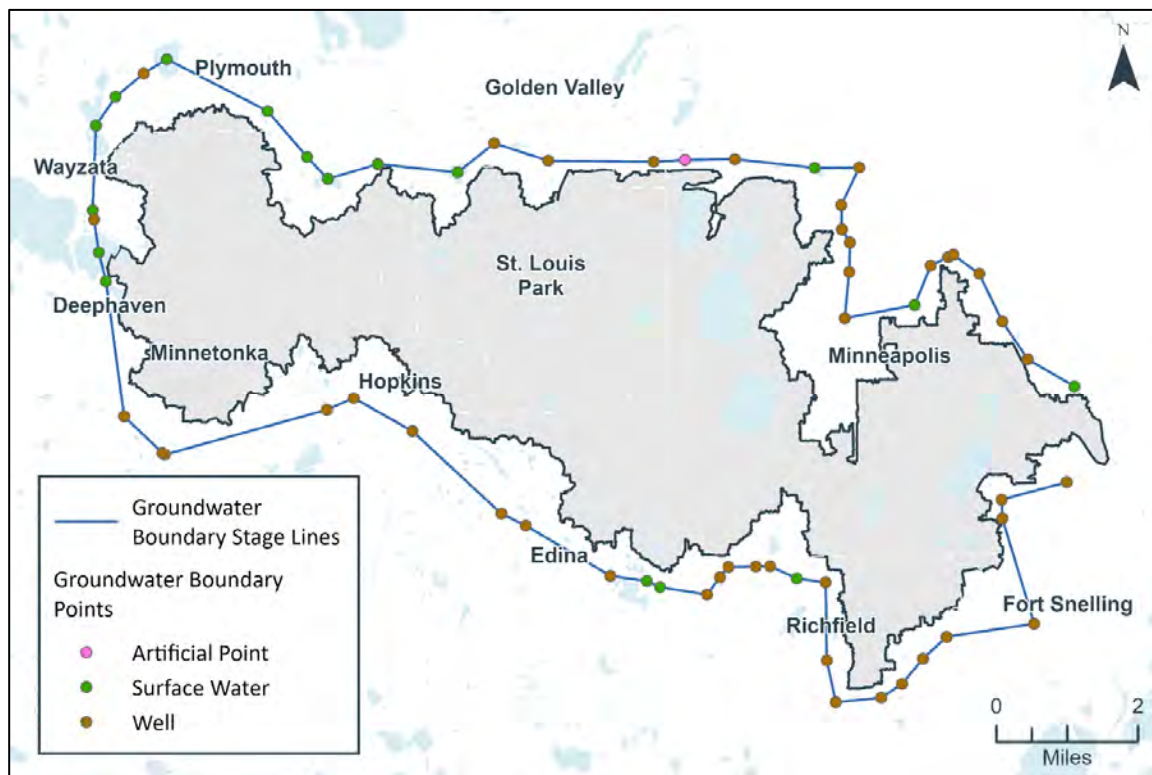


Figure 3-7. Groundwater Boundary Development

3.4.2 Groundwater Regions

Unlike OF, the StormWise groundwater numerical solution does not lend itself to direct parallelization. Therefore, the mesh was decomposed into multiple groundwater regions to improve simulation performance. StormWise assumes groundwater regions have lateral no-flow boundaries, allowing them to be solved independently. This forces any lateral exchange along groundwater region boundaries to occur through vertical exchange to the surface OF flow region, then laterally into the adjacent groundwater region. Locations where the surface domain is frequently wet offer continuous connectivity between groundwater regions.

The Lower Watershed lateral groundwater boundary, as discussed in Section 3.4.1, was divided into five regions at locations that are continuously or frequently ponded, such as along Minnehaha Creek centerline and through the chain of lakes or at locations that are not anticipated to laterally interact, such as at the Minnehaha Falls. These boundaries are also groundwater mesh generating elements; therefore, the boundary vertices were coarsened to a minimum of 250-foot spacing to limit the likelihood of small triangles as part of groundwater mesh generation. The Lower Watershed groundwater regions are shown in Figure 3-8.

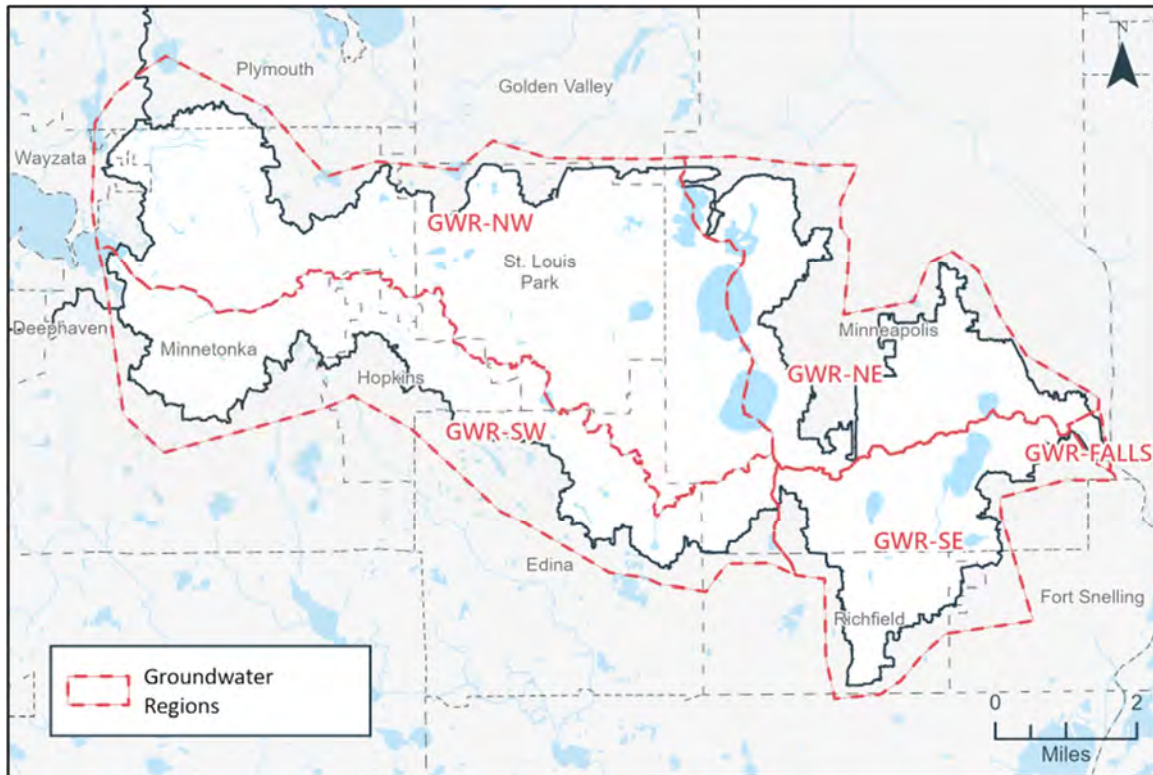


Figure 3-8. Groundwater Regions

3.4.3 Lower Boundary

StormWise requires a lower boundary of the groundwater domain to be the top of a confining layer. That is assumed to be the top of the bedrock surface, which was most recently updated as part of the Hennepin County Geologic Atlas in 2018 (Steenberg et al. 2018). At locations near Minnehaha Falls and downstream, the confining layer intersects or is above the ground surface elevation. This dataset was generated prior to the updated LiDAR surface and at a coarser resolution. The bedrock surface was adjusted to always be at least 25 feet below the ground surface. This update affected a small amount of the Lower Watershed, located directly around the falls, and was performed to prevent model errors, which occur when the bedrock surface raster is equal to or above the ground surface or initial water table. This modification to the lower confining layer raster is not expected to change model results. Figure 3-9 shows the bedrock surface for the Lower Watershed.

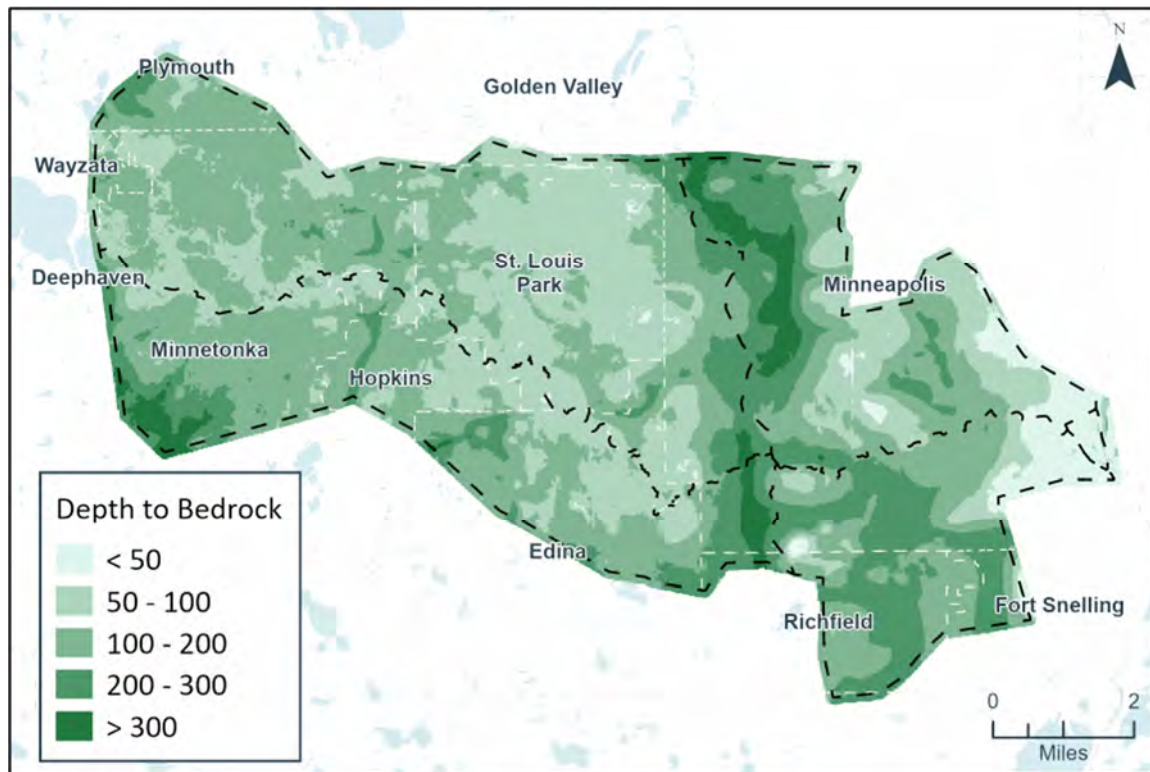


Figure 3-9. Bedrock Surface

3.4.4 Soils Spatial Data

The soil map layer is used heavily in the groundwater portion of the model for vertical and horizontal flow but is also used as part of the rainfall excess calculations at the surface. The Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) for Hennepin and Carver counties were acquired for model import. The “MUKEY” attribute for each soil polygon was used for reference and the various groundwater tables imported to the model all use this attribute. Figure 3-10 shows the variability of soil conductivity in the Lower Watershed.

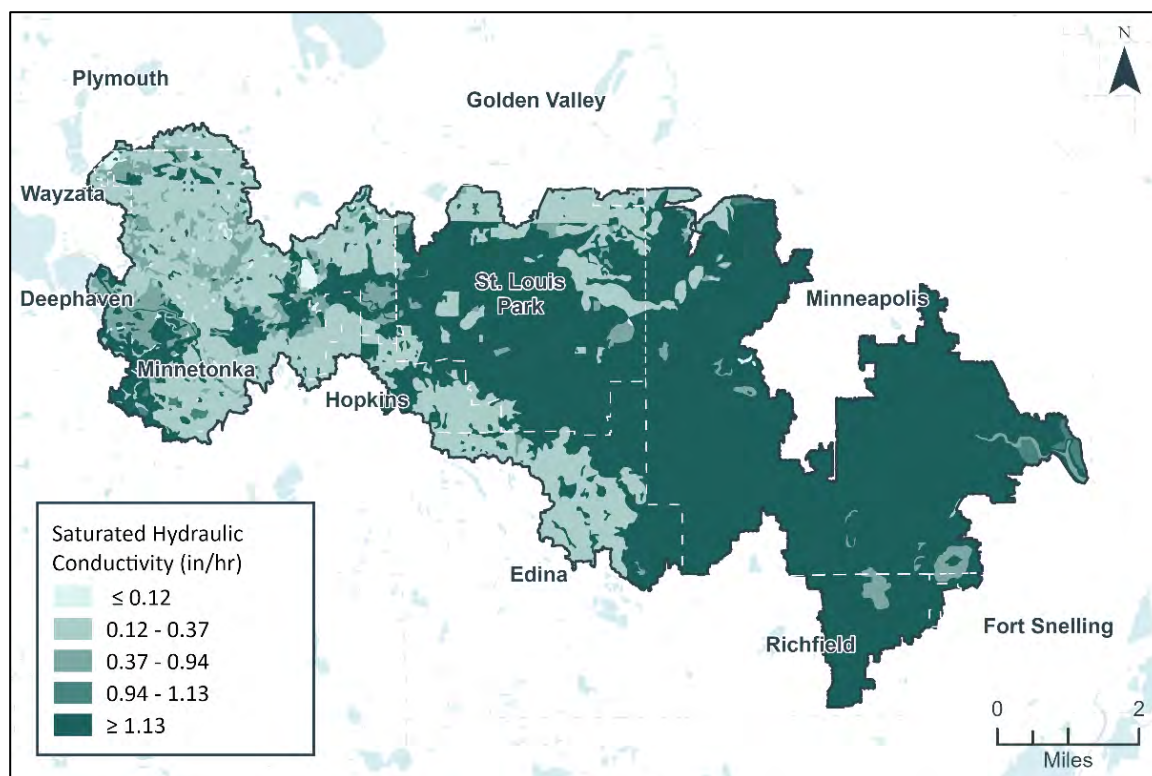


Figure 3-10. Lower Watershed Soil Texture

3.4.5 Vadose Zone and Groundwater Soil Parameters

Associated look-up tables for the soil map layer include hydraulic conductivity, fillable porosity, and vertical layer tables. Look-up tables were developed using the vertical layer parameters from NRCS soils process outlined in the StormWise User's Manual (Streamline 2024). These look-up tables were generated for the entire watershed by Streamline in April 2025. These tables include the vertical layers tables, which have soil parameters for each depth horizon below the surface extracted from NRCS. Note that calibration resulted in adjustments to the infiltration rates; these are discussed in more detail in Section 5.4.

SSURGO survey data commonly is available up to 6 feet deep. For this model build, the bedrock surface was used as a confining layer, which in some cases, can be more than 100 feet below the ground surface. In these cases, the lowest soil horizon data was assumed to represent the soil information from the bottom of the surveyed soil column to the confining layer. In many cases, these lower depths of soil are assumed to be saturated. In saturated conditions, StormWise uses horizontal groundwater flow hydraulics and requires conductivity and fillable porosity tables. For each MUKEY, porosity was assumed to be the saturated moisture content of the lowest soil horizon. Hydraulic conductivity of the saturated zone was assumed to be 10x more conductive such that the horizontal hydraulic conductivity was 10x the vertical hydraulic conductivity of the lowest soil horizon in each MUKEY. Anisotropy was assumed to be a compromise between sandy material with a horizontal to vertical hydraulic conductivity ratio of approximately 3x and clay/till materials of 100x-500x (Tipping 2011).

3.4.6 Crop Coefficients

Groundwater simulations are inherently continuous simulations and for accurate estimation of water balance components, evapotranspiration is required. Evapotranspiration is input as a time series of reference evapotranspiration for an ideal cover condition and endless water supply. To adjust the reference evapotranspiration for specific land covers, representative crop coefficients and root depth values are provided to StormWise. Crop coefficients are applied as a scalar of the potential evapotranspiration and adjust for the seasonal growth stages of various agricultural plants and expanded to various vegetation and open water cover conditions. For each land cover condition, monthly crop coefficients were calculated based on average soil temperature data from 2009 to 2024. Monthly variations in crop coefficient are shown in Figure 3-11. Additional details of this process are provided in Appendix C-10, “Crop Coefficients.”

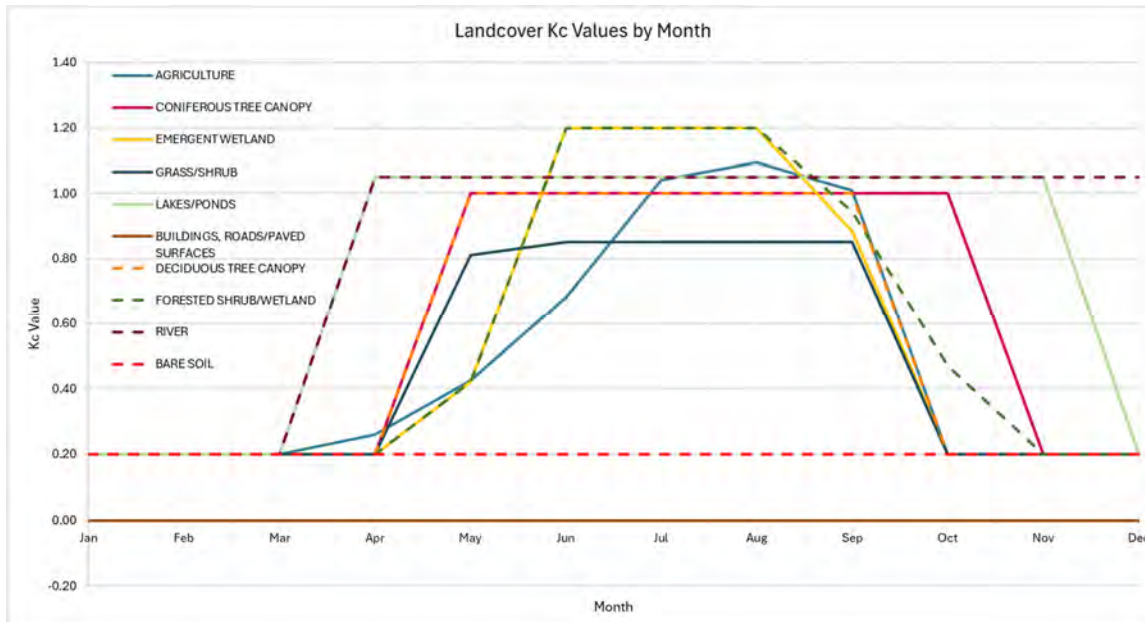


Figure 3-11. Crop Coefficient Annual Variability

3.5 Naming Convention

A standardized naming convention was created for watershed model elements that follows an AA-BBB-CCCCC scheme. The first sequence (AA) signifies the model element type, such as “NC” for Node – Channel. The second sequence (BBB) signifies the area or sub-element, such as “EDI” for Edina. The third sequence (CCCCC) is a six-digit numeric that unique identifies the element. Prior to import into the model all elements were updated accordingly.

Naming conventions for model elements are detailed as part of “Naming Convention” memo provided in Appendix C-11.

4 Watershed Model Build

This section details each individual model element created or imported into the watershed model, its purpose, and the reasoning behind modeling decisions. Types of model elements are separated into

five categories: map layers, surfaces, 1D elements, OF region elements, and groundwater region elements.

4.1 Phase 1: Surface Mesh

Phase 1 model build required importation of map layers, surfaces, tables, and OF region elements relevant to 2D OF. Each of the following items was imported into the model.

- OF: Lower Watershed boundary as discussed in Section 3.1. Through discussion, the Project Team decided that a single OF region would be used for the Lower Watershed. StormWise has optimized the OF region solver for surface hydrology and routing to take advantage of multi-core processors; therefore, a single OF region is used to represent the lower watershed.
- OF: Breaklines imported as shapefiles discussed in Section 3.1.
- Surface: Topographic and bathymetric surface with a buffer of 500 feet around the Lower Watershed surface boundary, as discussed in Section 3.1.
- Map Layer: Land cover polygons, as described in Section 3.1, were directly imported as a to StormWise. Land cover is used for rainfall excess calculations and assignment of surface roughness.
- Table: Manning's n values, or friction coefficients, to 1D and 2D computations, as described in Section 3.1. The land cover Map Layer is used to distribute roughness coefficients spatially.

StormWise computational mesh assumes flow occurs between nodes (or vertices) along the edge of each triangular element, making the location of vertices of high importance to align with drainage pathways. The initial surface mesh included breakpoints, vertices of breaklines, vertices of the OF boundary.

Breakpoints were the last 2D OF mesh element included in the model build. Within PCV and CCV, a denser breakpoint pattern was required and created as described in Section 3.1.7, these breakpoints were imported to the model. For the remaining areas of the OF, breakpoints were used to define the mesh density where not already specified by other geometric inputs. Breakpoints were assigned within the StormWise model using a 150-foot pattern, with 50-foot minimum distance from other mesh features, at the end of the build process. This prioritizes other mesh elements for defining the OF mesh, while keeping a maximum triangle size in areas lacking other elements. Approximately 90,000 breakpoints used to develop the mesh in the Lower Watershed model.

The final mesh generation in the Lower Watershed was heavily dependent upon Phase 2 CCVs and PCVs, and Phase 3 storm sewer and culvert inlets and outlets. The remainder of this section discusses the final mesh, and each subsequent section describes how the mesh was refined to accommodate the newly added features. Final surface mesh nodes include breakpoints, vertices of breaklines, vertices of the OF boundary, vertices of the CCVs and PCVs, and all 1D node interface points. Thoughtful development of these input datasets is critical to generating a high-quality mesh with limited elongated triangle features known to cause model instabilities. CCVs, PCVs, and 1D node interface points are discussed in more detail later in these sections.

These inputs result in a triangle overland flow mesh with:

- 663,435 triangles with average area of 4,925 square feet (Minimum: 150 square feet)
- 753,538 individual links

Figure 4-1 shows an example of the mesh generation elements and the final mesh for a subset of the Lower Watershed.

Boundary conditions for the OF domain were specified using two time/stage nodes that were added to the upstream end of the model at Gray's Bay Dam and downstream at the Mississippi River along Minnehaha Creek, where the channel links pass beyond the model domain. The rest of the OF region assumes a no-flow boundary condition. The upstream boundary condition was specified based on historical dam releases, while the downstream boundary condition is a static head value. As the downstream boundary condition is downstream of the falls, it is not expected for this elevation to influence model results upstream of the falls.

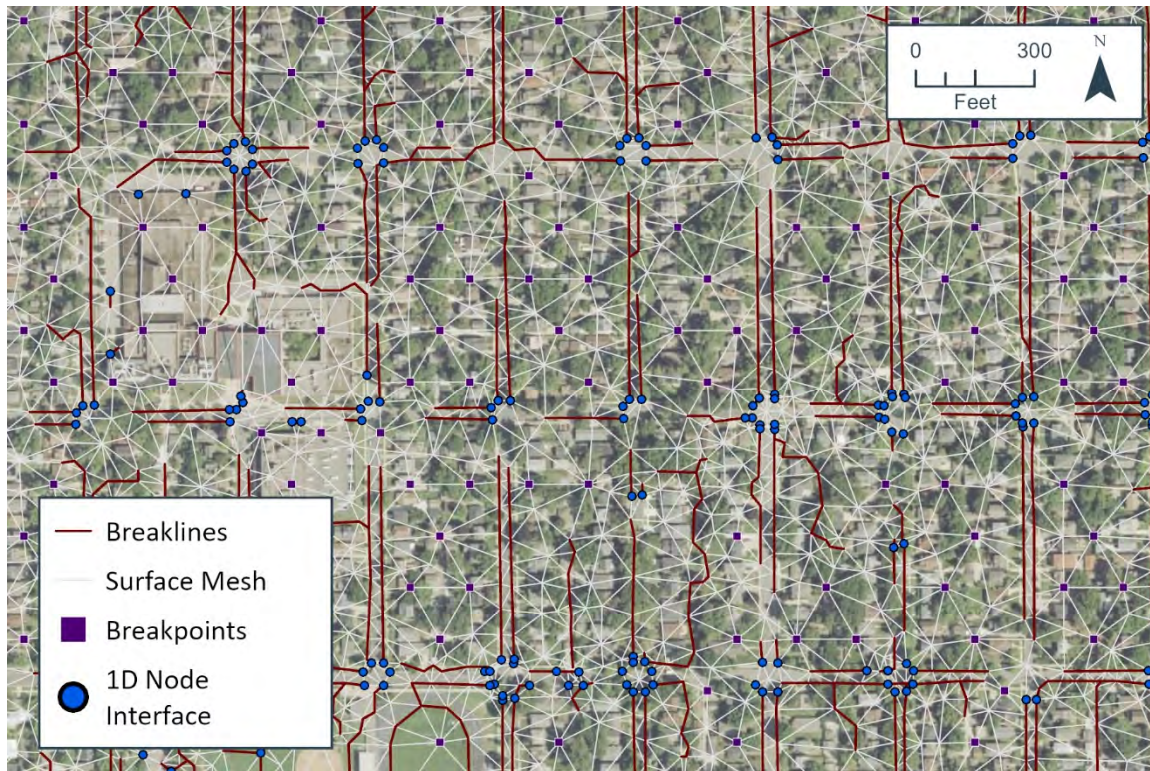


Figure 4-1. OF 2D Mesh Sample

4.2 Phase 2: Control Volumes

Phase 2 model build required importation of 1D elements relevant to the PCVs and CCVs. Each of the following items was imported into the model.

- 2D: PCVs and associated stage/area nodes were imported as shapefiles. Stage/area tables were extracted directly from the existing ground surface, including bathymetry. See Section 3.2 for more details.

- 2D: CCVs, channel links, channel cross sections, and channel stage/area nodes were imported as shapefiles. See Section 3.2 for more details.
- 1D: Rating curve links associated with the Minnehaha Creek, to represent bridges and large culverts, were manually digitized and the rating curves for each link were copy/pasted into StormWise. See Section 3.2 for more details.
- 1D: Weir links associated with control structures along Minnehaha Creek were manually digitized and associated geometric data was manually entered. See Section 3.2 for more details.

Stage/Area nodes are included anywhere a stage-area relationship is needed that is not captured in the 2D surface (CCV nodes, PCV nodes, storm sewer infrastructure nodes). A minimum amount of storage in all stage/area nodes is assigned within the Simulation Manager. Otherwise, stage/area tables are included at nodes to represent the amount of storage in a certain area. The storm sewer structures and channel nodes are not provided with unique stage/area tables. These nodes used the default minimum value as most of the volume being stored is already captured in the pipe and channel links themselves. For pond nodes, separate stage/area tables are included and are extracted directly from the provided ground surface.

2D Mesh Note: PVCs and CCVs act as mesh generating features. Here, the input features were simplified to limit vertex generation and the mesh was reconfigured to remove breaklines within a 10-foot proximity.

4.3 Phase 3: Storm Sewer Infrastructure

Phase 3 model build required importation of 1D elements relevant to the storm sewer infrastructure. All of the Phase 3 imports (geometric and attributes) were completed through .CSV imports generated through automated script, as discussed in Section 3.3. Each of the following items was imported into the model.

- 1D: Pipe links representing storm sewer pipes and culverts. Pipes can connect to either stage/area nodes or to the OF region directly. Some large culverts directly within the Minnehaha Creek were also included as pipe links. Over 36,000 pipe links are included in the model, most of which are within the gravity storm sewer system.
- 1D: Weir links included at each inlet to the storm sewer that connects a subsurface stage/area node to the OF mesh node. For these inlet structure locations, a representative standard inlet grate size was selected and used to develop model weir characteristics. This approach improves estimates of inlet capacity and its effect on localized flooding. These weir links are located at a single point in space; therefore, they do not have spatial linework associated with them and are tabular only in the model. Over 20,000 weir links are included.
- 1D: Stage/area nodes representing manholes, inlets, and outlets as part of the subsurface system. Over 36,000 stage/area nodes are included in this watershed model. The storm sewer structures are not provided with unique stage/area tables. These nodes used the default minimum value as most of the volume being stored is already captured in the pipe and channel links themselves.

- 1D: Node interface points connecting inlets and outlets of the storm sewer network to the OF surface.

The watershed model uses 1D node interface features to define the 2D mesh and provide the opportunity for a point on the 2D OF mesh to connect to other 1D features. Inlets and outlets were defined as 1D node interface points at locations of 1D/2D connectivity. For each inlet and outlet feature in the storm sewer data, a 1D node interface point is added with a naming convention that aligns with the stage/area part of the structure. Weir links are used to model the flow from the surface mesh (1D node interface) to the subsurface structure (stage/area node). Weir characteristics were developed based on the Neenah Foundry R-3067-V inlet (Neenah 2025) and were uniformly applied to each inlet weir link. See Appendix C-12, Neenah Foundry Catalog. In cases of culverts or cross-drains with open end treatments on either end of the pipe, 1D node interface features are used exclusively.

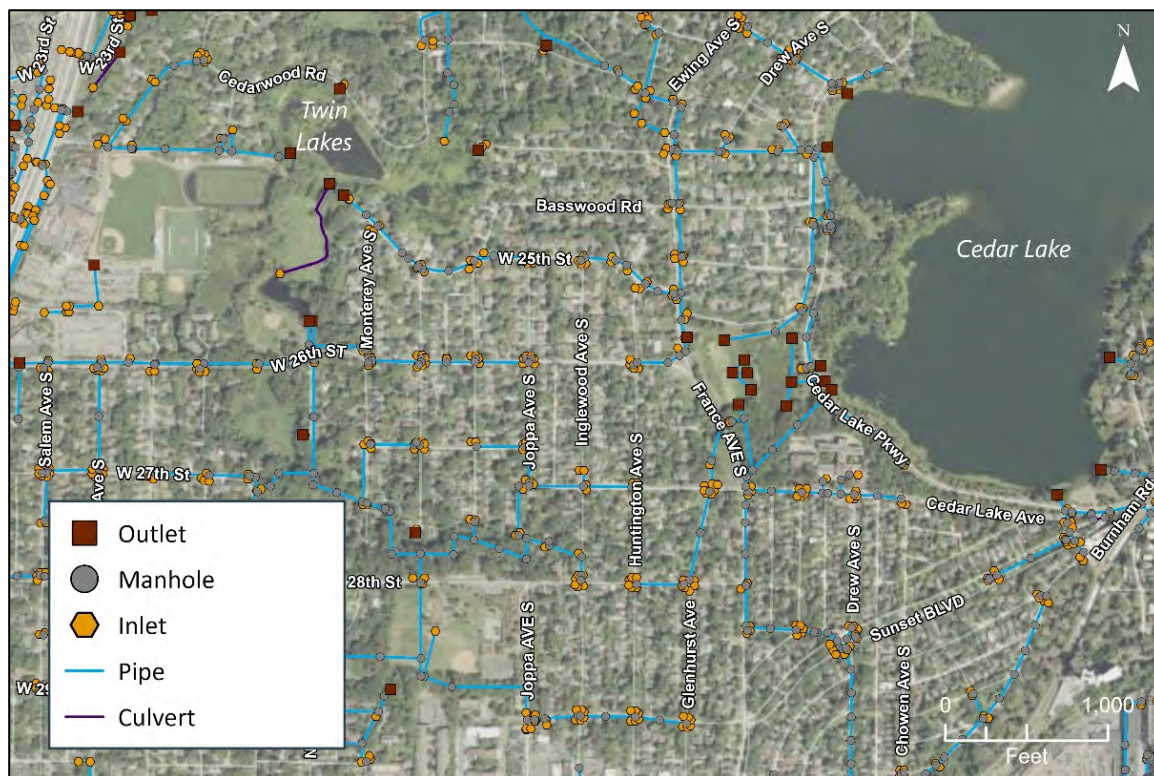


Figure 4-2. Detailed storm sewer infrastructure

2D Mesh Note: 1D node interface points act as mesh generating features. A systematic review of all mesh generation feature vertices was performed to limit proximity of vertices to more than 10 feet, with 10 feet being the preferred minimum triangle side length. Where closer than 10 feet, storm sewer inlets were combined and included with representative increases of inlet capacity, and parallel culverts were included as single pipe elements with multiple barrels.

4.4 Phase 4: Groundwater

Phase 4 model build required importation of map layers, surfaces, tables, and groundwater region elements relevant to 2D groundwater. This portion of the build represents the final Lower Watershed

model. See Appendix C-13 Groundwater Model for more details. Each of the following items was imported into the model.

- Groundwater: Lower Watershed groundwater regions (five regions) were imported as shapefiles, as discussed in Section 3.4.
- Groundwater: Boundary stage lines between each lateral groundwater boundary vertex described in Section 3.4. These lines are used to define lateral head conditions as part of model simulations.
- Surface: Confining layer surface equal to a modified top of bedrock surface with a buffer of 500 feet around the Lower Watershed surface boundary was imported as a raster, as discussed in Section 3.4.
- Map Layer: Soils spatial data representing soil units throughout the watershed were imported as polygons with “MUKEY” identifiers used to relate soil parameters, as described in Section 3.4.
- Table: Vertical Layers tables describing the required input Green and Ampt vertical infiltration parameters were imported. The soils map layer was used to distribute these parameters spatially. These tables are described in Section 3.4.
- Table: 2D Conductivity tables for lateral movement of water in the groundwater domain were imported. These inputs are described in Section 3.4.
- Table: Crop Coefficients, as described in Section 3.4, were imported into the model. As of version StormWise 4.08.03, the “typical year” crop coefficient table option does not perform as intended, so monthly crop coefficients were created for a long period of record to mimic the typical year approach.

One additional surface is required to simulate groundwater, the initial water table. It was assumed that the water table was equal to the ground surface. Future simulations should consider long-term simulations to set more realistic water table conditions and export water tables for use as initial groundwater conditions. Note that the water table cannot be lower than the top of confining layer.

Similar to the OF flow mesh, StormWise groundwater computational mesh assumes flow occurs between nodes (or vertices) along the edge of each triangular element. The initial surface mesh included groundwater region boundaries and a standard breakpoint pattern. The groundwater regions use a simplified mesh, compared to the OF region and surface mesh. The standardized breakpoint pattern at 300-foot spacing was used in each groundwater region to define a maximum groundwater honeycomb cell size. Figure 4-3 shows the groundwater mesh.

Boundary conditions for the groundwater domain were set by Boundary Stage Lines were specified around the entire groundwater boundary with the exception at the most downstream limit (see Figure 3-8). The groundwater regions were drawn to align with known water features and locations of known head condition. Boundary stage lines replicated these boundary locations. The boundary stage lines use two boundary stage sets, which act as time/stage conditions, and the model interpolates between these two points linearly. For this watershed model build, static elevations representing the normal or observed water level were used. The groundwater regions extend far enough past the OF region in the goal of reducing the reliance on boundary stage conditions to accurately predict groundwater levels in our Lower Watershed region.

Note that flood calibration was performed on the Lower Watershed model with vertical infiltration, but without 2D groundwater included. For the calibration model build groundwater specific elements were not required to be imported, these include the groundwater regions, groundwater boundary state lines, the bedrock surface, and the initial water table. The completed coupled model as described in this section is included as part of the electronic delivery package.

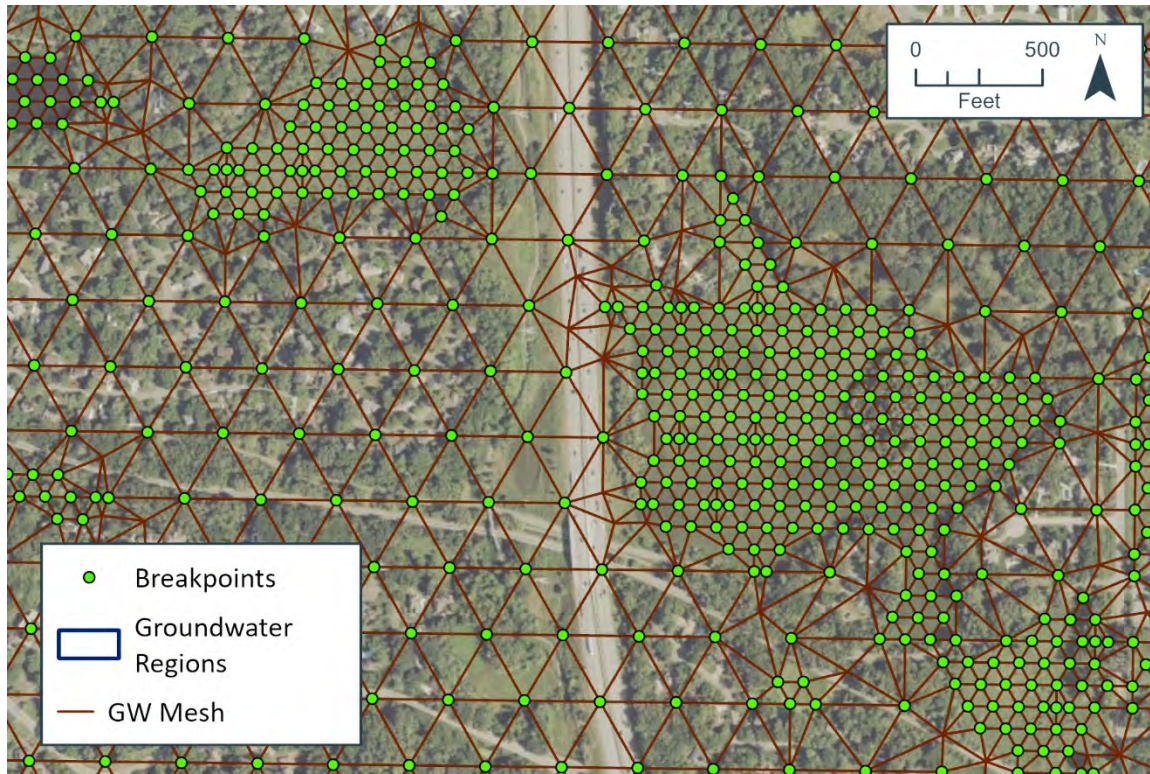


Figure 4-3. Groundwater Numerical Mesh

4.5 Simulation Parameters

Input simulation parameters were either selected as default parameters or through correspondence with the software developer Streamline. The Diffusive Wave equation set was selected for both 1D and 2D hydraulic calculations. This hydraulic solution removes local acceleration terms that become important where high velocity flows, hydraulic jumps, major flow reversals, and wave propagation are expected to occur. It is not anticipated that these hydraulic conditions exist or if they do be important for these model simulations. The intent of this model is watershed scale planning, the hydraulic equations are used to route locally generated runoff (2D grid), and pipe/channel flows. If detailed hydraulics are of interest, future efforts should consider the energy and/or the momentum equations. Other selected simulation parameters are shown below.

- **General**
 - o Minimum Calculation Times
 - Hydrology: 30 seconds
 - Surface Hydraulics: 0.01 second

- Groundwater: 14,400 seconds
- o Maximum Calculation Times
 - Surface Hydraulics: 2.561 seconds
- **Output Time**
 - o Hydrology: 15 minutes
 - o Surface Hydraulics: 15 minutes (during active response periods)
 - o Groundwater: 3600 minutes
- **Tolerances and Options**
 - o Energy Switch (2D): Diffusive Wave
 - o Energy Switch (1D): Diffusive Wave
 - o Time Marching: FIREBALL
 - o Default Dampening Threshold (1D and 2D): 0.1
 - o Minimum Node Surface Area (2D): 700 square feet
 - o dZ Tolerance: 0.0001
 - o Link Optimizer Tolerance: 0.00001
- **Simulation Times**
 - o 2025 Calibration Event:
 - Start: June 18, 2025
 - End: June 30, 2025
 - o 2014 Validation Event:
 - Start: June 12, 2014
 - End: June 24, 2014
 - o 100-year Event:
 - Start: May 28, 2014
 - End: June 5, 2014

4.5.1 Computer Set Up and Runtime

All models were built and simulated on a series of virtual machines. Specifics of the virtual machines are as follows:

- Virtual machine on VMware vSphere 8
- Central processing unit (CPU): INTEL(R) XEON(R) PLATINUM 8462Y+2.80GHz
- Operating system (OS): Windows Server 2025 w/ Remote Desktop Session Host Feature
- Configuration: 40-cores (split 20 per VM); 128GB RAM; Nvidia L4-24GB vGPU; 500GB OS Volume on NVMe-backed NFS storage

Approximate model build time: 16.4 hours

Approximate model runtime:

- 2025 calibration event (12 days simulation time): 22.0 hours

- 2014 validation event (12 days simulation time): 26.5 hours
- 100-year event (8 days simulation time): 17.3 hours

5 Model Calibration and Validation

The MCWD Lower Watershed model calibration focused on flooding and included calibration to one event and validation to a second event. To make the model calibration more efficient, the 2D groundwater components were removed. Inclusion of groundwater components allows the model to represent horizontal subsurface water movement, dynamic soil storage, surface water body storage, and exchange between the surface and subsurface. These processes are slow relative to the time scales of surface water rainfall/flood response. Omission of groundwater is anticipated to have only a limited impact on watershed conditions during and immediately after these flood-focused events. This section documents the data, decisions, and final calibration parameters and performance.

The Lower Watershed model calibration strategy is as follows:

1. Develop initial conditions for each calibration event as described in Section 5.1.3.
2. Conduct sensitivity simulations on the 2014 and 2025 events as described in Section 5.2.
3. Develop initial calibration simulations based on sensitivity results.
4. Review and compare performance metrics and flow hydrographs from initial calibration simulations.
5. Adjust infiltration rate, moisture content, water table, and impervious percent to improve flow volume and timing. Iterated until adequate model performance was achieved.
6. Adjust Manning's roughness and weir coefficients, where necessary, to improve stage observations and timing of response.

5.1 Calibration and Validation Data

For the MCWD Lower Watershed model, historical data served as initial conditions, boundary conditions, and as observed basis of comparison on which to assess model accuracy. Two events were selected one for calibration and one for validation as described below.

- Calibration Event: 2025 June
 - o USGS gage peak 6/25/2025.
 - o Intense rainfall over less than 24-hour period, which stresses the urban drainage system resulting in significant local flood inundation.
 - o Robust observation data available.
- Validation Event: 2014 June
 - o USGS gage peak 6/19/2014.
 - o Abnormally high basin-wide precipitation for weeks leading up to watershed-wide response during wet period.
 - o Observation data limited to downstream USGS stream gage and bi-weekly observations at major lakes.

5.1.1 Precipitation

Precipitation data from nearby rain gages was used as input to the model. Hennepin County West Mesonet was commissioned in 2017 providing a robust, dense network of rain gage data for more recent events. Figure 5-1 shows the rain gage locations relative to the Watershed, and Figure 5-2 and Figure 5-3 show the cumulative precipitation during the 2025 and 2014 events, respectively.

- Calibration Event: 2025 June
 - o Source: Hennepin County West Mesonet included four gaged locations
 - o Calibration Period Total Precipitation (average): 3.2 inches
 - o Reporting interval: 5-minute
- Validation Event: 2014 June
 - o Source: Minneapolis-St. Paul (MSP) (HPN07) weather station
 - o Validation Period Total Precipitation: 3.6 inches
 - o Reporting interval: 5-minute

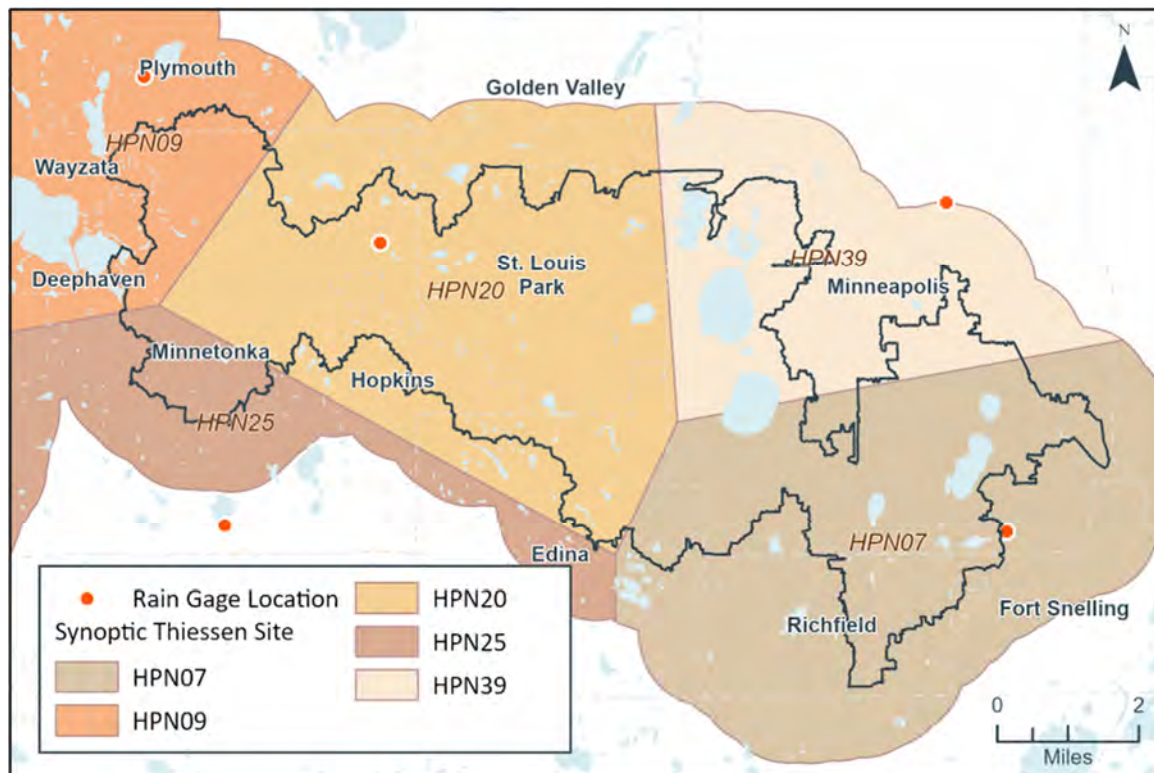


Figure 5-1. Rain Gage Locations

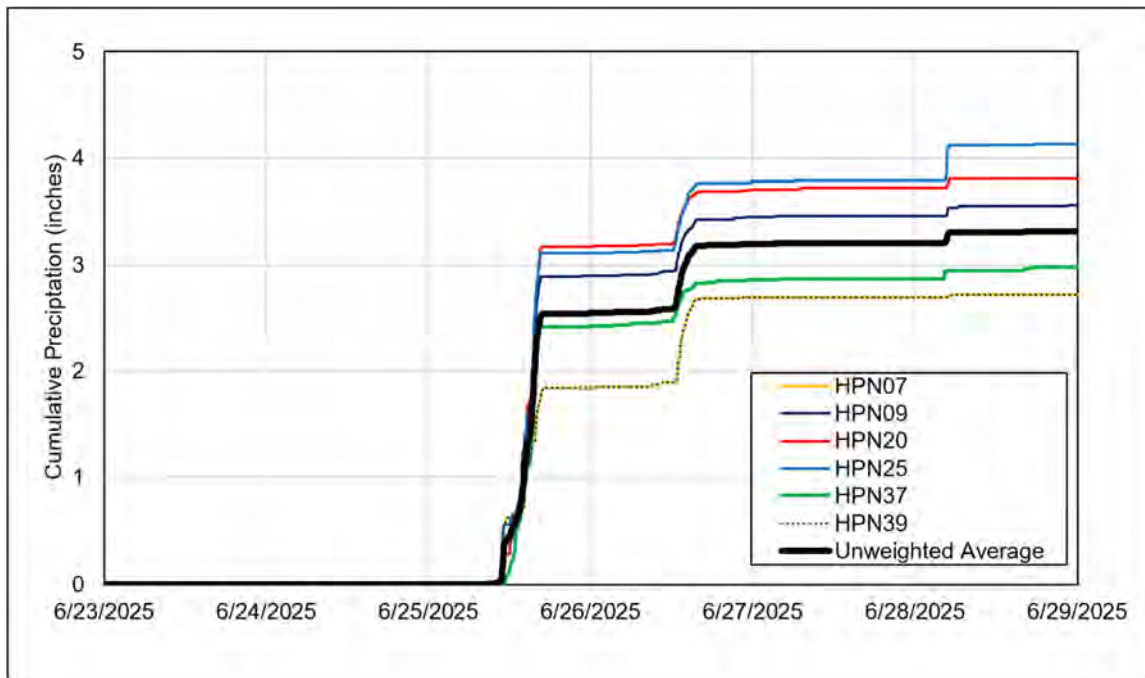


Figure 5-2. Cumulative Rainfall June 2025

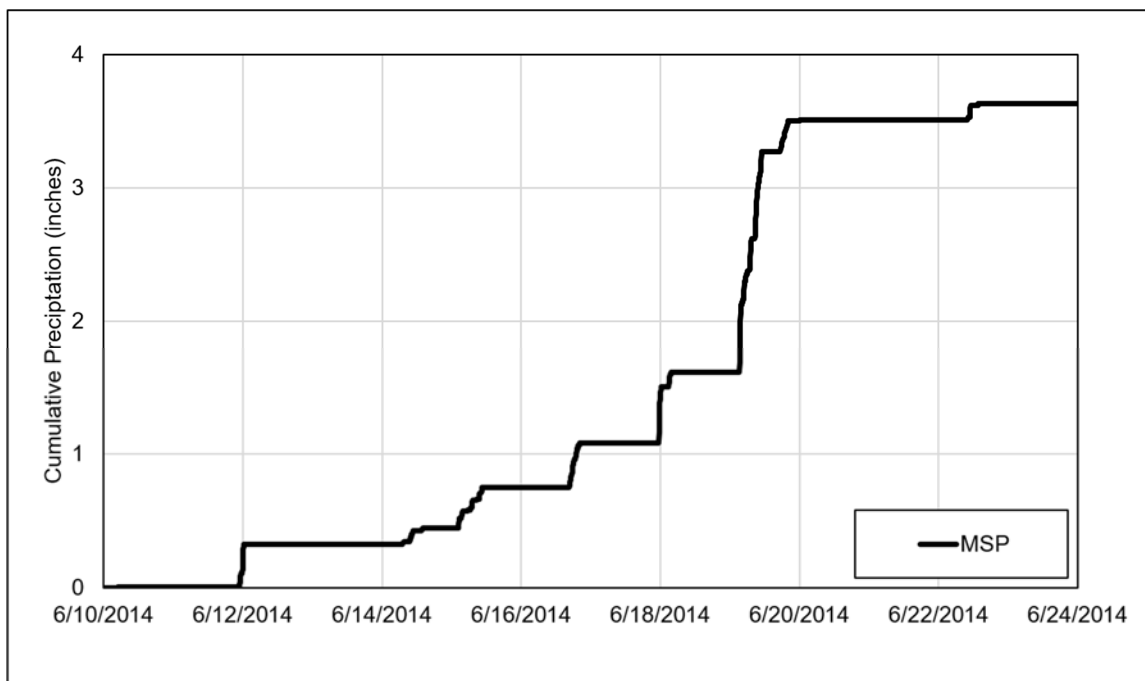


Figure 5-3. Cumulative Rainfall June 2014

5.1.2 Observation Data

Observed flow and stage data were available along Minnehaha Creek (Figure 5-5) and in some of the major lakes (Figure 5-4). These data were collected by the USGS, MCWD, and Minnesota

Department of Natural Resources (MNDNR). Section 5.1.4 describes the system response relative to the observations below:

- Calibration Event: 2025 June
 - o USGS Stream Stage and Flow
 - 1 Location
 - Name: USGS-05289800 (Minnehaha Creek at Hiawatha Avenue)
 - Temporal Reporting: 5 minute
 - o MCWD Stage and Flow:
 - 5 Locations
 - Name: MCWD- 1758010 (Gray's Bay Dam releases), MCWD-1834010 (, MCWD-5013010, MCWD-5009010
 - Temporal Reporting: 5 minute
 - o MCWD Stage Only:
 - 7 Locations
 - Name: MCWD-8209010, MCWD-2022010, MCWD-7907010, MCWD-5084010, MCWD-5088010, MCWD-4148010, MCWD-794010
 - Temporal Reporting: 5 minute
 - o MNDNR Lake Levels
 - 5 Locations
 - Name: Hiawatha, Nokomis, Harriet, Bde Maka Ska, Diamond
 - Note: observations made by volunteers and cooperative organizations through lake gage readings.
 - Temporal Reporting: Bi-weekly
- Validation Event: 2014 June
 - o USGS Stream Stage and Flow
 - 1 Location
 - Name: USGS-05289800
 - Temporal Reporting: 15 minute
 - o MNDNR Lake Levels
 - 5 Locations
 - Name: Hiawatha, Nokomis, Harriet, Bde Maka Ska, Diamond
 - Temporal Reporting: Bi-weekly

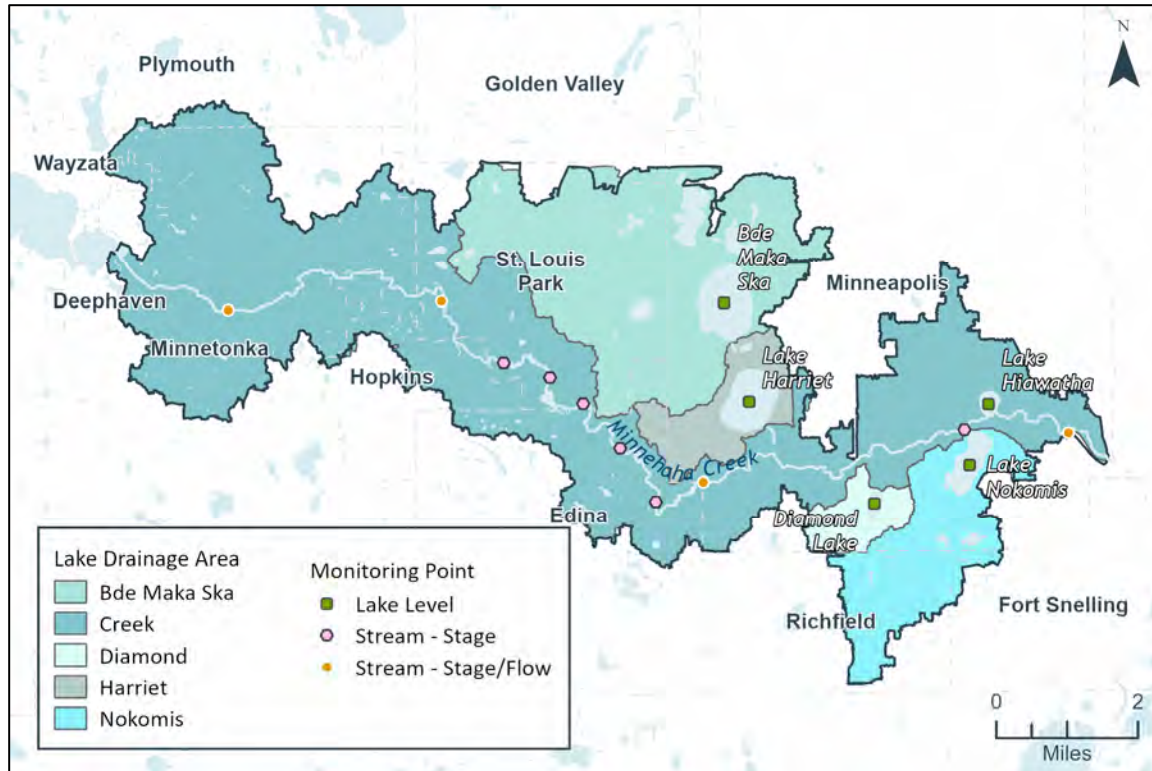


Figure 5-4. Lower Watershed Lake Stage Observation Locations

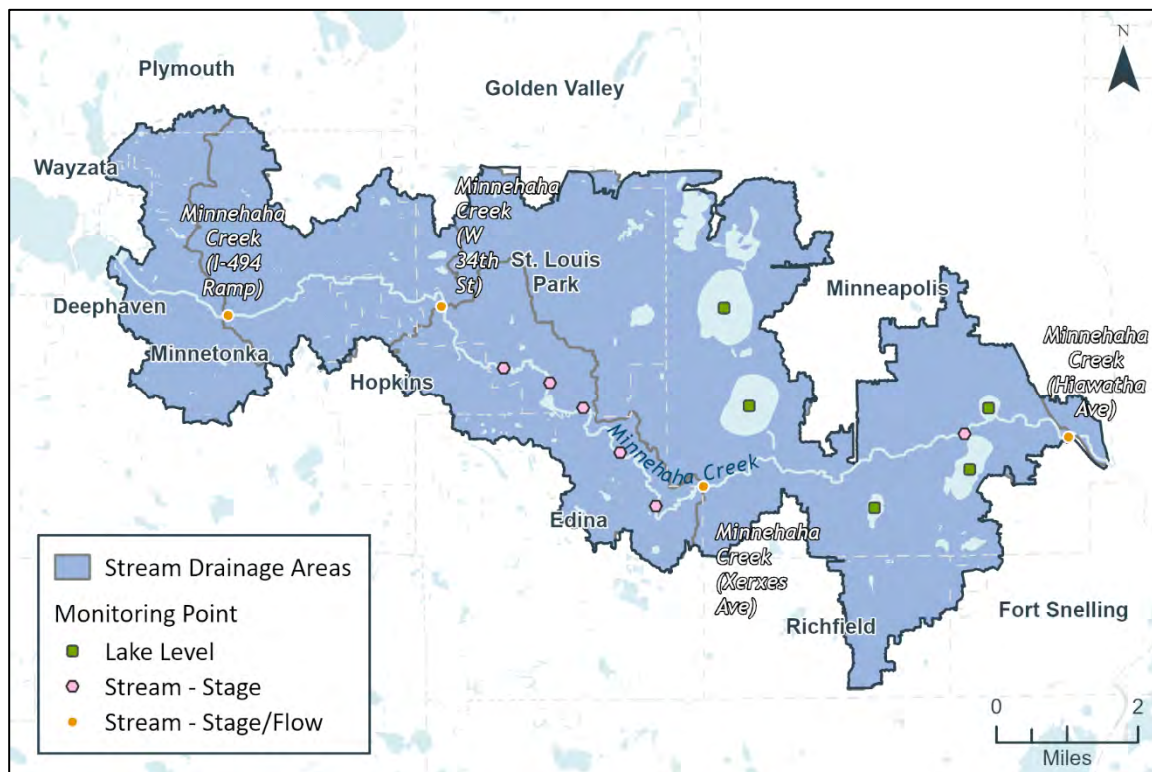


Figure 5-5. Lower Watershed Minnehaha Creek Flow and Stage Observation Locations

5.1.3 Initial Conditions

The Minnehaha Creek Watershed has a substantial amount of storage volume available within lakes, ponds, wetlands, and within the soil column. The process to develop required initial conditions is described below.

- Initial PCV Elevations
 - o Initial PCV elevations reflect the amount of water that is contained in each defined waterbody prior to an event occurring.
 - o Where observed data are available, the most recent MNDNR measurement was used. This includes five locations shown in Table 5-1.
 - o Where observed data are not available, the raw downloaded LiDAR elevations were reviewed. The downloaded LiDAR has a hydro-flattened water surface elevation, which provides an approximate normal pool elevation for waterbodies. The lowest LiDAR elevation in each PCV was used and was assumed to represent a normal water level condition.

Table 5-1: Initial Conditions for Lake Levels

Model ID	Lake Name	Initial Elevation (feet NAVD88)		
		6/12/2014	6/20/2025	100-year
PCV-017	Nokomis	817.00	815.94	816.45
PCV-039	Harriet	848.13	847.86	848.32
PCV-112	Bde Maka Ska	854.20	854.10	854.27
PCV-014	Diamond	822.84	822.31	822.99
PCV-037	Hiawatha	815.64	812.52	814.77

- Initial Depth to Water Table
 - o Depth to water table is the location where the soil becomes completely saturated. It partially defines the amount of soil storage available.
 - o Underneath all PCVs, the depth to water table was set to 0.0 feet (or at the ground surface), assuming the soil underneath a waterbody is typically saturated.
 - o SURGGO provides estimated depth to water table for the soils. The watershed-wide average of 2.4 feet was used as a starting point for calibration. The final depth to water table was selected as 2.0 feet and 3.0 feet for 2025 and 2014, respectively.
- Soil Initial Moisture Content
 - o Initial soil moisture content is the amount of soil pore space filled with water above the water table. It partially defines the amount of soil storage available.
 - o Underneath all PCVs, the soil moisture content was set to the saturation moisture content, assuming the soil underneath a waterbody is typically saturated.
 - o Moisture content under all other soils was selected based on observations at the MSP soil moisture sensor. A weighted average of the top 0.5 meter of soil was selected to initialize calibration and validation events. A moisture content of 50 percent saturated and 60 percent saturated was selected for 2025 and 2014 events, respectively.

5.1.4 System Response

Lower Watershed stream flows originate at the Gray's Bay Dam. Releases from the dam range from 0 to 300 cfs pending time of year, upstream Lake Minnetonka stage conditions, and downstream creek conditions. From the dam, Minnehaha Creek flows 22 miles eventually discharging into the Mississippi River. Along this stretch the creek flows through wetlands and over several level setting structures. The density of urban development in the lower watershed increases in the downstream direction (east,) ranging from large lot size curvilinear development residential areas near the dam, to dense residential/commercial gridded development near the watershed outlet. The density of drainage network increases with the density of development. USGS stream flow observations (Location 5) for the period of record (2006 to 2026) show the annual maximum flows range from approximately 100 cfs to more than 800 cfs.

Figure 5-6 shows the rainfall and subsequent stream flow response for the 2025 event along the entire 22 miles of stream. On the afternoon of June 25, approximately 2.5 inches of rainfall fell over the lower watershed in less than 6 hours followed by an additional 0.7 inches of rainfall on June 26. Dam releases at the upstream end of the lower watershed were maintained at approximately 150 cfs until after the second wave of precipitation where releases were increased to approximately 200 cfs late on June 26. Minnehaha Creek discharge closest to the dam (Location 2) has a muted response to rainfall and is primarily driven by dam releases. Dam releases require multiple days to reach the most downstream limits of the watershed. At the most downstream locations (Location 5 and Location 4), stream flows are flashy, rising and falling rapidly after precipitation events. The largest downstream (Location 5) flow peak in this event (414 cfs) occurs on the morning of June 26 primarily resulting from local urban drainage in the most downstream portions of the watershed. A secondary peak arriving late on June 26 is observed to have a similar magnitude to the first peak with less than half of the rainfall driving the response. This second peak occurs during the recession of the first hydrograph response with a sharp response from the more rapid responding areas of the lower watershed. After the event, stream flows throughout the system are elevated from pre-event conditions partially due to increased dam discharges and partially due to post-event baseflow entering the system.

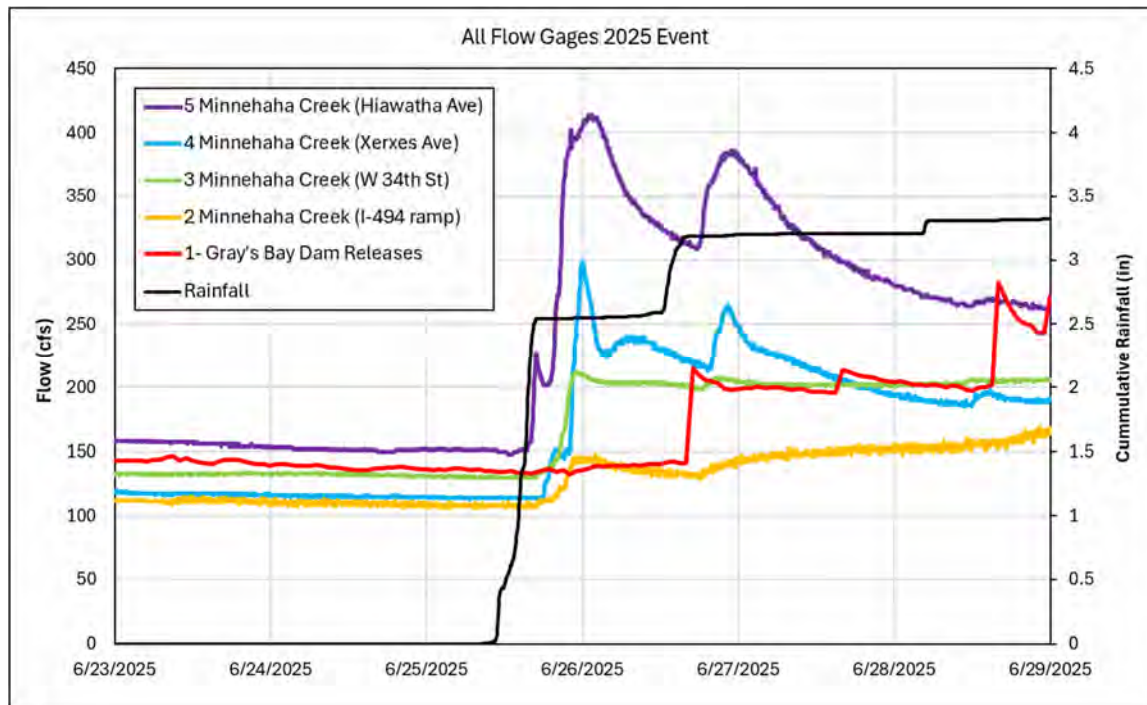


Figure 5-6. Lower Watershed Stream Flow 2025 – All Gages

5.2 Sensitivity Analysis

A sensitivity analysis was conducted on the key uncertain parameters to understand the impact of the parameter value adjustments on the model results, and to help identify the ranges of values to be used for calibration simulations. Sensitivity analysis was performed for both the 2025 and 2014 events.

An uncalibrated simulation was conducted using the base parameterization approach, as discussed in the previously described methodology. These initial parameter estimates act as a reference for comparing the sensitivity simulation results, in addition to the observed streamflow data. The sensitivity simulations were run by adjusting the following parameters uniformly, one parameter per simulation, for the ranges listed below. Sensitivity ranges attempted to reflect the expected uncertainty in the input parameters; however, they do not encompass the upper and lower bounds of parameter adjustments.

The sensitivity simulations for 2025 and 2014 events included the following:

1. Impervious Percent:
 - a. Adjustment: +/- 1 standard deviation (17.5% to 48.1%)
 - b. Base Average Impervious: 32.8%
 - c. Name: S1U and S1D
2. Saturated Hydraulic Conductivity
 - a. Adjustment: +/- 1 log [standard deviation] (3.5x to 0.29x)
 - b. Name: S2U and S2D

3. Initial Water Table Depth
 - a. Adjustment: +/- 1 standard deviation (+/- 0.5 feet)
 - b. Base average based on SSURGO: 2.4 feet
 - c. Name: S3U and S3D
4. Initial Soil Water Content
 - a. Adjustment: +/- 30% (lower bound is approximate wilting point)
 - b. Base is the average SSURGO which is set to the field capacity: ~60% saturated
($\text{Moisture Content}_{\text{Initial}} / \text{Moisture Content}_{\text{Saturated}}$)
 - c. S4U and S4D
5. Initial PCV Stage
 - a. Adjustment: + 1.0 feet in all PCVs (except the 5 with known values)
 - b. Base is a known elevation or the lowest LiDAR elevation in each PCV assumed to be a hydroflattened water surface
 - c. Name: S5D
6. Directly Connected Impervious Area
 - a. Adjustment: 2x or 0.5x of Base DCIA (11.6% to 32.0%)
 - b. Base Average DCIA: 23.2%
 - c. S6U and S6D

Simulations of the above 11 singular parameter adjustments were performed for both the 2014 and 2025 events. Figure 5-7 and Figure 5-8 show the simulated responses relative to the USGS stream gage (No. 05289800) near the downstream watershed limits.

A review of the uncalibrated hydrograph for the 2014 event showed a limited pre-event runoff response, an initial creek flow that was too low, a peak flow and volume that was too high, a multi-peaked shape, and no post-event base flow. The 2014 sensitivity simulations showed the largest sensitivity to initial moisture content, followed by impervious percent, and initial water table. Very limited sensitivity was observed from adjustments to DCIA, initial PCV stage, or hydraulic conductivity.

A review of the 2025 event showed no runoff production resulting from rainfall for the base or any of the sensitivity simulations. Only limited sensitivity was observed to any of the parameter adjustments. Section 5.4 - Calibration summarizes the causes of limited runoff and subsequent adjustments that were made to improve model accuracy.

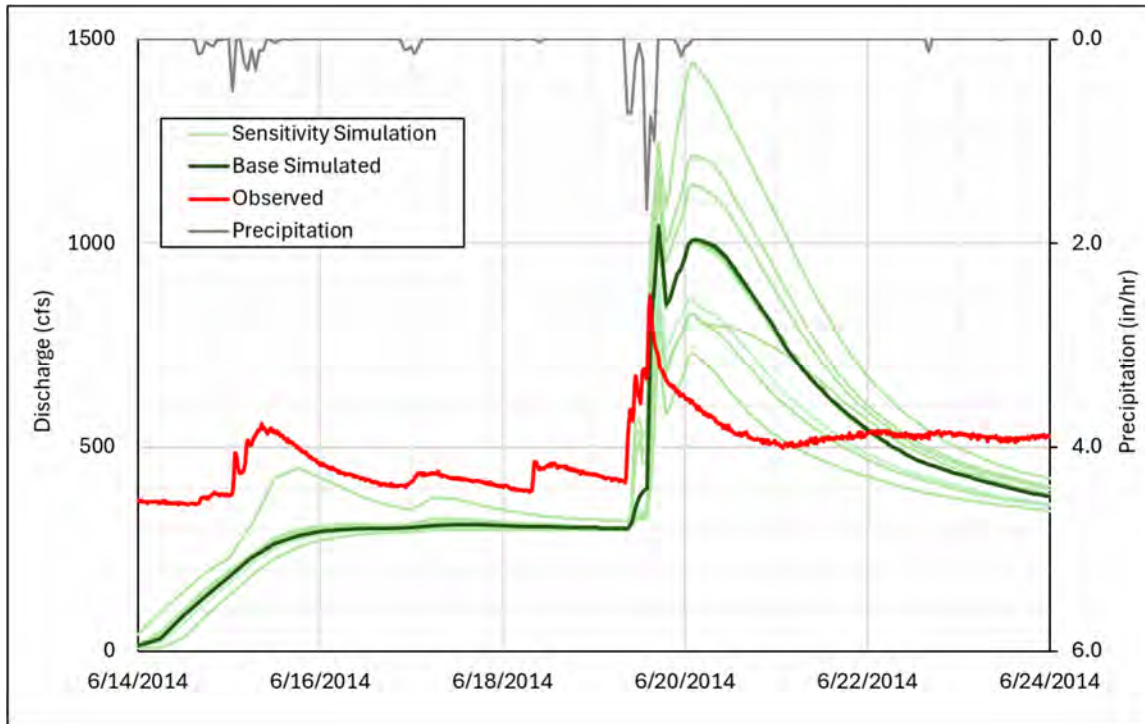


Figure 5-7. June 2014 Sensitivity Simulations at USGS 05289800

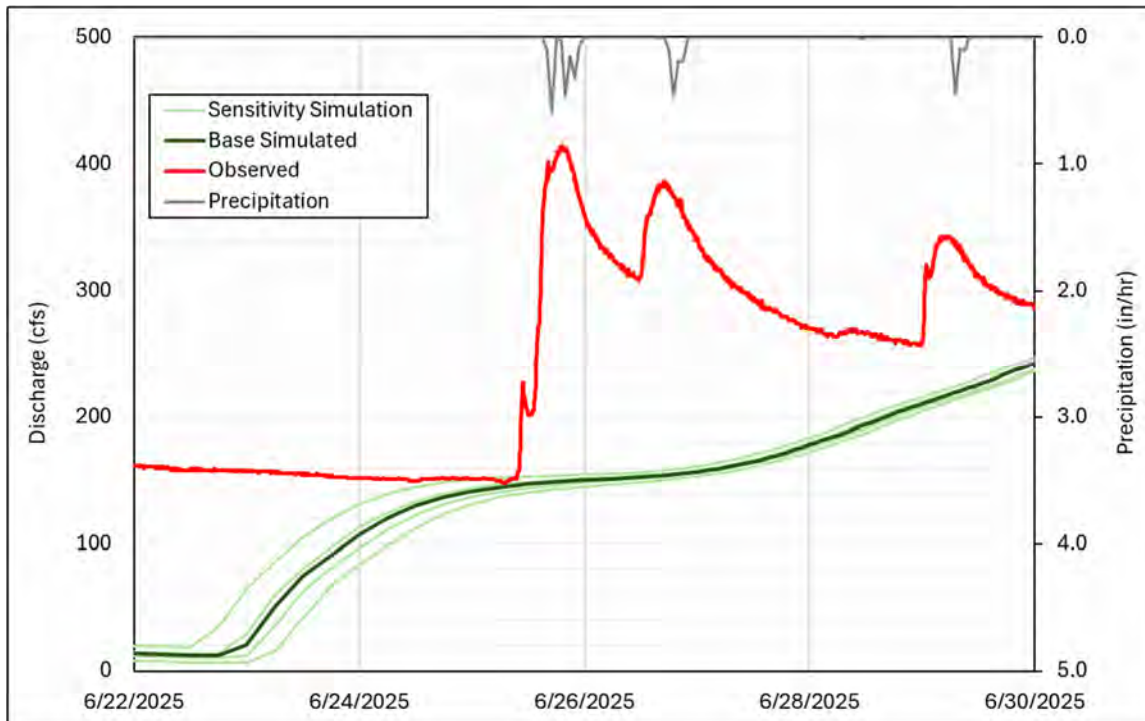


Figure 5-8. June 2025 Sensitivity Simulations at USGS 05289800

5.3 Performance Metrics

Three performance metrics were used for calibrating and validating the Lower Watershed StormWise model. The performance metrics were established based Moriasi et al (2015) to document the quality of calibration simulations with respect to the observed data (O is observed and P is predicted):

- Coefficient of Determination (R^2): coefficient of determination describes the collinearity between simulated and observed data. This is a commonly used metric in hydrologic modeling; however, it can be overly sensitive to high extreme values. Values range from -1.0 to 1.0 with those closer to 1.0 indicating a better fit.

$$R^2 = \left(\frac{\sum_{i=1}^n (O_i - \bar{O}) (P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^n (P_i - \bar{P})^2}} \right)$$

- Nash-Sutcliffe efficiency (NSE): NSE is a normalized statistic to determine the relative magnitude of the residual (error) variance compared to the measured data variance. This is a commonly used metric in hydrologic modeling; however, it can be overly sensitive to high extreme values. Values range from $-\infty$ to 1.0 with those closer to 1.0 indicating a better fit.

$$NSE = 1 - \left(\frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \right)$$

- Percent bias (PBIAS) is a statistical metric used to assess the accuracy and systematic errors of a predictive model. It quantifies the percentage by which the simulated results differ, on average, from the observed values and measures the average tendency of the simulated values to be higher or lower than the observed data. Positive values indicate an overestimation bias (simulated results too high) while negative values indicate an underestimation (simulated values too low). Values range from $-\infty$ to ∞ with values closer to 0 indicating a better fit.

$$PBIAS = \frac{\sum_{i=1}^n (O_i - P_i)}{\sum_{i=1}^n O_i} \times 100$$

In addition to the performance metrics, the resulting stage and flow hydrographs at each gage were visually reviewed to evaluate the overall fit to the observed data. Simulated flow and stage were extracted from the model results at the nearest link (flow) and node (stage) location. The location of the USGS stream gage was assumed to be upstream of the Hiawatha Avenue Bridge. Due to the rapid change in stream bed elevation and water surface elevation, an average of two upstream nodes were used for stage comparisons. Table 5-2 lists the target desired and acceptable values for the three metrics.

Table 5-2. Performance Metrics Target Values

Metric	Very Good	Good	Satisfactory	Not Satisfactory
R^2	$R^2 > 0.85$	$0.85 > R^2 > 0.75$	$0.75 > R^2 > 0.60$	$R^2 < 0.60$
NSE	$NSE > 0.80$	$0.80 > NSE > 0.70$	$0.70 > NSE > 0.50$	$NSE < 0.50$
PBIAS	$PBIAS < \pm 5\%$	$\pm 5\% < PBIAS < \pm 10\%$	$\pm 10\% < PBIAS < \pm 15\%$	$PBIAS > \pm 15\%$

5.4 Calibration

Initial sensitivity and calibration simulations for the June 2025 event performed poorly due in part to the model parameterization and in part to the input data and model set up. Prior to initial calibration, the following changes were made to input data and model set up:

- Longer ramp up time prior to rainfall events allowing the creek and connected relevant waterbodies to stabilize.
- Rainfall time series inputs were updated from hourly to 5-minute increments to better describe short bursts of intense rainfall.
- Rainfall data originated from only the MSP airport data for sensitivity. This was updated to include all nearby gages (available in the 2025) event to improve the spatial representation storm characteristics.
- Dam releases used daily average estimates and were updated to include observed hourly releases provided by MCWD.

The poor June 2025 sensitivity simulations showed no runoff generation. To identify the drivers of runoff generation, a breakout model was created for a small watershed area draining to Cedar Lake Pond where inflow pipe observations were available. The breakout model was identical to the full watershed model in all respects with exception of the model extent. As expected, initial model simulations with base parameters resulted in no runoff generation. A review of the watershed responses, as discussed in Section 5.1.4, showed a correlation between the responding timing and magnitude to urbanization of the watershed. The breakout model simulations identified two parameters for modification to better account for runoff: total impervious percent and infiltration rate (or saturated hydraulic conductivity).

The base parameter estimates for impervious percent aggregated impervious percent for land classifications over the entire watershed. Upon further review, Lower Watershed areas tended to have higher impervious percent relative to their upper watershed counterparts. An additional adjustment to impervious percent was required to improve runoff response at both local and watershed scales. These adjustments resulted in an increase of impervious percent from a weighted average of 33 to 46 percent. Table 5-3 shows the final calibrated impervious and DCIA inputs. Future calibration efforts may benefit from increased granularity of input land cover data to better target the location and magnitude of impervious adjustments.

Table 5-3. Calibrated Impervious and DCIA Model Inputs

Land Cover Description	Impervious %	DCIA %
Farmstead	40	9
Seasonal/Vacation	14	2
Single Family Detached	47	18
Single Family Attached	67	30
Multifamily	78	38
Manufactured Housing Park	64	39
Retail and Other Commercial	92	75
Office	88	68
Mixed Use Residential	94	43
Mixed Use Industrial	89	69

Land Cover Description	Impervious %	DCIA %
Mixed Use Commercial	94	78
Industrial or Utility	89	65
Institutional	75	35
Major Highway	79	45
Major Railway	82	46
Airport or Airstrip	92	32
Open Water	0	0
Developed, Open Space	16	0
Developed, Low Intensity	42	33
Developed, Medium Intensity	70	60
Developed, High Intensity	89	80
Barren Land (Rock/Sand/Clay)	0	0
Deciduous Forest	0	0
Evergreen Forest	0	0
Mixed Forest	0	0
Shrub/Scrub	0	0
Herbaceous/Grasslands	0	0
Hay/Pasture	0	0
Cultivated Crops	0	0
Woody Wetlands	0	0
Emergent Herbaceous Wetlands	0	0

Pitt and Lantrip (2000) examined infiltration rates for 150 tests in disturbed urban soils. As a result of compaction, sandy soils observed a reduction of infiltration rate from 13 to 1.4 inches per hour (90 percent reduction) and clayey soils observed a reduction of infiltration rate from 9.8 to 0.2 inches per hour (or 98 percent reduction). Gregory et al. (2006) evaluated the impacts of varying levels of compaction typical of site development and construction activity. Similar to the results observed by Pitt and Lantrip (2000), up to an 80 percent reduction in mean infiltration rate was observed in this study. Much of the Lower Watershed includes moderate to heavily developed commercial, residential, and industrial areas. To account for the impact of development on soil infiltration, the base SURGGO hydraulic conductivity was modified based on an intersection of the SURGGO soil classification and the blended land use to account for the density of development. Adjustments were made based on development intensity, as described below:

- Soils with less than 20 percent impervious were considered to have low development. Saturated hydraulic conductivity was modified by 0.25x the base SURRGO value.
- Soils with between 20 to 50 percent were considered moderate development. Saturated hydraulic conductivity was modified by 0.05x the base SURRGO value.
- Soils with more than 50 percent were heavily developed. Saturated hydraulic conductivity was modified by 0.025x the base SURRGO value.

This assumption reduced the infiltration rates in the most heavily developed areas of the Lower Watershed, resulting in higher flow rates and volumes and improved reflection of observed responses. Figure 5-9 shows the density of development with respect to adjustments in soil saturated hydraulic conductivity.

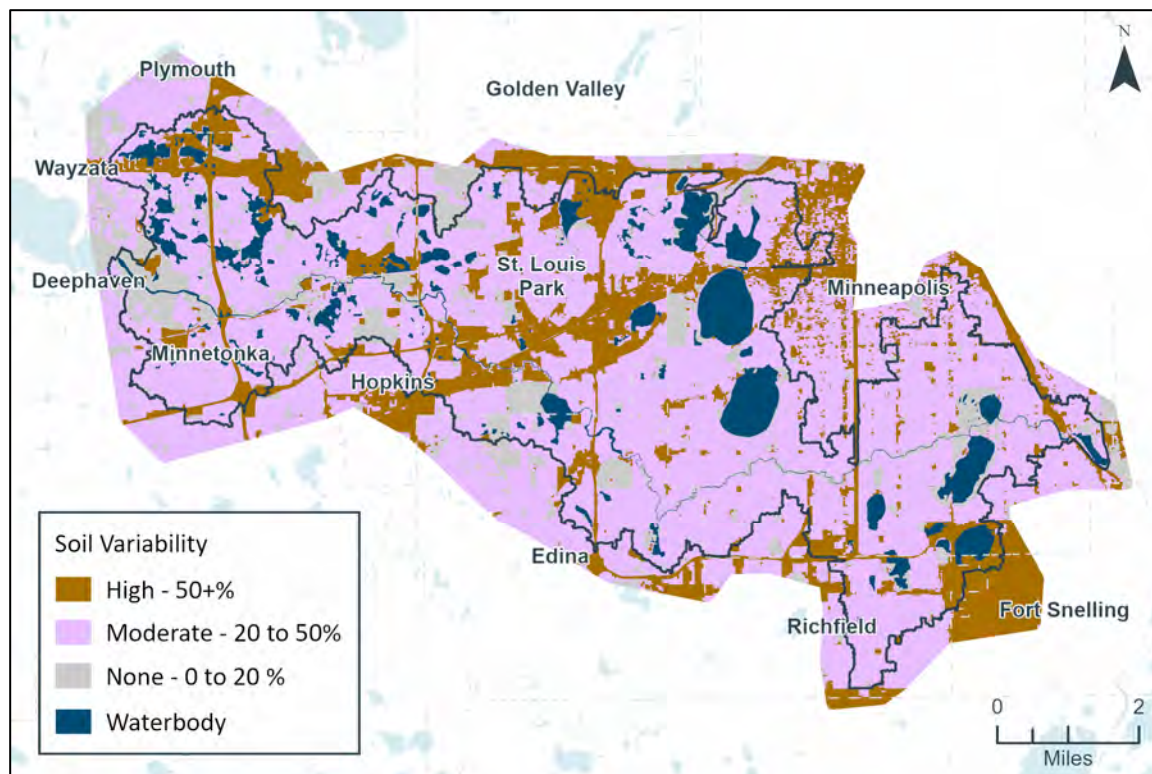


Figure 5-9. Lower Watershed Development Density Categories

Statistical calibration results are shown in Table 5-4 and Table 5-5 for the USGS outlet stream gages and MCWD flow observation gage sites. Figure 5-10 through Figure 5-22 show flow and stage hydrograph plots of observed and simulated results. These plots show that the model replicates timing and magnitude of runoff response. Specific takeaways from downstream to upstream are as follows:

- Minnehaha Creek at Hiawatha Avenue (USGS-05289800)
 - o **Simulated Peak flow and total volume** match within 5 percent error and all calibration statistics show high quality model performance.
 - o **Simulated Stage** is shifted slightly downward prior to the event and shows a much more muted response during the event, under estimating peak stage by approximately 1.0 feet.
 - o Future model improvements should focus on stage response. The USGS location is near a weir and multiple bridge crossings. Improvements should target geometric considerations of those structures, channel cross section accuracy, and channel roughness.
- Minnehaha Creek at Xerxes Avenue
 - o **Simulated Flow** is shifted higher pre- and post- runoff response. During the runoff event, simulated responses are flashier (rise and fall quickly) relative to observed stream responses resulting in higher peak flows and volumes by 75 percent and 24 percent, respectively.

- o **Simulated Stage** matches pre- and post-event observations well but shows a flashier response with higher peak stages.
- o Future model improvements should focus on reducing the total volume and flashiness of runoff response through a review of the upstream runoff generating parameters (hydraulic conductivity and impervious area).
- Minnehaha Creek at West 34th Street
 - o **Simulated flow** pre- and post- runoff event match observations well. During the runoff event, simulated responses are flashier relative to observed stream responses. This results in higher peak flows and volumes by 32 percent and 8 percent, respectively.
 - o **Simulated Stage** is shifted lower pre- and post-event by approximately 0.5 feet and shows a larger response to rainfall than the observed data.
 - o Future model improvements should focus on the total volume and flashiness of the runoff response through a review of the upstream runoff generating parameters (hydraulic conductivity and impervious area).
 - o Future data improvements review and resolve the vertical stage shift through adjustment of observation data or simulated channel/bridge geometry.
- Minnehaha Creek at I-494 Ramp
 - o **Simulated Flow** is shifted slightly higher pre- and post- runoff response. During the runoff event, simulated responses are flashier relative to observed stream responses resulting in higher peak flows and volumes by 40 percent and 34 percent, respectively.
 - o **Simulated Stage** is shifted pre-event by approximately 0.2 feet and matches the observed stage well post event. During the runoff response, simulated stage has a flashier response.
 - o Future model improvements should focus on a review runoff generating parameters (hydraulic conductivity and impervious area) near the dam to reduce the flashiness of the local system and consider including additional wetland storage not described in the bathymetry data between the observation and the dam.
 - o Future data improvements should confirm review the dam releases relative to I-494 ramp flows due to their relative proximity over long constant discharge periods it would be anticipated these flows would be near identical. Review flows at both locations and consider adjustments to dam release rating curves or stream flow rating curves.
- Lake Nokomis and Lake Hiawatha (continuous stage observations)
 - o **Simulated stages** match the observed continuous data peaks within 0.4 feet and 0.1 feet at Lake Hiawatha and Nokomis respectively. A statistical comparison and a review of the stage hydrographs show very good performance of the model at these locations.
- Bde Maka Ska, Lake Harriet, and Diamond Lake (bi-weekly observations)
 - o **Simulated stages** at these lakes were similar to observed data, but without additional frequency of observations a conclusive statement cannot be made.
 - o Future data improvements could look to install continuous level observations at one or multiple lake locations. Through a stage-volume relationship, which is known for all three of these lakes, stage observations can readily be converted into inflow/outflow rates and total volume.

Note that two of the four continuous creek flow measurement locations and three of the six continuous (creek or lake) stage measurement locations show that simulated responses are within the target calibration criteria. For those not matching the calibration criteria, the flow and stage plots for each location provide confidence in the model's ability to replicate runoff response timing and magnitude. Common discrepancies and potential resolutions are described below.

- Stage or flow shifted up or down from observed data. The vertical shift was observed in stage at USGS-05289800 (Hiawatha Avenue), flow at Xerxes Avenue, stage at West 34th Street, and flow at the I-494 Ramp. Many of the sites match the shape of the system response well but show a slight offset from the observed data. The shift results in poor statistical performance due to the compounding nature of numerous small errors. These errors could be a function of channel parameterization, uncertainty in available channel or control structure data, or uncertainty in observations. MCWD is in the process of verifying the vertical datum of both the stage observations and rating curve vertical datum. Note that the shift from North American Vertical Datum of 1988 (NAVD88) to National Geodetic Vertical Datum of 1929 (NGVD29) is 0.194 feet.
- Simulated responses tend to be flashier, rising and falling with response to rainfall faster than observed data. Examples of flashy sites are at Xerxes Avenue, at West 34th Street, and at the I-494 Ramp. Here, the location and magnitude of runoff generating parameter adjustments may be refined (hydraulic conductivity and impervious area estimates). Additionally, modeled storage conditions within the channel and connected wetland complexes are limited to the available LiDAR or bathymetric observations; substantial volume may exist beneath vegetation accounting for a delayed system response not captured in the simulated response.

Table 5-4. Statistical Performance for Flow

Location	Difference (%)		R ²	NSE	PBIAS (%)
	Peak Flow	Total Volume			
Minnehaha Creek at Hiawatha Avenue (USGS-05289800)	-4%	-4%	0.88	0.85	4%
Minnehaha Creek at Xerxes Avenue	75%	24%	0.75	-0.64	-28%
Minnehaha Creek at West 34th Street	32%	8%	0.85	0.50	-9%
Minnehaha Creek at I-494 Ramp	40%	34%	0.91	-5.89	-34%

Table 5-5. Statistical Performance for Stage

Location	Difference (feet)	R ²	NSE	PBIAS (%)
	Peak Stage			
Minnehaha Creek at Hiawatha Avenue (USGS-05289800)	-0.95	0.92	-0.34	0.07%
Minnehaha Creek at Xerxes Avenue	0.90	0.78	0.55	-0.01%
Minnehaha Creek at West 34th Street	-0.19	0.85	-1.37	0.05%
Minnehaha Creek at I-494 Ramp	-0.06	0.92	0.18	0.02%
Lake Nokomis	-0.09	0.96	0.83	-0.01%
Lake Hiawatha	-0.35	0.96	0.88	0.02%

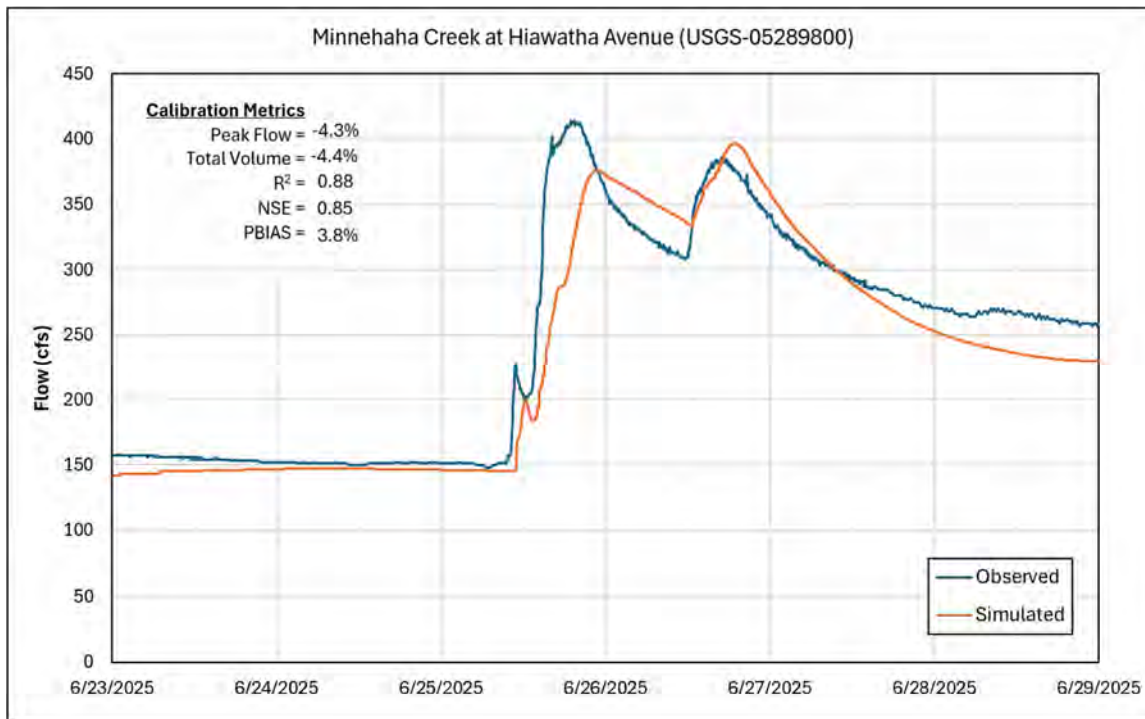


Figure 5-10. Minnehaha Creek at Hiawatha Avenue (USGS-05289800) 2025 Flow Calibration

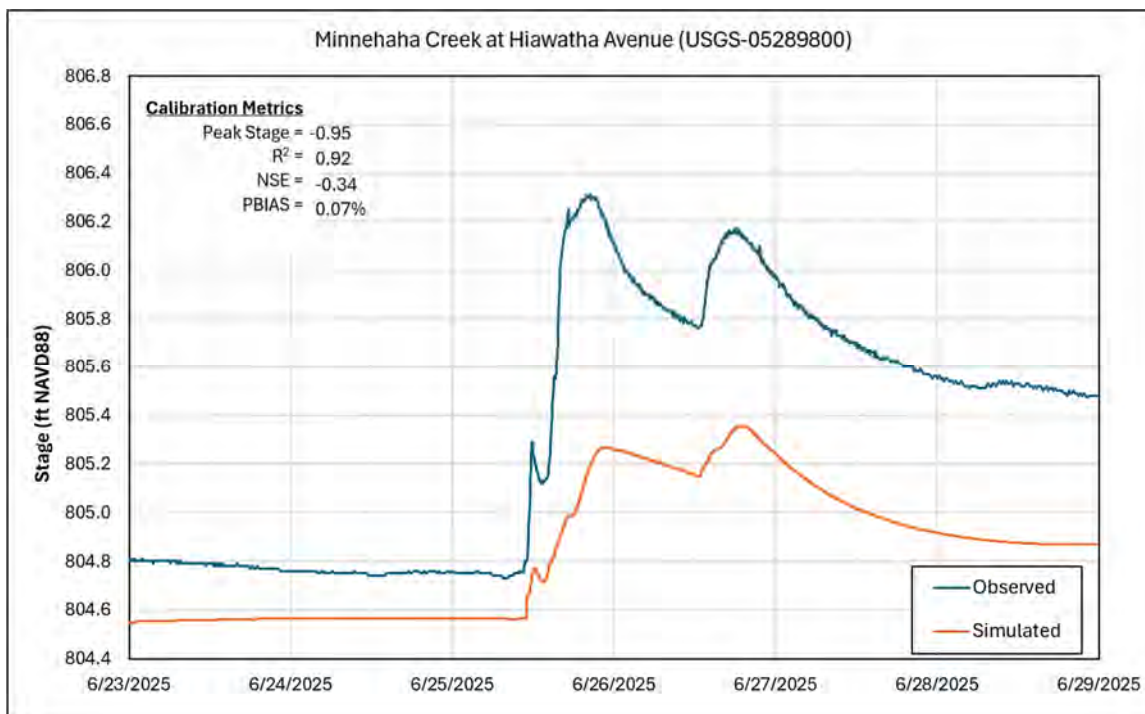


Figure 5-11. Minnehaha Creek at Hiawatha Avenue (USGS-05289800) 2025 Stage Calibration

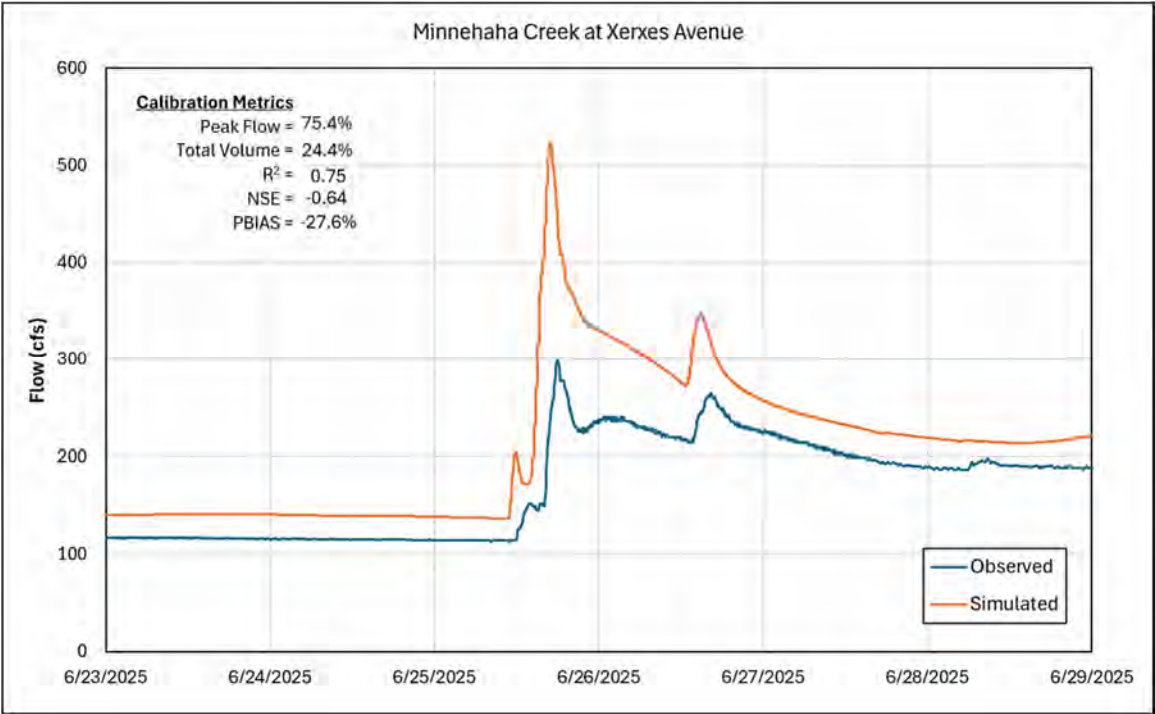


Figure 5-12. Minnehaha Creek at Xerxes Avenue 2025 Flow Calibration

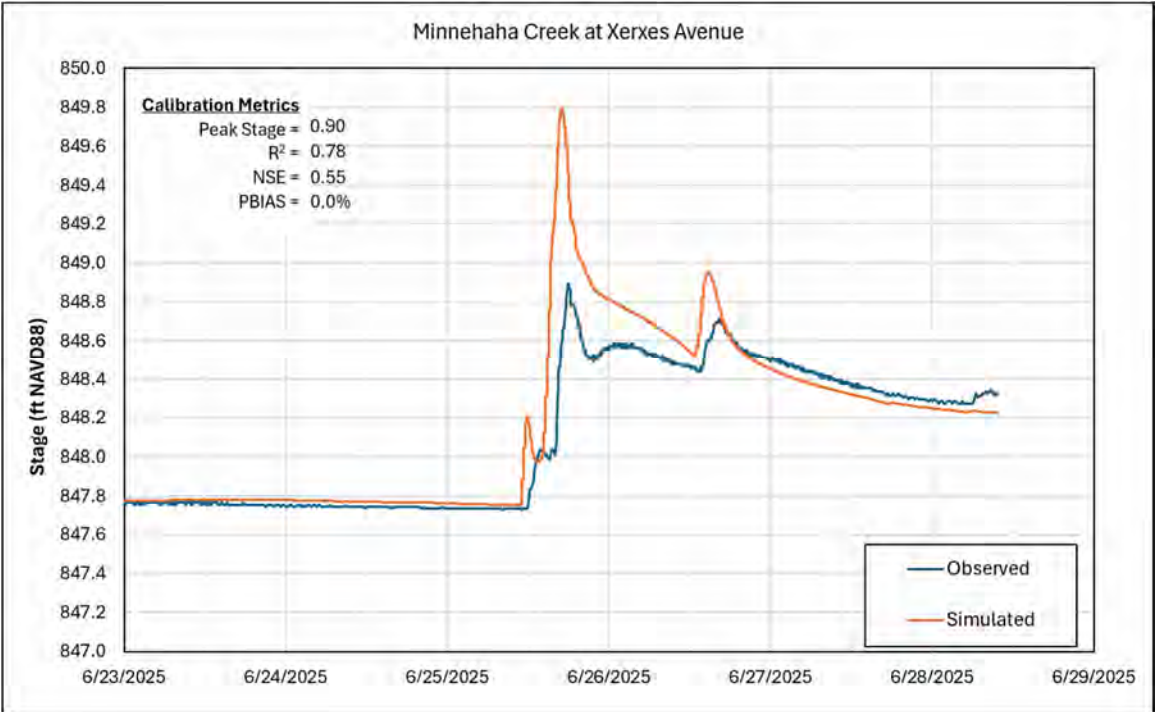


Figure 5-13. Minnehaha Creek at Xerxes Avenue 2025 Stage Calibration

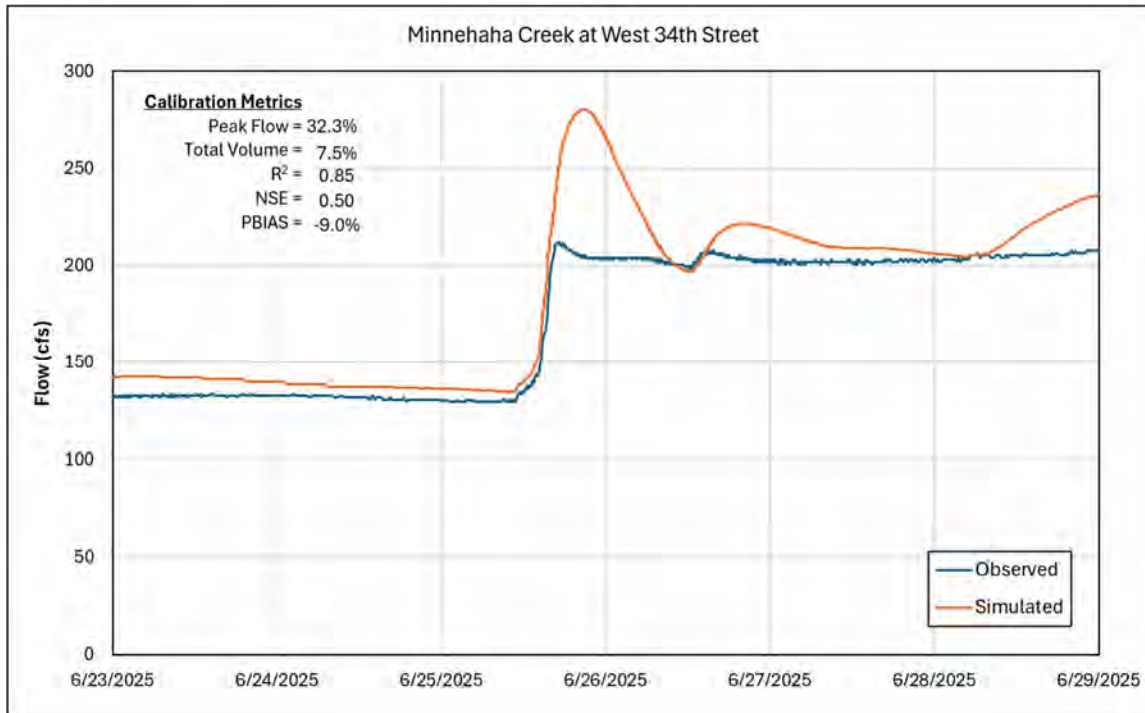


Figure 5-14. Minnehaha Creek at West 34th Street 2025 Flow Calibration

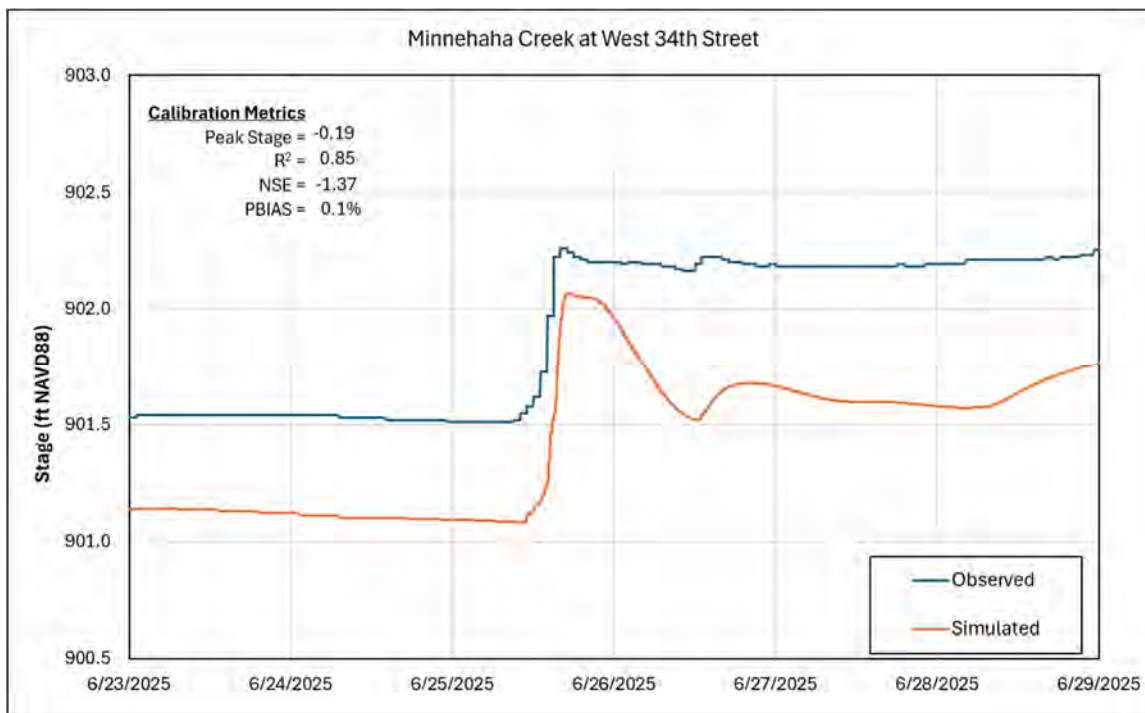


Figure 5-15. Minnehaha Creek at West 34th Street 2025 Stage Calibration

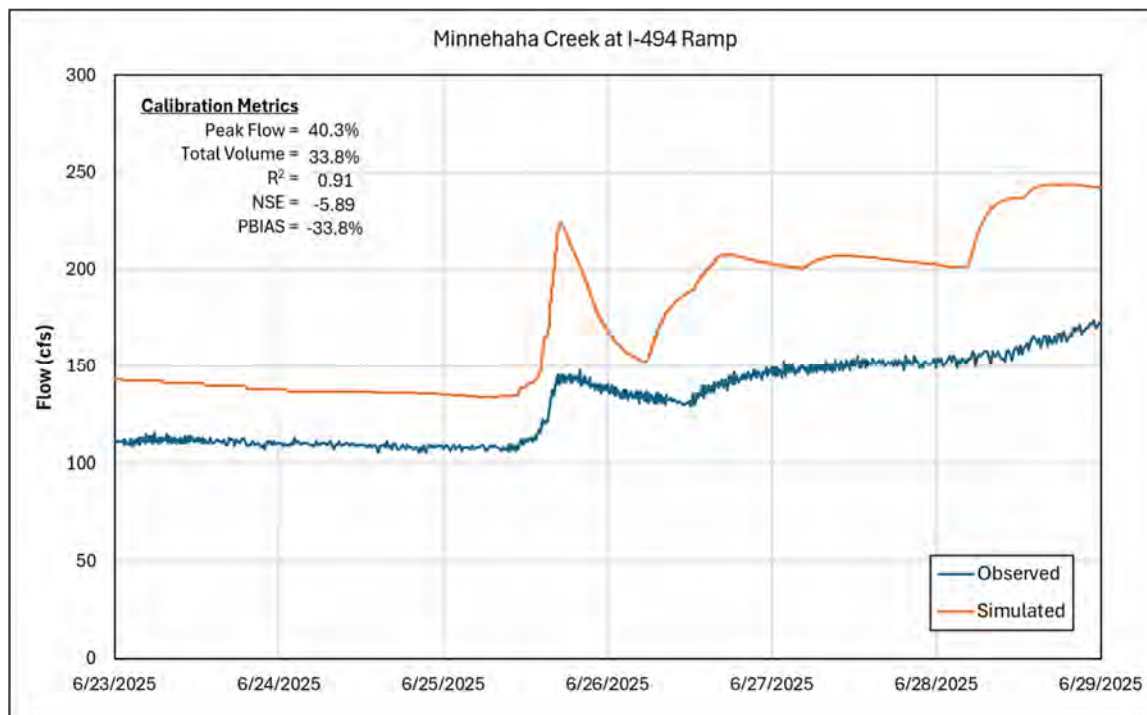


Figure 5-16. Minnehaha Creek at I-494 Ramp 2025 Flow Calibration

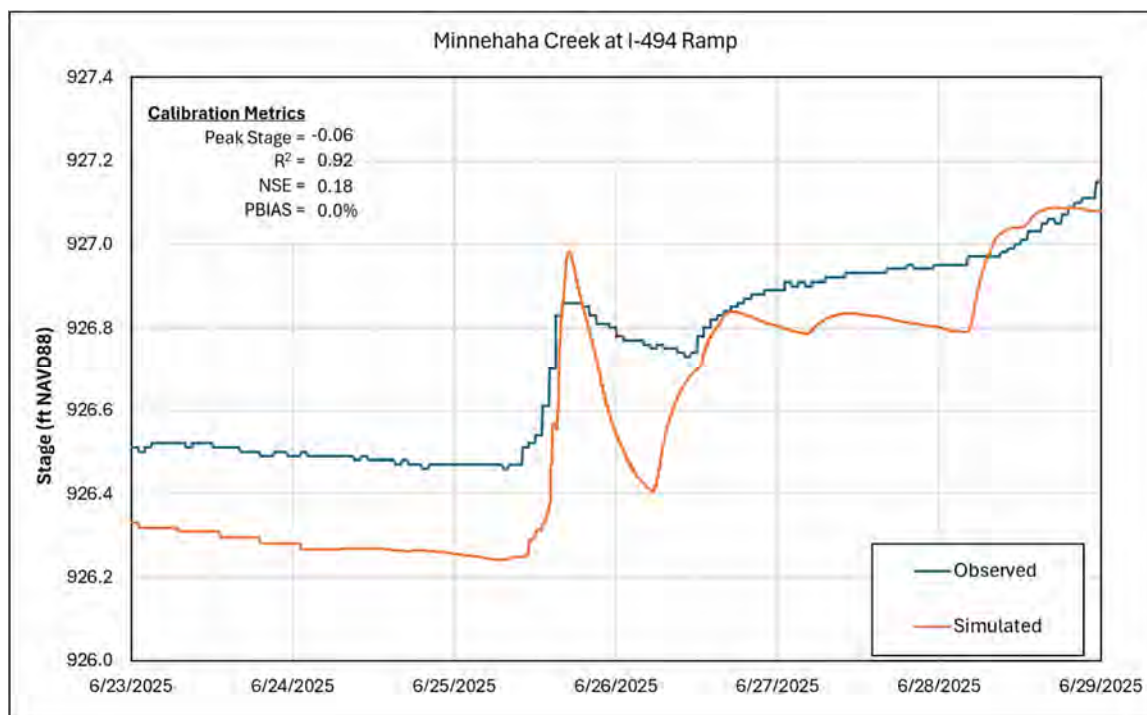


Figure 5-17. Minnehaha Creek at I-494 Ramp 2025 Stage Calibration

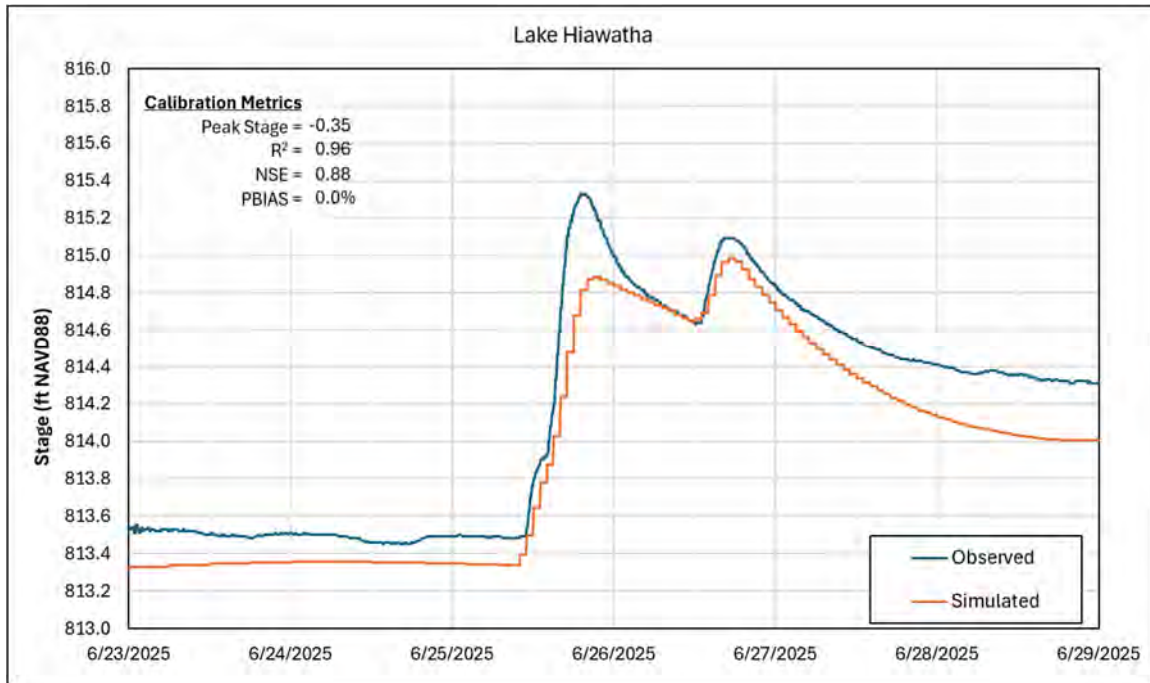


Figure 5-18. Lake Hiawatha 2025 Lake Level Calibration

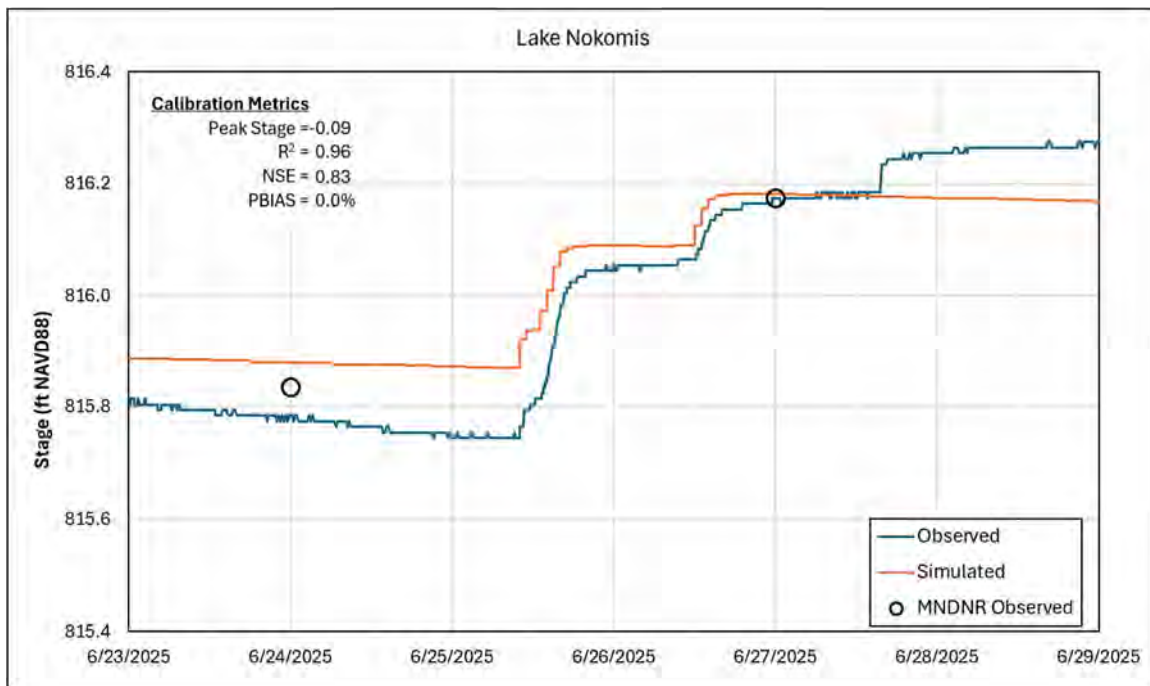


Figure 5-19. Lake Nokomis 2025 Lake Level Calibration

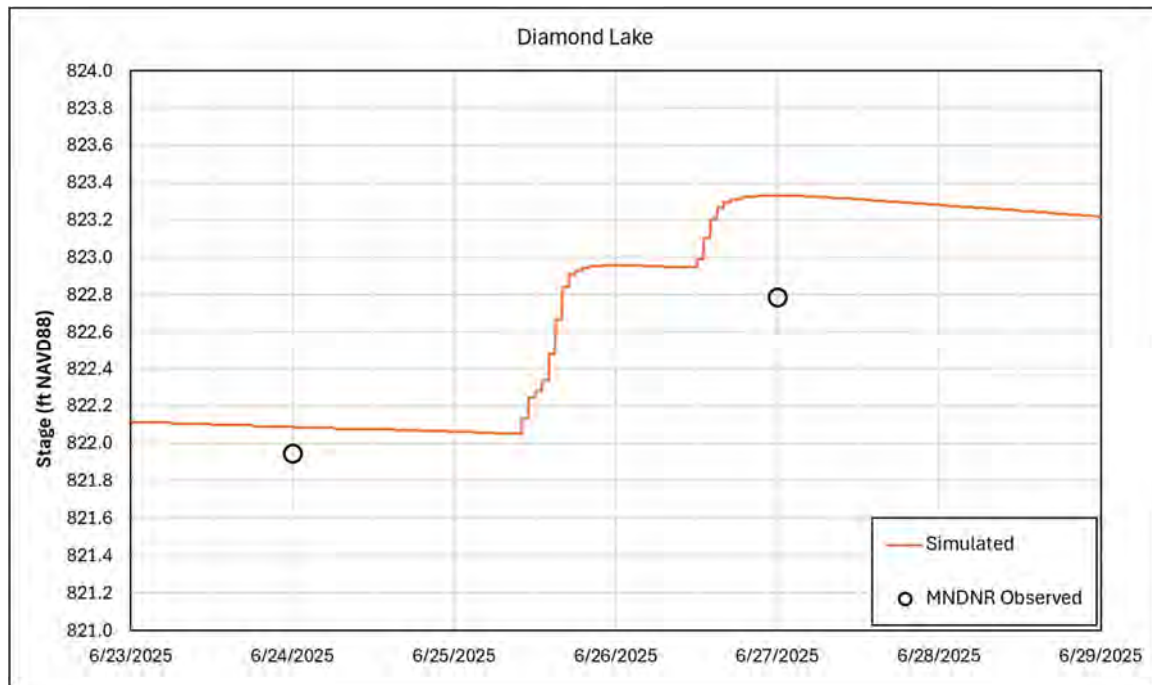


Figure 5-20. Diamond Lake 2025 Lake Level Calibration

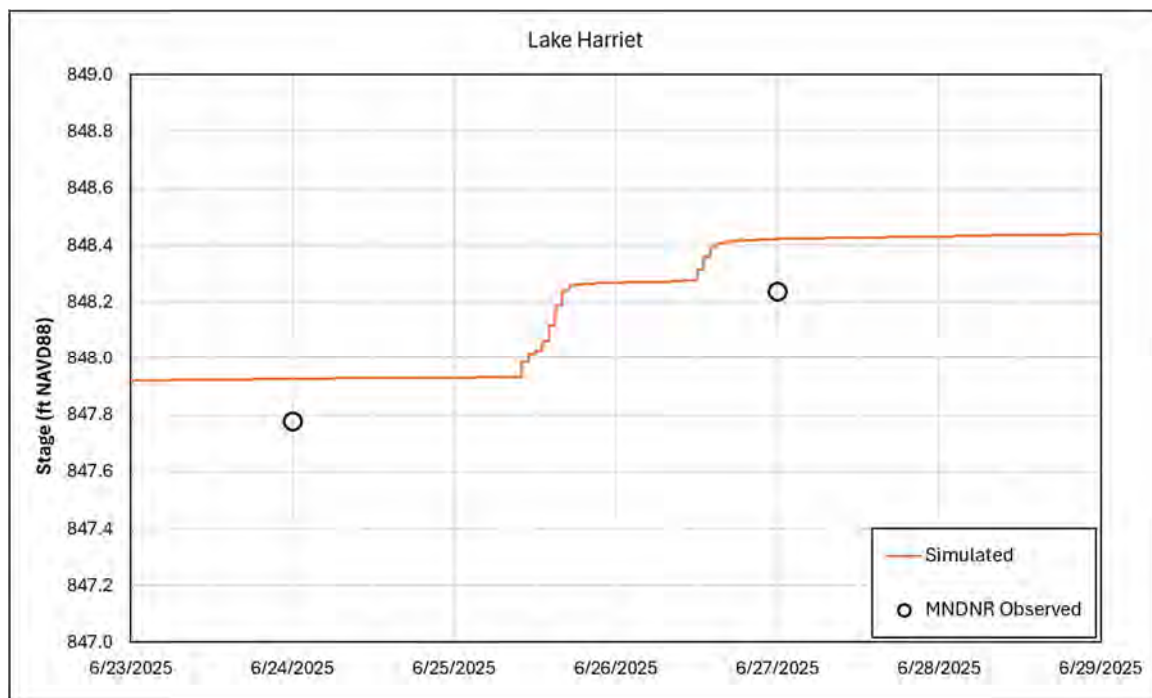


Figure 5-21. Lake Harriet 2025 Lake Level Calibration

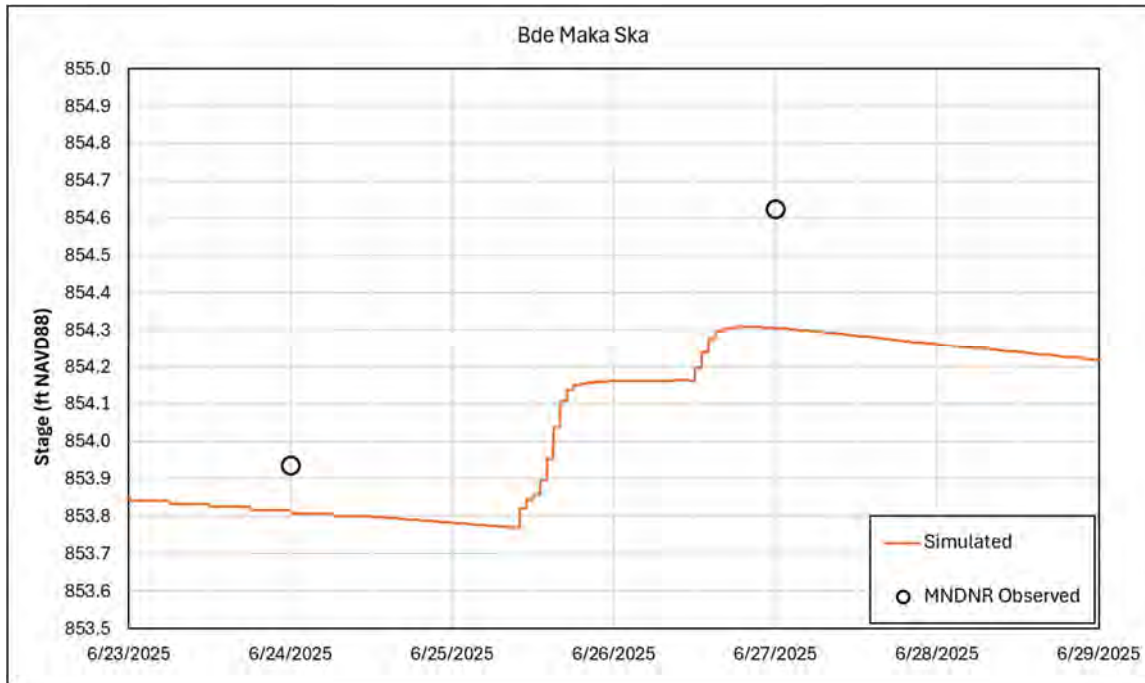


Figure 5-22. Bde Maka Ska 2025 Lake Level Calibration

5.5 Validation

The June 2014 event was used for model validation. Initial conditions were configured as described in Section 5.1.3. Initial soil moisture content and depth to water table were adjusted to reflect expected watershed conditions of 50 percent saturated soil and 3.0-foot depth to water table. Beyond the initial watershed conditions, no other modifications were made to the input parameters. Simulated and observed data are shown in Figure 5-23 through Figure 5-29. Key takeaways are as follows:

- Limited data were available for comparison
 - o USGS stage and flow (No. 05289800)
 - o Bi-weekly observations at the largest lakes in the lower watershed
- Observations at USGS stream gage (No. 05289800)
 - o Simulated flows overestimated peak by 25 percent and total volume by 10 percent
 - o Simulated peak stage within 0.1 feet
 - o Simulated flow and stage hydrographs show an elongated secondary peak which is not present in the observed data. This secondary peak appears to be a function of upstream watershed response, while the first peak is from flow originating closer to the USGS gage location.
 - o Future improvements may consider using spatially distributed rainfall (2014 event only uses MSP airport rainfall) to improve timing of the system response.
- Lake level observations

- o Simulated results had similar lake levels as observed data, but without additional frequency of observations (lake levels were bi-weekly) a conclusive statement cannot be made.

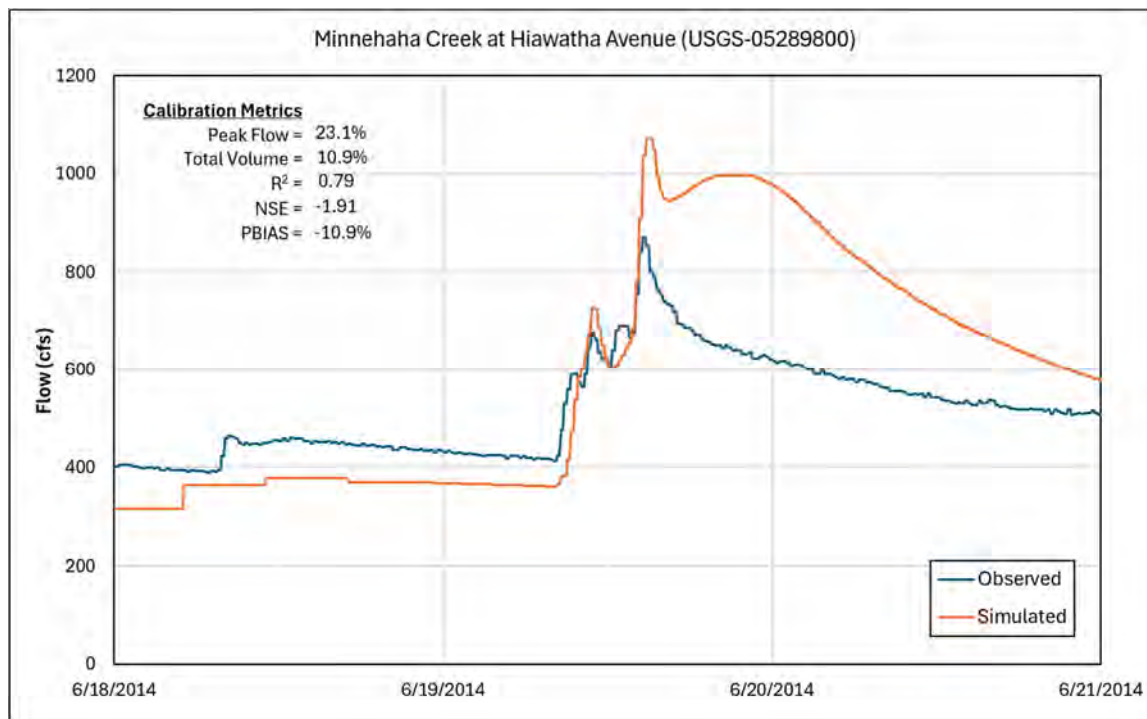


Figure 5-23. Minnehaha Creek at Hiawatha Avenue (USGS-05289800) 2014 Flow Validation

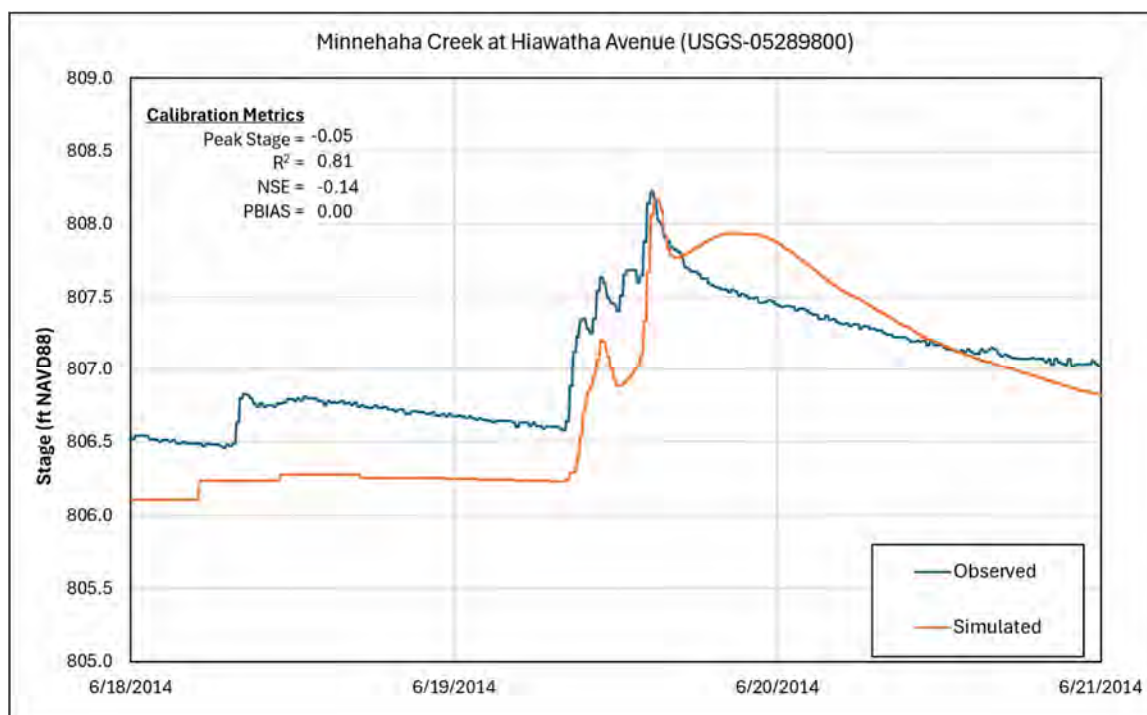


Figure 5-24. Minnehaha Creek at Hiawatha Avenue (USGS-05289800) 2014 Stage Validation

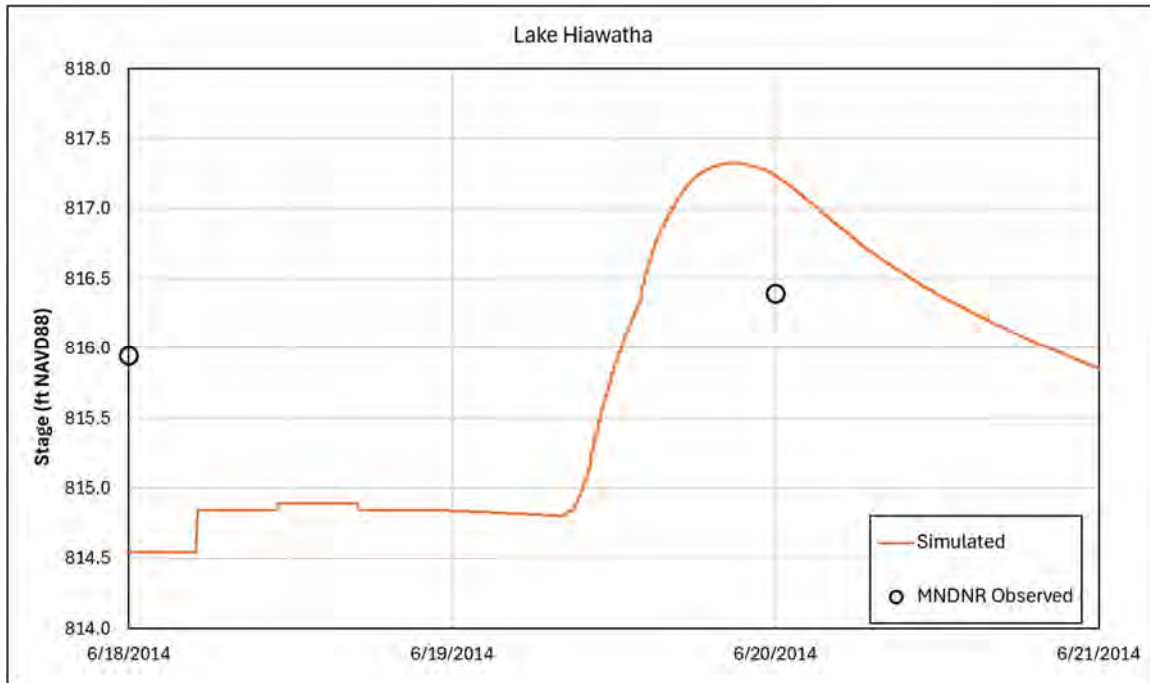


Figure 5-25. Lake Hiawatha 2014 Lake Level Validation

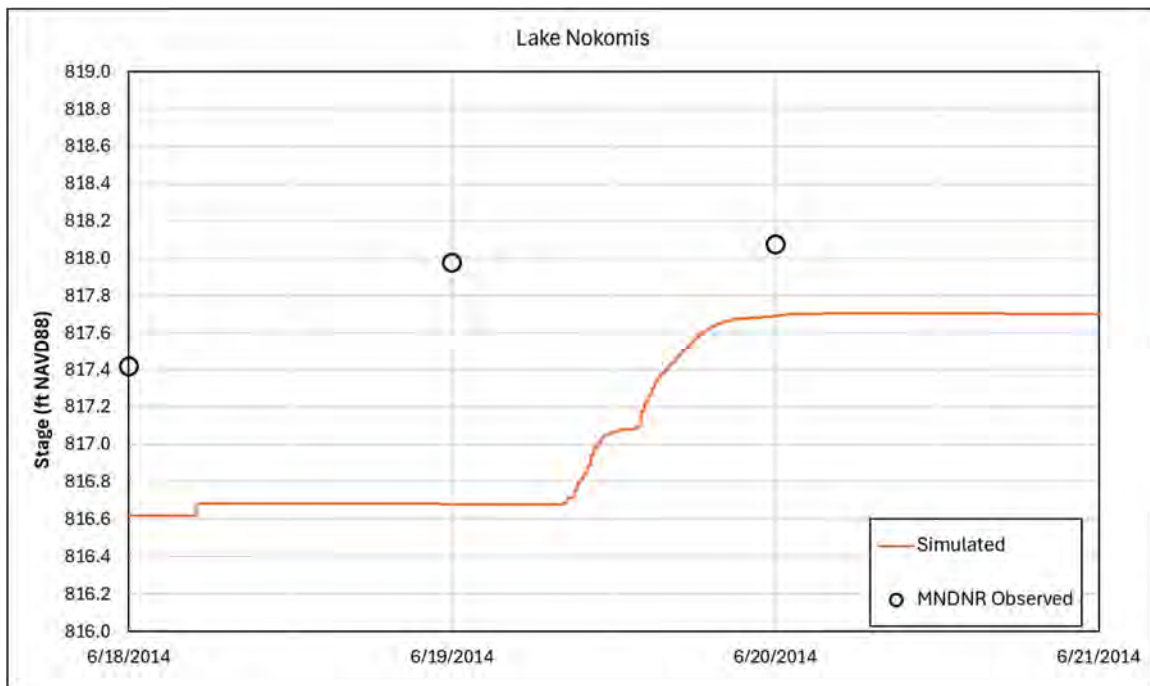


Figure 5-26. Lake Nokomis 2025 Lake Level Validation

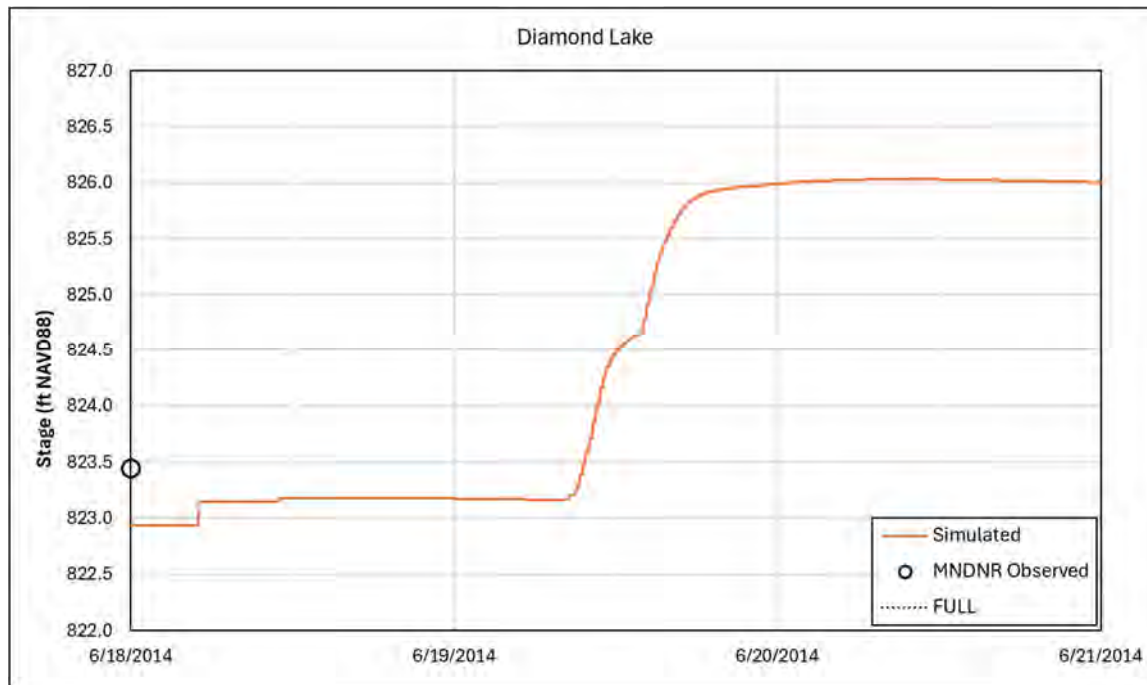


Figure 5-27. Diamond Lake 2025 Lake Level Validation

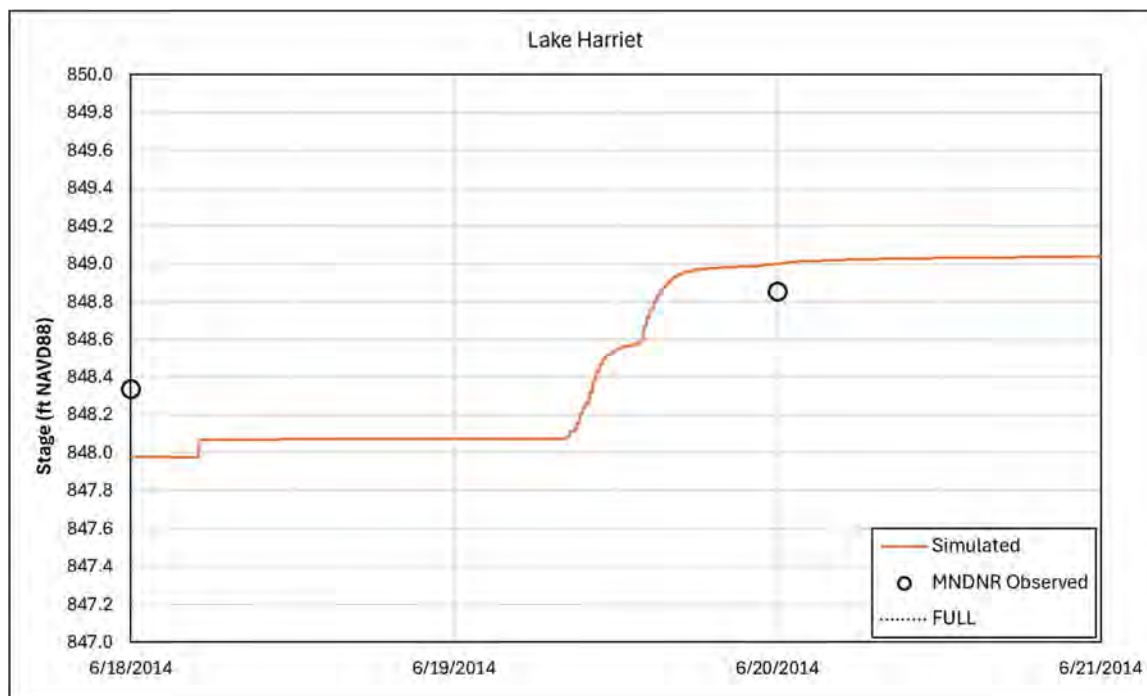


Figure 5-28. Lake Harriet 2025 Lake Level Validation

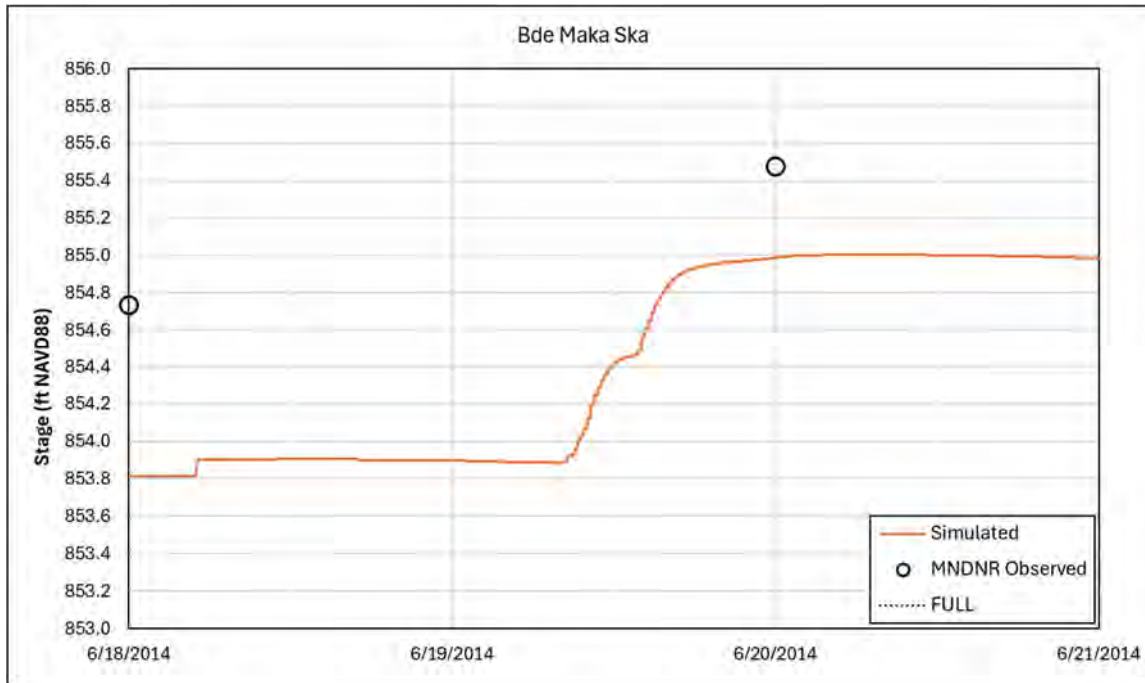


Figure 5-29. Bde Maka Ska 2025 Lake Level Validation

6 100-Year Event Simulation

To support flood risk identification and future application of this model, a single 100-year 24-hour design storm event was developed. Characteristics for the event are summarized below.

- Rainfall was a 24-hour duration, 100-year frequency with 7.49 inches of total depth derived from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 (Perica et al. 2013) and applied an MSE3 temporal distribution.
- Soil initial moisture content was set to a wetter than normal condition of 80 percent saturated.
- Dam releases were assumed to be at a maximum release of 300 cfs.
- Initial lake level where observations available were set to the 95th percentile of all observed lake level data as shown in Table 5-1.

Figure 6-1 shows the input rainfall and resulting runoff time series at the USGS (No. 05289800) stream gage location. FEMA FIS (2016) reports the 1-percent annual chance flood (100-year event) flow as 882 cfs near the outlet of Lake Hiawatha but notes the discharge at this location has been lowered assuming a set of levees contain the 100-year flood. At the same location the FIS documents the 2-percent (50-year) and 0.2-percent (500-year) discharges at 1,212 cfs and 1,580 cfs respectively. Simulated peak flows in this model at the USGS stream gage are approximately 1,350 cfs showing good agreement with the 50- and 500-year bounding flows. Figure 6-2 shows an example inundation map. Note that inundation extents from this model may differ from municipal stormwater models for some of the reasons listed below:

- **Rain On Grid.** A 2D approach was applied for this model where a grid over the entire watershed converts rainfall into runoff, and routes it from its origin to the stormwater network and eventually to the creek. This approach accumulates runoff over the entire watershed. For this reason, the 100-year inundation limits have been masked at depths below 0.25 feet to better show areas of deeper accumulation. Other modeling approaches may route runoff through subbasins directly to an inlet or larger trunkline limiting the origins of the inundated area to the proximity of the subbasin outlet.
- **Inlets.** All pipes and inlets are included in the model. At each inlet, a standard catch basin style and size was assumed. Inlets can restrict the amount of flow entering into larger pipes and result in flows bypassing the inlet showing inundation near these areas. Other modeling approaches may assume there is no inlet and restrictions only occur within the pipe network increasing the amount of water able to enter the stormwater system.
- **Calibration.** Calibration was performed to an observed event. This provides confidence in the system's response to similar events. Calibration also required adjustments to some of the base parameters controlling runoff generation. Other modeling approaches may not have the benefit of observed data for calibration, and therefore, would use common engineering practices to select input model parameters.

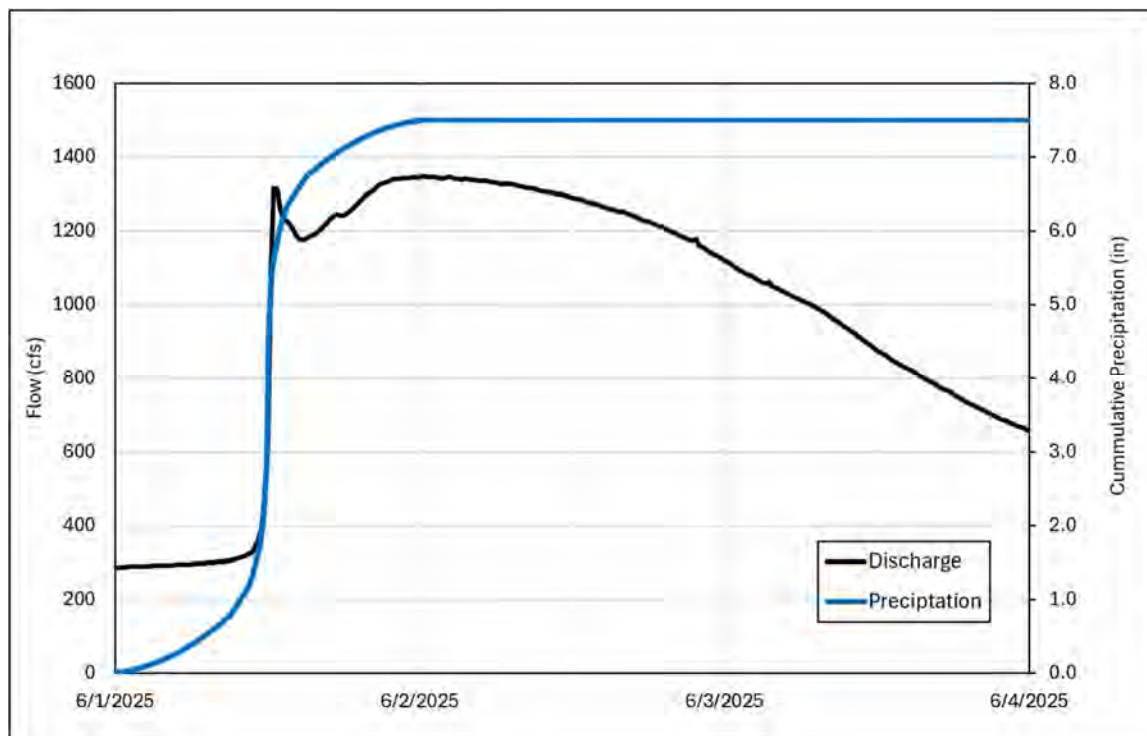


Figure 6-1. Input rainfall and observed runoff response at USGS Stream Gage

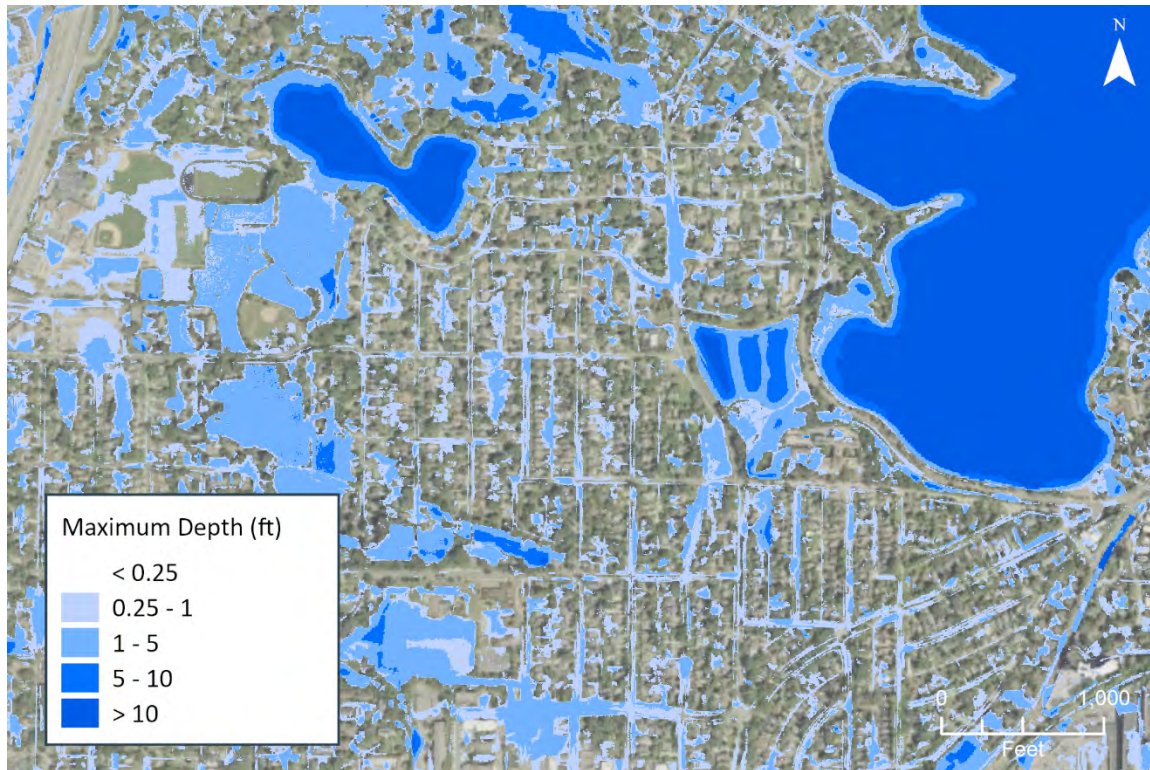


Figure 6-2. Example Inundation Limits from 100-year event

7 Recommendations

This report describes model development, calibration, and validation for the Lower Watershed of Minnehaha Creek. This model provides a quality and robust product useful for watershed planning purposes with the potential for a range of future applications. Future enhancements and improvements that could support expanded application of the model include:

- **Expanded Flood Calibration Refinement**
 - o Infiltration Measurements. Real measurements of infiltration across the watershed could help to hone the calibration adjustments in urban areas.
 - o Additional Event Calibration. Calibrate the Lower Watershed model to additional flood events. The combination of parameter adjustments to infiltration characteristics and initial conditions can be improved, helping to refine results of the current events, design storm events, and future applications of the model to flood conditions.
 - o Initial Condition Approach. Using additional calibration events to develop an approach to characterize soil wetness, water table depth, and initial lake and pond levels for other historical events or future event evaluations.
- **Groundwater Calibration**
 - o Simplify the Lower Watershed Model for Groundwater Evaluation. An integrated understanding of groundwater-surface water interactions can support an understanding of watershed dynamics or multiple seasons or years. However, the model currently requires approximately 24 hours of runtime to complete a 10-day event simulation.

Simplification of the 2D grid to coarse elements and/or conversion to mapped basins would result in faster runtimes and improved capability to simulation multiple seasons and/or years of system response.

- o Develop Breakout Model. Develop a sub-watershed scale model with surface and subsurface observations. The sub-watershed scale model runs faster than the full model and will allow for more rapid evaluation of watershed response and parameters for a larger scale simulation. Results at the breakout model scale can give insights into local response which may be applicable to portions of the watershed scale modeling efforts.
- **Model Set Up Refinement**
 - o Integration of additional stream crossings such as Tier 2 and Tier 3 bridges along Minnehaha Creek and evaluation of tributary bridges/crossings for integration.
 - o Stormsewer refinement. Stormsewer assumptions can be reviewed for refinement to conform with local design and implementation. Improving stormsewer information in the model, especially for larger pipes or areas conveying significant drainage area, may greatly improve model results in these areas.
 - o Storm sewer omissions. MNDOT dataset was omitted from storm sewer integration due to the amount of redundancy. However, up to 30 percent of this dataset may be unique to the MNDOT dataset and may benefit model drainage patterns.
 - o Lift station assumptions. Many of the lift stations include assumed maximum capacity and on/off elevations. Update these assumptions with information received from local partners.

8 Future Application

This watershed-wide model development is at the center of the CAF and is intended to be used as a numerical tool to describe the physical processes important to watershed response. Through this model build, the goals of model development were focused on describing both local and regional flooding conditions. To this end it includes a detailed representation of the watershed wide storm sewer infrastructure using the most current detailed topography and bathymetry, and numerical features intended to make the model simulations faster and more accurate. This detailed model development was paired with a targeted calibration and validation which refined the model inputs to better reproduce real events. Although some improvements have been noted throughout the above sections, the model is ready for application to support MCWD current and future needs.

- o **Watershed Planning.** Use the model as a tool to support 2027 Watershed Management Plan activities. The model can be used as a platform to bring people together around common goals and develop a shared understanding of some of the complex inter-related water challenges. It can be used to understand current and future flood risk and approaches to mitigate that risk.
- o **Supporting Partners.** Model development included aggregation, review, and refinement of vast amounts of project partner data for incorporation into a detailed watershed wide understanding of the storage and conveyance system. These data and processes can be provided to project partners to meet shared goals. Project partners have varying investments with respect to stormwater planning. This model can support partners as is

and be used to support their own planning purposes or provide a regional understanding of local project development.

- o **Evaluate Projects.** Use as a watershed wide model or divide out key project areas for purposes of project siting, feasibility, and design.

9 Electronic Data Package

Along with this report, an electronic data package is provided that includes supporting geographic information system data used to develop the model, relevant processing spreadsheets and workflow diagrams, and a complete preliminary StormWise Model of the Lower Watershed. Details of the data package are provided in Table 9-1.

Table 9-1. Electronic Data Package

Data	Description
C-7 Bridge Structure Data Summary	Bridge structure data summaries for those modeled along Minnehaha Creek. Includes tables populated for culvert and weir crossings represented as pipe links and weir links, respectively, in StormWise. Also includes bridge rating curves, connected to rating curve links, to be pasted into StormWise. See Appendix C-7.
Rainfall	Rainfall data used for StormWise simulations.
C-10 Crop Coefficients	Folder containing the spreadsheet in which the crop coefficients were developed (C-10 Crop Coefficients) and a folder containing the crop coefficient set CSVs generated (C-10 Crop Coefficient Set) for import to StormWise
C-13.1 Boundary Stage Points	Boundary stage point CSVs for import to StormWise. See Appendix C-13.
C-13.2 Reference ET	Reference ET data used for StormWise simulations. See Appendix C-13.
C-13.3 Vertical Layers Table	Vertical Layers Table, developed by StormWise developers, for the soils in the watershed. See Appendix C-13.
C-13.4 Impervious Set	Impervious set for import to StormWise. Used to represent the imperviousness of land cover types within the land cover raster. See Appendix C-13.
C-13.5 Roughness Set	Roughness set for import to StormWise. Used to represent the roughness of land cover types within the land cover raster. See Appendix C-13.
C-13.6 Fillable Porosity	Fillable porosity set for import to StormWise. Used to represent the fillable porosity of soil layers within the watershed. See Appendix C-13
C-13.7 Conductivity Set	Conductivity set for import to StormWise. Used to represent the conductivity of soil layers within the watershed. See Appendix C-13.
\\MCWD_Lower_Groundwater.gdb \\Boundary_Stage\\gw_boundary_stage_points	Boundary stage point shapefile, with water table elevations, used for the groundwater region boundary conditions
\\MCWD_Lower_Groundwater.gdb \\Boundary_Stage\\gw_all_regions_bsl	All groundwater boundary stage lines, not split by groundwater region. Attributes include to/from boundary stage points.
\\MCWD_Lower_Groundwater.gdb \\Boundary_Stage\\gw_XX_bsl	Boundary stage lines split by region. "XX" in the layer name represents region (ne, nw, se, sw). Attributes

Data	Description
	include to/from boundary stage points. Formatted as imported to StormWise.
MCWD_Lower_Groundwater.gdb\gw_XX_breakpoints	Breakpoints, generated in StormWise, used for groundwater mesh generation. "XX" in the layer name represents region (ne, nw, se, sw). This feature dataset contains four layers, representing breakpoints generated for each groundwater region.
MCWD_Lower_Groundwater.gdb\Mesh	Groundwater meshes generated using the groundwater region boundaries and breakpoints as input. This feature dataset contains four layers, representing the mesh generated for each groundwater region.
MCWD_Lower_Groundwater.gdb\gw_bedrock_surface_el	Bedrock surface elevation raster, or confining layer, used for groundwater modeling. Formatted as imported to StormWise.
MCWD_Lower_Groundwater.gdb\gw_region_boundaries	Groundwater region boundaries (ne, nw, se, sw), used for groundwater modeling. These boundaries were created along surface water features and wells with known water table elevations. Formatted as imported to StormWise.
MCWD_Lower_Groundwater.gdb\ssurgo_soil_texture	SSURGO soil texture polygons pulled for the lower watershed. Attribute table contains mu keys. Formatted as imported to StormWise.
MCWD_Lower_OF_Region.gdb\CCVs\CCV_bridge_crossing_links	Channel links representing Minnehaha Creek channel structures as bridges. See Appendix C-7. Formatted as imported to StormWise.
MCWD_Lower_OF_Region.gdb\CCVs\CCV_weir_crossing_links	Weir links representing Minnehaha Creek channel structures as weirs. See Appendix C-7. Formatted as imported to StormWise.
MCWD_Lower_OF_Region.gdb\CCVs\CCV_culvert_crossing_links	Pipe links representing Minnehaha Creek channel structures as culverts. See Appendix C-7. Formatted as imported to StormWise.
MCWD_Lower_OF_Region.gdb\CCVs\CCV_channel_links	Channel links for Minnehaha Creek. These links route flow between channel nodes. See Appendix C-6. Formatted as imported to StormWise.
MCWD_Lower_OF_Region.gdb\CCVs\CCV_cross_sections	Channel cross sections representing channel bathymetry. These inform channel geometry to model channel flows. See Appendix C-6. Formatted as imported to StormWise.
MCWD_Lower_OF_Region.gdb\CCVs\CCV_nodes	Point shapefile nodes that represent volume, stage, and area stored for each individual channel control volume polygon. See Appendix C-6. Formatted as imported to StormWise.
MCWD_Lower_OF_Region.gdb\CCVs\CCV_polygons	Polygon shapefiles representing channel control volumes. Each channel control volume polygon has an associated node. See Appendix C-6. Formatted as imported to StormWise.
MCWD_Lower_OF_Region.gdb\OF_Surface_Mesh\of_1D_node_interface_points	1D node interface points, exported from StormWise, composed of lower watershed inlets and building centroids. StormWise overland flow mesh inputs. See Appendix C-4. Formatted as imported to StormWise.
MCWD_Lower_OF_Region.gdb\OF_Surface_Mesh\of_breaklines	Breaklines following lower watershed surface flow paths. Developed as inputs for StormWise overland flow surface mesh generation. See Appendix C-4. Formatted as imported to StormWise.
MCWD_Lower_OF_Region.gdb\OF_Surface_Mesh\of_breakpoints	Breakpoints developed within StormWise. These are used to add increased detail to the StormWise surface mesh. See Appendix C-4. Exported from StormWise.

Data	Description
MCWD_Lower_OF_Region.gdb \OF_Surface_Mesh\of_surface_mesh	Surface mesh generated in and exported from StormWise. See Appendix C-4.
MCWD_Lower_OF_Region.gdb \PCVs\PCV_nodes	Pond control volume nodes formatted as imported to StormWise. See Appendix C-5.
MCWD_Lower_OF_Region.gdb \PCVs\PCV_polygons	Pond control volume polygons formatted as imported to StormWise. Each pond control volume polygon has an associated node, as represented in the layer's attribute table. See Appendix C-5.
MCWD_Lower_OF_Region.gdb \Storm_Sewer_Infrastructure\culvert_MR	Culverts compiled from MGIS compiled storm sewer infrastructure datasets from municipalities within the upper and lower watershed.
MCWD_Lower_OF_Region.gdb \Storm_Sewer_Infrastructure\inlet_MR	Storm sewer inlets compiled from MGIS compiled storm sewer infrastructure datasets from municipalities within the upper and lower watershed. Used as surface mesh elements and represented as weirs in StormWise.
MCWD_Lower_OF_Region.gdb \Storm_Sewer_Infrastructure\manhole_MR	Storm sewer manholes compiled from MGIS compiled storm sewer infrastructure datasets from municipalities within the upper and lower watershed.
MCWD_Lower_OF_Region.gdb \Storm_Sewer_Infrastructure\outlet_MR	Storm sewer outlets compiled from MGIS compiled storm sewer infrastructure datasets from municipalities within the upper and lower watershed.
MCWD_Lower_OF_Region.gdb \Storm_Sewer_Infrastructure\pipe_MR	Storm sewer pipes compiled from MGIS compiled storm sewer infrastructure datasets from municipalities within the upper and lower watershed.
MCWD_Lower_OF_Region.gdb \microsoft_building_footprints	Microsoft building footprint polygons used to burn elevated building footprints into the watershed surface digital elevation model to force flowpaths around buildings in the watershed.
MCWD_Lower_OF_Region.gdb \of_land_cover	Land cover polygons processed for import to StormWise. Used to represent land cover for ET and surface roughness values. See Appendix C-3 and Appendix C-10.
MCWD_Lower_OF_Region.gdb \of_region_boundary	Overland flow region boundary polygon developed to hydraulically represent the lower watershed. See Appendix C-1.
MCWD_Lower_OF_Region.gdb \watershed_upper_lower_boundary_updated	Upper and lower watershed boundary polygons with the updated lower watershed boundary.
MCWD_Lower_OF_Region.gdb \of_surface_el	Overland flow surface elevation raster including project developed bathymetry. Formatted as imported to StormWise.
Weir_Cross_Section_CSVs\Weir Weir_Cross_Section_CSVs\Cross_Sections	CSV files with channel cross section and weir data for import to StormWise.
URBAN_SOIL_Tables	Relevant tables for urban soils region including urban soils region shapefile and conductivity, fillable porosity, and vertical layers tables.

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Appendix A – Workshop Notes

Appendix A-1: Workshop 1 Meeting Minutes

<i>Project:</i>	MCWD 2D Model Build		
<i>Subject:</i>	Workshop 1: Goal Setting and Prioritization		
<i>Date:</i>	Thursday, June 13, 2024		
<i>Location:</i>	HDR Office & Microsoft Teams Conference Room 5Y 1601 Utica Avenue South Suite 600 St. Louis Park, MN 55416-3400		
<i>Attendees:</i>	Brian Beck (MCWD) James Wisker (MCWD) Becky Christopher (MCWD) Rebecca Neal (MCWD) Kate Moran (MCWD) Siddharth Saksena (VT) F. Warren McKinnie (Streamline) Andrew Judd (HDR) Nick Thomas (HDR) Ryan Fucci (HDR) Alex Miller (HDR) Ken Trefzger (HDR)		

The following items were discussed during the kickoff meeting for the 2D Model Build project:

1. Introductions

2. Workshop Series Overview

- Goal of the workshop is to develop a shared understanding of model objectives and key decision areas to guide the upcoming model build process.
- This is the first of four workshops and is the broadest. The next workshops will get increasingly technical and cover the topics of Surface Water Model Build, Groundwater Model Build and Model Calibration/Validation and Maintenance.
- One common goal of the workshops is to develop guidance documentation for model development which can be carried forward past this project.

3. Prioritized Model Scenarios and Discussion (MCWD presentation)

- MCWD Past Model Prioritization
 - The District has internally discussed the overarching model 'objectives', and wanted to go one step further within this workshop to discuss 'scenarios' of future model use to help guide the model build discussion.
 - Previous efforts to prioritize what the model should do have identified primary and secondary objectives.
 - Primary objectives: Flood extent and duration, GW/SW Impacts, Policy regulation scenarios analysis, Regional BMP strategy evaluations
 - Secondary objectives: Short term flood forecasting, Water quality evaluations, Boundary conditions, FEMA flood maps

- Secondary objectives may already have tools that can fill the need. However, it is a bonus if a model can be developed that also accomplishes secondary objectives.
- Climate Modeling Approach. The district suggested the following model uses:
 - Use 1 - Evaluate extent and magnitude of impacts due to increased precipitation
 - Interim Step (not associated with modeling) Develop specific goals that would minimize or avoid impacts due to increased precipitation
 - Use 2 - Evaluate MCWD known and potential projects at regional or local scale to evaluate effectiveness relative to the goals developed
 - Use 3 - Evaluate policy solutions or high-level strategies such as volume managed or zoning requirements
 - Use 4 - Run scenarios that characterize impacts of subwatershed-based projects and watershed-wide policy impacts relative to goals
 - These initial goals may relate to surface water bodies. These water features are the downstream recipients of upstream changes. These are also the most visible features and those that may be most related to the watershed districts purview. Currently, all goals (regulations) are site-specific. Here, we are looking at regional goals for a water body. These look to be proactive and typically around developed areas. Instead of waiting for redevelopment, are there regional opportunities that can be had in advance?
- Evaluate Impact of Climate Change Examples
 - Develop subwatershed plans to define objectives at confluence/outfall points on the creek
 - What is the percent frequency of out of bank flooding (consequence - high resolution surface mesh)
 - Does the frequency of localized flooding increase due to climate change (consequence - high-resolution pipe network)? Cities have or may ask for this understanding. MCWD intends to meet with associated partners to see what issues are in specific areas and develop regional goals to address them.
 - Accurately characterizing outfalls to creek (flows, impact on flood levels) could be important locations for system response evaluation.
 - Understand how groundwater impacts existing and future BMPs and their storage capacity.
- Note on District's responsibility for flooding. Typically, the District is associated with creek flooding, sometimes MCWD also associated with localized (non-creek) flooding. A Working definition of localized flooding is flooding that is the

responsibility of Cities, not the watershed District, things on the grid, not visually associated with the Creek or surface water bodies.

- Part of climate action plan is to define what MCWD is responsible for and what their partners are responsible for so each can more appropriately focus on goals.
- In City of Minneapolis, they have set established levels of service
 - 100 -year storm away from buildings
 - 10 - year storm within stormsewer
- Current regulatory paradigm is based on permitting changes on the landscape, which have cascaded down from MS4 requirements. Current projects such as pipe conveyance are specifically designed to not hit regulatory requirements. Cities can upsize their systems without consent from the district.
- What happens when conveyance impacts are intra-community? Sometimes these questions fall outside of regulation.
- It would be useful to have a framework between the District and the communities for these types of regional questions.
- Evaluate management strategies
 - Where are management strategies needed based on localized and regional flooding
 - Understanding if infiltrating more helps augment base flow later on during drought conditions
- Evaluate Policy Solutions
 - Evaluate upper watershed development under current plans/rules (water budget)
 - What is impact on rule or zoning changes based on climate scenarios (water budget)
 - Does the outlet at Grays Bay Dam need to be re-evaluated relative to changing flow conditions?
 - Would BMP Requirements for permits be useful?
 - What watershed conditions are conducive to different strategies.
 - For instance, soils are much more permeable in the lower watershed, are there opportunities for infiltration? Whereas, in the upper watershed soils are less permeable. Focus on infiltration where soils are suitable (lower watershed), and surface storage/wetlands where they may not be (upper watershed). This focus can be both through potential policies and specific BMMP siting.
 - It would be beneficial to understand interaction between surface water and groundwater movement, specific to how these impact effectiveness of BMPs.
- Evaluate policy solutions and management strategies together.
- How important is flooding vs. drought management in these scenarios?

- Most people put an emphasis on flooding, however drought and water balance will be important and long-term runs will be needed to quantify these impacts. A metric may look like 7q10 to evaluate baseflow and how the biota reacts to that. There may be paired SW/GW benefits from surface storage resulting in increased baseflow, but this is to be determined/quantified.
- Drought may affect more people than floods at a high level, and the District doesn't get blamed for a lack of supply. However, when it rains a lot, the blame falls on the water management and engineering community as to why there isn't a solution.
- If there are management strategies that both help flood and drought conditions that would be ideal. Increases to conveyance may not be the best solution.

4. Model Build Drivers (HDR presentation)

- Data Management: Data resolution, quantity, and/or accuracy for model input.
 - This includes 1D geometrics, GIS spatial data, meteorologic data, calibration data, and storage space.
 - Relative to storage space. Stormwise identifies a difference between 'scenario' and 'simulation' that is important relative to model size. Scenarios require full copies of a model, simulations do not.
 - There could be opportunities to preemptively look at things like landuse and discretize pre- and post- scenarios with just swapping the lookup tables. In the worst case, the team would just need multiple scenarios.
 - We need a model that meets the goal, is technically sound, and is manageable.
 - The team needs to keep in mind that the goals need to be accomplished first, and then elements like model runtime can be evaluated.
- Outputs: Type, location, spatial resolution, and temporal frequency of model results.
 - There are opportunities to modify outputs in postprocessing scripts pending what information is useful.
 - Siddharth noted that there are potential ways to get time series for entire 2D mesh. Currently only available to certain users.
- Model Detail: Numerical resolution of model or number of model elements
- Simulation Duration: Length of modeled evaluation period
- Model Build Drivers linkage and summary
- Runtime: Function of Level of Detail and Simulation Duration
 - Siddharth recommends leveraging 1D as much as possible, not just because of speed but because of physics. A consistent known water surface elevation will help facilitate accurate

groundwater movement. Going to 1D doesn't sacrifice accuracy if used correctly, it may be a win-win for accuracy and runtime.

- Tiered numerical element resolution should be considered based on how important certain features are to physics and/or where known priority areas are located.
- Warren suggests thinking about opportunities where we can simulate certain areas as mapped basins (without overland flow).
- Brian suggests City/community feedback to point to areas where higher resolution may be beneficial.
- Quality of data may also set a limit on model build requirements. If data is lacking, then it may not make sense to characterize elements in certain ways if it doesn't lead to more accurate results.
- Siddharth built a model in City of MPLS - Takes 1h to run 1h or simulation. Siddharth has a project in Cleveland of about the same size, takes 7 days to a run a 1-year simulation.
- Caution should be taken if choosing a runtime independent of other considerations. Aim to balance a model build that leverages good development practices instead of thinking with a runtime goal in mind.
- Changes to the 2D model elements are easy once the physics are established correctly with 1D elements, and areas that need higher resolution.
- Should keep in mind the number of long-term vs. short-term runs and characterize which scenarios need to be long term vs. short term.
- Are the simplifications considered to limit model runtime or the level of effort to build the model?
- Discussion of how we manage scenarios
 - Future scenarios should consider using long term simulations to guide and/or initialize shorter term ones.
 - Longer term models set the baseline for various climate conditions: very dry years, moderately dry years, moderately wet years, very wet years (etc). Then shorter-term models can be initialized to evaluate specific conditions. Then we look at longer term again relative to changes
- The project has a beginning and end date, but the end product needs to exist for 15-20 years. The District wants to log items that need to be managed beyond the life of the project itself. Can this be accommodated in a log throughout project lifespan off to the side?

5. Key Areas of Focus

- Nick - being strategic about model is constructed.
- Andrew – Regional implications between partners will be critical to future model uses.
- Samantha - Meeting expectations of Cities and setting clear goals.

- Brian - Understanding the differences between areas with localized flooding and where lower resolution is needed.
- Becky – Targeting locations of volume control vs. rate control.
- Becca – Ensuring the model is adaptable to support unpredicted partner questions.
- Ryan – Tool could help facilitate regional discussions, outside of regulations.
- James – Assuming the technical decision making will be sound, the tool will bring people together on a quantitative understanding of the watershed. Strategies will differ between upper and lower watersheds.
- Kate - getting the physics down, understanding where to prioritize detail.
- Warren – Be thoughtful in model build planning to minimize rework/lost time.
- Siddharth – Focus on getting the mass balance right throughout entire model.
- Alex – technical: groundwater regions and boundary conditions, general: build a model that can easily be run with different scenarios/simulations
- Ken - model within a timeframe that can answer one or two key things, show value of model to folks that you're trying to show.

Action Items

- Send Warren the specs on the PC setup
- Send Warren copy of presentation
- HDR to develop a long-term project log that exists beyond the scope of the project itself
- MCWD to assign scenarios into long term vs short term simulations buckets to see if this is critical in model development.

Appendix A-2: Workshop 2 Meeting Minutes

<i>Project:</i>	MCWD 2D Model Build	
<i>Subject:</i>	Workshop 2: Surface Water Model Build	
<i>Date:</i>	Wednesday, August 07, 2024	
<i>Location:</i>	HDR Office Conference Room 6A 1601 Utica Avenue South Suite 600 St. Louis Park, MN 55416-3400	
<i>Attendees:</i>	Brian Beck (MCWD) James Wisker (MCWD) Becky Christopher (MCWD) Rebecca Neal (MCWD) Kate Moran (MCWD) Siddharth Saksena (VT) - Virtual F. Warren McKinnie (Streamline) - Virtual	Andrew Judd (HDR) Nick Thomas (HDR) Ryan Fucci (HDR) Alex Miller (HDR) Leah Botting (HDR) Ken Trefzger (HDR) - Virtual

1. Introductions to New Members (9:00 - 9:10 am)

2. Workshop 2 Overview (9:10 – 9:30 am)

- Workshop 1 summary:
 - The model needs to show the watershed under current and future climate conditions, including both wet and dry scenarios.
 - The model will be used to plan and evaluate future policy and strategies.
 - MCWD noted the additional goal of stakeholder acceptance of the model and the importance of keeping the acceptance component in mind as the project moves forward.
- Objectives of workshop 2:
 - Develop an approach to create the surface water components of the model by stepping through a series of specific technical issues and discuss modeling choices as they align with district objectives.

3. Lessons Learned from Pilot Study (9:30 – 9:50 am)

- MCWD assessed a few different models.
 - Many of the issues in the pilot model weren't technical issues but rather incremental choices made by the modeling team diverging with the overall modeling goals over time. As a result, the watershed wide model build (this project) was structured with an emphasis on active communication and continued alignment relative to the District's goals.

- Outcomes:
 - Diverging goals resulted in a model that was calibrated to other models rather than observed data.
 - Diverging goals also resulted automation of the entire model build process rather than automation of a build process for stormwater infrastructure data specifically (District's Intent).
 - Model built entirely in 2D which had significant impacts on surface water-groundwater connectivity and model runtimes.
 - Models matched localized flooding modeling but couldn't effectively characterize streamflow.
 - Model did not integrate real or assumed channel bathymetry and relied upon hydroflattened surface
 - Calibration performed to other models rather than to observed data
- Takeaways:
 - Leverage expertise of similar model builds.
 - Goal oriented model build: Make sure the model answers the questions needed.
 - Communicate often: If issues arise in reaching stated goals, communicate to policy planning.
- Additional notes from Pilot Study discussion
 - Include detail where needed in the model (flooding in populated areas).
 - Use 1D channels, they improve computational efficiency and accuracy of SW/GW connectivity and channel conveyance. Need to account for bathymetry below hydroflattened water surface by creating a merged topo-bathy DEM. LiDAR only based DEMs aren't ideal for 2D channels because it typically includes the water surface and not the channel bottom.
 - Use bathymetry where it exists. When only using the stage-volume data, there was a 0.5 ft discrepancy between observed and simulated stages
 - MCWD advisors found improvements in model by, changing from the Green-Ampt to vertical layers from SSURGO and creating multiple groundwater regions.
 - 12,000-15,000 groundwater nodes for each groundwater region.
 - Siddharth mentioned that he prepared a report on the pilot study concerning the items that he did. He will send a copy of this report.
 - Pending intended use of the model there may be benefit in multiple models with varying detail to support answering different questions. For this project a single model will be developed, but future application may consider more than one.

Watershed overview of surface water features

- Setting the stage to show the watershed characteristics

- Surface water storage features: 20% of the watershed is represented in surface storage features.
 - Most data are from DNR and MCWD wetland survey.
 - DNR has bathymetry for many of the larger lakes, MCWD has bathymetry for a lot of the smaller water bodies.
 - Some DNR data intersects with MCWD data.
 - There are streams/channels/ditches in the watershed that aren't included in the DNR data.
 - 800 water bodies and 6,000 individual wetland features.
 - DNR stream information shows 52 miles of streams; 22 are Minnehaha Creek.
 - Wetlands are mostly in the upper watershed.
 - MCWD measured cross sections for Minnehaha Creek last year and gave data to HDR. They are open to collecting more data if needed. Gaps in cross section locations are typically at locations of recent built projects which have project specific data.
 - Consider how to merge the surface and bathymetry and cross section data.
 - It is important to be as detailed as possible when building the 1D channels, as they are difficult to edit if any changes arise. 2D meshes are easy to change but 1D features are not. If the 1D stage storage volume does not match the DEM, it can cause issues with the transfer to the groundwater region.
 - Search the data archives before MCWD goes back in the field. There is a GIS layer that is more inclusive (Interfluve).
 - The model needs to characterize the portions of Minnehaha Creek that run through lakes.
 - Need to identify the minimum threshold for surface water bodies to include.
 - Interfluve performed analysis of stream ordering in the District, available online, this information should be downloaded and reviewed for integration into the modeling effort.
 - MCWD has some wetland bathymetry developed through vegetation surveys
- Storm sewer pipes:
 - There are more pipe infrastructure data in the lower watershed; missing data in Edina, Orono, and Medina.
 - As part of a separate effort MCWD identified missing culvert locations and have begun to systematically collect those data for use in the model build.
 - The DNR data does not contain many manmade channels. Drawing in manmade channel links may be required.

4. Workshop 2: Surface Water Model Build (9:50 – 11:40 am)

a. Model Domain and Boundary Conditions

- Modeling tradeoffs

- Core needs: Model should be used for short- and long-term planning, in both flood and drought conditions, with reasonable run times.
 - Localized flooding will be captured; level of detail to be determined.
 - There is a tradeoff between level of detail and granularity of evaluation vs model runtime, model update, and model maintenance requirements.
- Boundary conditions: The hydrologic boundary that drains to the creek is slightly different from the administrative boundary.
 - Follow the hydrologic boundary.
 - Assume no flow leaving the boundaries.

b. 1D Storm Sewer Network

- Determine how to model the storm sewer network, including the level of modeling detail.
 - When determining level of detail, consider what element of the system is the limiting factor causing the flooding. For instance, are the inlets undersized and not able to allow all the water that enters the pipe, is the pipe undersized and not able to convey the flow downstream or is there a tailwater influence resulting in pipe backups.
 - If computational time becomes an issue, each model domain could be further subdivided.
 - One option is to have mapped basins entering into predefined locations along the pipe network such as inlets or manhole locations.
 - Con: flood inundation not mapped upstream of the location where water enters the 1D network.
 - Pro: limits 2D mesh, improves runtime, and depending on size of mapped basin most of the inundation may be post-processed from the model results at the inlet/manhole locations. Does not remove any input data resolution.
 - Consider modeling 2D mapped basins with 1D node outlets.
 - Blue spot method to identify the upstream limits of storm sewer inclusion proposed by Siddarth
 - Start with a 2D mesh over model area, identify blue spots (depressional areas of flooding that would be unrecognized if the pipe network was omitted), define “blue spot” as new mapped basin location with extended 1D network to assure that these flood-risk areas are accurately accounted for in the model.
 - Consider reaching out to individual communities to review these “blue spots” to confirm they have history of flooding and to increase early confidence in the model.
 - Include Groundwater in this analysis.
 - Consider using pond control volumes instead of mapped basins.
 - Pro: Allows visualization of flooding within model.

- Con: Omits lag time and assumes precipitation is immediately at the connection with the 1D network.
- Many urbanized communities are looking to upsize pipes. Consider how to model proposed upsizing of pipes.
 - Modeling mapped basins would allow upsizing pipes, but not the addition of grate inlets.
 - Start with 2D mesh, then make mapped basins for the areas that are not known to flood. For the areas that are known to flood and/or convey flow maintain the 2D mesh.
 - Brian noted most communities are targeting 12" diameter pipes and larger for upsizing. This could be considered to support identification of which conduits should be included in the model along with reviewing "blue spot" locations as described above.
- MCWD interested in reviewing q blue spot exercise with initial model setup/results with some of the downstream watershed communities (St. Louis Park, Edina, Mpls) to correlate their known flood areas with model flood areas (blue spots). HDR to create plan for model progression to "blue spot" identification. MCWD to create a plan for scheduling community involvement relative to project model schedule – likely between initial and final model build. Community involvement/engagement is important and may need to occur in parallel with continuation of the model build, calibration, and validation to deliver a final product on schedule.

c. Overland Flow

- Overland flow regions:
 - HDR presented preliminary overland flow regions for the lower watershed, which included approximately 50 individual regions.
 - Warren recommends breaking the lower watershed into less overland flow regions (3 max). Warren noted that having separate overland flow regions doesn't speed up the calculations because these can be done using parallel cores solving the finite volume equations. It's the groundwater regions that need to be run on the same processor because of the matrix it is solving. Siddharth and Warren recommended multiple overland regions if you want to see the volume of flow from the regions, otherwise, a single OF region may suffice.
 - The 2D mesh can be varied in the level of definition (coarser vs. finer mesh) to account for the different regions. More definition can be provided to an important area even if only 1 OF region is used.
- 2D elements such as breaklines and breakpoint patterns are defined in each overflow region. Re-specifying mesh generation parameters for many overland flow regions can become cumbersome if many overland flow regions are delineated.

- Wetlands and open sheet flow areas may not need mapped basins if it is more appropriate to use rain-on-grid. These areas will be defined during model build as-needed.

d. 1D vs. 2D Runoff, Storage, and Channels

- The mapped basin approach will not sacrifice resolution.
- Siddharth suggests pond control volumes for wetlands.
- How to capture Lake Minnetonka in the model:
 - Use separate pond control volumes connected by bridges.
 - Level pool for each pond control volume.
- We could have a depth storage curve for surface water bodies but without bathymetry, the groundwater interactions may be inaccurately modeled.
- Where there isn't good bathymetry Warren recommended editing the terrain so the bottom of the pond is at least 5 feet below the elevation that the water will never get below. In features anticipated to always be wet, the terrain needs to remain wet through the full run period. Need a good understanding of wetlands' live storage and outlets.
 - Siddharth: There are online high-resolution datasets that can help determine whether a wetland is wet or dry.
- Can include pond control volumes to represent stormwater treatment facilities within mapped basins.
 - If water pools on the surface for extended periods, a pond control volume would accurately handle seepage into the ground.
- How far upstream to include 1D channels vs overland flow pathways:
 - Treat the channel as a 1D control volume if the control volume can easily be delineated. If not, use a break line in the DEM.
 - Not including 1D channels might end up being more work.
 - Siddharth recommends using 1D channels where the range of flows is contained within the 1D channel section.
- Fine scale models often are delineated to go to swales instead of impervious areas, but this model will not be that detailed.

5. Workshop Outcomes:

Technical topics where decisions were made during the workshop:

- Model domain: It was decided that the model domain will be the watershed's hydrologic boundary.
- Bathymetry: Integrate bathymetric data with LiDAR into a continuous topo-bathy dataset instead of using just stage storage data at a storage feature (i.e. pond/wetland).
- 1D Channels: Use 1D channels far enough upstream to where the topographic data makes it difficult to define a channel.

- 1D Pond Control Volumes: Use 1D Pond Control Volumes in all continuously wet storage features (lakes, ponds, wetlands).
- Lake Minnetonka: The separate portions of Lake Minnetonka will be modeled as separate pond control volumes connected by bridges, culverts, or simple channels. Exact split was not defined.

Technical topics where a direction was identified, but specific decisions were not made within the workshop – these will be further reviewed with the technical team after the approach is advanced:

- 1D vs. 2D modeling: a blue spot identification approach was identified to support selection of 1D storm sewer extents, and locations of localized flooding. Additionally, this information would support selection of mapped basin vs. 2D overland flow areas and whether pond control volumes would be valuable to map inundation in these areas.
- Overland flow regions: It was suggested that the lower watershed use a limited number of overland flow regions, with Warren suggesting 3 or less may be a reasonable starting point.

Technical topics that have been identified but ongoing discussion will be required with the technical team:

- Minimum water body size: through Task 3 progression HDR and MCWD will determine the minimum size threshold for which water bodies to include in the model.
- Bathymetry: Define best method to identify and merge bathymetry with cross section data.
- Localized flooding: Create methods for identifying/verifying the locations of localized flooding.

Action Items:

- HDR
 - o Advance and review plan for “blue spot” exercise.
- MCWD
 - o Develop plan for engaging partner communities to identify localized flooding locations where more refined modeling may be of interest.
- Siddharth:
 - o Send a copy of the pilot study report.

Appendix A-3 Workshop 2a Meeting Notes

Short Term Evaluation

Instructions

1. Review Surface Water Model Approach Pros and Cons MS Word Document
2. In below two matrices, characterize how well each surface water model approach would perform relative to each of the objectives. Use one of three classifications: negative, neutral, or positive. Include a text description justifying each classification.
3. Prepare to discuss at the workshop 12/17/2024
4. Provide matrix spreadsheet to HDR (nicholas.thomas@hdrinc.com) prior to workshop for documentation purposes.

Definitions

Local Flooding: Flooding due to conveyance limitations in storm sewer network

Regional Flooding: Flooding on receiving waterbodies (Example: Minnehaha Creek, Six Mile Creek, Lake Minnetonka)

Evaluation Matrix

Characterization of flood extent and duration using *NOAA Atlas 14 precipitation events and future precipitation event based scenarios*.

Objectives	Surface Water Model Approach		
	Mostly Mapped Basins	Mostly 2D Rain on Grid	Hybrid
Capability to identify and understand local flooding areas <i>See local flooding definition</i>	OVERALL - Neutral MCWD - Near-Neutral/Negative . May miss some flooding in areas where there are many small pipes. Challenges with processing/visualizing information. SS - Neutral . Doesn't account for water getting 'stuck' within a node. Challenges determining where flooding occurs within node if it is flooding. Fairly easy to change areas to 2D/Hybrid once this is implemented. Suggested development of Mapped Basins regardless of approach. WM - HDR - Neutral , delineated subbasins may have additional value to stakeholders.	OVERALL - Positive WM - Positive . Still requires thoughtful placement of model elements, 2D isn't a solve-all. Saves model setup time compared to Mapped Basins. SS - more difficult to change from 2D to Mapped basin once a model area is built. HDR - Positive , ease of evaluation/interpretation of results. Requires need to include denser 1D network, related to laterals, etc.	OVERALL - Neutral HDR - Neutral/Negative , introduces subjectivity, inherit model complexity and inconsistency, difficult to manage explain choices to stakeholders MCWD - Neutral/Negative - Hybrid regions may be necessary depending on lack of data. SS - WM - Positive . Should include clear definitions of what is mapped basins vs. what is 2D. ie 2D in non-dendritic areas and known flooding areas.
Capability to identify and understand regional flooding areas <i>See regional flooding definition</i>	OVERALL - Positive MCWD - Positive , lower watershed does not include much surface storage; regional flooding is driven by 1D conveyance SS - ease of calibration if data is available. WM - Neutral , requires more care when defining river channels. HDR - Positive , stage area nodes can be cut directly from surfaces, compared to a 2-d approach that is limited by cell-size.	OVERALL - Positive MCWD - Positive SS - difficult to calibrate unless fine resolution data is available. If lake-governed water level causes water to dynamically seep out into urban areas a 2D model will be able to more easily identify this. WM - Positive , Advantage for when riverine flooding flows out of bank. HDR - Neutral ,	OVERALL - Neutral MCWD - Neutral SS - Positive , simple 1D hydrology for feeding basins to provide flow conditions, ~50% runtime efficiency increases compared to fully 2d approach. WM - HDR - Neutral , concerns with stakeholder interpretation of why certain areas are different than others, added time to define hybrid approach.
Evaluate regional policy or stormwater practice implementation <i>Examples: policy regulation scenarios, regional application of best management practices, changes in pipe size or intake structure</i>	OVERALL - Positive MCWD - SS - Positive/Neutral , may require additional postprocessing to help <i>identify</i> policy changes. WM - Positive Requires postprocessing for impacted structure evaluation. HDR - Easiest to iterate scenarios where there are changes in storage. May require less post-processing for evaluation of structures impacted.	OVERALL - Positive MCWD - SS - Positive , May be able to more easily and rapidly identify <i>why</i> things are happening beyond just <i>that</i> things are happening, when compared to Mapped Basins. WM - Positive . Requires postprocessing for impacted structure evaluation. HDR - Although small scale, 2D would allow for better analysis of improvements to curblines.	OVERALL - Positive MCWD - SS - Positive WM - Positive HDR -
Evaluate planned individual regional scale projects <i>Examples: regional detention, wetland complex, new housing development</i>	OVERALL - Positive MCWD - Positive . Easiest to use in undeveloped areas. Easiest to incorporate large development scenarios SS - Neutral . The impact of changes on the results may be magnified compared to 2D approach, since things are lumped. WM - Positive , easiest (but not by much) to incorporate regional scale projects due to the nature of the computational network. HDR - Positive Ease of incorporating design iterations.	OVERALL - Positive MCWD - Positive . May lead to better results in urban areas. SS - Positive WM - Neutral , need to be mindful of changes to computational network when comparing pre/post scenarios. Difficulties using the subset-extract tool. HDR - Neutral Advantages to detailed design, but may be cumbersome during design iterations.	OVERALL - Neutral MCWD - SS - WM - HDR - Neutral
Describing groundwater/surface water interaction <i>Examples: Impact of groundwater on initial and continuous surface storage, impact of groundwater on baseflow conditions</i>	OVERALL - Negative MCWD - Negative SS - Negative WM - Neutral . Requires more effort than 2d HDR - Negative . In known areas of interest, 2D would be used.	OVERALL - Positive MCWD - Positive SS - Positive WM - Positive HDR - Positive . Excels at GW/SW interaction	OVERALL - Neutral MCWD - Neutral SS - Positive WM - Neutral HDR - Neutral

Lower focus compared to regional policy

*MCWD is based on Brian Beck, did not confer with Becky/Kate.

Long Term Evaluation

Instructions

1. Review Surface Water Model Approach Pros and Cons MS Word Document
2. In below two matrices, characterize how well each surface water model approach would perform relative to each of the objectives. Use one of three classifications: negative, neutral, or positive. Include a text description justifying each classification.
3. Prepare to discuss at the workshop 12/17/2024
4. Provide matrix spreadsheet to HDR (nicholas.thomas@hdrinc.com) prior to workshop for documentation purposes.

Definitions

Local Flooding: Flooding due to conveyance limitations in storm sewer network

Regional Flooding: Flooding on receiving waterbodies (Example: Minnehaha Creek, Six Mile Creek, Lake Minnetonka)

Evaluation Matrix

Characterization of flood extent and duration using long term historic precipitation and future climate projections.

Objectives	Surface Water Model Approach		
	Mostly Mapped Basins	Mostly 2D Rain on Grid	Hybrid
Capability to identify and understand local flooding areas <i>See local flooding definition</i>		MCWD - 2nd Phase model will be a regional/long-term model, after localized flooding is understood. Exacerbates the runtime, questions how much benefit this has. Infiltration in the lower watershed becomes more important. SS - may want to look at simplifications to 2d areas during long-term model.	
Capability to identify and understand regional flooding areas <i>See regional flooding definition</i>			
Evaluate regional policy or stormwater practice implementation <i>Examples: policy regulation scenarios, regional application of best management practices, changes in pipe size or intake structure</i>			
Evaluate planned individual regional scale projects <i>Examples: regional detention, wetland complex, new housing development</i>			
Describing groundwater/surface water interaction <i>Examples: Impact of groundwater on initial and continuous surface storage, impact of ground on baseflow conditions</i>			

Appendix A-4: Workshop 3 Meeting Minutes

<i>Project:</i>	MCWD 2D Model Build	
<i>Subject:</i>	Workshop 3: Groundwater Model Build	
<i>Date:</i>	Thursday, August 08, 2024	
<i>Location:</i>	HDR Office Conference Room 6A 1601 Utica Avenue South Suite 600 St. Louis Park, MN 55416-3400	
<i>Attendees:</i>	Brian Beck (MCWD) James Wisker (MCWD) Becky Christopher (MCWD) Rebecca Neal (MCWD) Siddharth Saksena (VT) - Virtual F. Warren McKinnie (Streamline) - Virtual Kelton Barr ()	Andrew Judd (HDR) Nick Thomas (HDR) Ryan Fucci (HDR) Alex Miller (HDR) Cody Barrett (HDR) Ken Trefzger (HDR) - Virtual Amber Ritchie (HDR) - Virtual

1. Introductions to New Members (9:00 - 9:10 am)

2. Workshop 3 Overview (9:10 – 9:20 am)

Workshop 1 Review:

- Our goal is to develop a watershed model that represents short and long-term conditions well and serves as an effective planning tool for the future.
 - Long-term analysis: Understand water balance, including surface and groundwater interactions, under wet or dry cycles.
 - Short-term analysis: Evaluate the impact of specific rainfall events on flooding and stormwater infrastructure performance.
- Watershed model applications: Evaluate future policies or projects at a watershed or localized scale, assess impacts of changes (climate, operations, land-use), and gain stakeholder acceptance.
- A key connection of Workshop 1 (Goal Setting and Prioritization) to Workshop 3 (Groundwater Model Build) is appropriate characterization of the groundwater/surface water interactions and the model's ability to represent low flow drought conditions.

Workshop 3 Objectives:

- Discuss and develop framework for decision making throughout the model build process.
- Priorities for the Groundwater elements of the model
 - The groundwater elements can reproduce watershed water balance
 - Regional & localized variability can be captured by the model

- It's unclear at this point how well we'll be able to predict localized flooding on a property/parcel scale due to groundwater

3. Lessons Learned from Pilot Study (9:20 – 9:40 am)

- A set value below the DEM is not a good way to approximate the initial water table elevation
 - o Leverage known water table elevations such as lakes/monitoring wells whenever possible
 - o Water table results from a simulation without rainfall can be reimported as a more stabilized initial condition.
- Depth to bedrock and confining layers in the glacial material above the bedrock will impact how much storage space is available for the surficial aquifer

4. Workshop 3: Groundwater Model Build (9:40 – 10:40 am)

Watershed overview of groundwater features

- Subsurface dynamics vary between the upper and lower watersheds
 - o Upper watershed: Many of the quaternary deposits in the upper watershed are made up of thick fine-grained tills acting as aquitards, resulting in limited connectivity to the deeper layers including connectivity to the bedrock. Significant municipal water supply pumping does occur within the bedrock layers beneath the upper watershed (Prairie du Chein and Jordan). In the upper watershed, water table changes and vertical fluxes occur over long timescales and seasonal changes are muted.
 - o Lower watershed: Prevalence of coarse-grained layers in the quaternary deposits result in more infiltration and vertical water transfer. Seasonal changes in water table can be observed.
 - o Some of the bedrock aquifers (Platteville formation) limit vertical movement of water but are highly transmissive laterally and are colloquially noted as "aquitardifers".
 - o Portions of Minnehaha Creek are gaining and other portions are losing
- Modeling Considerations
 - o Bedrock and composition and thickness of overlying quaternary deposits can help indicate flow rates through layers.
 - o Watershed locations with increased prevalence and thickness of near surface sand layers, indicating increased SW/GW connectivity, should include a deeper groundwater model domain which may consist of multiple coarse and fine-grained layers. Where fine-grained tills are thick and vertical water movement is limited, we may be able to simplify the modeling approach.
 - o There is not anticipated to be a significant amount of conductivity between the upper and lower watershed groundwater.
 - o Tritium concentration can guide "age of water" and time-of-travel assumptions.
 - o Groundwater modeling should focus on the surficial aquifer.

- o Surface water cells and groundwater mesh dynamically communicate, integrating where infiltration occurs due to land use variability, and where ground water emerges due to rising water tables. and other effects.

General Discussion

- This modeling is important as it allows the District to shift from narrative-based discussions to data and model-driven groundwater analysis.
- The team should document trade-offs in technical modeling decisions and communicate them in a way that non-technical people can easily understand. Consider creating an evaluation matrix for high-level decisions. Another option would be a summary document following the model build that provides a non-technical narrative of these decisions.
- Create a modelers log which tracks incremental decisions in the model build at a more granular scale than the guidance documentation.

2D Groundwater Modeling Introduction

- Groundwater mesh contains horizontal cells connecting the surface to model bottom
 - o Bedrock can be modeled with either homogeneous soil or discrete layers.
 - o Updated Hennepin County data and metadata can be utilized.
- Areas where higher model resolution is desired may be good locations for break out models and future evaluations:
 - o In historical channels and wetlands which have been developed over time, especially around the chain of lakes where groundwater has caused flooding.
 - o Where known perched groundwater tables exist. Some neighborhood-level data exists; more can be collected as needed.

Groundwater Model Lateral Extents

- Groundwater and surface water mesh domains don't always match.
 - o Lateral limits must be paired with a boundary condition
 - They may be influenced by the level of confidence in our assumptions.
- It would be valuable to locate the preliminary lateral extents outside of the surface watershed boundary. This allows for the lateral limits to be better aligned with locations of known boundary conditions (head, flux, no flow) and for uncertainty in these inputs to be located away from the area of interest (watershed).
- Known head conditions along the lateral extents from measured groundwater levels in wells and stages from surface water bodies would be appropriate boundary conditions.
 - o Siddarth: Using as many known points as possible will be helpful
 - o Kelton: Caution against using the Mississippi as a known point. It's much lower in elevation than most of the Minnehaha Creek Watershed. Groundwater is raised within the domain by the creek.
 - o Groundwater materials can be refined near Minnehaha Falls to mimic connectivity at this location.

- A realistic average head condition that can be applied across all simulations could be favorable to collecting historical data for every simulation. However, it may depend on the influence of boundary conditions heads to the model results. The boundary heads may need to vary within a simulation (e.g. seasonally) or between different simulation runs to capture initial conditions and system response within the simulation period appropriately.
- Interpolations can be made between known boundary condition head points.
 - o Siddarth: A function-based interpolation may be more representative than a linear interpolation. Include multipliers at each point that capture seasonal variability.
 - o Long-term well records should be analyzed to support multipliers by location. It won't capture all local fluctuations but will be better than large linear interpolations.

Groundwater Model Bottom Extents

- Timescale of simulations should be considered in the bottom extent decision.
 - o If we have future scenarios without localized flow systems, we might want to include some bedrock. If future scenarios are localized, we might want to go shallower.
- In the lower watershed, a combination of Platteville and lower till could be ok.
 - o Pilot study found that some mid-level sand layers are important for hydrogeology, it may be beneficial to include those.
- Siddarth: Abrupt changes between vertical layers could be a problem
 - o A 10' change between adjacent GW cells may work, but a 100' change would lead to errors.
- A confining till layer may be harder to identify and create within the model. It would come with additional uncertainties.
- In lower watershed where there's more permeability, we want to make sure its deep enough to capture the surface/groundwater interaction
 - o Kelton: The deeper the model extends, the more there is to consider.
 - Ex.) pumping from municipalities outside the domain.
- Metro model 3 may not be very useful as the surficial layers were intended to account for reasonable infiltration to support groundwater recharge rather than localized near surface flow systems.

Subsurface Representation: Capturing Surficial Layers

- Kelton: Through an MCES project in 2020, HDR and Kelton applied a process to capture quaternary layers. The subsurface characterization could use the same approach
 - o Took metadata about 3D info in aquifers and aquitards
 - o Assess downward flow (based on thickness of material, hydraulic gradient, and conductivity)
 - o Calculate aggregate vertical permeability
 - o Calculate overall vertical permeability and time of travel
 - Can calibrate time of travel result with tritium concentration in well data

- o Create a time-of-travel map for across watershed. We could apply same approach to the vertical model to characterize subsurface.
- Would homogenous system work? Do we need more discrete layers?
 - o SSURGO data only works for certain thickness and is assumed to be leveraged for the nearest surficial soils.
 - o Homogenous system:
 - Potentially improve runtimes but may less accurately capture GW flow
 - Minimal effect on short term flooding scenarios
 - Less complexity, but assumptions may lead to unrealistic response within the model.
 - o Discrete layers:
 - Groundwater finds a more realistic path of least resistance
 - More accurate for long-term scenarios
 - We may want multiple layers in lower quaternary layers
 - Siddarth: Stratify SSURGO layers as much as possible because there's methodology and data available. There are lots of options in infiltration zones
 - Delineating the creek and outside boundaries thoughtfully may help define discrete zones inside and shrink runtimes
 - o Siddarth: My current preference is to use homogenous zones for better surface water results. However, if we're more interested in groundwater levels long term, multiple layers may be better. Depends on what question we want to answer
 - o James: We care most about surficial aquifer layer in this project
 - o Kelton: Residence time is not the most important thing because head at the upper table will impact those times immediately.
 - o Brian: We need to come up with a rationale and document how we define the layers to best service the model goals
 - Test how much vertical layer refinement influences runtimes and decide on an approach from there

Subsurface Representation: Groundwater Flow Regions

- Groundwater flow regions to be delineated for optimal computational speed and physical representation
 - o Groundwater regions cannot communicate with each other except at location of surface ponding where water can exchange through the surface domain, or if a boundary condition is supplied.
 - o 12k-15k cells per region is suggested for computational efficiency.
 - o Upper watershed contains disconnected lakes
 - Warren: Using creek locations is a reasonable approximation for GW region divides. Since the groundwater regions can't communicate with each other it is valuable to look at water tables over time to see if there's a significant difference between them. If there is, you may decide to combine regions to make it more physically representative.

- Siddarth: Run a preliminary simulation run to see exported water table results from one simulation and import and new initial condition. Sometimes using smoothing between regions and starting the water table in a more realistic location can help alleviate large discrepancies between regions.
- Brian: majority of creeks dry up in summer, so lakes may be best approximation.
- SSURGO ranges for subsurface parameters are acceptable
 - o Brian: There are permits which include additional infiltration/geotechnical data, but it is likely more work than it's worth
 - o Siddarth: SSURGO is my go-to and the best starting point.
 - o Warren: If there's no existing data source that's better, stay with SSURGO. You can always calibrate later. However, porosity in SSURGO is typically higher. That parameter may need to be modified in the model. Saturated conductivity and SSURGO conductivity values are usually the first parameters to adjust in calibration.
- Additional Closing Remarks:
 - o We didn't dig into data collection or assumptions on surface water (ponds and wetlands). Followup with technical advisory group as this moves forward.
 - o There will be more opportunities to collect data after the initial model build

5. Workshop Outcomes:

Technical topics where decisions were made during the workshop:

- Subsurface Initial Parameters: Use SSURGO data for near surface and Geologic Atlas Data, Homogeneous or Layered, from the HDR (2020) study.
- Groundwater Model Lateral Extent: Approach to include a groundwater domain that is larger than the surface domain was chosen. The location should be collocated with areas of known head (waterbodies or well locations with groundwater levels). The exact boundary requires refinement but a tentative was defined based on nearby waterbodies and wellpoints.
- Groundwater Model Lateral Boundary Condition: Use known head as lateral boundary points with interpolation between known head locations. Develop either longer term average or seasonally varying boundary condition depending on range of variability and influence on model results. Consider a non-linear function to interpolate between known head locations.
- Subsurface Representation (near surface): Upper quaternary or near surface soils will be represented using SSURGO layering and initial parameters.

Technical topics where a direction was identified, but specific decisions were not made within the workshop – these will be further reviewed with the technical team after the approach is advanced:

- Groundwater Model Lower Extent: Lower model domain should consider either bedrock or a confining till layer.

- Subsurface Representation (deeper): Lower quaternary soils may be layered based on Geologic Atlas Data or homogenized similar to the process applied by HDR (2020).
- Groundwater Flow Region Boundaries: Boundaries should be set along creeks, streams, lakes, and other features that are continuously wet or frequently wet. Exact locations have yet to be defined.

Technical topics that have been identified but ongoing discussion will be required with the technical team:

- Groundwater Model Lower Boundary Condition: It is anticipated that a seepage or flow loss boundary condition will be used for the lower boundary, but additional review is required to determine appropriate source of information and selected seepage rates.

Action Items:

- Documented in model outcomes. HDR to advance and review with technical team.

Appendix A-5 Workshop 4 Meeting Minutes

<i>Project:</i>	MCWD 2D Model Build	
<i>Subject:</i>	Workshop 4: Calibration and Validation	
<i>Date:</i>	Wednesday, April 09, 2025	
<i>Location:</i>	Virtual	
<i>Attendees:</i>	Brian Beck (MCWD) Siddharth Saksena (VT) F. Warren McKinnie (Streamline)	Andrew Judd (HDR) Nick Thomas (HDR) Alex Miller (HDR) Sam Brandt (HDR)

1. Introductions (1:00 - 1:05 pm)

2. Workshop Overview (1:05 – 1:15 pm)

Review of Workshops 1-3

- Recapped surface and groundwater model builds and methods
- Siddharth asks for confirmation HDR is still using 1D channels, Nick confirms

3. System Response Overview (1:15 – 1:30pm)

System Response/MCWD Overview from Brian

- Lower watershed largely lacks storage, wetlands filled in with development
 - Upper watershed has more wetlands/storage
- Soils in lower watershed generally allow for more infiltration and/or are developed and may not be reflective of the SSURGO classification
- Water Level Monitoring
 - Peaks are more intense as you travel down Minnehaha Creek
 - Brian notes that the upper portion of the lower watershed, just downstream from Gray's Bay Dam, still has notable wetlands which result in peak flow dampening
 - Wetland water levels show evapotranspiration is a driver of system response in summer months.
 - Uncalibrated hydrologic models have historically overestimated peaks and underestimated base flow
- Edina and Minneapolis have much higher runoff
 - Storage in Minnetonka and SLP seem to reduce storm peaks
 - A or B soils in lower watershed but lots of compaction
- MCWD has built both P8 and StormWise models that ended up having similar results, both requiring increased infiltration to improve water balance, baseflow, and peak flow representation.

Comments

- Siddharth notes that understanding future operation of the dam will be important
 - o Brian says operations plan is based on elevation level of the lake
- Brian has calculated continuous dam discharges going back to 2018 using lake levels and tailwater conditions.
- Siddharth asks how HDR will calculate ET – important for the upper watershed
 - o Brian has ET calcs based on real time data
 - o University of Minnesota has an ET reference used to check calcs
 - o Siddharth says satellite-based data for ET may be useful
 - o Project team will rely upon ET calculations validated with U of M measured data. Where anomalies exist or as a watershed wide model validation, satellite data may be used.
- Warren says that PCVs are crucial for calculating ET from lakes in mapped basin type surface water modeling

4. Calibration & Validation Approach (1:30 – 2:00 pm)

Calibration and Validation Definitions

Strategy Overview

- Warren says that SSURGO saturated conductivities tend to be too high compared to actual conditions
 - o May want to reference geotechnical logs local to the project
 - o Brian suggests finding or collecting data on representative soils within the watershed
 - o Initial models will be parameterized with SSURGO representative parameters with the anticipation they will be refined in calibration. Refinement will rely upon SSURGO noted parameter ranges and in-situ infiltration testing where available.
- Siddharth emphasizes the importance of having representative results for both high and low flow events
 - o Important to consider how parameters impact each other
 - o For large scale models, focus on making sure the physics and model connectivity are accurate then adjust model parameters at the end
- Warren underscores the importance of calibrating to both extremes and low flows
 - o He further suggested that related parameters should be adjusted together to avoid unrealistic inconsistencies in simulated results.
 - o 2D models typically are much faster to calibrate as they better reflect the physics

Sensitivity Analysis

- Nick notes that HDR will plan to consider related parameters in the calibration and potentially as part of the sensitivity analysis per previous discussion
- Warren says that porosity and hydraulic conductivity may be impacted by urban compaction/development
 - o Alex asks if HDR should set up map layers to account for this

- Warren says urban soils should generally be unclassified, could change the map zone to indicate urban areas
- o Initial model build will rely upon SSURGO classification and look to refine these inputs relative to urbanization as part of the calibration/validation task
- Warren says that for initial conditions, spin up (~1yr) the normal conditions before running
 - o Difficult to separate ground and surface water here
 - o Siddharth says HDR can simplify ground surface here for computational efficiency
- Nick asks if we are missing parameters from our list of considerations
 - o Siddharth says impervious percentage has a big impact on the runoff generation and is most relevant to a mapped basin approach since the 2D approach inherently describes the surface variability.

Calibration Process

- Nick asks for comments on the calibration process slide
 - o Warren says, for mapped basins additional calibration parameters may include the unit hydrograph and time of concentration
 - o Siddharth says the mass balance error should be reduced before moving into calibration (<5%, Warren shoots for <2-3%)
 - Mass balance error is evaluated at each node and on a model wide basis and accounts for all inflows, outflows, and storage in the model.
 - Nick confirms with Warren that this is driven by the numerical solution of the model and can be addressed through improved mesh generation (short sides) and connectivity of different model, amongst others.
 - o Siddharth asks what time window we plan to use for our calibration
 - Brian agrees with Nick that we cannot be particular about specific event at this time
 - Events should be selected based on specific goals for each event
 - Siddharth says HDR should aim for different types of representation, timescale is important as well
 - Andrew says that HDR may want to select events that can isolate the upper or lower watershed
 - Siddharth likes the idea of selecting an event that isolates the lower watershed

5. Data Type, Location, & Availability (2:00 – 2:30 pm)

Review of Data Availability

- Brian says that MCWD has added ~10 new sites since sending this data over last year (for surface water at least)
 - o Nick confirms that most new gages cover 2024/2025 so far

- o 8 or more of the stream stage sites have rating curves developed
 - In the lower watershed surface water graphic, the ones we have highlighted should have rating curves
 - Mill Pond in Edina has a weir which MCWD has used to estimate flow
 - Warren suggests if not matching observations well, reviewing model link results to determine if flows are backwater influenced.
- o Brian says that they have project specific pipe flow, particularly in the lower watershed which could be used to get a better understanding of runoff/response
- o Andrew asks if the MCWD gages will be maintained for the foreseeable future
 - Brian says not necessarily but likely at least as long as the project requires
- o Brian says we could potentially install level sensors to document how water levels differ across Lake Minnetonka
- Alex asks about overlap between calibration events and gages
 - o Nick says that HDR can vary which gages we are leveraging for calibration based on events
 - o Andrew says HDR should aim to hold 2-3 gages across calibrations with different events for consistency
 - o Siddharth says HDR should do some analysis on data from gages (flow and precipitation) to see if patterns/responses have changed during the period of record
 - o Siddharth warns that Atlas-14 only captures data through 2012 and won't be representative of more recent conditions
 - o Brian says we have both the driest and wettest period on record (within the last ~6 years) at many gages
- Siddharth says HDR should have different calibration quality criteria for surface water vs groundwater
- Brian says sediment cores have been collected for lake bottoms that can give an indication of sediment type
 - o University of Minnesota may have a repository of core data

6. Historical Events to Consider

Event Types to Consider

- Brian says HDR should consider how calibration and validation events are delineated. Calibration events should target a particular system response, where validation events may try to encompass all of the critical system response characteristics
- Warren asks if there are any events Brian wants to include, specifically
 - o 2014 flood of record, multiple large events in a row. Warren suggests including events like this which resonate with stakeholders.

- o Siddharth recommends including events that have cause nuisance flooding that may be muted if we only focused on the creek
- For calibration, team agrees that it is most effective to simulated upper and lower watershed responses and perform calibrations independently
- Andrew says HDR should consider spatial rainfall patterns when targeting events
- Nick asks if the same events should be chosen for the upper and lower watershed
 - o Siddharth says to consider doing an analysis of the rainfall time series for each cell to understand spatial-temporal variability
 - o Group generally concurs that the upper and lower do not need to use the same events
- Brian recommends also looking for events that have homogenous coverage across the watershed but also may capture localized hot spots that could get larger watershed response and local nuisance responses.

7. Performance Metrics (2:30 – 2:40 pm)

Statistical Performance Metrics

- Warren recommends including root mean square error, mean error. Siddharth expands that these metrics may be normalized so events can be compared more readily to one another.
- Siddhaarth says that, for hourly scales these metrics may be correlated in time and bias metrics. “Very good” for a daily scale could be “good” for an hourly scale
- Should also look at the log-scale of the time series data to see low flows better
- Siddharth says that for the time series plot (Muddy Creek), if HDR includes multiple events in the time series, we may want to normalize response metrics to rainfall to compare the overall performance

8. Critical Items for Model Build (2:40 - 3:00 pm)

- Siddharth
 - o Likes the approach in general
 - o The more work we do in the build itself will make calibration easier in the end and that calibration only occurs at the very end
- Warren
 - o Storm selection will be important, recommends having a discussion over storm selection before diving too far into analysis
 - o We will probably be pleasantly surprised with the limited amount of calibration needed as we add more detail
- Andrew
 - o Reiterates that we will need to hone in on what calibration parameters we are using and identify where gaps exist in the data we need
- Alex

- o Echoes Siddharth's comments of having a solid model build before calibration
 - o Notes importance of run times on calibration durations and project schedule
- Sam
 - o Improving and untangling stormwater infrastructure data for input to model
- Brian
 - o Representation of storage in upper/lower watershed

Next Steps

- HDR will continue with the model build in close collaboration with MCWD and begin reviewing observed precipitation data relative to stream flow and groundwater response to identify a suite of events for calibration and validation.
- MCWD will provide:
 - o Stream level locations and data installed in 2024 and 2025
 - o Stream rating curves where available
 - o Lake bottom sediment core information
- Technical Advisory Team will be engaged as the model build and calibration/validation continue.



Appendix B – Data Registry

Included as part of the electronic delivery package.



Appendix C – Detailed Data Refinement

Memo

Date: Tuesday, August 04, 2026
Project: 2-D Watershed-Wide Model
To: MCWD
From: HDR
Subject: Appendix C-1: Watershed Boundary Adjustment Process

Introduction

This document details the development of a new lower watershed boundary for better representation of overland flow with respect to the DEM and stormwater infrastructure used in the MCWD 2D Watershed-Wide Model. The ArcHydro extension of ArcGIS Pro, paired with ArcHydro technical papers, was used to delineate storm inlet drainage areas which were aggregated into a final updated lower watershed boundary.

Updated Lower Watershed Delineation

Required Components

1. Watershed DEM
2. Stormwater infrastructure inlets
3. Stormwater infrastructure pipes, for reference
4. Watershed boundary polygon
5. Watershed boundary polyline

First, watershed sinks were identified using sink identification approach 1 in *ArcHydro: Identifying and Managing Sinks*. This workflow requires a watershed DEM and identifies sinks, or depressional areas, that exist in the topography.

1. Sink Evaluation
 - a. This step identifies potential sinks within the watershed. No minimum threshold was used as to have more sinks to select from in the step to follow.
 - i. Input: Watershed DEM
 - ii. Outputs: Sink Polygons, Sink Drainage Area
2. Sink Selection
 - a. Select sinks output from the previous step with an area greater than 100 ft². These sinks will be the base features for delineating watershed drainage areas.

Next, artificial sinks were created by buffering MGIS inlets. These steps utilized section 4.2.1 of *ArcHydro – Stormwater Preprocessing and Analyses*.

1. Buffer Inlets

- a. MGIS inlets contained by and within 500 ft outside of the initial watershed boundary were buffered to 10 ft.
2. Assign Hydro ID to Inlet Buffers
 - a. Run the buffered MGIS inlets through the assign Hydro ID tool.
3. Append Inlets to Sinks
 - a. ArcHydro only requires a HydroID field, so any fields not shared by the buffered inlet and selected sink feature classes can be deleted.
 - b. Run the append tool to combine the inlets and selected sinks into one feature class, now referred to as the sink feature class
4. Dissolve Sinks
 - a. To prevent overlapping sink polygons and, subsequently, grouped sink delineations, run the dissolve tool on the sink feature class.

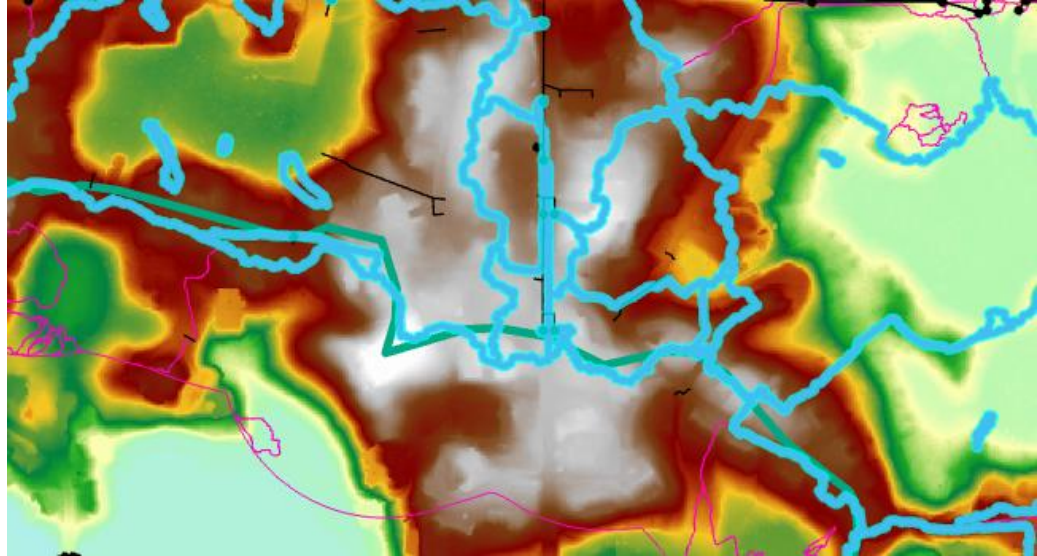
With the sink feature class created, use case 3 of *ArcHydro: Overview of Terrain Preprocessing Workflows* was used to delineate subwatersheds representing sink drainage areas.

1. Create Sink Structures
 - a. Inputs: Sink Polygon Feature Class, DEM
 - b. Output: Sink Polygons, Sink Polygon Raster, Sink Points, Sink Point Raster
2. Add DeepBurn Field to Sink Polygon Feature Class
 - a. Calculate Field
 - i. Field Name: DeepBurn
 - ii. Set DeepBurn = 650
3. Level DEM
 - a. Input: Sink Polygon Feature Class
 - b. Output: Leveled DEM
 - c. Input Fill Elevation Field: DeepBurn
4. Fill Sinks
 - a. Inputs: Leveled DEM, Sink Polygons
 - b. Output: Filled DEM
5. Flow Direction
 - a. Input: Filled DEM
 - b. Output: Flow Direction Raster
6. Adjust Flow Direction in Sinks
 - a. Inputs: Flow Direction Raster, Sink Point Raster, Sink Polygon Raster
 - b. Output: Sink Adjusted Flow Direction Raster
7. Sink Watershed Delineation
 - a. Inputs: Sink Adjusted Flow Direction Raster, Sink Point Raster, Sink Points
 - b. Outputs: Sink Watershed Raster, Sink Watersheds
8. Append Coastal Attachments
 - a. Inputs: Filled DEM, Sink Watershed Raster, Sink Watersheds

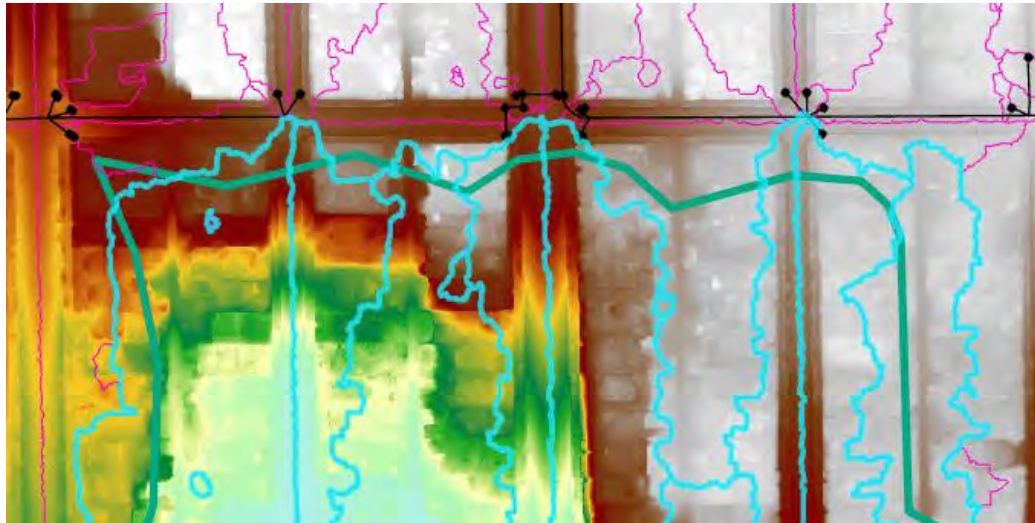
Next, the sink watershed delineation polygons were manually selected with respect to stormwater infrastructure and the existing watershed boundary. Here, stormwater infrastructure

was referenced as not to include inlets that drain outside of the watershed in the new watershed boundary's fringes. See below for examples.

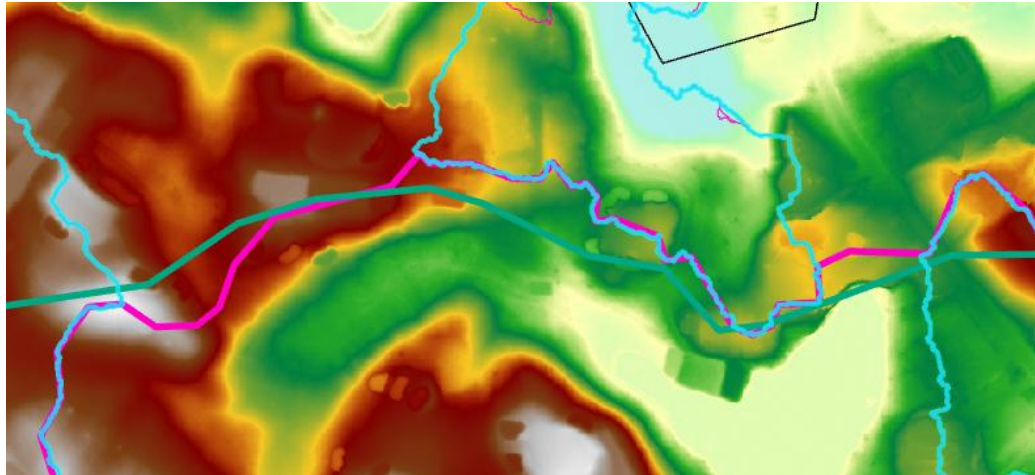
1. General Example (Existing Watershed Boundary = Green, Sink Delineations = Pink, Sink Delineations Selected for New Boundary = Light Blue, Stormwater Pipes/Inlets = Black)
 - a. The existing watershed boundary was referenced during the selection process. Where appropriate, delineations that coincided with the existing watershed boundary were selected.



2. Boundary Change Due to Stormwater Infrastructure (Existing Watershed Boundary = Green, Sink Delineations = Pink, Sink Delineations Selected for New Boundary = Light Blue, Stormwater Pipes/Inlets = Black)
 - a. As seen below, the right center polygon of which portions were included in the initial watershed boundary, was not selected. This is because the polygon drains to an inlet which transports water outside of the watershed.



3. Manual Splits to Sink Delineations (Existing Watershed Boundary = Green, Final Watershed Boundary = Pink, Existing Sink Delineations = Light Blue, Stormwater Pipes/Inlets = Black)
 - a. Where sink delineations connected with the outside of the existing watershed boundary, they were split by referencing the DEM and existing watershed boundary. These split polygons were then selected for use in the updated watershed boundary (see thick pink line below).



Finally, with sink delineations identified for use in the updated watershed boundary, merge all selected polygons. The result is a single polygon representing a watershed boundary that reflects both the DEM and stormwater infrastructure used for modeling.

1. Select all sink delineations representing the updated watershed boundary, including those on the interior.
2. Merge into one polygon
3. Run the Simplify Polygon tool on the new watershed boundary polygon
 - a. Simplification Algorithm: Retain Critical Bends (Wang-Muller)
 - b. Simplification Tolerance: 100ft
4. Run the Feature Vertices to Points tool on Simplify Polygon output
5. Run the Generate Near Table tool on the Feature Vertices to Points output
 - a. Search Radius: 25ft
6. Review and edit the watershed boundary so that it has no vertices within 25ft of one another
7. Generalize to 10ft
8. Visually review the simplified watershed boundary and confirm that it follows high points and does not create conflicts with stormwater infrastructure
9. Export to StormWise

References

- ESRI (Environmental Systems Research Institute). (2019, August). Arc Hydro: Overview of Terrain Preprocessing Workflows. Available online at: <https://www.esri.com/content/dam/esrisites/en-us/media/technical-papers/arc-hydro-overview-of-terrain-preprocessing-workflows.pdf>
- ESRI (Environmental Systems Research Institute). (2019, January). Arc Hydro: Stormwater Preprocessing and Analyses. Available online at: <https://downloads.esri.com/archydro/archydro/doc/Arc%20Hydro%20-%20Stormwater%20Processing.pdf>
- ESRI (Environmental Systems Research Institute). (2020, July). Arc Hydro: Identifying and Managing Sinks. Available online at: https://www.esri.com/content/dam/esrisites/en-us/media/technical-papers/arc-hydro-overview-of-terrain-preprocessing-workflows.pdf?srsId=AfmBOorGY2b6kAi-wmSyk67OHy5rSZfIU9JQBekoVT_rLHiJZ30snq7-

Memo

Date: Tuesday, August 04, 2026

Project: 2-D Watershed-Wide Model

To: MCWD

From: HDR

Subject: Appendix C-3: Land Cover Process

To represent roughness, imperviousness, and evapotranspiration of the surface within the StormWise model domain, a landcover raster is required. Through email coordination with Moore Engineering , it was decided that the watershed's land cover would be best represented with a blend of two land use datasets. The selected datasets were chosen as they receive periodic updates, allowing for future revisions with changing land cover. This document details the steps taken in ArcGIS Pro to develop this raster.

1. Required Components and Background
 - a. National Land Cover Database (NLCD)
 - i. Link: <https://www.usgs.gov/centers/eros/science/national-land-cover-database>
 - ii. Applied for non-developed land uses
 - b. Generalized Land Use (GLU)
 - i. Link: <https://gisdata.mn.gov/dataset/us-mn-state-metc-plan-generl-Induse2020>
 - ii. Applied for developed land uses
 - c. Watershed boundary (upper and lower) buffered to two miles
2. GIS Polygon Processing
 - a. In ArcGIS Pro v.3.4, import the NLCD (raster) and GLU (polygon) datasets
 - b. For flexibility, clip each raster using the buffered watershed boundary
 - c. Convert the NLCD to a shapefile.
 - d. Perform a Union of the clipped NLCD polygons and GLU polygons providing a polygon describing the spatial and attribute variability of both input data sets.
 - e. Add an integer attribute to use as a land cover descriptor which will connect to model input tables describing land use characteristics.
 - f. Below attribute values were used for each the GLU and NLCD attributes. GLU highlighted in green (Agricultural, Park, Recreational, or Preserve, and Golf Course) were assumed to be non-developed areas where NLCD land cover descriptions were used.

GLU Description	Attribute Value
Agricultural	100
Farmstead	111
Seasonal/Vacation	112
Single Family Detached	113
Single Family Attached	114
Multifamily	115
Manufactured Housing Park	116
Retail and Other Commercial	120
Office	130
Mixed Use Residential	141
Mixed Use Industrial	142
Mixed Use Commercial	143
Industrial or Utility	151
Institutional	160
Park, Recreational, or Preserve	170
Golf Course	173
Major Highway	201
Major Railway	202
Airport or Airstrip	203
Undeveloped	210
Open Water	220

NLCD Description	Attribute Value
Open Water	11
Developed, Open Space	21
Developed, Low Intensity	22
Developed, Medium Intensity	23
Developed, High Intensity	24
Barren Land (Rock/Sand/Clay)	31
Deciduous Forest	41
Evergreen Forest	42
Mixed Forest	43
Shrub/Scrub	52
Herbaceous/Grasslands	71
Hay/Pasture	81
Cultivated Crops	82
Woody Wetlands	90
Emergent Herbaceous Wetlands	95

- g. Dissolve the shapefile based on the final classification attribute to simplify the resulting GIS file. This shapefile can be imported into the StormWise model.
- 3. Impervious Calculations
 - a. Impervious area is a required model input. Including impervious areas result in direct runoff generation without regard to soil infiltration. NLCD produces an impervious layer representing the percentage of land surface covered by impervious areas at a 30-meter resolution. Zonal Statistic to Table was run using the update land cover shapefile as a basis to run the statistics. The outputs are shown in the table below.
 - b. Directly Connected Impervious Areas (DCIAs) are a subset of total impervious areas and are a model input requirement. DCIA represents areas where impervious surfaces are directly connected to the storm system and would result in increased runoff production. Microsoft building footprints (2025) are continually updated polygon set of satellite derived building outlines. It was assumed in residential land uses that buildings would drain to pervious surface and therefore not be included as DCIA and all other impervious areas would be connected. In commercial and industrial areas the entire impervious area was assumed to be connected. See below table for input DCIA.

Land Cover Description	Land Cover Zone	Impervious %	DCIA %
Farmstead	111	18	9
Seasonal/Vacation	112	4	2
Single Family Detached	113	29	18
Single Family Attached	114	49	30
Multifamily	115	60	38
Manufactured Housing Park	116	48	39
Retail and Other Commercial	120	75	75
Office	130	68	68
Mixed Use Residential	141	75	43
Mixed Use Industrial	142	69	69
Mixed Use Commercial	143	78	78
Industrial or Utility	151	65	65
Institutional	160	47	35
Major Highway	201	60	45
Major Railway	202	62	46
Airport or Airstrip	203	63	32
Open Water	11	0	0
Developed, Open Space	21	11	0
Developed, Low Intensity	22	34	33
Developed, Medium Intensity	23	62	60
Developed, High Intensity	24	86	80
Barren Land (Rock/Sand/Clay)	31	0	0
Deciduous Forest	41	0	0
Evergreen Forest	42	0	0
Mixed Forest	43	0	0
Shrub/Scrub	52	0	0
Herbaceous/Grasslands	71	0	0
Hay/Pasture	81	0	0
Cultivated Crops	82	0	0
Woody Wetlands	90	0	0
Emergent Herbaceous Wetlands	95	0	0

Memo

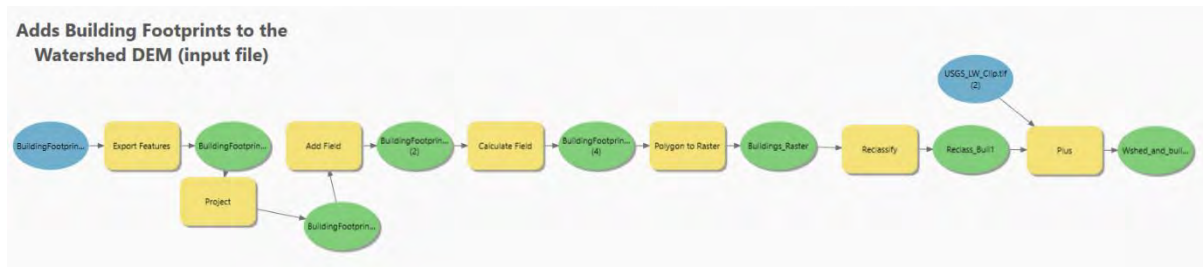
Date: Wednesday, March 05, 2025
Project: 2-D Watershed-Wide Model
To: MCWD
From: HDR
Subject: Appendix C-4: Surface Mesh

1. Required Components:

- a. Watershed boundary polygon
- b. Watershed boundary polyline
- c. Dem buffered to 500ft within watershed boundary
- d. Stormwater infrastructure inlets
- e. Channel Control Volumes (CCVs)
- f. Pond Control Volumes (PCVs)
- g. Groundwater region boundaries

2. Data Preparation

- a. Adjust base DEM to include Buildings. Using Microsoft building outlines, convert to raster and add 10 feet to the DEM at building footprint outlines.
 - i. This adjustment encourages the automated stream delineation procedure to avoid building footprints



- b. Create an accumulation weight raster to simplify breaklines in the upper third of the lower watershed and within parks/natural spaces. This is done with an accumulation weight raster that will force a higher accumulation threshold in these spaces.
 - i. Go through the area within the watershed boundary, creating polygons in the upper third of the lower watershed, defined as the area to the west of US-169, parks/large fields. These polygons will be referred to as natural spaces. In these natural spaces, less breakline detail is required to capture representative flowpaths than in the watershed's denser, more urban areas.
 - ii. Create a copy of the watershed boundary polygon.
 - iii. Run the Pairwise Erase tool on the watershed boundary polygon with the natural space polygons as the erase features
 - iv. Append the natural spaces to the erased watershed boundary polygon.
 - v. Create a field called "raster_weight" in the watershed/natural spaces polygon feature class.
 1. In this field, assign a value of 1 to the non-natural space polygon and a value of 0.1 to the natural space polygons. This

will be the accumulation weight raster for the Derive Stream as Line tool. Here, for an accumulation threshold of 5,000, the non-natural spaces will have an accumulation threshold of 5,000 where the natural spaces will have an accumulation threshold of 50,000. This will create coarser stream networks in these large, open spaces where less detail is required to capture flow paths.

- vi. Run the Polygon to Raster tool on the polygons feature class
 1. Value field: raster_weight
 2. Cell size: 1.64
 - a. This is the cell size of the DEM to be used as input to the Derive Stream as Line tool

3. Automated Process (currently completed through model builder)

- a. Derive stream as line. 5000 sq ft accumulation threshold. Input adjusted DEM with inlets as the target end point.
 - i. This threshold generates lines that include desired detail along gutter lines. The following processes remove many of the other additional delineated features that are unnecessary for StormWise modeling
- b. Singlepart to multipart
- c. Select and delete streams of less than 20 ft in length
 - i. These features can often be erroneous, small pockets of low area, and/or create unintentional mesh elements
- d. Select and delete streams within 2 ft of building footprints
 - i. Building footprints and LiDAR processing are not perfect. The 2 foot buffer is meant to confirm these streamlines are not the result of erroneous processing.
- e. Generalize all streams with a max offset of 10 ft using point remove approach
 - i. 10 feet was found to be effective at maintaining alignment along gutters lines and does not seem to oversimplify the natural flow paths
- f. Select and delete breaklines formed outside of the watershed boundary
- g. Delete breaklines within 25 ft of the watershed boundary
 - i. Breaklines close to the watershed boundary result in overly small mesh elements that may not be necessary.



4. Manual refinement of breaklines

- a. In the upper third of the lower watershed, add breaklines to represent curb lines that were missed by the 50K square feet accumulation threshold
- b. Remove breaklines within ponded areas or without a clear flow/drainage path
 - i. It is assumed these will be captured as part of a pond control volume or are not active areas of conveyance
 - ii. Future: Breaklines will be refined/removed where overlapping with PCVs and CCVs.
- c. Remove breaklines that go through buildings.
- d. Consolidate breaklines within approximately 10 feet of each other
 - i. Close parallel lines will result in an over-detailed mesh

- ii. 10 feet is the current target minimum (practical) mesh element size, some may necessarily be smaller
- e. End relevant breaklines within 10 ft of outlets
 - i. An automated procedure has been developed to snap delineated end points to inlets. DEM resolution is 0.5 m (1.6 ft). Selection of a tolerance of 10 ft resulting in snapping of auto-generated end points to the appropriate inlet point.

Manual Edits Example: pink lines are edited, and white lines are pre-edit



5. Snap Lines to Points - Automated breakline process results in flow paths that terminate at the raster cell center point where an inlet is located. However, the breakline does not end at the inlet point exactly. Without adjustment, stormwise would use breakline endpoints and the inlet points (as 1D-2D connections) and generate very small cells. HDR developed a simple script to snap the final breakline vertex to the inlet
 - a. Once manual edits of the breaklines are completed, use the provided Snap Lines to Points python script to snap breaklines to inlets
 - b. Create a unique ID field, in text, for the breaklines
 - c. Input Points Feature Class: Inlets
 - d. Input Lines Feature Class: Breaklines
 - e. Snapping Tolerance: 10ft
 - f. The script will create a new output feature class in the specified output folder
6. Generate a Stream Centerline Specific Breakline – The groundwater domain was divided into groundwater flow regions, north to south, at Minnehaha Creek.

- a. The groundwater flow region boundary, which was simplified from the stream centerline used for Channel Routing, was traced to generate a continuous feature from Gray's bay dam to the watershed outlet.
 - b. The polyline was split at the limits of each CCV.
 - c. Densify was used to create vertices along the channel segments at 25 foot increments.
7. Generate PCV and CCV Break Points in GIS
 - a. Open Watershed Boundary, Pond, and Channel Control Volume Outlines in GIS
 - b. Use the Generate Tessellation using the Triangle Shape type over the extent of the Watershed Boundary. This process will be completed for both the CCVs and PCVs using the below size inputs:
 - i. Pond Control Volumes: 1,500 sq ft size input (50 ft side length).
 - ii. Channel Control Volumes size: 312.5 sq ft size input (25 ft side length).
 - c. Convert Tessellations to Polylines using Polygon to Line tool
 - d. Convert Polylines to vertices using feature vertices to points tool
 - e. Select Vertices within PCVs (or CCVs), inverse selection, and delete all other vertices outside of the control volume.
 - f. Select vertices within 25 feet of the PCV (or CCV) boundary and delete.
 - g. Save the final breakpoints for CCVs and PVCs as shapefiles for import into Stormwise.
8. Data preparation for StormWise mesh generation
 - a. Select and delete breaklines within 25 ft of the watershed boundary if not done already
 - i. Mesh points close to the watershed boundary result in overly small mesh elements that may not be necessary.
 - b. Re-check breakline geometry to remove any unnecessary and or small branches, close parallel/sharp-angled lines, or endpoints/edges within 10ft of other mesh-generating features (inlets, outlets, PCVs, CCVs, watershed boundary)
 - i. Breakline vertices and edges will connect with both those of other breaklines and those of other mesh-generating features. Any breakline edge or vertex that isn't exactly coincident with another mesh-generating feature is likely to cause small vertices.
 - c. For the features in steps 5a-5c, add a field called "name" where each feature class has a unique character tag followed by numbers identifying individual features. HDR used the format "NI-XXX-000000" for inlets, and "OF-BKL-000000", giving each feature the same name length/format. See Naming Convention deliverable for more information. See specific formatting below
 - i. Inlets: "NI-XXX-000000"
 - ii. Breaklines: "OF-BKL-000000" + "0"
 - iii. These steps serve to make the data easier to work with in StormWise and cross reference in GIS.
 - d. HDR generated a simple Model Builder that takes in all mesh-generating features, converts polyline and polygon features to points, then buffers all mesh-generating points to $\frac{1}{2}$ the target distance and runs an intersection on this buffer. Here, a 5ft buffer was used so intersections of features <10ft from each other could be identified and corrected.



9. StormWise Mesh Generation

- a. Prepare GIS data for integration: Inlets, CCV break points, PCV break points, edited/snapped breaklines, watershed polygon feature class, all in "NAD 1983 (2011) StatePlane Minnesota South FIPS 2203 (US Feet" projection, for export to StormWise
- b. Add watershed raster to StormWise
- c. Select overland flow region and add watershed polygon shapefile
- d. Add Inlets shapefile to the "Breakpoint" feature class
- e. Add GIS generated break point patterns for Channel and Pond Control Volumes.
- f. Create breakpoint pattern for open areas using the "Create Overland Flow Graphic Element" button, pressing z, clicking on the map, and running with the standard inputs
 - i. Doing this for the entire watershed surpassed the computational limit of this function. For this reason, we split the watershed into three parts, creating polygons to be used as "fences" in StormWise. For this case, activate the fence for the area being processed and select the "use active fence" option before running. The polygons used for this are located in the shared GIS folder.



Memo

Date: Tuesday, August 04, 2026

Project: 2-D Watershed-Wide Model

To: MCWD

From: HDR

Subject: Appendix C-5: Pond Control Volumes

Introduction

This document details the development of pond control volumes (PCVs) for implementation into StormWise for the MCWD 2D watershed wide model build. Though several options were explored in the previously provided *Phase 2 Model Build – Pond Control Volume Options* document, the use of surface contours at elevations of anticipated uncontrolled overland flow was selected to derive PCVs. PCVs represent the entire polygon as a stage (elevation) storage relationship where the water surface is flat and water entering any part of the PCV is immediately available to discharge from an outlet point. Using a controlling elevation contour maintains most of the overland space as 2D flow while confining the 1D (stage-storage) hydraulics to occur only where the waterbody is anticipated act as a ponded feature. Here, ArcGIS Pro v3.3 was leveraged for PCV processing prior to exporting to StormWise. Using USGS LiDAR water body polygons as the basis for PCV creation, representative contours surrounding these polygons were selected for use as PCVs. These PCV outlines were further refined through the semi-automated process described in the following sections.

Pond Control Volume Development

First, contours were developed across the entire watershed. Contours representative of PCV area relative to the USGS LiDAR water body polygons were then selected. The following steps detail this process.

1. Contour (Spatial Analyst Tools)
 - a. The creation of dense contours allows for the selection of PCV outlines coincident with the stage of water bodies they represent. This was accomplished using Contour (Spatial Analyst Tools) in ArcGIS Pro
 - i. Input Raster: Watershed DEM
 - ii. Contour Interval: 1
 - iii. Output: 1ft Contours for the entire watershed
2. Contour Selection
 - a. Next, contours were selected surrounding the LiDAR water body polygons selected as PCV basis. The following rules were used to select representative

contours, helping mitigate small StormWise mesh elements and improving model functionality.

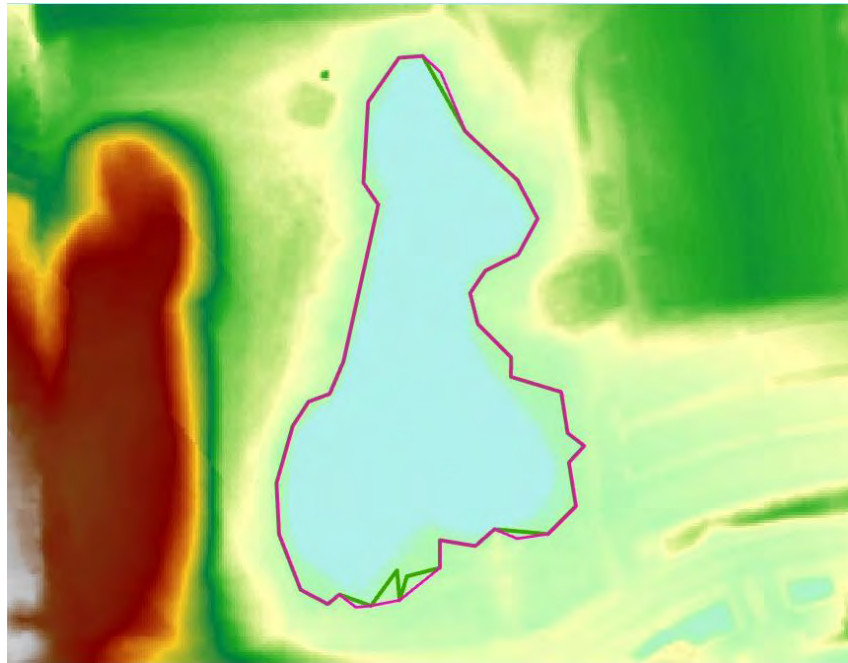
- i. Choose the highest elevation contour possible without overtopping to infrastructure (roads, homes, etc.)
- ii. Avoid having inlets less than 10ft from the outside of contours (for mesh generating purposes)
- b. Example (all contours light green, selected contour pink, LiDAR polygon blue)



Next, the selected PCV contours were edited as the vertices of the output contours are too dense. Exporting the selected contours to StormWise as PCVs as is would cause the generation of small mesh elements.

1. Generalize
 - a. Select all PCV contours identified in the previous step.
 - b. Use the point removal Generalization with 10 ft offset selected
2. Edit PCV Contours
 - a. The generalized contours must be manually reviewed and edited to confirm they are still representative of the boundary and transition between 1D and 2D hydraulics. In the generalization process, tight corners or deviation from the representative water body elevation may occur. Utilizing the Reshape tool in ArcGIS Pro, the following guidelines were used to make edits to generalized PCV contours.
 - i. Remove sharp corners or vertices <10ft apart generated by the generalization of small coves in the contour
 - ii. Confirm that generalized contours do not excessively deviate above/below the original contour

- b. Example (generalized contour green, generalized and edited contour pink)



3. Where pond control volumes are close and separated by a berm, make edges coincident and connect in Stormwise with a weir
 - a. This will simplify the model mesh for computational efficiency.
4. Run a check of inlet/outlet proximity to pond control volumes. Where <10ft from one another, adjust the PCV feature to encompass the outlet/inlet

Next, a node must be created for each PCV for implementation in StormWise.

1. Feature to Point
 - a. Run Feature to Point on the PCV polygon feature class with the centroid option selected.
2. Adjust Centroids
 - a. Some centroids may fall outside of PCV polygons depending on geometry. Review PCV centroids and move centroids inside of PCV boundaries where necessary.

Finally, assign names to each PCV and Node, assigning each PCV's node to a "Node_Name" field within the PCV feature's attribute table. See Naming Convention deliverable for more information.



Memo

Date: Tuesday, August 04, 2026

Project: MCWD 2-D Watershed-Wide Model Build

To: MCWD

From: HDR

Subject: Appendix C-6: Channel Control Volumes

Introduction

This document details the development of bank lines, channel control volume polygons, channel links, and channel nodes for implementation into a watershed-scale StormWise model for the lower Minnehaha Creek Watershed. The following processes used both HEC-RAS (version 6.5) and ArcGIS Pro.

HEC-RAS Processing

HEC-RAS was used to develop cross sections, which could also be completed in GIS software. Using the cross sections and centerline, edge lines are generated. Edge lines connect cross section end points following an offset from the centerline, these are the precursor to the channel control volumes.

1. This process began with the bathymetry development of a HEC-RAS model of Minnehaha Creek. The following features are required for cross-section and edge line development:
 - a. Channel centerline
 - b. Survey/cross-section locations
 - c. Terrain
2. Cross sections were created within a HEC-RAS geometry following the steps below.
 - a. Place cross-sections at:
 - i. Surveyed cross-section locations. Confirms the model is using observed data where it is available
 - ii. Upstream and downstream of bridge, culvert, or hydraulic structure crossings. Integrating pipe culverts, bridges, or weirs requires upstream and downstream bounding cross sections. Even if structures are not

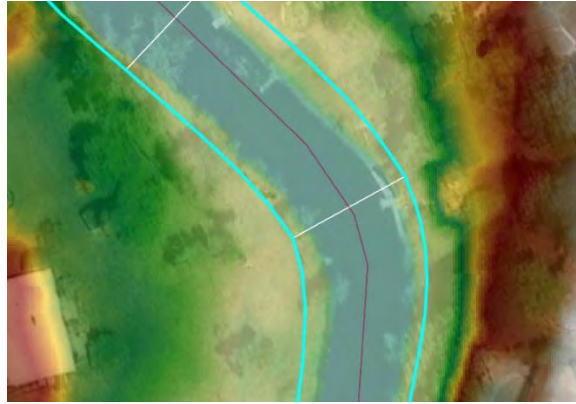
included as part of this model, the cross sections are available for future refinement.

- iii. Locations of hydraulic change (width, depth, slope, major meanders). Captures conveyance and hydraulic losses appropriately within the system.
 - b. Cross sections should extend past the edge of the low-flow channel bank. In channel flows are intended to be described by 1-D elements for improved hydraulic representation and model efficiency.
 - c. Add new cross sections so that spacing is less than 500 feet between cross sections. Water surface elevation variation and appropriate connectivity to the storm sewer network is a function of cross section and node placement. Closer spacing allows for improved streamwise description of water surface elevation changes and exchange with the 2D mesh nodes along channel banks.
 - d. Extend cross sections to encompass smaller coves (or off-channel pockets of backwater); larger coves will be accounted for in StormWise and do not need to be encompassed by the edge lines
3. Update edge lines to new cross sections
 4. Export edge lines and cross sections as a shapefile for use in ArcPro

ArcGIS Pro Processing

ArcPro is used to refine generated cross sections, centerline, and edge lines for integration into a Stormwise model. Note: Though not modeled in HEC-RAS, several channel control volumes were added in addition to those along Minnehaha Creek, to connect two pond control volumes, for example.

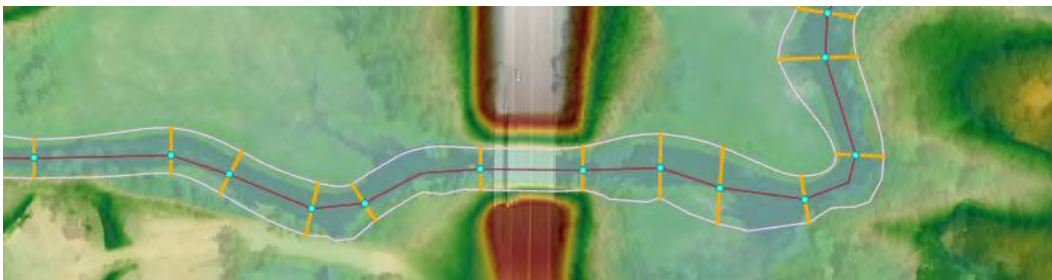
1. Import edge lines, cross sections, centerline, and terrain
2. Use the generalize tool to generalize the edge lines to 10 feet to limit small 2D cell faces. Adjust edge lines so they do not cross into the stream or through obvious low points. Edge lines should be representative of the creek bank lines. If they cross into the stream or through obvious low points, the model will misrepresent flow in and out of the channel. Edge lines were automatically generated within HEC-RAS based on cross section end points; between cross sections, bank lines may be located in less desirable places these locations should be reviewed in more detail.
3. Example (Edge Lines: selected in bright blue, Channel Centerline: brown, Channel Cross Sections: white)



4. Channel node locations were set at the location of the intersection between each channel cross-section and channel centerline. Use the intersect tool with the channel cross sections and the channel centerline as input and output, respectively. Nodes represent the computational points within the channel control volume and each require upstream and downstream cross sections.
 - a. General pattern (Channel Centerline: brown, Edge Lines: light pink, Channel Cross Sections: orange, Channel Nodes: selected in bright blue)



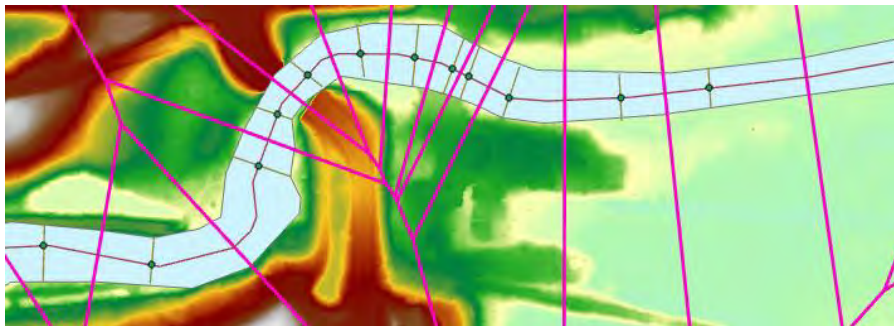
- b. At bridges



5. Channel links connect each node and were created using the Split Line at Point tool, split the channel centerline with the channel nodes.

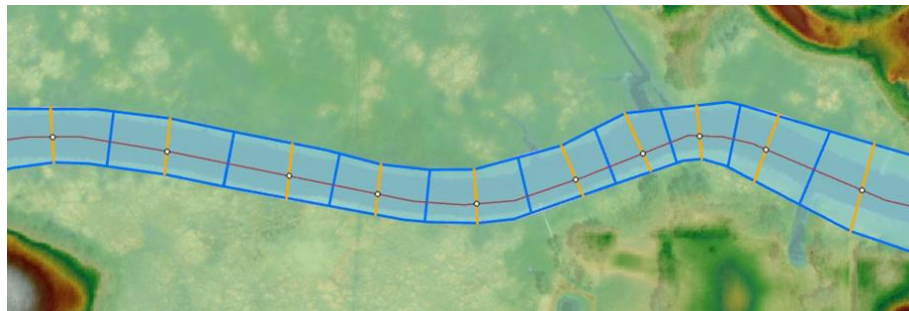
6. Polygons of the channel were generated using the Polygons from Polylines – XTools Pro tool. Using the adjusted channel edge lines, connect the end points with polylines and run the tool to generate a polygon of the channel.
7. Each channel node will have a respective polygon called a channel control volume polygon. This requires splitting of the entire channel polygon into many smaller polygons. To automate this, the Thiessen Polygons – XTools Pro tool was used with the channel nodes as inputs. Once generated, pan through the entire channel and adjust the Thiessen polygon output where necessary so each polygon will have a node when the Thiessen polygon output is used to split the entire channel polygon.

- a. Thiessen Polygon Output: pink

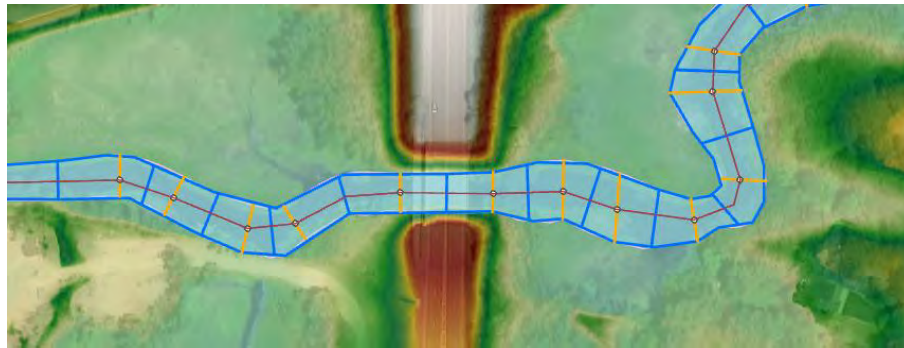


8. Run the Split Polygons tool with the entire channel polygon as the input feature and the Thiessen polygon output as the split features. The result should be one polygon for each channel node.

- a. General example (Channel Control Volume Polygons: blue, Channel Cross Sections: orange, Channel Nodes: white, Channel Centerline: brown)



- b. At Bridges



9. Where the channel crosses through major, static water bodies, create Pond Control Volumes (PCVs). Channel Control Volume Polygons and all other features can be deleted from these areas. PCVs represent surface water storage in StormWise and improve the representation of interactions between the channel and storage areas. “Phase 2 Model Build – Pond Control Volumes” describes the process to generate PCVs in detail. In general:
10. Identify water bodies and or low-lying areas the channel passes through. See example below.

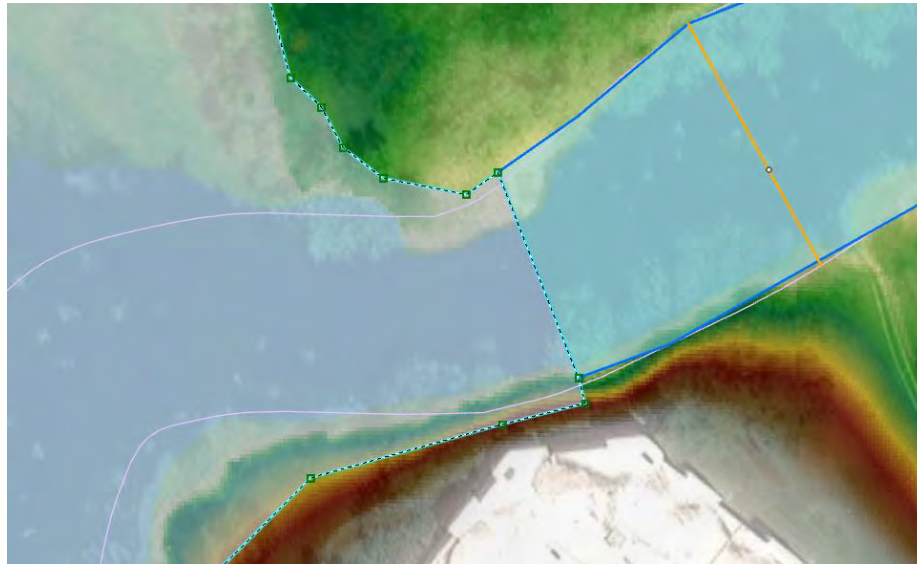


- a. Using DEM as reference, construct polygons representing bank lines of water bodies/low-lying areas. These polygons will be referred to as PCVs. The edges of PCVs must coincide with channel control volume polygon edges (not cross sections). Generalize the PCV polygon to 10ft to avoid small mesh elements when imported to StormWise. Confirm PCV and channel control volume polygon edges are still coincident See below.

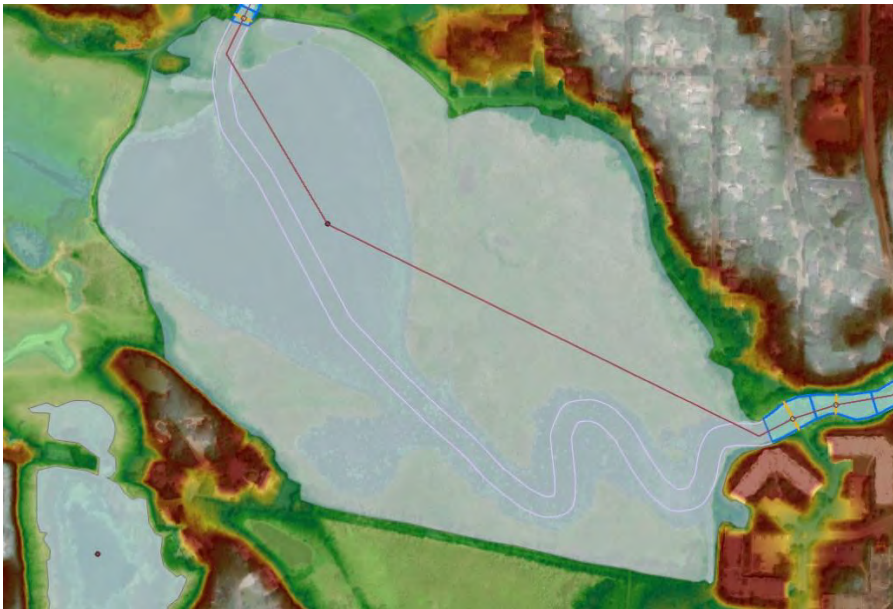
Entire PCV (in light purple)



Coincident edges



- b. Create a node in the center of the PCV and connect the upstream and downstream channel node to this new node with new links.



11. Add fields/populate fields for input to StormWise. This process references the channel nodes to their associated channel control volume polygon. See the provided Naming Convention deliverable for the detailed naming convention used.

a. Channel Nodes

- i. Add and populate a "NAME" field

b. Channel Control Volume Polygons

- i. Add and populate a "NAME" field
- ii. Create a field called "NODENAME". Use the "Spatial Join (Analysis Tools)" tool to assign channel node "NAME" field to each associated channel control volume polygon's "NODENAME" field.

c. Cross Sections

- i. Add and populate a "NAME" field

d. Channel Links

- i. Add and populate a "NAME" field
- ii. Add a field "FROM_NODE"
- iii. Add a field "TO_NODE"
- iv. Use the "Features to Points (Xtools Pro)" tool's "End of Line" function for the "TO_NODE" field. Repeat the following steps with the tool's "Start of Line" tool for the "FROM_NODE" field.



12. Spatial join the channel nodes to the Xtools Pro nodes. Join the channel nodes' "NAME" field to the Xtools pro nodes.
13. Spatial join the Xtools Pro nodes to the channel links feature class. Copy the node name column from this output into the relevant "FROM_NODE" and "TO_NODE" field of the original channel links feature class.
14. Package the channel nodes, channel control volume polygons, cross sections, channel links, and Pond Control Volume Outlines, as shapefiles, for export to StormWise.



Memo

Date: Tuesday, August 04, 2026

Project: 10400835 – MCWD 2D Model Development

To: MCWD

From: HDR

Subject: Appendix C-7: Minnehaha Creek Crossing Data Summary

As part of HDR’s ongoing development of the Minnehaha Creek Watershed District (MCWD) Stormwise 2D model, over 90 bridges along the Minnehaha Creek (Creek) have been identified for potential inclusion into the model. In addition, HDR has reviewed existing 1D models containing previously developed bridge geometry and supporting documentation from various stakeholders throughout the Creek. HDR intends to leverage this data to expedite creation of the 2D model and improve its accuracy where possible. For details and data on tier one crossings implemented in StormWise, see Electronic Data Package Item C-7: Minnehaha Creek Crossing Data Summary. Due to the large number of crossings along the Creek, bridges were sorted into various “Tiers” based on their hydraulic impact to peak water surface elevations (WSEs) as documented in the effective FEMA Flood Insurance Study (FIS). The geometry data source (HEC-RAS or XPSWMM) was also considered since bridges modeled in HEC-RAS generate headwater and tailwater rating curves that can be directly imported into Stormwise. However, bridge data sourced solely from XPSWMM must first be recreated in HEC-RAS before being implemented into Stormwise. Table 1 summarizes findings from the bridge geometry data review.

Table 1. Bridge Structure Data Summary

Data Source	Bridge Tier				Total
	1	2	3	Outdated	
HEC-RAS (Various Sources)	15	34	2	3	56
XPSWMM (MCWD Model)	0	20	16	3	38
					94

Tier 1: Critical Crossings with significant impact (1' or greater) to WSE of Minnehaha Creek

Tier 2: Crossings impacting (<1') WSE and/or structure within the 500-year Annual chance Flood

Tier 3: All remaining crossings

Outdated: Bridge was reconstructed after model data was generated



- Tier 1 represents structures with significant impact (deemed 1' or greater) to the Creek's peak WSE in either the 100-year or 500-year annual chance flood events and will be initially included in the Stormwise 2D model.
- Tier 2 represents structures with an impact of <1' to the peak 100 or 500-year WSE, or a structure with a low chord located below the 500-year annual chance flood. These structures, while not critical, should be next in-line for inclusion into the 2D model.
- Tier 3 structures have no apparent impact to the 100-year or 500-year peak WSE, do not have a low chord below the 500-year WSE, and are considered the least critical for inclusion into the 2D model.

A large portion of the bridge models and supporting documentation reviewed by HDR was generated between 2001-2003 as part of the initial Hennepin County FIS that was made effective on September 2nd, 2004. Since then, several bridges along the Creek have been reconstructed (identified via MnDOT Bridge GIS Portal), and an updated FIS was made effective on November 4th, 2016. Table 2 lists the reconstructed bridges and their corresponding tier.

Table 2. Bridges Reconstructed along Minnehaha Creek since 2003

Bridge	Tier	Year Reconstructed
Lyndale Ave	1	2011
28th Avenue South	2	2020
Portland Ave	2	2006
West 37th St	2	2017
I-35W	3	2008
BNSF Railway	3	2007

It's likely that any bridge reconstruction prior to 2016 has a corresponding HEC-RAS model that is up to date and part of the effective FIS. This project may benefit from current HEC-RAS models for all the outdated tier 1-2 bridge crossings, as well as any HEC-RAS models that can be used in lieu of the tier 2 XPSWMM based data to facilitate a more efficient and congruent modeling process. These bridges can be integrated as part of this project or in future refinements to the watershed wide model.

Model Implementation:

In StormWise, the default method for connecting channel nodes is through standard channel links. However, for Tier 1 hydraulic structures identified in the study, bridge rating curve links, weir links, and culvert links were utilized to more accurately represent the geometry and hydraulic behavior of these structures. Using available as-builts, each Tier 1 structure was reviewed and assigned the link type that best represented its geometry. HEC-RAS bridge rating curves were input for bridge rating curves, where relevant input values were selected for culvert and weir links using feature geometry. See the provided spreadsheet documenting StormWise inputs used for each feature represented as a culvert or weir link. Table 3 lists the number of

Tier 1 crossings assigned to each link type. Figures 1 and 2 provide as-built examples of features assigned as culvert and weir links, respectively.

Table 3. Hydraulic Structure Link Type Breakdown

Link Type	Count
Bridge Rating Curve	9
Culvert	6
Weir	2
Total	15

Figure 1. France Ave S. Bridge (Culvert Link)

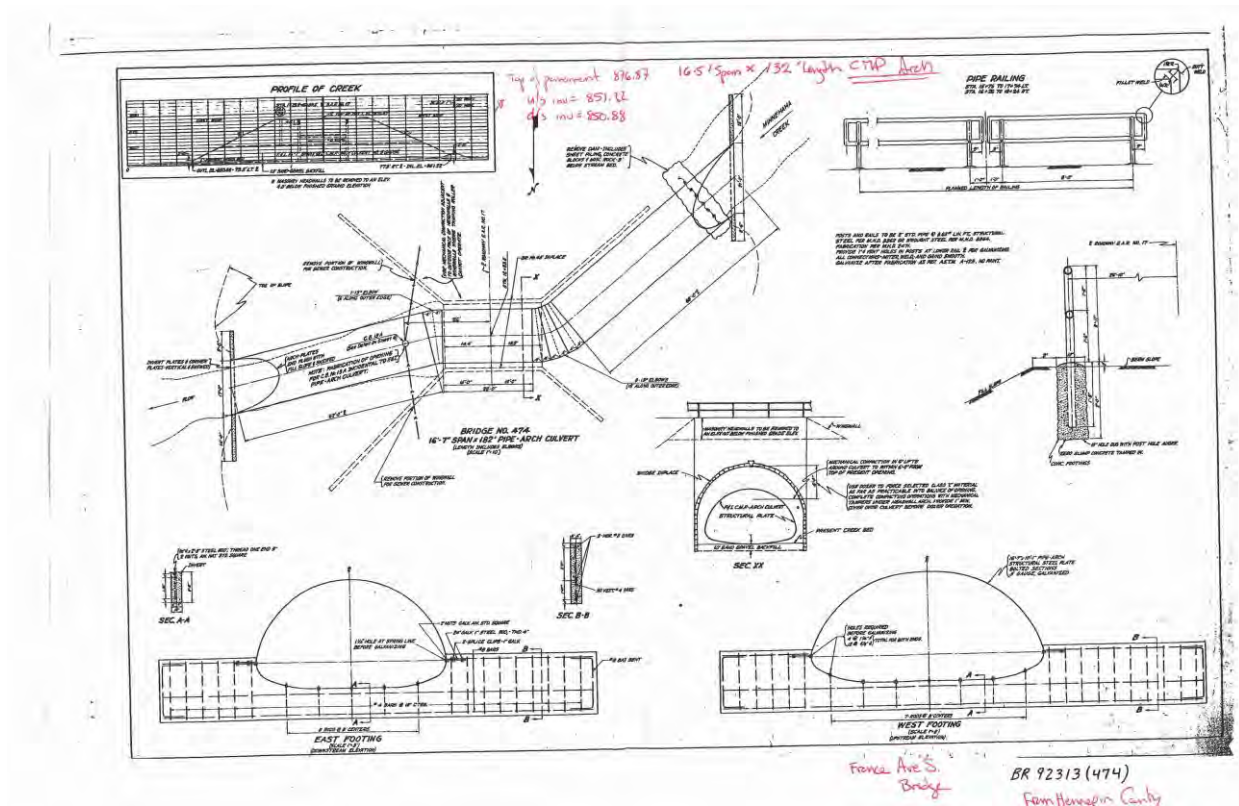


Figure 2. Hiawatha Avenue Weir (Weir Link)

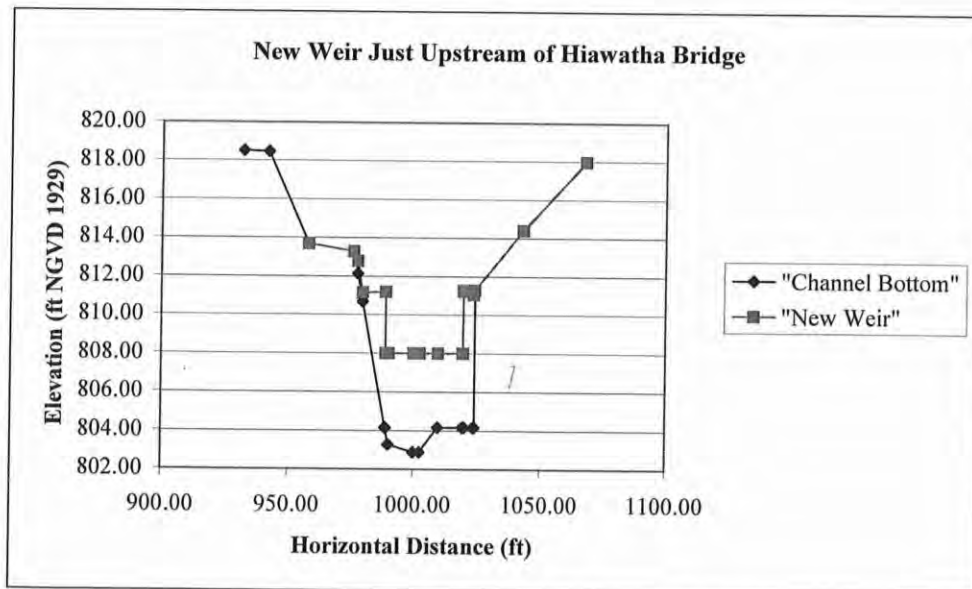
New Weir Just Upstream of Hiawatha Avenue Bridge

HEC-2 = Archpxl.dat RS = 11.3

Horizontal Distance		Elevation-BOTTOM		Elevation-TOP	
metric (m)	english (ft)	metric (m)	english (ft)	metric (m)	english (ft)
284.10	932.09	249.48	818.50		
287.10	941.93	249.47	818.47		
292.00	958.01	248.01	813.68	248.01	813.68
297.50	976.05	247.89	813.29	247.89	813.29
298.00	977.69	247.54	812.14	247.74	812.80
298.62	979.72	247.10	810.70	247.24	811.15
301.42	988.91	245.11	804.17	247.25	811.19
301.43	988.94	245.10	804.13	246.28	808.01
301.80	990.16	244.84	803.28	246.28	808.01
304.80	1000.00	244.72	802.89	246.28	808.01
305.59	1002.59	244.72	802.89	246.28	808.01
307.80	1009.84	245.11	804.17	246.28	808.01
310.74	1019.49	245.11	804.17	246.28	808.01
310.78	1019.62	245.11	804.17	247.27	811.25
310.90	1020.01	245.11	804.17	247.26	811.22
311.97	1023.52	245.11	804.17	247.21	811.06
312.10	1023.95	245.11	804.17	247.28	811.29
312.10	1023.95	247.28	811.29	247.28	811.29
317.90	1042.98	248.23	814.40	248.23	814.40
325.50	1067.91	249.32	817.98	249.32	817.98

Sta 52+91

swmm cross section highlighted



Memo

Date: Tuesday, August 04, 2026
Project: 2-D Watershed-Wide Model
To: MCWD
From: HDR
Subject: Appendix C-8: Storm Infrastructure Assumptions

Scripts developed as part of the MCWD watershed-wide model pilot study systematically re-formatted and consolidated storm sewer datasets from all overlapping owners (state, county, city) into a single GIS schema (MGIS). To support model development, data gaps and erroneous attributes were flagged and populated based on a variety of methods depending on the gap type and available data. The intent of this document is to review previously developed assumptions and refine them where necessary. Where data are unavailable or erroneous, gap filling methods will be generated for storm sewer infrastructure on a source-by-source basis.

The MGIS to Model Ready Scripting (script) is divided into three parts: “Project Folder Set Up”, “Topology Correction”, and “Attribute Correction”. This memo focuses on “Attribute Correction”.

Update Structure Attributes

This section will define current script assumptions and gap fill approaches for Structures which include manholes, inlets, and outlets. For aspects which require refinement a process to refine will be described. “pipes” include pipes and culverts.

- 1a – Fix Structure Rim
 - o *Existing script:* Update structure with rim elevation from digital elevation model (DEM)
 - o *Refinement:* Update script to flag and replace if rim elevations > 0.5' different from DEM. Review flags to confirm appropriate application of acceptable difference
- 1b – Fix Structure Invert Elevation
 - o *Existing script:* Updates structure invert elevations. If invert elevation is null, connected pipes are checked for invert values. The lowest invert value of all connected pipes are used, if any. If invert is populated, but <= 50, it is assumed as a measure down (depth value) and subtracted from the rim elevation or from them DEM if rim is not populated.
 - o *Refinement:* Existing logic was retained as a first pass, with an added check for excessively high structure invert elevations. Here, the script checks a structure's invert elevation against that point's DEM elevation. If the structure invert elevation is higher than the point's DEM elevation, the invert elevation is set to null and replaced with existing logic. In addition, a second pass was added to the script following the update of pipe attributes to update structure invert elevation based on assumed pipe inverts.

- 1c – Fix Structure Combination Field
 - o *Note:* Script comments indicate this script “Sets combination style to “Yes” if it is null (for inlets only)”; however, based on review of the code, the logic may be applied to all structures rather than just the inlets. Verification is recommended.
- 1d – Fix Structure Grate Size (inlets only)
 - o *Existing script:* Adjusts inlet grate length and width to assumed values if null. (length =36, width = 24)
 - o *Refinement:* Updated script to adjust inlet grate length and width to updated assumed values if null based on most typical values in dataset (length =2.75 ft [33 inches], width = 1.26 ft [15.125 ft])
- 1e – Fix Structure Outlet Length Width (outlets only)
 - o *Existing script:* Adjusts outlet length and width to mean of connected pipe sizes (if available) or else an assumed value of 24
 - o *Refinement:* None, maintain current approach
- 1f – Fix Outlet Type (outlets only)
 - o *Existing script:* Changes outlet type to assumed value of “Pipe” if null
 - o *Refinement:* None, maintain current approach

2-Update Pipe Attributes

This section will define current script assumptions and gap fill approaches for Pipes which include pipes and culverts. For aspects which require refinement a process to refine will be described.

- 1a – Add To/From Nodes
 - o *Existing script:* Populates the Node From and Node To fields for pipes based on connected structures.
 - o *Refinement:* None, maintain current approach
- 1b – Fix Pipe Size
 - o *Existing script:*
 - Adjusts pipe size parameter. If size is populated with value < 0 or == 999, size is set to null.
 - If value is < 6, value will be assumed as feet and converted to inches (note: HDR reviewed the MGIS pipe size data by source and validated this assumption to be appropriate).
 - If no value found, pipe size will be determined from mean of upstream and downstream pipes (if available), otherwise set to 24. Uses closest pipe size from the following list when determining mean pipe size:
 STANDARD_PIPE_SIZES = [6.0, 8.0, 9.0, 10.0, 12.0, 14.0, 15.0, 16.0, 17.0, 18.0, 20.0, 21.0, 22.0, 24.0, 25.0, 26.0, 27.0, 28.0, 29.0, 30.0, 31.0, 32.0, 33.0, 35.0, 36.0, 39.0, 41.0, 42.0, 43.0, 44.0, 45.0, 48.0, 50.0, 51.0, 54.0, 55.0, 57.0, 58.0, 58.5, 59.0, 60.0, 65.0, 66.0, 69.0, 71.0, 72.0, 73.0, 78.0, 80.0, 84.0, 88.0, 90.0, 95.0, 96.0, 102.0, 117.0, 120.0, 121.0]

- o *Refinement:*
 - Script adjusts pipe size parameter. If size is populated with value < 0 or == 999, size is set to null.
 - If no size value is found and the pipe is connected to another pipe upstream, the missing pipe size will be determined from the mean of upstream and downstream pipe sizes (if available).
 - If mean of upstream and downstream pipe sizes is not available or if the pipe is not connected to another pipe upstream, an assumed pipe size of 15 inches will be used.
 - Justification for the 15 inches default pipe size assumption is provided in Section 3 of this memo.
- 1c – Fix Pipe Material
 - o *Existing script:* Adjusts pipe material. Material is checked from connecting pipes first, otherwise set to Unknown.
 - o *Refinement:* HDR reviewed material distributions for MGIS pipe data by source (without clipping to the watershed). In addition to checking connecting pipes for material, a default pipe material of reinforced concrete will be used to populate missing values. Justification for this assumption is provided in Section 3 of this memo. Roughness coefficients will be defined in the model based on pipe material and will not be stored in the model ready dataset.
- 1d – Fix Pipe Shape
 - o *Existing script:* Changes pipe shape to assumed value of “Circular” if null
 - o *Refinement:* None, maintain current approach
- 1e – Fix Pipe Width
 - o *Existing script:*
 - The intention of the existing script is to populate an assumed pipe width and height if the pipe is not circular. However, HDR identified a bug in the existing script causing the assumed pipe width and height to be populated for circular pipes only (skipping non-circular pipes).
 - The intention of this part of the script is to update the width field for non-circular pipes to be equal to the pipe diameter field, if available, or else set it to 24.
 - o *Refinement:*
 - Script logic was corrected to apply the pipe width and height assumptions for non-circular pipes.
 - Script logic was updated to apply a default uniform width/height assumption of 18 inches for arched pipes and non-circular pipes (including non-arched).
 - In addition to updating the script, non-circular, non-arched pipes missing height and width values were manually reviewed, and width and height values were manually assigned using surrounding features.
- 1f – Fix Pipe Length
 - o *Existing script:* Checks pipe length in the attribute field. If attribute pipe length differs from geometry pipe length by more than 20%, or if the attribute pipe length is null, it

populates the attribute pipe length with the geometry shape length. Otherwise, it keeps whatever is in the pipe attribute field.

- o *Refinement:* None, maintain current approach
- 1g – Fix Pipe Inverts
 - o *Existing script:* Updates missing pipe upstream and downstream invert elevations from DEM (for culverts) or from adjacent structure inverts (for pipes).
 - o *Refinement:* Existing script approach was refined to estimate pipe inverts based on DEM if upstream and downstream pipe invert elevations are not available. If pipe is a culvert or pipe endpoint is an outlet, assume the invert is equal to the DEM elevation. If the pipe is not a culvert and the pipe endpoint is either a manhole or an inlet, assume the invert from an assumed cover depth (4 ft.) offset from DEM. Justification for the 4 ft. default pipe cover assumption is provided in Section 3.
- 1h – Fix Pipe Slope
 - o *Existing script:* Updates pipe slope if length, upstream and downstream invert are populated. (calculates slope based on attribute pipe length, not the geometry shape length). If slope is negative, it flags this as an issue in the Issues field.
 - o *Refinement:* None, maintain current approach

3- Update Pipe Attributes Check Results

1b – Fix Pipe Size

Summary:

Presently, the MGIS to MR script sets a default pipe diameter of 24" to features missing pipe diameter data. To validate or replace this default diameter, the pipe diameter distribution was explored both on a source-by-source and entire dataset basis.

Results:

MGIS Pipe Diameter Distribution, Not Including Null or Zero Values

Source	Count	Average Pipe Diameter (ft)	Median Pipe Diameter (ft)
ChanhassenData	8,452	17.50	15
DeephavenData	N/A	N/A	N/A
EdinaData	7,655	17.32	15
ExcelsiorData	605	14.40	12
GoldenValleyData	216	18.60	12
GreenwoodData	38	15.21	12
HopkinsData	N/A	N/A	N/A
LongLakeData	559	17.56	15
MaplePlainData	226	N/A	N/A
MedinaData	947	16.41	15
MinnetonkaData	12,931	17.29	15

Source	Count	Average Pipe Diameter (ft)	Median Pipe Diameter (ft)
MinnetristaData	1,533	15.10	15
Mound	1,464	13.82	12
MplsData	41,696	20.04	15
PlymouthData_Updated	12,952	18.47	15
RichfieldData	4,806	19.18	15
ShorewoodData	1,598	14.09	12
SpringParkData	31	13.97	12
StBoniData	412	11.16	12
StLouisParkData	8,867	15.75	12
VictoriaData	2,971	17.23	15
WayzataData	1,805	13.81	12
Entire Dataset	109,764	18.19	15

Conclusion:

As the median pipe diameter across the entire dataset is 15", HDR recommends replacing the existing default pipe diameter of 24" with a default pipe diameter of 15"

1c – Fix Pipe Material

Summary:

The distribution of pipe material was explored both on a source-by-source and entire dataset basis. For clarity, the provided results include only the most common material for each source.

Results:

Most Common Pipe Material for Each Data Source, not Including Null Values

Source	Pipe Material	Count	Percentage
ChanhassenData	Reinforced Concrete	7,672	74.60%
DeephavenData	Steel	1	100.00%
EdinaData	Reinforced Concrete	5,869	65.83%
ExcelsiorData	Reinforced Concrete	129	82.69%
GoldenValleyData	Reinforced Concrete	179	83.64%
HopkinsData	Unknown	776	100.00%
LongLakeData	Reinforced Concrete	488	87.46%
MedinaData	Reinforced Concrete	889	93.88%
MplsData	Reinforced Concrete	31,510	63.20%
MinnetonkaData	Reinforced Concrete	10,226	80.25%
MinnetristaData	Reinforced Concrete	1,398	92.09%
Mound	Reinforced Concrete	998	92.07%
PlymouthData_Updated	Polyvinyl Chloride	54	75.00%
RichfieldData	Reinforced Concrete	4,903	95.59%

Source	Pipe Material	Count	Percentage
ShorewoodData	Reinforced Concrete	134	77.91%
StLouisParkData	Reinforced Concrete	8,203	94.34%
VictoriaData	Unknown	192	98.46%
WayzataData	Reinforced Concrete	976	54.07%
Entire Dataset	Reinforced Concrete	73,574	71.35%

Conclusion:

Hopkins and Victoria have very limited pipe material information as indicated by the percentage of “Unknown” material features. Deephaven and Plymouth, while having different most common pipe materials than the other sources, have relatively few features. With the most common material across the entire dataset being reinforced concrete, HDR recommends a default material of reinforced concrete for all features missing material data.

1g – Fix Pipe Inverts

Summary:

To populate missing invert elevation data, three methods for invert estimation were considered including (1) calculating inverts based on cover depth relative to the DEM, (1) calculating inverts based on minimum pipe slope, and (3) flagging pipes for manual review and refinement. The project team concluded that the cover depth approach would best represent invert elevations where missing. To explore the distribution of cover depth on both a source-by-source and entire dataset basis, the approximate cover depth was calculated for pipes with existing invert elevations and pipe diameters. To calculate approximate cover depths, a typical 6 inch pipe wall thickness was assumed for the top of the pipe. This check utilized the model ready pipe dataset as the script populates missing invert elevations with manhole invert elevations.

Results:

Distribution of Calculated Cover Depth

Source	Count	Average Cover Depth (ft)	Standard Deviation	Median Cover Depth (ft)
ChanhassenData	7,516	4.26	3.03	3.45
EdinaData	6,990	4.35	2.82	3.69
ExcelsiorData	40	2.47	2.16	2.11
GoldenValleyData	108	3.60	2.18	3.09
HopkinsData	20	3.23	1.18	2.69
MinnetonkaData	9,871	3.87	2.81	3.19
MinnetristaData	4	2.32	0.86	2.40
Mound	984	3.55	2.38	3.13
MplsData	37,875	5.26	4.25	4.46
PlymouthData_Updated	12,100	4.06	2.60	3.46

Source	Count	Average Cover Depth (ft)	Standard Deviation	Median Cover Depth (ft)
RichfieldData	4,204	4.39	3.04	3.75
ShorewoodData	39	3.10	1.30	3.09
StLouisParkData	43	3.88	2.24	3.45
VictoriaData	17	10.10	10.37	7.45
WayzataData	3	0.89	0.42	1.10
Total	79,822	4.66	3.62	3.89

Conclusion:

With a median cover depth of 3.89 ft across the entire dataset, HDR recommends a uniform default cover depth of 4.0 ft be used for the calculation of missing invert elevations. This depth is consistent with local design standards and aligns with the findings of this check.

Memo

Date: Tuesday, August 04, 2026

Project: 2-D Watershed-Wide Model

To: Brian Beck (MCWD)

From: HDR

Subject: Appendix C-9: Storm Infrastructure Duplicative Dataset Evaluation Process

Introduction

As part of the development of a 2D watershed model for the Minnehaha Creek Watershed District (MCWD or District), the District provided HDR with a package of twenty-eight (28) storm sewer infrastructure datasets from agency and municipal sources across the region. These datasets were consolidated into the standardized MetroGIS (MGIS) format for use in model development. Upon review of the consolidated MGIS dataset, HDR noted that several of the original storm sewer datasets contain closely overlapping features and may be redundant. Any redundant data must be reviewed and removed prior to integration into the 2D model.

Due to the significant number of storm sewer features across the entire watershed, it would be impractical to manually review all individual features to identify redundancies for the 2D model. Additionally, while various GIS spatial analyses were considered to identify redundancies, HDR concluded that using a spatial analysis approach across the entire watershed scale for this dataset could introduce other unintentional errors and omissions in the 2D model.

Therefore, to address these redundancies efficiently across the entire watershed scale, HDR developed a random sampling process to review closely overlapping datasets and evaluate the potential impacts of omitting them. HDR's initial data review identified Hennepin County, Carver County, and MNDOT sources as potentially redundant. These datasets were reviewed as part of the random sampling process to evaluate their overall redundancy and make statistically significant conclusions on whether to omit them from the 2D model.

In addition, HDR identified other potential redundancies when comparing the culvert feature class (cPipes) to the storm sewer pipe feature class (pipes). In this instance, with just 385 potentially redundant pipes identified, the entire population of overlapping features was manually reviewed rather than utilizing a general random sampling approach.

Following this approach, HDR recommends omitting datasets that are found to be at least 80% redundant as determined through a random sampling statistical analysis with a 90% confidence level and 5% margin of error. This recommendation was used as the basis for the analysis and conclusions described in this memorandum.

Analysis Approach

The analysis approach is described in the following steps.

1. Identify datasets for review which may have substantial overlap with other data sources
 - a. MNDOT, Hennepin County, and Carver County storm sewer pipes
 - b. Culvert features
2. Perform a random sampling of a statistically significant number of storm sewer pipes across the entire watershed to evaluate data sources for potential redundancy and omission
 - a. Overlapping MNDOT features
 - i. MNDOT – Pipes (4,641)
 - ii. MNDOT – Inlets (4,257)
 - iii. For a population of 4,641 features, approximately 160-360 features from the **MNDOT dataset** are required in the random sample for statistical significance (assuming 5% margin of error)
 1. 80% Confidence Level = 159
 2. 85% Confidence Level = 199
 3. 90% Confidence Level = 258
 4. 95% Confidence Level = 355
 - b. Overlapping Hennepin County features
 - i. Hennepin County – Pipes (4,072)
 - ii. Hennepin County – Inlets (3,621)
 - iii. For a population of 4,072 features, approximately 160-360 features from the **Hennepin County dataset** are required in the random sample for statistical significance (assuming 5% margin of error)
 1. 80% Confidence Level = 158
 2. 85% Confidence Level = 198
 3. 90% Confidence Level = 256
 4. 95% Confidence Level = 352
 - c. Overlapping Carver County Features
 - i. Carver County – Pipes (228)
 - ii. Carver County – Inlets (141)
 - iii. For a population of 228 features, approximately 95-145 features from the **Carver County dataset** are required in the random sample for statistical significance (assuming 5% margin of error)
 1. 80% Confidence Level = 96
 2. 85% Confidence Level = 109
 3. 90% Confidence Level = 125
 4. 95% Confidence Level = 144
 - d. To evaluate all four MNDOT/Hennepin County datasets with 80–95% confidence, a total of approximately 640 to 1,440 randomly sampled features across all datasets would be required (e.g., 160–360 samples per dataset).

3. Selected storm sewer pipes were sampled randomly from all overlapping features. The random sample was then verified to confirm that a representative number of random features were sampled from each overlapping municipality.
 - a. Culvert features were identified for review by using “select by location,” and 385 MGIS culverts were identified as being within 10 feet of MGIS pipes. Due to the relatively small number of features, all (385) were manually reviewed following the process outlined below.
4. Each random sampling also included an evaluation of features adjacent to the randomly selected features. For each sampling, a visual buffer was applied including features within a roughly 50-100 ft. radius of the randomly selected feature to identify potential redundancies.
5. With each random sampling, a determination was made whether the features in the duplicate datasets inside the visual buffer area are redundant (yes/no) using a comparison of feature geometry, attribute completeness, and attribute quality. The following checks were used to determine potential feature redundancy.
 - a. Geometry – is the feature a direct geospatial copy? If not, is the feature visually similar via connectivity or orientation but offset from the comparison feature?
 - b. Attribute Completeness/Quality – are the primary attribute fields complete? If so, are the attributes reasonable?
 - i. Pipes/Culverts (in order of priority)
 1. Inverts
 2. Diameter
 3. Material
 4. Slope (where inverts are missing)
6. The result of each random sample determination was recorded in a point feature class as a single point (one for each visual buffer area) along with any relevant notes from the review explaining the selected result
 - a. Fields included for random sample point feature class
 - i. Unique ID
 - ii. Redundancy_Check (Y/N)
 - iii. Notes
 - iv. Municipality
7. Since missing inlet points can be regenerated through the “MGIS to Model Ready” script process, a separate random sampling analysis was not performed for inlets. Instead, determinations on inclusion or omission of a source’s inlets were made based on the quality of that source’s pipe data.
8. Based on the random sampling analysis, a final determination was made whether to omit the dataset or evaluate the dataset further
 - a. If more than 80% of the features within the random sampling are identified as redundant based on this random sampling, then the dataset may be omitted from future processing (this determination should be made separately for each of the four feature classes)

- b. If less than 80% of the features within the random sampling are identified as redundant based on the random sampling, further evaluation of the individual datasets may be warranted.

Results

The following section summarizes the results of the duplicative dataset evaluation for pipes and inlets in Hennepin County, Carver County, MNDOT as well as for MGIS culverts. A random sample analysis was performed for pipe data in Hennepin County, Carver County, and MNDOT. Determinations on the inclusion or omission of a source's inlets were made based on the quality of that source's pipe data.

1. Hennepin County Inlets/Pipes

- a. Pipes:

Hennepin County Randomly Sampled Subset Distribution Check

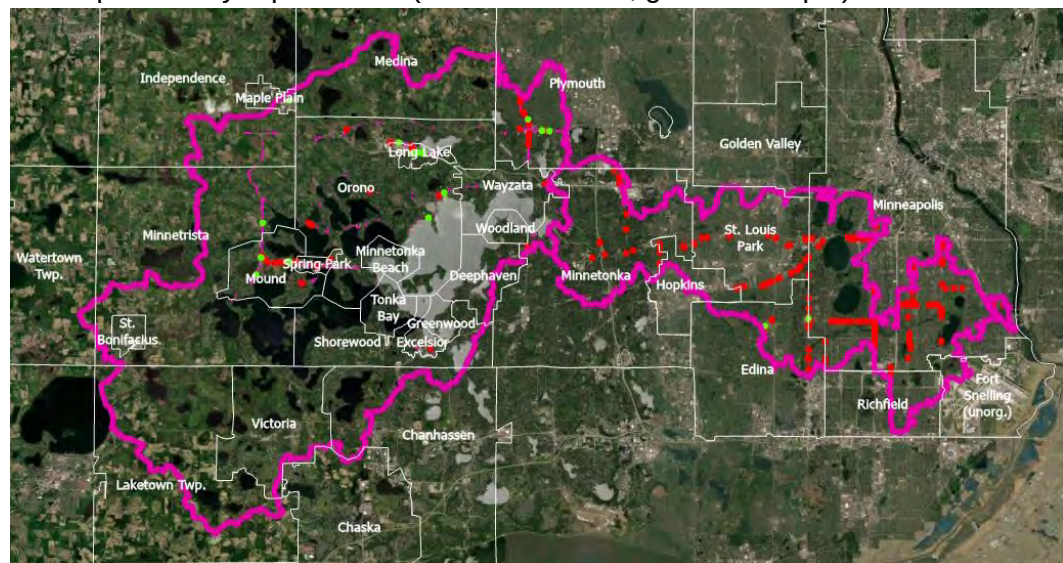
Municipality Intersected	All Intersections		Randomly Sampled Subset	
	Count	Percentage (of 3921)	Count	Percentage (of 260)
Edina	287	7.32%	23	8.85%
Golden Valley	0	0.00%	0	0.00%
Minnetonka	444	11.32%	20	7.69%
Hopkins	105	2.68%	5	1.92%
MNDOT	332	8.47%	24	9.23%
Minneapolis	2014	51.36%	140	53.85%
Plymouth	348	8.88%	24	9.23%
Richfield	23	0.59%	2	0.77%
Saint Louis Park	539	13.75%	34	13.08%
Wayzata	6	0.15%	1	0.38%
Victoria	0	0.00%	0	0.00%
Saint Bonifacius	0	0.00%	0	0.00%
Spring Park	93	2.37%	5	1.92%
Shorewood	0	0.00%	0	0.00%
Mound	194	4.95%	13	5.00%
Minnetrista	41	1.05%	1	0.38%
Medina	0	0.00%	0	0.00%
Maple Plain	7	0.18%	1	0.38%
Long Lake	134	3.42%	8	3.08%
Greenwood	0	0.00%	0	0.00%
Excelsior	16	0.41%	1	0.38%
Deephaven	0	0.00%	0	0.00%

Municipality Intersected	All Intersections		Randomly Sampled Subset	
	Count	Percentage (of 3921)	Count	Percentage (of 260)
Chanhassen	0	0.00%	0	0.00%
Carver	0	0.00%	0	0.00%
Null	203	5.18%	11	4.23%

Hennepin County Pipe Review Results

Area	Approx. % Unique	Approx. % Redundant
Entire Watershed	10.0%	90.0%
Upper Watershed	34.5%	65.5%
Lower Watershed	1.0%	99.0%

Hennepin County Pipe Subset (red = redundant, green = unique)



Hennepin County Pipe Review Results by Municipality

Data Source	Total Number of Features Intersecting	Number of Features	Approx. % Unique	Approx. % Redundant
Edina	287	23	8.7%	91.3%
Minnetonka	444	20	0.0%	100.0%
Hopkins	105	5	0.0%	100.0%
MNDOT	332	24	16.7%	83.3%
Minneapolis	2014	140	0.7%	99.3%
Plymouth	348	24	12.5%	87.5%
Richfield	23	2	0.0%	100.0%

Data Source	Total Number of Features Intersecting	Number of Features	Approx. % Unique	Approx. % Redundant
Saint Louis Park	539	34	0.0%	100.0%
Wayzata	6	1	0.0%	100.0%
Spring Park	93	5	0.0%	100.0%
Mound	194	13	23.1%	76.9%
Minnetrista	41	1	100.0%	0.0%
Maple Plain	7	1	100.0%	0.0%
Long Lake	134	8	62.5%	37.5%
Excelsior	16	1	0.0%	100.0%
Null	203	11	36.4%	63.6%

- b. **Hennepin County Recommendations:** With approximately 90% of the Hennepin County pipe network identified as redundant, it is recommended that the Hennepin County pipes and inlets be omitted in the watershed. The random sampling procedure indicates that omitting the pipe network would have a limited effect on the model quality.

2. MNDOT Inlets/Pipes

- a. Pipes:

MNDOT Randomly Sampled Subset Distribution Check

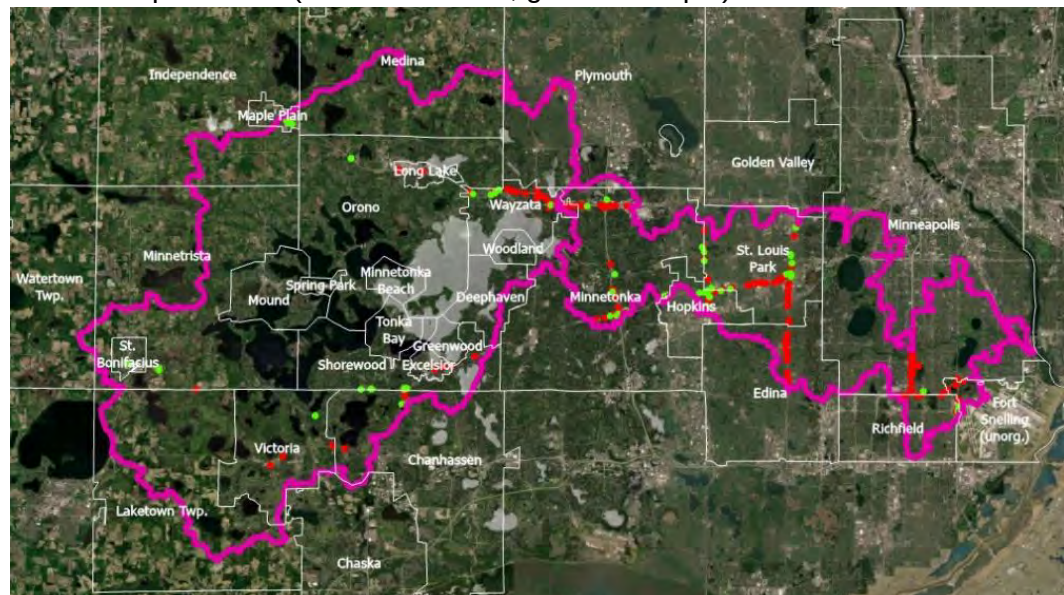
Municipality Intersected	All Intersections		Randomly Sampled Subset	
	Count	Percentage (of 4271)	Count	Percentage (of 260)
Edina	339	7.94%	20	7.69%
Golden Valley	53	1.24%	2	0.77%
Minnetonka	867	20.30%	52	20.00%
Hopkins	248	5.81%	21	8.08%
Hennepin County	1162	27.21%	68	26.15%
Minneapolis	999	23.39%	58	22.31%
Plymouth	18	0.42%	1	0.38%
Richfield	492	11.52%	32	12.31%
Saint Louis Park	1000	23.41%	56	21.54%
Wayzata	563	13.18%	36	13.85%
Victoria	82	1.92%	4	1.54%
Saint Bonifacius	34	0.80%	1	0.38%
Spring Park	0	0.00%	0	0.00%

Municipality Intersected	All Intersections		Randomly Sampled Subset	
	Count	Percentage (of 4271)	Count	Percentage (of 260)
Shorewood	129	3.02%	12	4.62%
Mound	0	0.00%	0	0.00%
Minnetrista	29	0.68%	2	0.77%
Medina	0	0.00%	0	0.00%
Maple Plain	41	0.96%	4	1.54%
Long Lake	187	4.38%	4	1.54%
Greenwood	73	1.71%	2	0.77%
Excelsior	161	3.77%	3	1.15%
Deephaven	0	0.00%	0	0.00%
Chanhassen	113	2.65%	12	4.62%
Carver	10	0.23%	1	0.38%
Null	81	1.90%	3	1.15%

MNDOT Pipe Review Results

Area	Approx. % Unique	Approx. % Redundant
Entire Watershed	29.9%	70.1%
Upper Watershed	48.1%	51.9%
Lower Watershed	23.2%	76.8%

MNDOT Pipe Subset (red = redundant, green = unique)



MNDOT Pipe Review Results by Municipality

Data Source	Total Number of Features Intersecting	Number of Features in Sample	Approx. % Unique	Approx. % Redundant
Edina	339	20	0.0%	100.0%
Golden Valley	53	2	50.0%	50.0%
Minnetonka	867	52	30.8%	69.2%
Hopkins	248	21	66.7%	33.3%
Hennepin County	1162	68	17.6%	82.4%
Minneapolis	999	58	1.7%	98.3%
Plymouth	18	1	0.0%	100.0%
Richfield	492	32	12.5%	87.5%
Saint Louis Park	1000	56	26.8%	73.2%
Wayzata	563	36	19.4%	80.6%
Victoria	82	4	25.0%	75.0%
St Bonifacius	34	1	100.0%	0.0%
Shorewood	129	12	41.7%	58.3%
Minnetrista	29	2	50.0%	50.0%
Medina	41	4	100.0%	0.0%
Long Lake	187	4	25.0%	75.0%
Greenwood	73	2	0.0%	100.0%
Excelsior	161	3	0.0%	100.0%
Chanhassen	113	12	33.3%	66.7%
Carver	10	1	0.0%	100.0%
Null	81	3	33.3%	66.7%

- b. **MNDOT Recommendations:** With approximately 70.1% of the MNDOT pipe dataset identified as redundant, omission of the entire dataset is not recommended. Further assessment of the dataset, however, identified municipalities that are potentially redundant with respect to the MNDOT pipe dataset as seen above. Per this further assessment, it is recommended that MNDOT data intersecting Edina, Minneapolis, Plymouth, Richfield, Wayzata, Greenwood, Excelsior, and Carver be reviewed for assessment of removal. It is recommended that MNDOT inlets intersecting with these municipalities be omitted as well.
- c. **4/25/2025 Update:** After further discussion with MCWD, it was decided to omit MNDOT pipes and inlets to facilitate the initial model build. Further evaluation whether to incorporate these omitted MNDOT features may be beneficial following the model build and calibration.

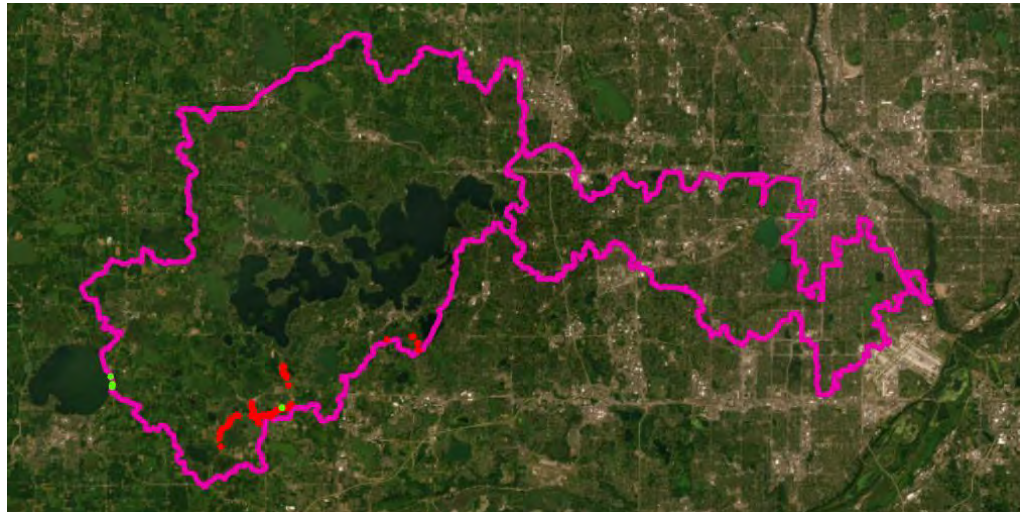
3. Carver County Inlets/Pipes

a. Pipes:

Carver County Pipe Review Results

Area	Approx. % Unique	Approx. % Redundant
Entire Watershed	8.0%	92.0%

Carver County Pipe Subset (red = redundant, green = unique)



Carver County Pipe Review Results by Municipality

Data Source	Number of Features	Approx. % Unique	Approx. % Redundant
Chanhassen	8	0.0%	100.0%
Golden Valley	109	1.8%	98.2%
None	8	100%	0%

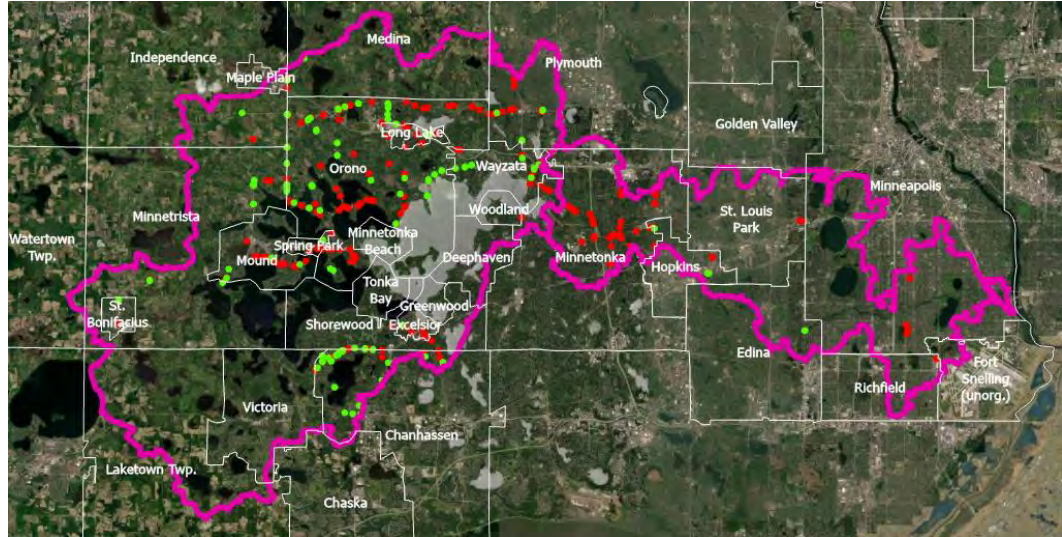
b. Carver County Recommendations:

With the redundancy of the Carver County pipe representative sample determined to be 92%, it is recommended that the dataset be omitted. In line with previous recommendations, it is also recommended that Carver County inlets be omitted.

4. MGIS Culverts

- a. 385/2109 (18.3%) of culverts were identified as intersecting MGIS pipes. Of these intersecting culverts, 282/385 (73.2%) were identified as redundant.

Intersecting Culvert Subset (red = redundant, green = unique)



- b. **MGIS Culverts Recommendations:** It is recommended that all 282 culverts identified as redundant be removed from the dataset.

Conclusions

Redundancy in storm sewer and culvert pipes were identified in source datasets to the MGIS data aggregation workflow. This analysis selected a sample of each potentially redundant dataset to review for potential omission from the aggregated dataset. The results indicate that Hennepin County and Carver County Data may be omitted without substantial loss of relevant data. MNDOT data may require additional review and omission from particular regions of the watershed area. MGIS culverts manually identified as redundant should be omitted from the final dataset.

Memo

Date: Tuesday, August 04, 2026

Project: 2-D Watershed-Wide Model

To: MCWD

From: HDR

Subject: Appendix C-10: Crop Coefficients

Note: With the update to land cover selection 03/2026, the previously developed crop coefficient and root depth values were adapted to the new selection. As such, all existing sections (sections 1-8) have been left unchanged, with additional sections added to reflect later work.

1.0 Introduction

To represent evapotranspiration in StormWise, an input table containing crop coefficients and rooting depths for each land cover type is required. StormWise requires each land cover type in this table to have crop coefficient values and rooting depths for each modeled day, month, and year. For this project, a land cover raster containing 11 land cover types is used and the corresponding input table was developed for an average year. The single crop coefficient approach from Chapter 6 of the Food and Agricultural Organization publication 56 (FAO 56), “Crop evapotranspiration—Guidelines for computing crop water requirements,” was used to calculate crop coefficients (K_c) for each land cover type present (FAO 1998). Here, evapotranspiration under standard conditions, ET_c , is calculated for each land cover type as the product of reference evapotranspiration, ET_0 , and a crop coefficient, K_c , developed for each land cover type. Reference evapotranspiration, ET_0 , data for the modeled Minnehaha Creek Watershed has been provided to HDR from MCWD. This document outlines the development of crop coefficients and, if applicable, rooting depths for each of the following land cover types present in the land cover raster. For detailed calculations, see Electronic Data Package Item C-10: Crop Coefficients.

- Agriculture
- Bare soil
- Coniferous tree canopy
- Deciduous tree canopy
- Emergent wetland
- Forested shrub/wetland
- Grass/shrub
- Lakes/ponds
- River
- Buildings
- Roads/paved surfaces

2.0 Crop Coefficient Background

In FAO 56 Chapter 6, Table 11 provides general lengths for the four distinct growing stages; initial, developing, mid-season, and late-season (L_{ini} , L_{dev} , L_{mid} , and L_{late}) for various land cover types, climates, and locations. Similarly, Table 12 of FAO 56 Chapter 6 provides reference initial, mid-season, and end-of-season crop K_c values ($K_{c\ ini}$, $K_{c\ mid}$, and $K_{c\ end}$). For each of the land cover types present in the watershed, representative growing stages and K_c values were extracted from Tables 11 and 12, respectively.

To properly relate the FAO reference values to the seasonal behavior of the land cover types in the Minnehaha Creek Watershed, growing season start and end dates are required for each land cover type. Using the middle of each month as the reference date (D_{ref}), the average monthly K_c for each land cover type was calculated using the following logic.

Definitions:

- $D_{initial} = \text{growing season start date} + L_{ini}$
- $D_{developing} = D_{initial} + L_{dev}$
- $D_{mid-season} = D_{developing} + L_{mid}$
- $D_{late-season} = D_{mid-season} + L_{late}$
- If $D_{late-season} < D_{freeze}$ then $D_{late-season} = \text{growing season end date}$

K_c Calculation:

- If $D_{ref} \leq D_{initial}$
 - o $K_c = K_{c\ ini}$
 - o For the initial period, K_c equals $K_{c\ ini}$
- If $D_{initial} < D_{ref} < D_{developing}$
 - o $K_c = (((D_{ref} - D_{initial}) / (D_{developing} - D_{initial})) * (K_{c\ mid} - K_{c\ ini})) + K_{c\ ini}$
 - o During the development period, K_c linearly increases from $K_{c\ ini}$ to $K_{c\ mid}$
- If $D_{developing} < D_{ref} < D_{mid-season}$
 - o $K_c = K_{c\ mid}$
 - o During the midseason period, K_c equals $K_{c\ mid}$
- If $D_{mid-season} < D_{ref} < D_{late-season}$
 - o $K_c = (((D_{ref} - D_{mid-season}) / (D_{late-season} - D_{mid-season})) * (K_{c\ late} - K_{c\ mid})) + K_{c\ mid}$
 - o During the late season period, K_c linearly decreases from $K_{c\ mid}$ to $K_{c\ late}$

ET_c Calculation:

- $ET_c = K_c * ET_0$
- This calculation is completed using the K_c , which varies over a calendar year, determined for each land cover layer.

3.0 Developed Land Cover Types

Within the land cover raster used, both the buildings and the roads/paved surfaces categories are assumed to have 100 percent impervious coverage. Impervious areas do not allow covered soil to evaporate and generally represent surfaces with little or no vegetation. Under this analysis, areas with 100 percent impervious coverage are assumed to have no evaporation

potential. This means the year-round K_c value for both the buildings and the roads/paved surfaces category will be zero.

4.0 Agriculture Land Cover

To give more detail to the agriculture land cover type, the 2022 Hennepin County Census of Agriculture was leveraged. From this census, the top three crop types in Hennepin County were determined to be soybeans, hay, and corn. Using the reported acreage of these crops, the fraction of each was determined. Average monthly K_c values were determined for each of these three crops. Using the crop fractions, the K_c values for each of the three crops were weighed and used to calculate one representative agriculture category, aligning with the land cover raster used. See **Table 1** below.

Table 1. Hennepin County Crops with Fractions (USDA 2022)

Crop	Count (ac)	Fraction
Soybeans	7169	0.43499
Forage (hay)	4944	0.29998
Corn (grain)	4368	0.26503
TOTAL	16481	-

5.0 Growing Season Determination

Surface Water Growing Seasons

The growing seasons for the Lakes/ponds and River land cover types were determined using ice-in and -out data from the Minnesota Department of Natural Resources (MNDNR) (MNDNR 2025). Using the available data for lakes within the watershed, the median date at which the lakes were reported frozen and thawed were pulled as the growing season start and end, respectively. It was assumed that rivers experienced open water sooner than the lakes/ponds in the spring and later in the fall/winter, so a buffer of 15 days on either end of the lakes/ponds growing season was used to represent this. See **Table 2** for the median ice-in and -out dates of the lakes used.

Table 2. Median Ice-in and -out Dates Informing Lakes/Ponds Growing Season

Lake	Median Ice-In Date	Median Ice-Out Date
Minnetonka Lower	8-Dec	13-Apr
Minnetonka Upper	-	14-Apr
Christmas	3-Dec	12-Apr
Diamond	-	25-Mar
Nokomis	1-Dec	4-Apr
Hiawatha	-	5-Apr
Harriet	10-Dec	7-Apr
Bde Maka Ska	11-Dec	9-Apr
Lake of the Isles	29-Dec	7-Apr
Cedar Lake	-	9-Apr

AVERAGE	10-Dec	7-Apr
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Growing Seasons for Remaining Land Cover Types

For the following land cover categories, growing season was determined by soil temperature.

- Agriculture
 - o Soybeans
 - o Hay
 - o Corn
- Bare soil
- Coniferous tree canopy
- Deciduous tree canopy
- Emergent wetland
- Forested shrub/wetland
- Grass/shrub

Each of these land cover categories was assigned a benchmark soil temperature where planting/germination is expected; this is the growing season start date. Similarly, the growing season is expected to end once the soil temperature is at or below freezing. Where available, recommended growing season start soil temperatures for each of the land cover categories was used. Where not available, a default assumption of 50°F was assigned based on Pathak et. al, 2012. With these benchmarks determined, data from the National Oceanic and Atmospheric Administration's (NOAA) soil temperature maps by depth station MPXM5, located in Chanhassen was leveraged. The dataset contains daily soil temperature data from 2009-2024 and was used to assign a date to each of these benchmark soil temperatures (NOAA 2025). Here, the average spring date at which each soil temperature was met or exceeded was determined for each benchmark. See **Table 3** for a summary of growing seasons and sources for all land cover types present.

Table 3. Growing Season Soil Temperature and Dates for MCWD Land Cover Types

Land Cover Category	Growing Start				Growing End			
	Type	Date	Source - Type	Source - Date	Type	Date	Source - Type	Source - Date
AGRICULTURE - Corn	55° soil temp	17-May	(Nair)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
AGRICULTURE - Soybeans	55° soil temp	17-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
AGRICULTURE - Hay	43° soil temp	11-Apr	(Pathak, 2012)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
BARE SOIL	32° soil temp	15-Mar	Assumed	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
CONIFEROUS TREE CANOPY	50° soil temp	2-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (28F)	27-Oct	Assumed	(NCEI, 2024)
DECIDUOUS TREE CANOPY	50° soil temp	2-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
EMERGENT WETLAND	50° soil temp	2-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
FORESTED SHRUB/WETLAND	50° soil temp	2-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (28F)	27-Oct	Assumed	(NCEI, 2024)
GRASS/SHRUB	50° soil temp	2-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)

[illegible]

Table 8. Rooting Depths for the Watershed Model Land Cover Raster Categories by Month

Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AGRICULTURE	0	0	0	0.45	0.45	2.12	2.12	2.12	2.12	2.12	0	0
BARE SOIL	0	0	0	0	0	0	0	0	0	0	0	0
CONIFEROUS TREE CANOPY	0	0	0	0	3	3	3	3	3	3	0	0
DECIDUOUS TREE CANOPY	0	0	0	0	3	3	3	3	3	3	0	0
EMERGENT WETLAND	0	0	0	0	3	3	3	3	3	3	0	0
FORESTED SHRUB/WETLAND	0	0	0	0	3	3	3	3	3	3	0	0
GRASS/SHRUB	0	0	0	0	3	3	3	3	3	3	0	0
LAKES/PONDS	0	0	0	3	3	3	3	3	3	3	3	0
RIVER	0	0	0	3	3	3	3	3	3	3	3	3
BUILDINGS	-	-	-	-	-	-	-	-	-	-	-	-
ROADS/PAVED SURFACES	-	-	-	-	-	-	-	-	-	-	-	-

9.0 Updated Land Cover Selection

Per discussions with the project team, updated land cover selections were made during the month 03/2026, to provide more flexibility in implementing future land cover changes. For this, two land cover datasets, the Metropolitan Council's Generalized Land Use (GLU) set and the USGS' National Land Cover Database (NLCD) were blended. Here, selected land cover types from the GLU set were replaced by values from the NLCD. See below for a definition of each set's land cover types and replacements made.

Generalized Land Use (GLU):

- Agricultural – Replaced with NLCD
- Farmstead
- Seasonal/Vacation
- Single Family Detached
- Single Family Attached
- Multifamily
- Manufactured Housing Park
- Retail and Other Commercial
- Office
- Mixed Use Residential
- Mixed Use Industrial
- Mixed Use Commercial
- Industrial or Utility
- Institutional
- Park, Recreational, or Preserve – Replaced with NLCD

- Golf Course – Replaced with NLCD
- Major Highway
- Major Railway
- Airport or Airstrip
- Undeveloped – Replaced with NLCD
- Open Water – Replaced with NLCD

National Land Cover Database (NLCD):

- Open Water
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land (Rock/Sand/Clay)
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrub/Scrub
- Herbaceous/Grasslands
- Hay/Pasture
- Cultivated Crops
- Woody Wetlands
- Emergent Herbaceous Wetlands

With the framework developed, all GLU zones defined by “Replaced with NLCD” above were removed, and the NLCD zones for these locations were appended. In raster form and as imported to StormWise, the GLU values are defined by a three-digit code and the NLCD values by a two-digit code. See the following section for a key.

10.0 TCMA to New Land Cover Conversion

To generate new values for both crop coefficients and rooting depths based on the new land cover types, a combination of direct and blended TCMA values was used based on land cover type alignment. For blended values, a combination of impervious and grass/shrub TCMA values was used, weighted by the GLU/NLCD layer’s impervious percentage. See Table 9 for a key including numeric code, source, impervious percentage, label, and TCMA value used for each new land use category.

$$K_{c \text{ blended}} = \%_{\text{impervious}} * K_{c \text{ impervious}} + (1 - \%_{\text{impervious}}) * K_{c \text{ grass/shrub}}$$

Table 9. New Land Use Selections Key

Code	Source	Impervious %	Label	TCMA Value Used
111	GLU	17.8	Farmstead	Blended
112	GLU	4.0	Seasonal/Vacation	DECIDUOUS TREE CANOPY
113	GLU	28.7	Single Family Detached	Blended
114	GLU	48.9	Single Family Attached	Blended
115	GLU	59.9	Multifamily	Blended
116	GLU	47.7	Manufactured Housing Park	Blended
120	GLU	74.6	Retail and Other Commercial	Blended
130	GLU	67.9	Office	Blended
141	GLU	74.6	Mixed Use Residential	Blended
142	GLU	69.1	Mixed Use Industrial	Blended
143	GLU	77.5	Mixed Use Commercial	Blended
151	GLU	65.0	Industrial or Utility	Blended
160	GLU	47.1	Institutional	Blended
201	GLU	59.7	Major Highway	Blended
202	GLU	61.6	Major Railway	Blended
203	GLU	63.4	Airport or Airstrip	Blended
11	NLCD	0	Open Water	LAKES/PONDS
21	NLCD	10.7	Developed, Open Space	Blended
22	NLCD	33.8	Developed, Low Intensity	Blended
23	NLCD	62.2	Developed, Medium Intensity	Blended
24	NLCD	85.6	Developed, High Intensity	Blended
31	NLCD	0	Barren Land (Rock/Sand/Clay)	BARE SOIL
41	NLCD	0	Deciduous Forest	DECIDUOUS TREE CANOPY
42	NLCD	0	Evergreen Forest	CONIFEROUS TREE CANOPY
43	NLCD	0	Mixed Forest	DECIDUOUS TREE CANOPY
52	NLCD	0	Shrub/Scrub	GRASS/SHRUB
71	NLCD	0	Herbaceous/Grasslands	GRASS/SHRUB
81	NLCD	0	Hay/Pasture	AGRICULTURE
82	NLCD	0	Cultivated Crops	AGRICULTURE
90	NLCD	0	Woody Wetlands	FORESTED SHRUB/WETLAND
95	NLCD	0	Emergent Herbaceous Wetlands	EMERGENT WETLAND

With TCMA to new land use assignments made, new Kc and rooting depth values were generated. See Tables 10 and 11 for these values, respectively.

Table 10. Kc Values for the Updated Land Cover Raster Categories by Month

Code	Label	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
111	Farmstead	0.16	0.16	0.16	0.16	0.67	0.70	0.70	0.70	0.70	0.16	0.16	0.16
112	Seasonal/Vacation	0.20	0.20	0.20	0.20	1.00	1.00	1.00	1.00	1.00	0.20	0.20	0.20
113	Single Family Detached	0.14	0.14	0.14	0.14	0.58	0.61	0.61	0.61	0.61	0.14	0.14	0.14
114	Single Family Attached	0.10	0.10	0.10	0.10	0.41	0.43	0.43	0.43	0.43	0.10	0.10	0.10
115	Multifamily	0.08	0.08	0.08	0.08	0.32	0.34	0.34	0.34	0.34	0.08	0.08	0.08
116	Manufactured Housing Park	0.10	0.10	0.10	0.10	0.42	0.44	0.44	0.44	0.44	0.10	0.10	0.10
120	Retail and Other Commercial	0.05	0.05	0.05	0.05	0.21	0.22	0.22	0.22	0.22	0.05	0.05	0.05
130	Office	0.06	0.06	0.06	0.06	0.26	0.27	0.27	0.27	0.27	0.06	0.06	0.06
141	Mixed Use Residential	0.05	0.05	0.05	0.05	0.21	0.22	0.22	0.22	0.22	0.05	0.05	0.05
142	Mixed Use Industrial	0.06	0.06	0.06	0.06	0.25	0.26	0.26	0.26	0.26	0.06	0.06	0.06
143	Mixed Use Commercial	0.04	0.04	0.04	0.04	0.18	0.19	0.19	0.19	0.19	0.04	0.04	0.04
151	Industrial or Utility	0.07	0.07	0.07	0.07	0.28	0.30	0.30	0.30	0.30	0.07	0.07	0.07
160	Institutional	0.11	0.11	0.11	0.11	0.43	0.45	0.45	0.45	0.45	0.11	0.11	0.11
201	Major Highway	0.08	0.08	0.08	0.08	0.33	0.34	0.34	0.34	0.34	0.08	0.08	0.08
202	Major Railway	0.08	0.08	0.08	0.08	0.31	0.33	0.33	0.33	0.33	0.08	0.08	0.08
203	Airport or Airstrip	0.07	0.07	0.07	0.07	0.30	0.31	0.31	0.31	0.31	0.07	0.07	0.07
11	Open Water	0.20	0.20	0.20	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	0.20
21	Developed, Open Space	0.18	0.18	0.18	0.18	0.72	0.76	0.76	0.76	0.76	0.18	0.18	0.18
22	Developed, Low Intensity	0.13	0.13	0.13	0.13	0.54	0.56	0.56	0.56	0.56	0.13	0.13	0.13
23	Developed, Medium Intensity	0.08	0.08	0.08	0.08	0.31	0.32	0.32	0.32	0.32	0.08	0.08	0.08
24	Developed, High Intensity	0.03	0.03	0.03	0.03	0.12	0.12	0.12	0.12	0.12	0.03	0.03	0.03
31	Barren Land (Rock/Sand/Clay)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
41	Deciduous Forest	0.20	0.20	0.20	0.20	1.00	1.00	1.00	1.00	1.00	0.20	0.20	0.20
42	Evergreen Forest	0.20	0.20	0.20	0.20	1.00	1.00	1.00	1.00	1.00	1.00	0.20	0.20
43	Mixed Forest	0.20	0.20	0.20	0.20	1.00	1.00	1.00	1.00	1.00	0.20	0.20	0.20
52	Shrub/Scrub	0.20	0.20	0.20	0.20	0.81	0.85	0.85	0.85	0.85	0.20	0.20	0.20
71	Herbaceous/Grasslands	0.20	0.20	0.20	0.20	0.81	0.85	0.85	0.85	0.85	0.20	0.20	0.20
81	Hay/Pasture	0.20	0.20	0.20	0.26	0.42	0.68	1.04	1.09	1.01	0.20	0.20	0.20
82	Cultivated Crops	0.20	0.20	0.20	0.26	0.42	0.68	1.04	1.09	1.01	0.20	0.20	0.20
90	Woody Wetlands	0.20	0.20	0.20	0.20	0.42	1.20	1.20	1.20	0.94	0.47	0.20	0.20
95	Emergent Herbaceous Wetlands	0.20	0.20	0.20	0.20	0.42	1.20	1.20	1.20	0.88	0.20	0.20	0.20

Table 10. Rooting Depth Values for the Updated Land Cover Raster Categories by Month

Code	Label	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
111	Farmstead	0	0	0	0	0	3	3	3	3	3	0	0
112	Seasonal/ Vacation	0	0	0	0	3	3	3	3	3	3	0	0
113	Single Family Detached	0	0	0	0	0	3	3	3	3	3	0	0
114	Single Family Attached	0	0	0	0	0	3	3	3	3	3	0	0
115	Multifamily	0	0	0	0	0	3	3	3	3	3	0	0
116	Manufactured Housing Park	0	0	0	0	0	3	3	3	3	3	0	0
120	Retail and Other Commercial	0	0	0	0	0	3	3	3	3	3	0	0
130	Office	0	0	0	0	0	3	3	3	3	3	0	0
141	Mixed Use Residential	0	0	0	0	0	3	3	3	3	3	0	0
142	Mixed Use Industrial	0	0	0	0	0	3	3	3	3	3	0	0
143	Mixed Use Commercial	0	0	0	0	0	3	3	3	3	3	0	0
151	Industrial or Utility	0	0	0	0	0	3	3	3	3	3	0	0
160	Institutional	0	0	0	0	0	3	3	3	3	3	0	0
201	Major Highway	0	0	0	0	0	3	3	3	3	3	0	0
202	Major Railway	0	0	0	0	0	3	3	3	3	3	0	0
203	Airport or Airstrip	0	0	0	0	0	3	3	3	3	3	0	0
11	Open Water	0	0	0	0	0	3	3	3	3	3	0	0
21	Developed, Open Space	0	0	0	0	0	3	3	3	3	3	0	0
22	Developed, Low Intensity	0	0	0	0	0	3	3	3	3	3	0	0
23	Developed, Medium Intensity	0	0	0	0	0	3	3	3	3	3	0	0
24	Developed, High Intensity	0	0	0	0	0	3	3	3	3	3	0	0
31	Barren Land (Rock/Sand/ Clay)	0	0	3	3	3	3	3	3	3	3	0	0
41	Deciduous Forest	0	0	0	0	3	3	3	3	3	3	0	0
42	Evergreen Forest	0	0	0	0	3	3	3	3	3	3	0	0
43	Mixed Forest	0	0	0	0	3	3	3	3	3	3	0	0
52	Shrub/Scrub	0	0	0	0	3	3	3	3	3	3	0	0
71	Herbaceous/ Grasslands	0	0	0	0	3	3	3	3	3	3	0	0
81	Hay/Pasture	0	0	0	0.45	0.45	2.12	2.12	2.12	2.12	2.12	0	0
82	Cultivated Crops	0	0	0	0.45	0.45	2.12	2.12	2.12	2.12	2.12	0	0
90	Woody Wetlands	0	0	0	0	3	3	3	3	3	3	0	0
95	Emergent Herbaceous Wetlands	0	0	0	0	3	3	3	3	3	3	0	0

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ELECTRONIC DATA PACKAGE ITEM C-10: Crop Coefficients

Memo

Date: Tuesday, August 04, 2026
Project: 2-D Watershed-Wide Model
To: MCWD
From: HDR
Subject: Appendix C-11: Naming Convention

1.0 - Introduction

This document outlines the naming convention used for model elements in the 2-D watershed-wide model developed for the Minnehaha Creek Watershed District. Each feature's name follows the following general convention: AA-BBB-CCCCC. The naming convention includes overall type (AA), subtype (BBB), and six digits for a unique identifier (CCCCC).

2.0 – Overland Flow Features

Overland flow features follow the naming conventions described in Table 1. Where relevant, the subtype was related to the municipality from which the feature was sourced - see Table 2. The unique identifier field assigned (six-digit integer string, CCCCC) is unique within each feature type but may not be unique in the context of all model elements.

Table 1. Naming Convention for Overland Flow Features

Category	Feature Type	Overall Type for Naming Convention	Subtype for Naming Convention*
Nodes	Storm Sewer Manhole	"NM"	Municipality Code
	Storm Sewer Inlet	"NI"	Municipality Code
	Storm Sewer Outlets	"NO"	Municipality Code
	Pond Control Volume Node	"NP"	"PCV"
	Channel Control Volume Node	"NC"	"CCV"
	Tailwater or Time/Stage Node	"NT"	Varies
Links	Pipes/Culverts	"LP"	Municipality Code
	Weirs	"LW"	Varies

Category	Feature Type	Overall Type for Naming Convention	Subtype for Naming Convention*
	Channels	"LC"	"MC"
	Rating Curves	"LR"	"MC"
	Drop Structures	"LD"	Varies
Cross Sections	Channel	"XC"	"MC"
	Weir	"XW"	Varies
Misc. Overland Flow Region	Region Boundary	"LW"	-
	Breakpoints	"OF"	"BKP"
	Breaklines		"BKL"
	Pond Control Volume		"PCV"
	Channel Control Volume		"CCV"
	Channel Feature		"CCF"
	Boundary Stage Lines		"BSL"
	Simplification		"SIM"
	1D Node Interface – Building Centroids	"1D"	"BLD"

*Features with "Varies" in the subtype field have either not yet been utilized or may span multiple subtypes. Weir links, for example, have been developed as a part of the channel control volume system, but also represent inlet and storm sewer infrastructure connections.

Table 2. Municipality Codes Used for Relevant Overland Flow Feature Subtypes

Municipality	Subtype Code
Carver County	"CVC"
Chanhassen	"CHA"
Deephaven	"DEE"
Edina	"EDI"
Excelsior	"EXC"
Golden Valley	"GVA"
Greenwood	"GRN"
Hennepin County	"HCN"

Municipality	Subtype Code
Hopkins	"HOP"
Independence	"IND"
Long Lake	"LLK"
Maple Plain	"MAP"
Medina	"MED"
Minnetonka	"MTK"
Minnetrista	"MTR"
MnDOT	"DOT"
Mound	"MOU"
Minneapolis	"MPL"
Orono	"ORO"
Plymouth	"PLY"
Richfield	"RFD"
Shorewood	"SHW"
Spring Park	"SPK"
Saint Bonifacius	"SBO"
Saint Louis Park	"SLP"
Three Rivers	"TRV"
Victoria	"VIC"
Wayzata	"WYZ"

3.0 – Groundwater Features

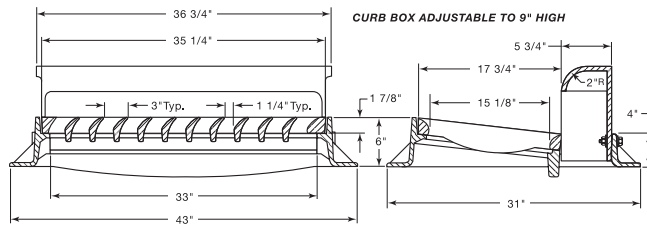
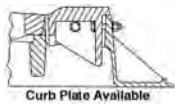
- Regions (4)
 - "GW-NE", "GW-SE", "GW-SW", "GW-NW"
- Breakpoints
 - GW-BKP-000000
- Boundary Stage Lines:
 - GW-BSL-000000

4.0 – Examples

- Feature: Storm Sewer Manhole from Minneapolis Dataset
 - Model Name: NM-MPL-000001
- Feature: Minnehaha Creek Channel Cross Section
 - Model Name: XC-MC-000001
- Feature: Channel Control Volume
 - Model Name: OF-CCV-000001
- Feature: Groundwater Boundary Stage Line
 - Model Name: GW-BSL-000001

R-3067-V Combination Inlet Frame, Grate, Curb Box

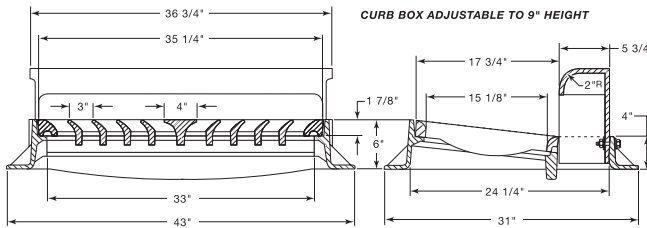
Heavy Duty



CATALOG NUMBER	GRATE TYPE	SQ. FT. OPEN	WEIR PERIMETER LINEAL FEET
R-3067-V	V	2.4	5.8

R-3067-VB Combination Inlet Frame, Grate, Curb Box

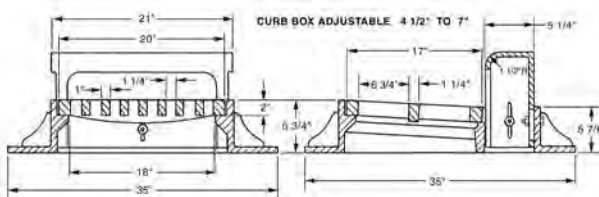
Heavy Duty



CATALOG NUMBER	GRATE TYPE	SQ. FT. OPEN	WEIR PERIMETER LINEAL FEET
R-3067-VB	V	2.7	5.8

R-3070 Combination Inlet Frame, Grate, Curb Box

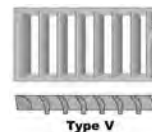
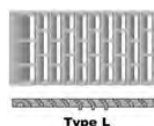
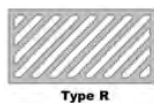
Heavy Duty



Standard Grate (shown): Type A

Alternate Grate(s):

CATALOG NUMBER	GRATE TYPE	SQ. FT. OPEN	WEIR PERIMETER LINEAL FEET
R-3070	A	0.9	4.5
R-3070	L	0.8	4.5
R-3070	R	0.9	4.5
R-3070	V	1.3	4.5



Available Curb Boxes: 1-1/2" Radius Open (standard), 1-1/2" Radius Barred, 3" Radius Open
Enviro-Curb Boxes available, see p. 129.

Memo

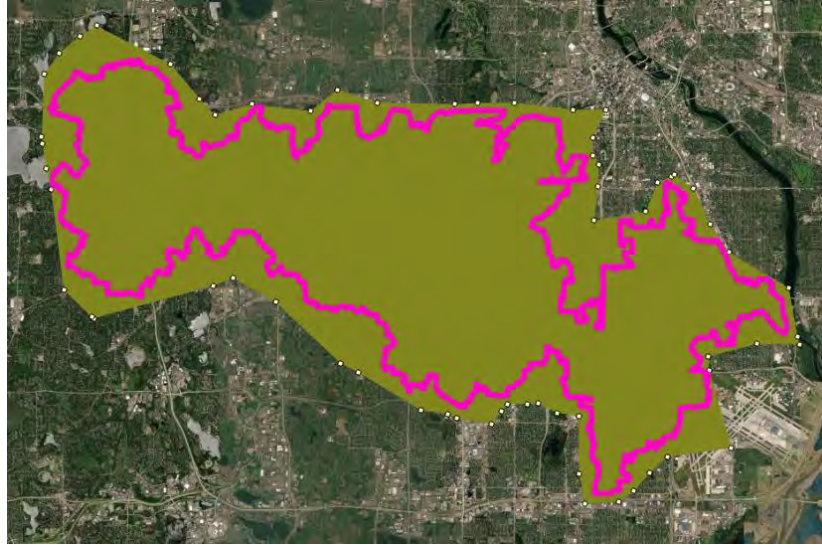
Date: Wednesday, June 04, 2025
Project: 2-D Watershed-Wide Model
To: MCWD
From: HDR
Subject: Appendix C-13: Groundwater Model

This document outlines the groundwater modeling workflow in StormWise, which uses GIS preprocessing to define groundwater regions and boundary conditions. Through structured data inputs like vertical soil layers, ET rates, porosity, and conductivity, StormWise simulates subsurface flow and its interaction with surface water features across the watershed. Model setup includes importing region shapes, boundary stage lines, and associated tables to support accurate hydrologic representation.

Preprocessing in ArcGIS

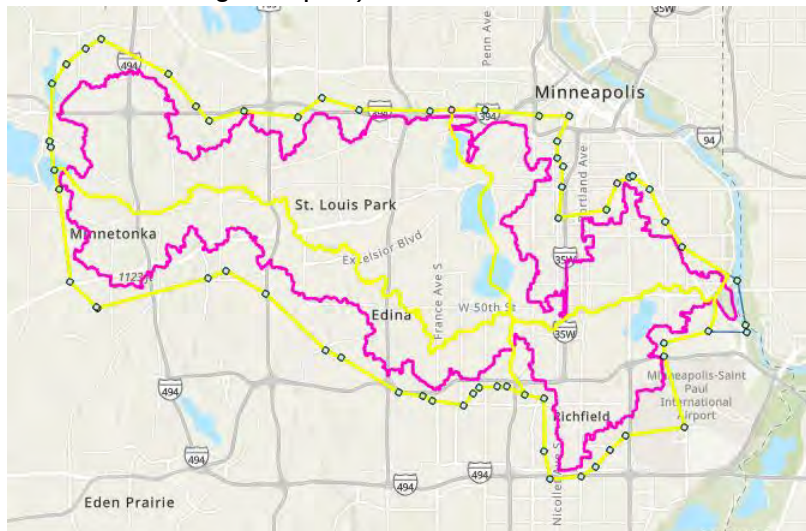
1. Required Components
 - a. Well locations with average static water table level from an external source
 - b. DEM with hydro-flattened water body surfaces
2. Select Groundwater Region Boundary Points
 - a. Identify wells and surface water bodies located outside of the model's overland flow region.
 - b. Place points in the center of the selected water bodies and at well locations in one feature class.
 - i. Each of these locations will serve as a vertex of the groundwater region polygon and provide static water table elevation values to be interpolated along the boundary stage lines.
 - c. In this point feature class, create the following fields and assign field values as described below:
 - i. Type
 1. Either "Well" or "Surface Water" depending on location type
 - ii. NAME
 1. See the provided Naming Convention deliverable.
 - iii. WaterEl
 1. Using the well source data, pull an average static water table elevation for each point. Here, the Minnesota Geological Survey's County Well Index was used to identify relevant wells and pull their static water elevations (MGS 2025).
 2. Use the Add Surface Information tool to calculate the z (elevation) value of each surface water body point, pulling hydro flattened water surface elevations from the DEM (ensure the DEM does not have bathymetry if using this method)
3. Draw Groundwater Region Boundary

- a. Connect all the selected groundwater region boundary points into a polygon bounding the model's overland flow region.
- b. Example: (groundwater region = green, well/surface water points = yellow, overland flow region = pink)

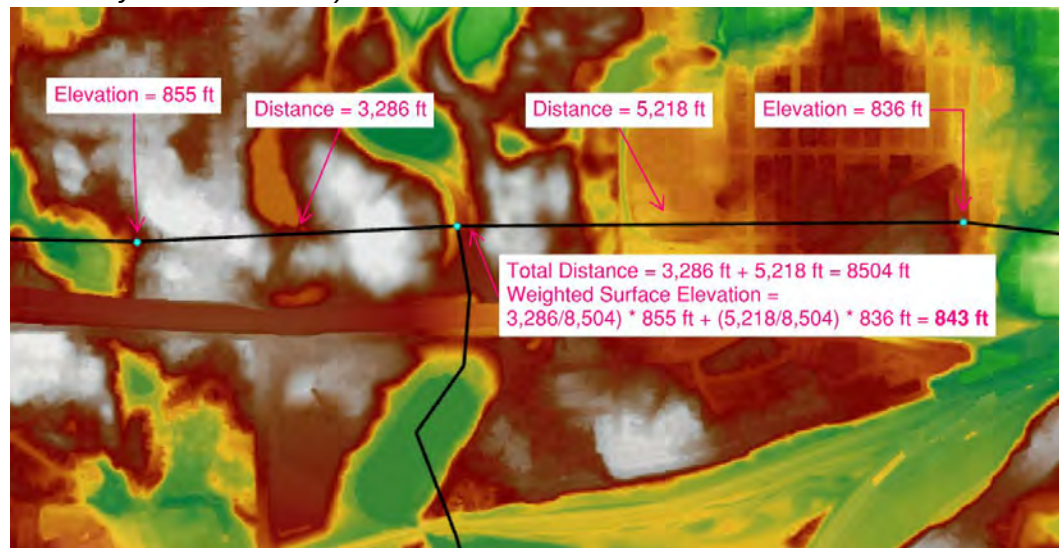


4. Split Groundwater Region Boundary

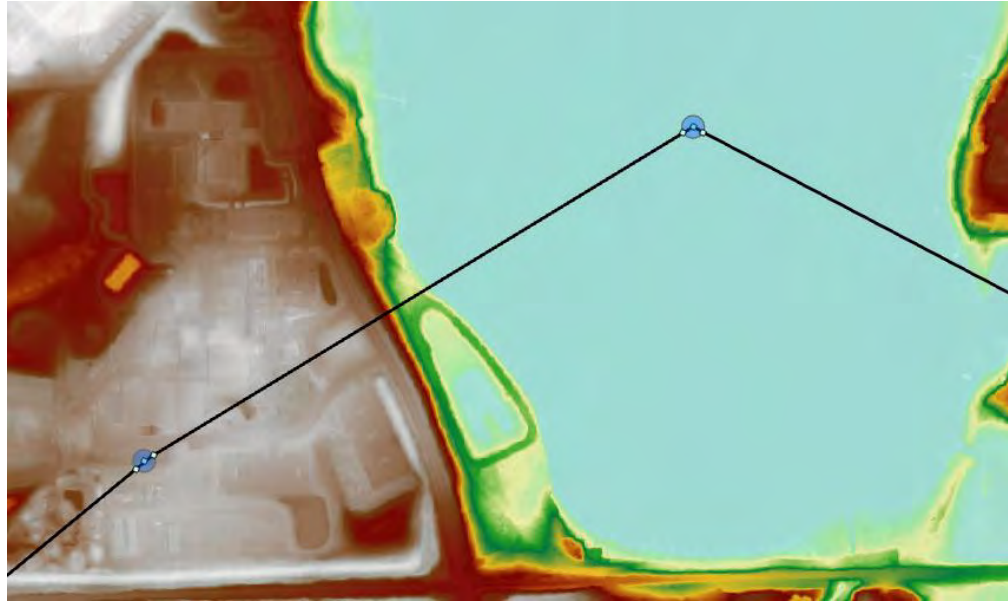
- a. The groundwater region boundary should be split into subregions, following surface water bodies within the region. In the example below, note that the groundwater subregion divides follow the chain of lakes from North to South and Minnehaha creek from East to West, dividing the groundwater region into four. It is best to place boundaries along paths of consistent/known water table elevation, hence the following of surface water features here. A fifth groundwater region was later added downstream of the Minnehaha Falls to cover a small amount of model area that acted independently from the main four regions.
- b. Example: (groundwater regions = green, well/surface water points = yellow, overland flow region = pink)



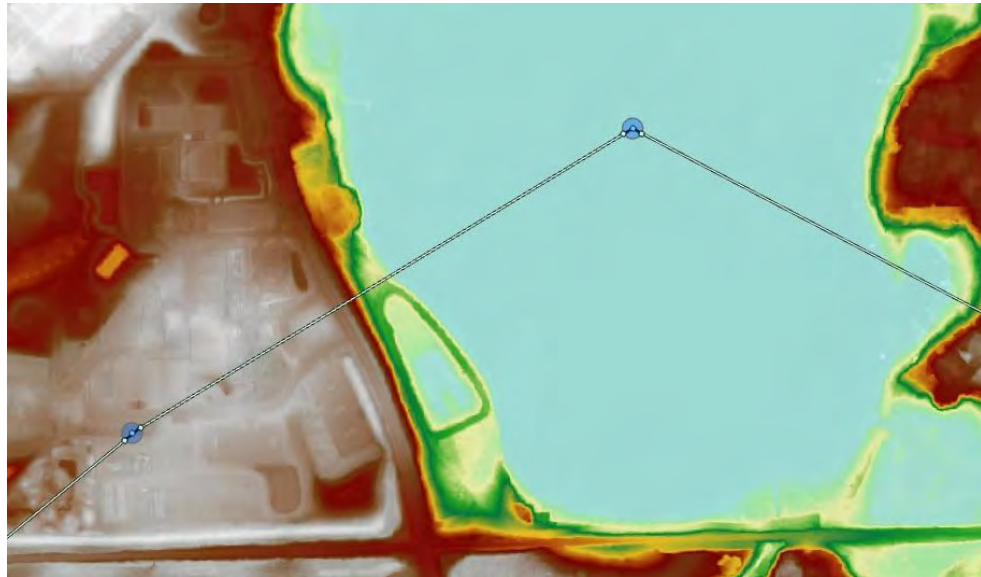
- c. In the groundwater region shapefile, assign unique names to each groundwater subregion in the NAME field
 - i. In the example above, the format “GW-XX” was used with XX = NE, NW, SE, SW, corresponding to the relative location of the subregion. The fifth, independent region was called “GW-FALLS” as this one does not connect to upstream groundwater regions and was included to cover a small area of OF region.
5. Ensure there is a point at each intersection between the groundwater boundary divisions and the outer groundwater boundary line. In the lower watershed, one point was added to the boundary point feature class to enforce this requirement.
 - a. In the NAME field of the additional point or points, assign a unique name per the model naming convention – see Naming Convention deliverable for details.
 - b. Interpolate the water elevation for the “WaterEI” field using the nearest neighboring groundwater boundary points. See the example below (groundwater boundary/divides = black)



6. Buffer each groundwater boundary point to 50ft
 - a. In StormWise, the groundwater boundary requires individual line segments with to and from nodes of known water surface elevation. Here, the water elevation along the line will be interpolated using these to and from nodes. These lines, however, cannot have coincident edges. Hence, a 50 ft buffer is used on the points to provide a 100 ft distance between the line segments on either side of a point.
7. Run the Intersect tool on the groundwater boundary and water level point buffers with the output set to point geometry. These will be start/end points of the groundwater boundary lines. See below. (buffer circles = blue, intersection points = teal, groundwater boundary = black)



8. Create lines along the groundwater region boundary, connecting the intersection points. These are called boundary stage lines. See below. (boundary stage lines = teal)



9. Add the following fields to the groundwater boundary stage lines
 - a. Groundwater_Region
 - i. Will be populated with the name of the one of the four groundwater regions it is representing
 - b. BDRY_Stage1
 - i. Will be populated with the name of one of the water level points the line is related to
 - c. BDRY_Stage2
 - i. Will be populated with the name of the other water level point the line is related to

10. Select each groundwater region individually, using that selection to select connected groundwater boundary stage lines and calculate the Groundwater_Region field = the name of the groundwater region used.
11. Using the Features to Points - XTools Pro tool or similar, generate a point at the start point of each groundwater boundary stage line. Use Spatial Join with a 70 ft distance to join the name of the water level point to this point. Next, use spatial join to join the name of the water level point field, from the Xtools Pro output, to the BDRY_Stage1 field of the groundwater boundary stage lines.
12. Repeat the above step, generating a point at the end of each boundary stage line and using spatial joins to pull the name of the other bounding point to the BDRY_Stage2 field of the groundwater boundary stage lines.
13. StormWise requires vertices on the groundwater boundary at groundwater boundary stage line endpoints. Select the groundwater boundary and, using the Edit Vertices tool, add vertices to the groundwater boundary at the intersection points generated in previous steps.
14. Split the groundwater boundary lines into separate feature classes by groundwater region they are connected to. StormWise will require a separate import of these lines to each of their respective groundwater regions.
15. Prepare groundwater region and boundary stage line shapefiles for export to StormWise.

Groundwater Tables

Each of the following tables has slightly different formatting requirements for import to StormWise. To populate these tables, HDR created dummy tables for each within StormWise, then exported them and filled out the correctly formatted, exported table with the relevant information. See StormWise Help for formatting and import requirements for specific datasets.

Boundary Stage Points

1. Background: Provides reference water level to boundary stage line endpoints for interpolation along the lines.
2. StormWise Location: 2D Features -> Groundwater -> Boundary Stage Points
3. Requirements:
 - a. CSV format of the ArcPro Groundwater Boundary Points table, described above, with name and water elevation values for each. See Electronic Data Package Item C-13.1.

Reference ET

1. Background: Provides information on time-varied ET rates for ET calculation for land cover layers.
2. StormWise Location: In project file structure -> Resources -> ReferenceET
3. Inputs:
 - a. Reference ET Rate (id^{-1} , mmd^{-1}) by year, month, day, and hour in text file format. See StormWise Help for formatting.
4. Approach:

- a. HDR was provided with reference ET data from MCWD. See Electronic Data Package Item C-13.2 for that used in StormWise.

Vertical Layers Table

1. Background: The vertical layers table contains an array of soil data for each soil type. This method allows for vertical discretization of the soil column into layers.
2. StormWise Location: Tables -> Rainfall Excess Methods -> Vertical Layers Sets
3. Inputs:
4. Approach:
 - a. HDR and MCWD coordinated with StormWise developers to have a vertical layers table developed for the model. StormWise developers developed the required vertical layers table in line with the "Tutorial - Vertical Layer Parameters from NRCS Soils" section of the StormWise help system (Streamline 2024). See Electronic Data Package Item C-13.3.

Impervious Set Data

1. Background: Provides imperviousness information for land cover map layer zones
2. StormWise Location: Tables -> Impervious Sets
3. Inputs: Imperviousness of values within land cover map layer
4. Approach:
 - a. In StormWise, use the extract option in the impervious set window to extract all land cover types from the map layer. (Note: land cover raster must be imported for this step) Here, Buildings, Lakes/Ponds, River, and Roads/Paved Surfaces were set to 100 percent imperviousness with 100 percent DCIA. All other land values were kept as zero. See Electronic Data Package Item C-13.4

Roughness Set

1. Background: Provides surface roughness information for land cover map layer zones
2. StormWise Location: Tables -> Roughness Sets
3. Inputs: Shallow flow roughness values, deep flow roughness values, and cutoff for depth for shallow/deep flow transition.
4. Approach:
 - a. Roughness values for land cover zones were populated with data from multiple references. See Electronic Data Package Item C-13.5

Crop Coefficient Set

1. Background: The Reference ET rate is scaled by coefficients from the Crop Coefficient Set that are specific to land cover map layer zones.
2. StormWise Location: Tables -> Evapotranspiration -> Crop Coefficient Sets
3. Inputs: Crop coefficient, root depth, irrigation rate, and irrigation efficiency by year, month, and day for each relevant land cover map layer zone.
4. Approach: See the provided Crop Coefficient spreadsheet and memo, Appendix and Electronic Data Package item B-7, for details on crop coefficient development.

Fillable Porosity Set

1. Background:

2. StormWise Location: Tables -> 2D Groundwater -> Fillable Porosity Sets
3. Inputs: Fillable porosity above and below ground for soil groups
4. Approach:
 - a. The below-ground fillable porosity for each soil type was represented as that soil type's "MC_Saturated" value from the vertical layers table. A uniform value of 1.0 was applied to each soil type to represent the above-ground fillable porosity. See Electronic Data Package item C-13.6.

Conductivity Set

1. Background:
2. StormWise Location: Tables -> 2D Groundwater -> Conductivity Sets
3. Inputs: Horizontal conductivity for soil groups
4. Approach:
 - a. The conductivity set was created using the saturated hydraulic conductivity from the bottom layer of each soil group in the vertical layers table. Multiply the saturated hydraulic conductivity from the vertical layers table by ten for each soil group. See Electronic Data Package item C-13.7

Groundwater Model Build

1. Create groundwater regions in StormWise representing each section of the groundwater region generated in the steps above.
2. Import each groundwater region's respective shape.
3. Generate a breakpoint pattern within each groundwater region using 250ft spacing and a 50ft buffer between other features.
4. Import the boundary stage line feature classes to their respective watershed region.
5. Import the boundary stage point set data to the groundwater boundary stage points under the 2D features tab.

References

Minnesota Geological Survey (MGS)

2025 County Well Index (CWI) - <https://cse.umn.edu/mgs/cwi>

Streamline Technologies

2024 Tutorial - Vertical Layer Parameters from NRCS Soils

ELECTRONIC DATA PACKAGE ITEM C-13.1 Boundary Stage Points

ELECTRONIC DATA PACKAGE ITEM C-13.2 Reference ET

ELECTRONIC DATA PACKAGE ITEM C-13.3 Vertical Layers Table

ELECTRONIC DATA PACKAGE ITEM C-13.4 Impervious Set

ELECTRONIC DATA PACKAGE ITEM C-13.5 Roughness Set

ELECTRONIC DATA PACKAGE ITEM C-10 Crop Coefficients

ELECTRONIC DATA PACKAGE ITEM C-13.6 Fillable Porosity Set

ELECTRONIC DATA PACKAGE ITEM C-13.7 Conductivity Set



Appendix D – Task 3B Report

Appendix D Task 3b Non-Pipe Stormwater Feature Development Summary

Date: September 22, 2025

Project: Minnehaha Creek 2-D Watershed-Wide Model

To: Brian Beck (MWCD)

From: HDR Inc.

Subject: Draft - Task 3b: Non-pipe Stormwater Feature Development Summary

Introduction

This memorandum describes steps taken to process Non-pipe Stormwater Feature (NPSF) data into model inputs for the initial model build (Task 5). The workflows described below are taken from the previously provided memorandum *Task 3a: Non-pipe Stormwater Feature Dataset Strategy Development REV1* dated January 9, 2025. Each workflow description includes a summary of steps used to carry out each workflow, as well as description of where the workflow diverged from the approach outlined in the Task 3a memo. Organization of the workflows and memo is as follows:

- Surface Water Bodies
 - Workflow 1 – Define Lake and Pond Extents
 - Workflow 2 – Associate Bathymetry to Lakes and Ponds
 - Workflow 3 – Define Wetland Extents
 - Workflow 4 – Associate Bathymetry to Wetlands
 - Workflow 5 – Create Seamless Surface
 - Workflow 6 – Develop Model Input
- Outlet Control Structures
 - Workflow 7 – Locate Outlet Control Structures
 - Workflow 8 – Associate Hydraulic Information to Outlet Control Structures
 - Workflow 9 – Develop Model Input for Outlet Control Structures
- Culverts
 - Workflow 10 – Locate Culverts
 - Workflow 11 – Associate Hydraulic Information for Culverts
 - Workflow 12 – Develop Model Input for Culverts

Surface Waterbodies

Surface waterbodies within the watershed include ponds, lakes, wetlands, artificial basins, and other depressed landforms. For representation in a StormWise model, surface waterbodies rely on accurate characterization of the stage-storage volume of potential water stored within the

feature this includes both above and below the normal water level. Many of these features will be represented by a Pond Control Volume (PCV), which are 1D representations of water storage, inflow, and outflow of a waterbody.

Previous workflows assumed all waterbodies would require augmentation of the topography to accurately characterize the surface water storage. The workflows applied for the preliminary model build, described below, identify all potential PCV locations and then target specific ones for bathymetry integration.

Workflow 1 – Define Lake and Pond Extents

This workflow identifies the extents of lakes and ponds within the model area. The proposed Task 3A memo method identified 849 lake and pond features from the previously identified GIS datasets (Lake_GDB, LakeBathymetricOutlinesContoursDEM, LAKE_POLYGONS, 20240725_National_Hydrography, and 20240725_DNR_Hydrography). These features often did not accurately align with the LiDAR depiction of the feature or the surrounding topography. In addition, a number of features were relatively small in surface area and were not clearly visible in the most recent LiDAR topography. This feature dataset is used to identify potential PCV locations. Due to the dated or inaccurate representation of the feature outline they were deemed inappropriate for use as outlines for bathymetry generation.

Another dataset, not previously defined in the Task 3A memo was instead used for bathymetry generation. Woolpert Inc. (2023) developed a Digital Elevation Model (DEM) based on more recently flown LiDAR data (2022). As part of the DEM processing breaklines were defined along the edge of water for Lakes-Ponds of larger than 2 acres in size which are used to hydro-flatten the water surface to a constant representative elevation. These breaklines accurately describe the land-water boundary within the DEM and were deemed the most applicable for bathymetry integration. Lake and Pond Extents were defined by the 'LiDARBreaklinePolygons_MCWD_1mi' which represents the 405 hydroflattened surfaces within 1 mile of the watershed boundary. This layer does not include Lake Minnetonka or its bays. Lake Minnetonka as defined by 'Lake_GDB' (provided by MCWD) was added to this layer to define the lake and pond extents.

Workflow 2 – Associate Bathymetry to Lakes and Ponds

This workflow assigns bathymetry, either observed or estimated, to the lake and pond extents identified in Workflow 1.

Assigning Known Bathymetry

Where bathymetry is known, it is assigned directly to the lake and pond extents identified in Workflow 1. Where there was overlap in known bathymetry sources for a given feature, the following order of preference was used:

- 'Lake_GDB'
- 'LakeBathymetricOutlinesContoursDEM'
- 'All Lakes Contours'

Estimating Waterbody Bathymetry

Where bathymetry is unknown, it is estimated prior to assigning it to each feature. The method used calculates an estimated maximum depth and volume, which is processed into bathymetric contours.

ESTIMATION OF MAXIMUM DEPTH

The Task 3a memo recommended a method for creating a relationship between pond area and maximum depth based on features with known bathymetry within the Big Woods Subsection Ecoregion (222Mb, Ecological Classification System, Minnesota DNR). This method did not result in a high-quality fit and therefore it was not used.

Instead, an empirical method from Heathcote et al. (2015) was used to estimate maximum waterbody depth based on the localized change in elevation. Localized change in elevation is determined from a buffer around each waterbody and the difference between mean buffer elevation and mean water surface elevation of the waterbody. Details of the calculations are included as part of the electronic submission package. Results of applying this approach to MCWD features are shown in Figure 1. To estimate maximum depth of features with unknown bathymetry, the following equation was used:

$$\log_{10} Z_{\max} = 0.35 + \log_{10} \text{elevation change}_{25} * 0.79$$

Where $Z_{\max}$ is the maximum depth (m) and $\text{elevation change}_{25}$ is the elevation change in the buffer at 25% of D the equivalent diameter. Where A is the waterbody surface area (m^2) and D is:

$$D = 2 * \sqrt{\frac{A}{\pi}}$$

Figure 2 provides a comparison between observed and estimated maximum waterbody depth for the 305 features in the Big Woods Subsection Ecoregion as they vary with surface area. In general the Heathcote et al. (2015) method provides a similar increasing trend in maximum water body depth with increasing surface area. However, the estimated maximum depths show less variability than the observed ones. Figure 3 provides additional context in that the Heathcote et al. (2015) provides less variation in maximum depth than was observed. The method tends to overestimate maximum depths for shallower features, and underestimate depths for larger features.

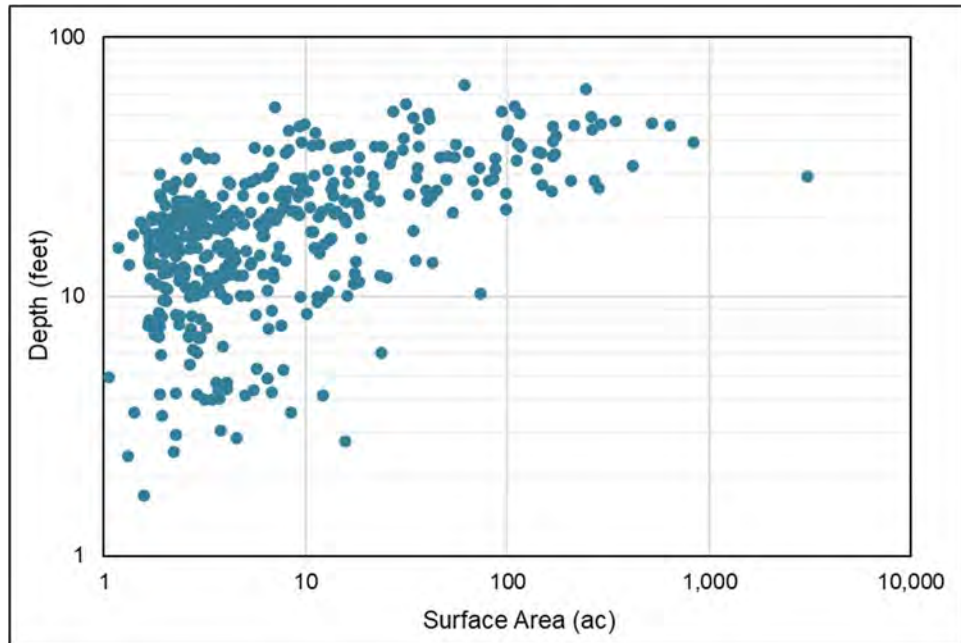


Figure 1. Unknown Waterbodies: Estimation of Maximum Depth as a Function of Waterbody Area

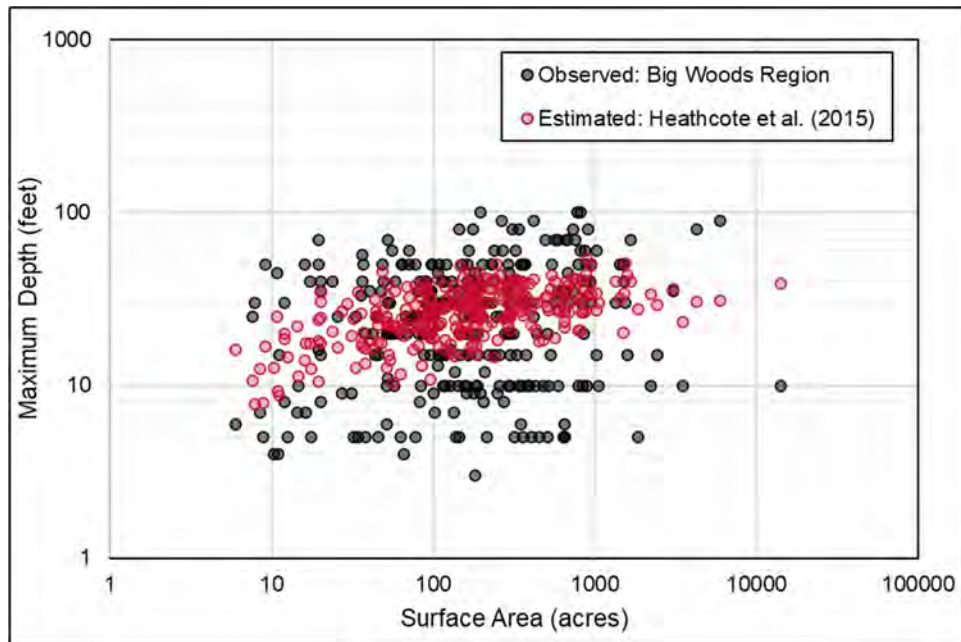


Figure 2. Big Woods Ecoregion Waterbodies: Observed and Estimated Maximum Depth as a Function of Waterbody Area

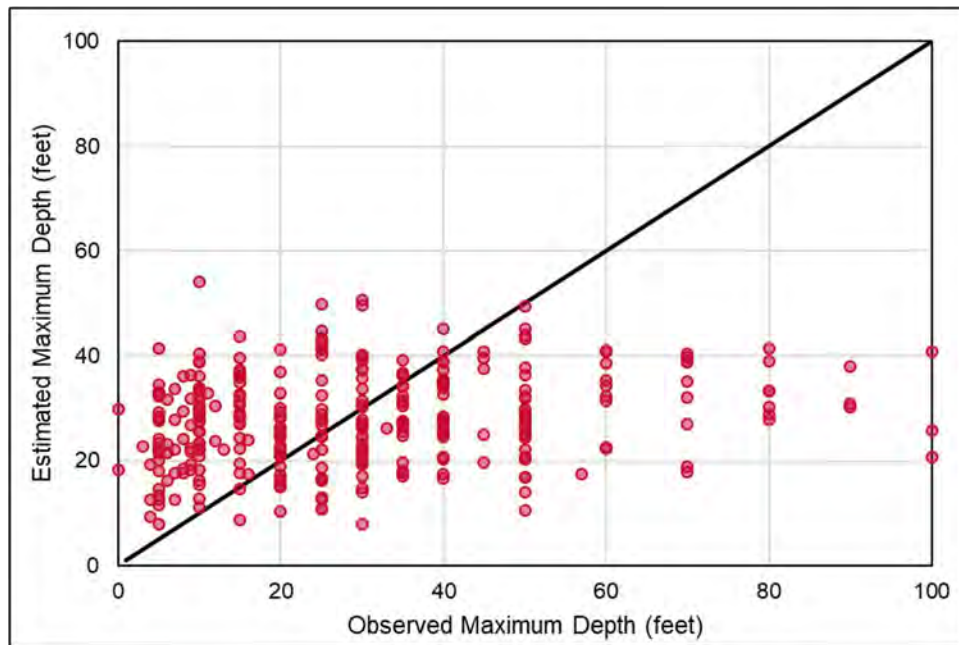


Figure 3. Big Woods Ecoregion Waterbodies: Observed vs. Estimated Maximum Depth

ESTIMATION OF WATERBODY VOLUME

Waterbody volume with unknown bathymetry was estimated using an empirical method by Delaney et al. (2022). Delaney et al. (2022) used the same approach as Heathcote et al. (2015) to calculate waterbody volume but focused on Minnesota waterbodies as input for the regression analysis. Both methods used the following equation:

$$\log_{10} V = c \log_{10} A + d \log_{10} DE_{25}$$

Where V is the water body volume (m^3), DE_{25} is the elevation change in the buffer at 25% of D the equivalent diameter, and c and d are empirical constants determined through regression analysis.

The Delaney et al. (2022) method was selected due since its parameters were developed encompassing the Minnehaha Creek Watershed. A comparison between Delaney et al. (2022) and Heathcote et al. (2015) methods applied to the MCWD waterbodies shows the Delaney method results in more storage volume for the same surface area and less variability (Figure 2). Details of the calculations are included as part of the electronic submission package.

Figure 5 shows the observed Big Woods Ecoregion volumes along with estimated ones from the Delaney et al. (2022) method. Although the Delaney et al. (2022) method refined the analysis to include waterbodies throughout central Minnesota, it always results in a higher estimate of waterbody volume than the observed data. Figure 6 shows a direct comparison of the observed volume as compared to the estimated one for the same waterbodies, which also shows the overprediction of waterbody volume. These relationships affect the below normal water level bathymetry, therefore during normal to high pool conditions are anticipated to have a limited impact on watershed response. However, during dry periods where the waterbodies may be

below normal pool conditions the total storage volume available is likely to be overestimated. This relationship should be considered for future refinement as part of the final model build.

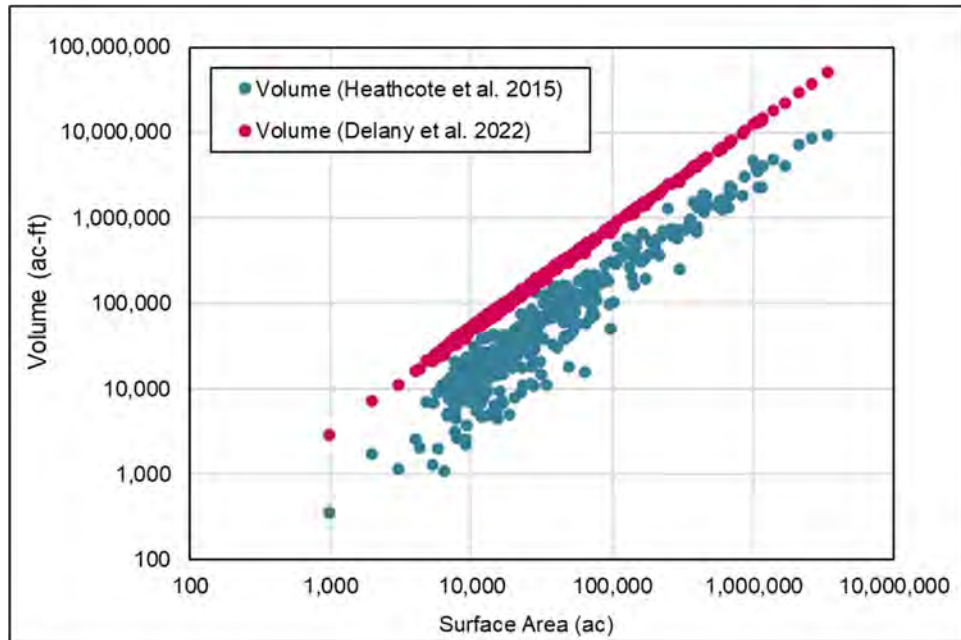


Figure 4. Unknown Waterbodies: Estimation of Volume as a Function of Waterbody Area

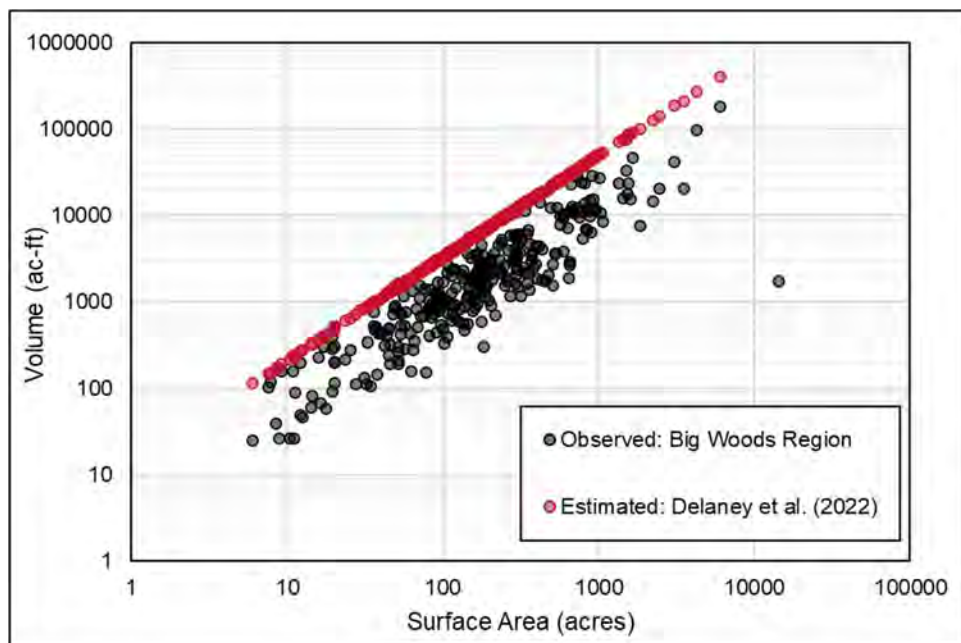


Figure 5. Big Woods Ecoregion Waterbodies: Observed and Estimated Maximum Depth for Big Woods Ecoregion Waterbodies Comparison of Estimated Volumes as a Function of Waterbody Area

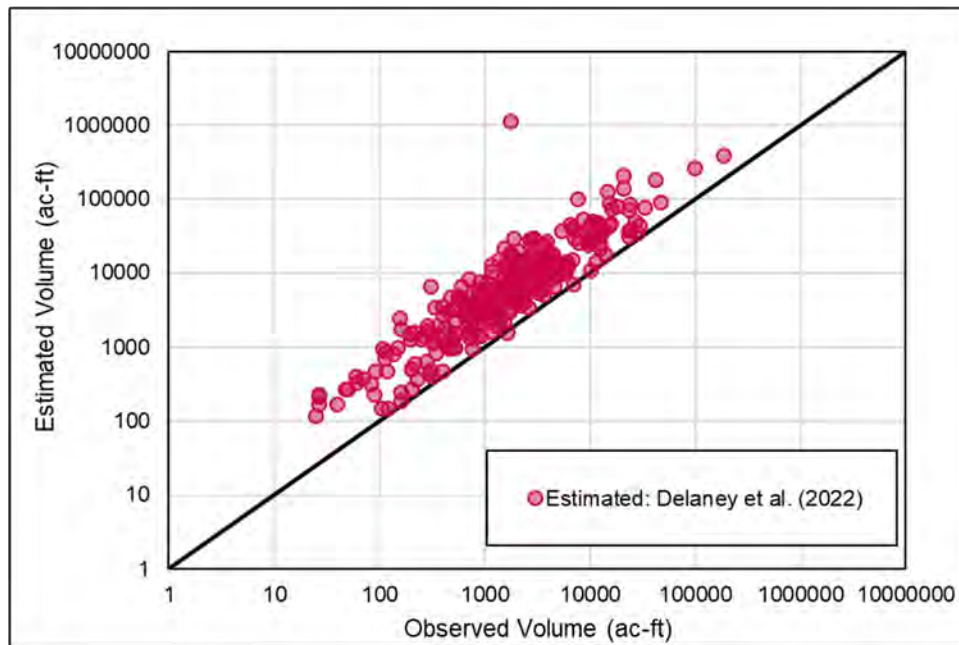


Figure 6. Comparison of Estimated Volumes as a Function of Area

VOLUME DISTRIBUTION OF KNOWN WATERBODIES

Storage volume versus depth characteristics were aggregated and summarized for regional waterbodies with known bathymetry. The resulting relationship is a normalized depth vs. normalized storage function and is used to validate the selected approach to distribute the storage volume along the depth for the estimate waterbodies. To determine the relationship between depth and volume for each feature with known bathymetry:

- Bathymetric contours were assigned to surface water bodies with known bathymetry within the Big Woods Subsection Ecoregion (Figure 7 - 222Mb, Ecological Classification System, Minnesota DNR). In areas where bathymetric contours traverse multiple features they were manually split. Figure 8 shows an example waterbody which includes set of contour lines with multiple closed contours at the same depth.

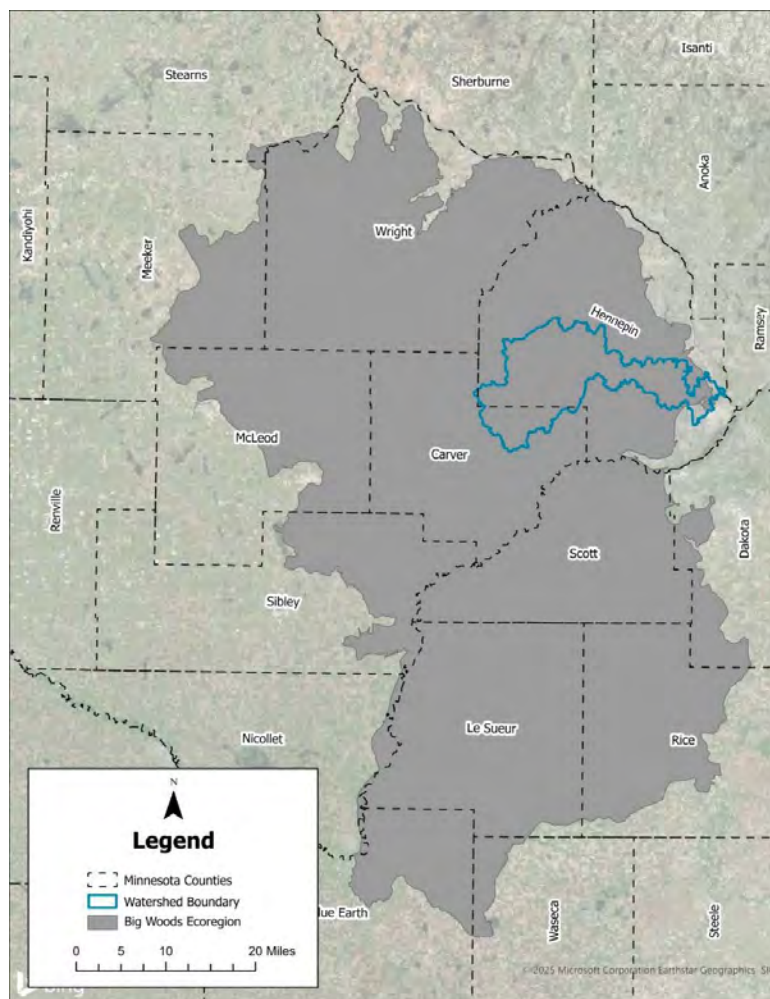


Figure 7. Big Woods Ecoregion (Grey), Compared to Watershed District Extents

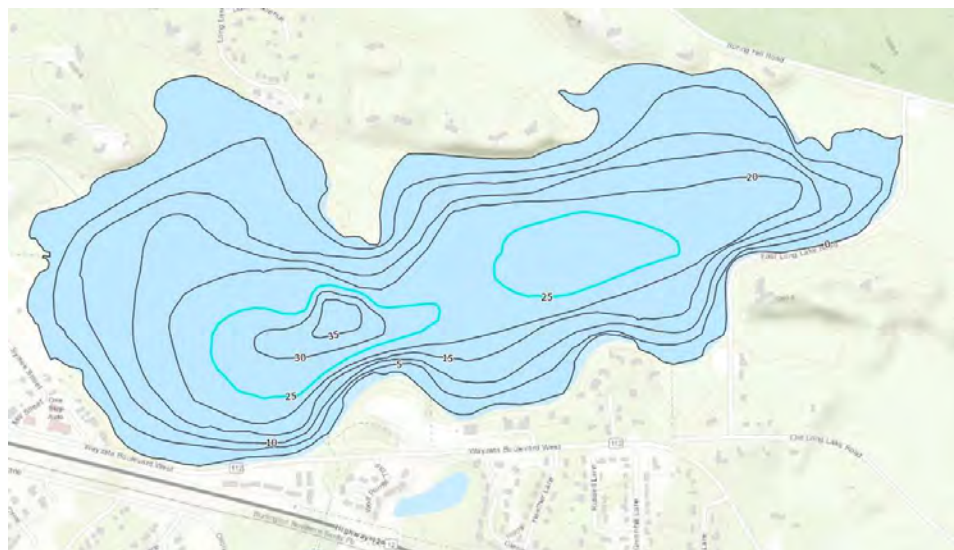


Figure 8. Lake with Multiple Closed Bathymetric Contours at the Same Depth

- Where contour polylines did not create complete polygons, polygons were completed and separate multi part features.
- Multipart features were separated.
- Using these modified bathymetric contour lines the area of each bathymetric contour was calculated.
- A depth volume relationship was created for each lake:
 - The total area of each contour within each lake was recorded. For lakes with multiple contour polylines at the same depth, the sum of their areas was used.
 - Incremental volumes between each contour interval were calculated and summed to create a total cumulative volume.
 - Cumulative volumes at each of 25th, 50th, 75th, 90th and 100th percentile depths for each waterbody were determined through linear interpolation.
 - Interpolated volumes were normalized by the total volume.
 - Figure 9 shows the 25th, 50th, 75th, 90th and 100 percent normalized depth vs the normalized volume. These data were used to validate the estimated volume distribution is reasonable.

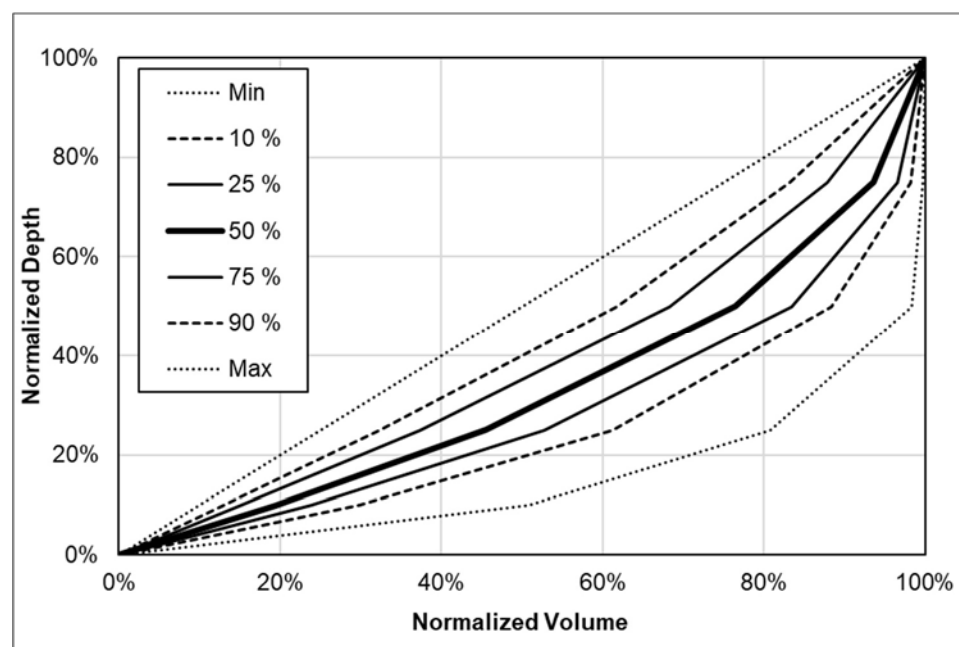


Figure 9. Normalized Lake Volume vs. Percentile Depth of Known Features

FITTING OF CONTOURS BASED ON CALCULATED WATERBODY DEPTH AND VOLUME

Distributing the storage volume of each water body over the maximum depth was intended to use the observed relationships of storage volume vs. depth from regional waterbodies as described in Task 3A memo. However, the combination of estimated maximum depth, estimated maximum volume, normalized vertical storage volume distribution and the known surface area did not result in reasonable vertical storage relationships. It is assumed the variability of approaches to calculate each input (depth, volume, distribution, surface area) did not result in compatible relationships.

Instead, distributions of the storage volume over the total depth were determined for each water body which maintained the maximum depth, total volume, and surface area. Areas of each incremental depth contour at the 25th, 50th, 75th, 90th and 100th percentile depths were estimated using the following steps:

- The 0th percentile depth, or water surface, was maintained from observed geospatial data.
- Each lower depth percentile (25th, 50th, 75th, and 100th) was assumed to have a smaller area than the contour interval above it. Each successively lower contour interval was calculated as the area of the above interval multiplied by a scalar value. The scalar was assumed to be constant for each waterbody and be applied to each incremental area such that:
 - $A_{25} = XA_0$ and $A_{50} = XA_{25}$ and $A_{75} = XA_{50}$ and $A_{100} = XA_{75}$
 - Or $A_{25} = XA_0$ and $A_{50} = X^2A_0$ and $A_{75} = X^3A_0$ and $A_{100} = X^4A_0$
 - Where $A_0, A_{25}, A_{50}, A_{75}, A_{100}$ is the contour area at 0th, 25th, 50th, 75th, and 100th percentile depth, respectively and X is the scalar.
- Scalar values were assumed to be less than 1.0 and more than 0.0 and were optimized to match the total volume. Where scalar values of more than 1.0 were required to match total volume, they were manually set to 0.95. Where scalar values of less than 0.0 were required to match total volume, they were manually set to 0.05. This method resulted in maintaining 97% of the estimated storage volume in all of the features.
 - Of the 405 waterbodies with estimated volume the scalar value was reduced to 0.95 for 37 features and increased to 0.05 for 1 feature.
- Figure 10 shows a comparison of the fitted vertical volume distribution to the observed ones. More than 50% of the fitted curves are within the observed vertical volume distribution. The median fitted curve closely aligns with the 90th percentile observed distribution. This results in more storage volume placed lower in the waterbody than expected from other regional waterbodies. This difference may result in increasing surface water groundwater connectivity at the waterbody locations.

More information is included in the 'Calc_Heathcote' spreadsheet included as part of this submission.

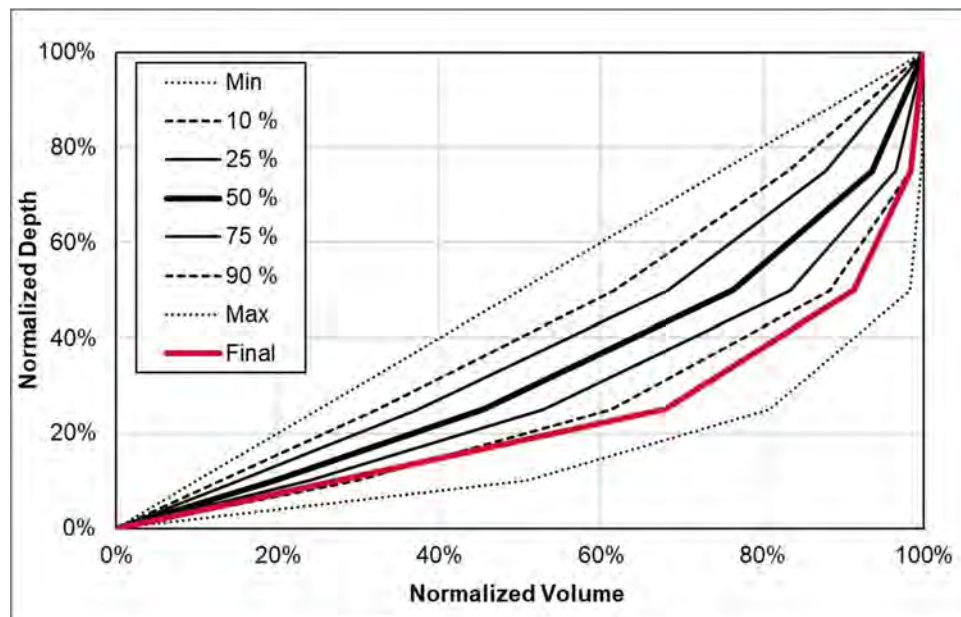


Figure 10. Comparison of Normalized Depth vs. Normalized Volume between Observed and Fitted Features

GEOSPATIAL CONTOUR CONVERSION

A GIS workflow was followed to take the estimated depths and areas associated with each estimated contour and convert them into geospatial features. The following steps were performed:

- Created negative (inward) buffers from each surface waterbody extent at 2-foot intervals.
- For each surface waterbody, found the closest match between each target area value and the area of these buffer polygons.
- Converted the selected buffer polygons to lines and assign the associated depth value to each contour.
- Figure 11 provides an example of estimated bathymetry surfaces blended into the LiDAR above water elevation data.

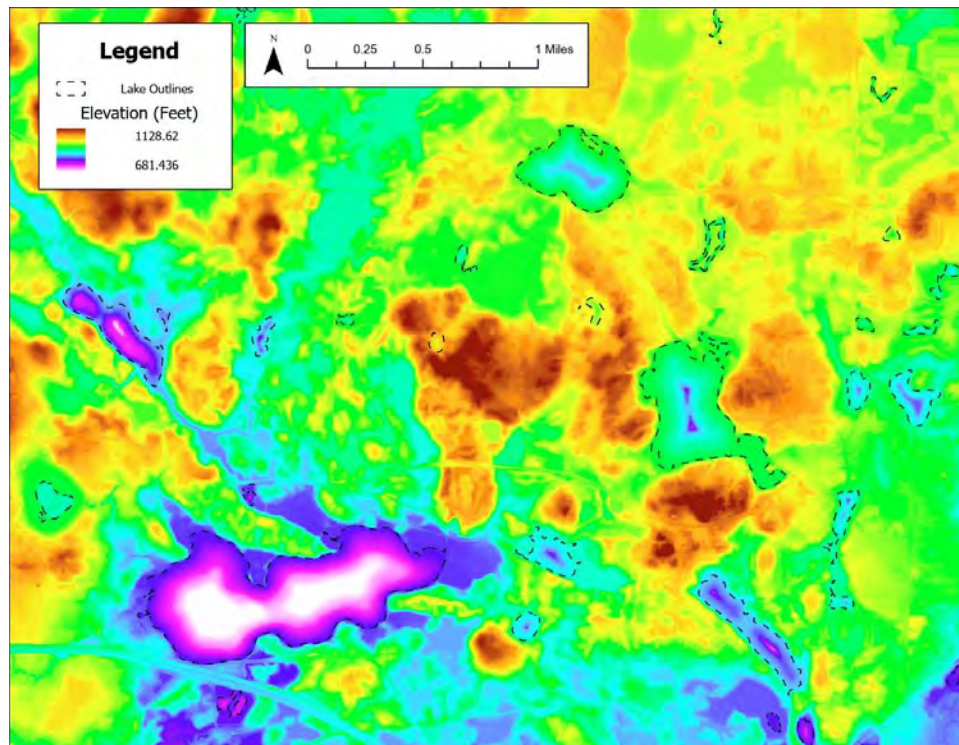


Figure 11. Sample Representation of LiDAR Modifications to Include Bathymetry Approximation

Workflow 3 – Define Wetland Extents

This workflow was to identify the extents of wetlands within the model area. Due to the output from this workflow not aligning with the LiDAR being used for the model build, the output is not intended to be used as part of the model build.

This workflow followed the process outlined in the Task 3a Memo, using features from:

- 'Lake_POLYGONS'
- 'MCWD Wetlands'

Workflow 4 – Associate Bathymetry to Wetlands

The intention of this workflow was to assign estimated bathymetry to wetland extents identified in Workflow 3. Due to the output from Workflow 3 not aligning with the LiDAR being used for the model build, the output is not recommended to be used as part of the model build.

To define the depth of the features:

- An 18-foot inward buffer (assumed 6:1 slope) was taken from the edge of each feature.
- A depth of 3 was assigned to this buffered feature, and a depth of 0 was assigned to the original edge of each feature.

Workflow 5 – Create Seamless Surface

Using data created in the above Workflows, a modified terrain that incorporates bathymetry was developed for use in the model.

The recommended model surface does not include modifications resulting from features identified in Workflows 3 and 4.

For bathymetries estimated as part of Workflows 2 and 4, it is necessary to convert depth contours to bathymetric surfaces:

- Create TIN surface based on depth contours
- Convert TIN surface to depth raster
- Create bathymetric raster by subtracting depth raster from 'Terrain_2024USGS_OPR.USGS_OPR_MN_CentralMissRiver_MCWD_FT.tif'
- Mask the newly created bathymetric raster by the feature extents developed as part of Workflows 1 and 3 (Workflow 3 unused).

Mosaic rasters in the following order, keeping information from the last raster on the list:

- LiDAR: 'Terrain_2024USGS_OPR.USGS_OPR_MN_CentralMissRiver_MCWD.tif'
- Estimated Wetlands: 'Workflow4_output.tif' (unused)
- Estimated Ponds/Lakes: 'Workflow2_output.tif'
- Lake Contours: 'Lake_bathymetric_elevation_modelElev.tif'
- Lake Rasters: 'lakeGDBElev.tif'

Workflow 6 – Develop Model Input

Generated surfaces from Workflow 5 are directly imported to the StormWise model. Each of the features with bathymetry estimated will be included in the model as PCVs. A future memorandum will provide details on the PCV generation process.

Outlet Control Structures

Water levels within many constructed surface waterbodies within the watershed are controlled by an outlet control structure. For the purposes of this memo, outlet control structures are defined as drop structures that control the water level of a surface waterbody and include a weir and pipe. These features are included in the model as attached to specific waterbodies PCVs and describe the stage-discharge relationships associated with these structures.

No outlet control structure data were available to support a preliminary model build. Many of these features are planned for survey and to be included as part of the final model build.

Workflow 7 – Locate Outlet Control Structures

Due to lack of existing data, no outlet control structures will be included in the initial model build.

Workflow 8 – Associate Hydraulic Information to Outlet Control Structures

Due to lack of existing data, no outlet control structures will be included in the initial model build.

Workflow 9 – Develop Model Input for Outlet Control Structures

Due to lack of existing data, no outlet control structures will be included in the initial model build.

Culverts

Culverts in a 2D model allow for the flow of water across topographic features that would otherwise be limited by topography as overland flow. Culverts can be represented as pipe links in StormWise, which are 1D hydraulic elements that connect nodes to one another with inputs including, inverts, length, shape, cross sectional dimensions, and roughness. Including these features allows for flow that may be artificially blocked by higher ground to flow through the elevated feature and downstream.

Culverts included as part of this memo have previously been identified as part of the model ready dataset or identified with previously surveyed data. Additional culverts are planned for survey and will be included as part of the final model build.

Workflow 10 – Locate Culverts

This workflow identifies location of culverts within the watershed. The starting culvert shapefile is “CulvertMR” in the “BMI Project Data” dataset provided by the District for use in the model. The CulvertMR shapefile includes line features of existing culverts. Additionally, culvert survey was supplied by MCWD, which had 4 point features (equating to 2 culvert features) representing culvert locations not identified by the above shapefile. These 2 culvert features were manually added. Culverts outside of the watershed were removed. Integration of culverts and the respective attributes are included as part of the model ready scripting assumptions. Future refinement of these assumptions may be made and documented in future memos.

Workflow 11 – Associate Hydraulic Information for Culverts

This workflow creates a new culvert shapefile with all required model inputs (shape/geometry, size, material/Manning’s N, invert elevations, inlet configuration/FHWA code). The information for these attributes was incorporated into a new shapefile of “CulvertMR_Updates_V1”.

Information was incorporated into this layer based on the following priority order:

- Information from MCWD survey (from ‘Culvert Survey’ shapefile)
- Existing GIS information (from ‘CulvertMR’ shapefile)
- Where culverts lacked existing GIS information and survey information, assumptions were incorporated as follows:
 - Missing shape: assumed circular
 - Missing size: assumed 18" (average pipe size)
 - Missing material: assumed concrete (0.012)
 - Missing invert elevation: assumed lowest elevation in LiDAR within 20' radius of invert

Data was associated with each feature based on the culvert ID from Workflow 10.

Workflow 12 – Develop Model Input for Culverts

As discussed in the Task 3a Memo, scripts developed as part of Task 4 were used to input the data into StormWise from the geospatial datasets created in Workflows 10 and 11.

The following tables were used to convert information into a format usable by StormWise. include Manning’s roughness coefficient, the values provided in **Error! Reference source not found.** were applied based on materials in existing GIS information and survey.

Table 1: Culvert Manning’s Roughness Coefficients

Material	Manning's coefficient
Concrete	0.012
Vitrified Clay	0.011
Metal/Steel	0.013
Corrugated Metal	0.024
Plastic	0.010
Other	0.011

No information was provided in GIS data source or survey on culvert inlet configuration. Federal Highway Administration (FHWA) culvert codes, as described in StormWise handbook, were used for inlet configurations. Assumptions on inlet configuration were made based on the size of the culvert and the culvert material, as described in **Error! Reference source not found..**

Table 2: Assigned FHWA Culvert Codes

Culvert Characteristics	FHWA Key	FHWA Description
Size: Large (greater than 48") Material: Concrete/Clay/Smooth Metal/Plastic	1	Circular Concrete, Square edge w/headwall
Size: Large (greater than 48") Material: Corrugated Metal	4	Circular CMP, Headwall
Size: Small (less than or equal to 48") Material: Concrete/Clay/Smooth Metal/Plastic	3	Circular Concrete, Groove end projecting

Size: Small (less than or equal to 48") Material: Corrugated Metal	6	Circular CMP, Projecting
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Summary

Transmitted alongside this memo are the following datasets to be used directly by the preliminary model:

- **LiDAR_Lakes_EST_Bathy** : Modified LiDAR to include lake and pond bathymetry
- **MCWD_LakePondExtents_MR20250731** : Lake and Pond extents considered for bathymetric modifications
- **MCWD_WetlandExtents_MR20250731** : Wetland extents considered for bathymetric modifications
- **MCWD_Culverts_MR20250731** : Model ready culvert data

Updates to these datasets as a result of data collection performed as part of Task 6 are expected to be incorporated into the final model build. Recommendations of options for these efforts were included in the Task 3a memo. Prioritization and execution of data collection and refinement efforts will be based on future project team consensus.

References

Delaney, C., Li, X., Holmberg, K., Wilson, B., Heathcote, A., Nieber, J. (2022). Estimating Lake Water Volume With Regression and Machine Learning Methods. *Front. Water* 4:886964. doi: 10.3389/frwa.2022.886964

Heathcote, A.J., del Giorgio, P.A., and Prairie, Y.T. (2015). Predicting bathymetric features of lakes from the topography of their surrounding landscape. *Can. J. Fish. Aquat. Sci.*

Woolpert Inc., 2023. "Lidar Mapping Report for the U.S. Geological Survey, MN Central Miss River 4 B22"



Appendix E – Task 4 Script Documentation

Memo

Date: 4/7/2026

Project: MCWD 2D Watershed-Wide Model

To: Brian Beck (MCWD)

From: Bryan Blaisdell, PE, GISP, CFM, Nick Thomas, PhD, PE

Subject: Appendix E - Task 4 Script Documentation

As part of the development of a 2D watershed model for the Minnehaha Creek Watershed District (MCWD or District), the District provided HDR with a package of stormwater data processing scripts for review and refinement. These scripts (referred to as “Raw to MGIS” and “MGIS to Model Ready”) were developed through previously completed efforts and automate several important data processing tasks required for stormwater hydraulic modeling, including (1) standardizing and consolidating stormwater utility data from municipal/agency datasets into a single, unified geodatabase as well as (2) identifying and correcting issues within the stormwater utility dataset’s geometry and attributes.

On December 13, 2024, HDR held a workshop meeting with the District to discuss potential script modifications for implementation. Script modifications were categorized as *Scope Requirements* (modifications required for the main project scope), *Potential Immediate Enhancements* (modifications to enhance the development of the 2D model within the project scope), and *Potential Long-Term Improvements* (modifications recommended for further consideration in future project phases).

The following memo documents the script modifications completed as part of the 2D watershed modeling project.

Process Overview

The MCWD stormwater data process consists of two tools: “Raw to MGIS” and “MGIS to Model Ready.” The “Raw to MGIS” script converts raw municipal stormwater utility data (including pipes, culverts, manholes, inlets, and outlets) to the unified MGIS geodatabase schema using configured field and value mapping tables. Once consolidated, features in the MGIS geodatabase are then input into the “MGIS to Model Ready” script, which converts the data from the MGIS schema to a simplified model-ready schema and identifies and corrects issues with the geometry and attributes.

Revisions to the “MGIS to Model Ready” script included the ability to apply specific feature updates from a Manual Overrides geodatabase and a Surveyed Features geodatabase, enabling manual database refinements to be incorporated directly into the automated workflow for repeatability. The manual override and survey import process allows for addition, exclusion, and replacement of specific features and attributes. A diagram of the full process workflow is shown in **Figure 1**.

As part of the manual override and survey import process, globally unique identifiers (GUIDs) were added to features in the raw municipality datasets to improve feature tracking and enable the automated feature replacement workflow. **GUIDs should be maintained and updated as needed in future changes to the raw municipal datasets to ensure workflow continuity.**

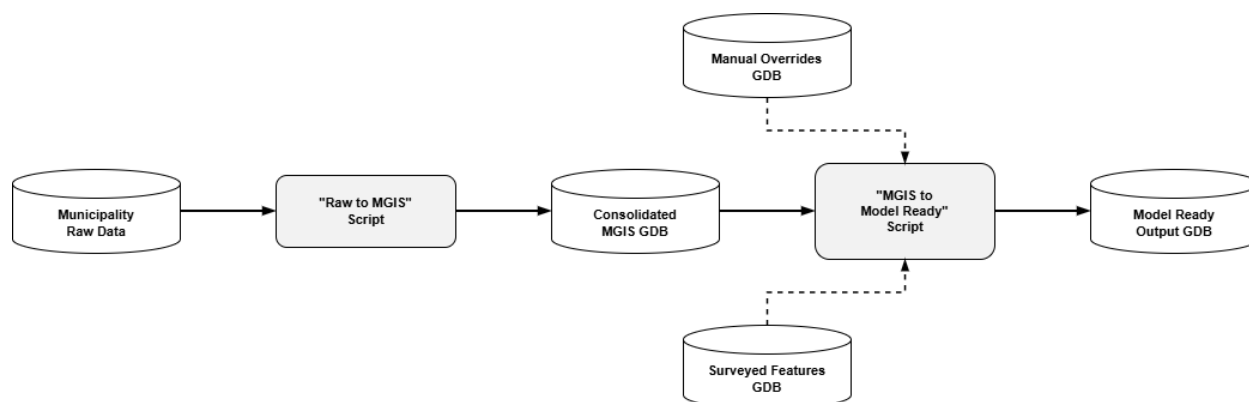


Figure 1: Full Process Workflow (Raw Data to Model Ready)

Modifications to the “Raw to MGIS” and “MGIS to Model Ready” tool package included the script files listed below (other supporting script files, `__init__.py`, `cursors.py`, `logger.py`, `testconfig.py`, and `tqdm_arcpy.py` were unchanged):

- **`_strings.py`** - String constants used for defining field names, file paths, source abbreviations, and other strings across the tool package
- **`core.py`** – “Raw to MGIS” processing (parsing raw data using mapping tables, applying field/value mapping, loading features into MGIS geodatabases)
- **`model_input.py`** – “MGIS to Model Ready” processing (geometry and attribute gap-filling and correction)
- **`utils.py`** - Shared utilities (including *ProjectInfo* class where input geodatabase names are defined)

In addition to these script files, the following input files were developed or updated to be incorporated into the workflow (“*Model Ready.lyrx*” was unchanged):

- ***ModelInputDatabase_Blank.gdb*** – Template geodatabase containing the empty Model Ready feature classes, domains, and schema used as the target for the MGIS to Model Ready process.
- ***MGIS_MSWGP_Manual_Overrides.gdb*** – Geodatabase containing manually added (A), excluded (E), or replaced (R) features. Each feature includes an OVERRIDE field (A/E/R) and is matched to the MGIS dataset by MGIS_GUID. Used by *load_mgis_data* to apply overrides during data loading.
- ***MGIS_MSWGP_Surveyed_Features.gdb*** – Geodatabase containing surveyed stormwater features with the same Add (A)/Exclude (E)/Replace (R) structure as the manual overrides GDB. Used by *load_mgis_data* to incorporate field-surveyed geometry and attributes during data loading.
- ***mappings.json*** – Configuration file defining the field mapping between MGIS and Model Ready feature classes. Updated to include Count and Structure_Type/PipeType field mappings for Inlets, Outlets, Pipes, and cPipes.

“Raw to MGIS” Script Updates

The “Raw to MGIS” process includes the following tools, each of which can be run separately:

1. Load Data
2. Load Data (Batch)
3. Load Data (Consolidated)

Each of the tools provides a different level of control over the “Raw to MGIS” process. For this project, only the new “Load Data (Consolidated)” tool was used (discussed below under “Consolidated Batch Processing to MGIS GDB”).

Path and Data Source Configuration (*_strings.py*)

- Path references to raw data (RAW_DATA_PATH), mapping tables (MAPPING_TABLES_PATH), and the MGIS geodatabase (MCWD_MSWGP), previously stored in the value and field mapping tables, were added to the *_strings.py* file to improve tool package portability. The value and field mapping tables were updated to store only relative file names, while the *_strings.py* file was updated to store absolute folder paths. **These paths should be updated to reflect the locations of the input files whenever the script location is moved.**
- Municipal data source abbreviations were added in the SOURCE_ABBREVIATIONS dictionary to standardize feature naming conventions in the “MGIS to Model Ready” script. Abbreviations use 3-letter codes (e.g., “EdinaData”: “EDI”, “MinnetonkaData”: “MTK”). Refer to *Feature Naming Convention* for more information on the updated feature naming convention.

Feature Type Classification (*core.py*, *_strings.py*)

- The script was updated to support new *type_field* and *type_value* parameters in the ValueMap mapping tables (“__ToolInfo” tab) to improve MGIS feature filtering and analysis. These parameters are optional and can be used to automatically assign a type attribute to features when imported into the MGIS geodatabase. The *type_value* parameter is used to assign a type attribute, while the *type_field* parameter specifies the target attribute for where the type attribute should be stored. For example, Deephaven gravity main features are assigned a type attribute of “GravityMain” in the “PIPE_DATAT” MGIS field to differentiate gravity mains from pressure mains.

Mapping Table Updates (**_FieldMap.xlsx*, **_ValueMap.xlsx*, *core.py*)

- Mapping tables were reviewed and updated for importing raw data into the MGIS geodatabase. Updates included mapping table corrections, adding *type_field* and *type_value* parameters, renaming files, and adding the MGIS_GUID field. A separate detailed changelog of specific mapping table changes is provided with the script files. In addition to these revisions, the “Raw to MGIS” script was updated to replace literal “<Null>” strings from the mapping tables with null values.

Raw Data Geodatabases

- Raw data geodatabases were updated to assign all input features a unique MGIS_GUID value. This unique GUID value is used in the manual override process added to the “MGIS to Model Ready” script. Refer to *Manual Override and Survey Data Integration* for more information.

Consolidated Batch Processing to MGIS GDB (core.py)

- A new consolidated batch processing workflow was added to enable execution of the “Raw to MGIS” Load Data process for all raw municipal datasets in a single run. The “Load Data (Consolidated)” process reads an input spreadsheet containing names of all raw data folders and MGIS GDBs, runs the existing “Raw to MGIS” workflow for each folder to create individual municipal datasets matching the MGIS schema, and then consolidates them into a single consolidated geodatabase (*MCWD_MSWG_P.gdb*) for later processing by the “MGIS to Model Ready” script.

“MGIS to Model Ready” Script Updates

Project Folder/Data Loading (model_input.py, utils.py)

The project folder/data loading process includes the following steps, each run separately:

1. Create Project Folder
2. Load MGIS data into project folder
3. Load MGIS datasets into model ready format
4. Add model ready datasets to Pro map
5. Import DEM to project

Manual Override and Survey Data Integration (load_mgis_data, update_mgis_data)

- The MGIS data loading process was updated to incorporate changes from the Manual Overrides and Surveyed Feature geodatabases into the Model Ready geodatabase. This approach combines the benefits of precise manual editing with the automated workflow. In parallel with the script development process, HDR performed extensive review of the stormwater data features, applying specific manual edits to the Manual Overrides geodatabase, which could not otherwise be captured by the automated process. The manual override and survey import process supports Add (A), Exclude (E), and Replace (R) operations:
 - o Add (A) – for adding new data such as features missing from the raw datasets or new surveyed features,
 - o Exclude (E) – for excluding data such as extraneous features contained in the raw datasets not required for modeling, and
 - o Replace (R) – for moving, editing, or replacing feature geometries or attributes.

The process requires each feature in the raw dataset to have its own GUID in the MGIS_GUID field; these GUIDs are carried throughout the “Raw to MGIS” and “MGIS to Model Ready” script processes. The “MGIS to Model Ready” script reads the manual override and survey import geodatabases and automatically updates the Model Ready geodatabase to capture the manual changes systematically with each tool run.

- The script was updated to automatically exclude MGIS features with inactive status values (e.g., ABANDONED, INACTIVE, FAILED, or REMOVED) from the Model Ready geodatabase.

Clipping Network to Watershed Boundary (load_mgis_data)

- The clipping logic for loading data was updated to include full pipe features overlapping the input watershed boundary, along with any structures connected to that pipe network. To achieve this,

feature classes are loaded in a specific order (lines before points) so that structures connected to pipes are captured.

Domain Validation (validate_domains)

- The Model Ready geodatabase uses domains to set valid attribute values for fields such as pipe material, pipe shape, and structure type. The domain validation process was improved to handle cases where the MGIS dataset contained an attribute value not matching the defined domains. The script was updated to check for invalid or empty values prior to appending them to the Model Ready geodatabase.

DEM Import (import_dem)

- The DEM Import process was improved to handle the following use cases: (1) when the user provides a project boundary with buffer, the DEM is clipped to the project boundary with buffer applied; (2) when the user provides a project boundary only, the DEM is clipped to the project boundary without a buffer; and (3) when a project buffer is not provided, the full DEM is used.

Topology Correction (model_input.py)

The Topology Correction process consists of the following steps (which may be run altogether or separately):

1. Flag or delete empty geometry
2. Split multipart geometries
3. Snap pipes to structures
4. Flag lines with same beginning and end vertex
5. Split at structures and intersections
6. Add artificial nodes
7. Remove disconnected nodes

Pipe Snapping (snap_pipe_ends)

- At the beginning of the project, HDR noted that the original script snapped structure points (manholes, inlets, outlets) to nearby pipe endpoints. This approach could potentially move points away from surveyed structure locations. Based on coordination between HDR and MCWD, the issue was addressed by Bolton & Menk and implemented into the updated “MGIS to Model Ready” script. In the updated snapping function, pipe endpoints are snapped to the nearest structure point within the specified tolerance. This preserves surveyed structure locations while adjusting pipe geometry to establish network connectivity.
- Additionally, the script was updated to round all feature coordinates to a specified grid tolerance (0.005 map units) to prevent snapping failures due to closely matching point coordinates that could not otherwise be differentiated at the spatial reference’s default XY resolution. The script generates a CSV snap log output recording the feature class, OID, vertex index, and snapping distance in feet for each snapped vertex.

Disconnected Feature Removal (remove_disconnected_nodes, flag_unsnapped_structures)

- The geometry validation process was updated to automatically remove orphaned structure points that do not intersect any pipe or culvert in the network from the dataset. Structures outside of the snapping tolerance that remain unsnapped after the snapping process are flagged by the script in

the Issues field (these may be reviewed manually when running geometry validation steps separately).

Attribute Validation (*model_input.py*)

The Attribute Validation process consists of a single step called “Update attributes” which runs all associated attribute correction subprocesses.

Feature Naming Convention (update_feature_name)

- The script was updated to generate a unique Model_ID for each feature based on a naming convention. The naming convention follows the format: {feature type prefix}-{source abbreviation}-{sequential unique identifier}. The feature type prefix identifies the feature type (e.g., NI for node inlet, NM for node manhole, NO for node outlet, and LP for line pipe or culvert), while the source abbreviation identifies the feature’s source municipality (e.g., EDI for Edina). An example ID for an inlet feature from the Edina dataset is NI-EDI-000001.

Missing Pipe Node Export (add_to_from_nodes)

- In instances where pipe endpoints do not have a connected structure, the missing pipe nodes are exported as a point shapefile (*missing_pipe_nodes.shp*) in the project folder. While most pipe endpoints should previously be automatically assigned a point through *add_artificial_nodes* in the Topology Correction step, there may be fringe cases where a pipe remains disconnected when the script assigns to/from node IDs during attribute validation. These missing pipe nodes can be reviewed manually and corrected as needed using the Manual Overrides process.

Multi-Pass Attribute Processing (process_features)

- To address circular dependencies when populating structure and pipe attributes, the attribute processing logic was updated for multiple sequential passes. For example, gaps in structure invert data can be estimated from the inverts of connected pipes, while pipe inverts can also be estimated from structure inverts. The script was updated based on the following logic order: (1) clearing invalid invert values for all features, (2) populating structure attributes from known pipe data, (3) processing pipe attributes and gap-filling missing inverts, and (4) reprocessing structures to fill any remaining gaps from pipes as estimated in step 3.

Invert Elevations (fix_pipe_inverts, clear_pipe_invalid_inverts, clear_structure_invalid_inverts)

- The script was updated to automatically clear invalid inverts outside the expected elevation range for the project area (700-1200 ft.) or above the DEM ground surface elevation. When calculating missing invert elevations for storm sewer pipes connected to manholes or inlets, inverts are estimated based on typical storm sewer installation depths; the script calculates missing inverts as equal to the DEM surface elevation minus a typical assumed 4-ft. cover depth minus the pipe diameter (converted to feet). For culvert pipes and pipes connected to outlets, missing inverts are assumed directly from the DEM elevation.

Rim Elevation (fix_structure_rim)

- The script was updated to replace structure rim elevations with the DEM elevation when the rim elevation differs from the DEM by more than 0.5-ft. Instances where the rim elevations were replaced are noted in the FLAG_Rim_Elevation flag field.

Pipe Attributes (fix_pipe_size, fix_pipe_material, fix_pipe_shape, fix_pipe_width_height, fix_pipe_slope)

- The default assumed pipe diameter was changed from 24-in. to 15-in. to be more representative of the typical storm sewer pipe size in the watershed. The script populates missing pipe diameters based on the mean size of connected upstream and downstream pipes. If upstream pipes exist, the script estimates the pipe's missing diameter as the mean of the connected pipe diameters. If there are no upstream pipes or no valid diameters from any connected pipes, the default pipe diameter of 15-in. is used (default assumptions are recorded in the FLAG_Diameter flag field).
- The default assumed pipe material was changed from "Unknown" to "Reinforced Concrete" to be more representative of the typical storm sewer pipe material in the watershed. Additionally, the script treats unknown or other material input values (e.g., "Unknown", "UNK", "Other", and "OTH") as null. Missing pipe materials are estimated from connected pipe materials where available, otherwise defaulting to Reinforced Concrete where unavailable.
- Pipe shape values were normalized for consistency. "Other" and "Round" pipe shape values are standardized to "Circular." For non-circular pipes, missing pipe width and height values are filled using an assumed 18-in. default. Additional notes are added to the FLAG_Width and FLAG_Height flag fields for arched pipes that may require manual review.
- Pipe slopes are automatically recalculated from the upstream invert, downstream invert, and pipe length attributes.

Inlet Type and Grate Size (fix_inlet_type_and_grate_size)

- The script was updated to classify inlets connected to culvert pipes as "Culvert" type without assigning a size and to classify inlets connected to storm sewer pipes as "Storm Inlet" filling missing size values with an assumed grate dimension of 2.75-ft. length × 1.26-ft. width.

Processing Workflow

The recommended workflow to run the "Raw to MGIS" and "MGIS to Model Ready" tools is described below:

Running "Raw to MGIS"

Before running the "Raw to MGIS" tool, verify that the raw municipal data geodatabases have been assigned MGIS_GUID values for all features and that the mapping tables (field maps and value maps) are updated and accurate. If input file locations have changed, update the file path references in *_strings.py* (RAW_DATA_PATH, MAPPING_TABLES_PATH). Prepare blank MGIS geodatabases where the outputs will be saved. To run the "Load Data (Consolidated)" tool, update the "Input Main Mapping Table" with the MGIS_GDB and Raw_Data_Folder names for all raw data sources to be processed. Next run the "Load Data (Consolidated)" tool, which will convert the data from the raw format to the MGIS schema and prepare the consolidated MGIS geodatabase (*MCWD_MSWGP.gdb*).

Running "MGIS to Model Ready"

Once the consolidated MGIS geodatabase is completed, prepare the Manual Overrides and Surveyed Features geodatabases. If input file locations have changed, update the file path references in *utils.py* (TEMPLATE_GDB, MANUAL_OVERRIDES_GDB, SURVEY_GDB, MAPPINGS_FILE).

For Data Loading, run Tool 1 (“Create Project Folder”), Tool 2 (“Load MGIS data into project folder”), Tool 3 (“Load MGIS datasets into model ready format”), and Tool 5 (“Import DEM to project”). Tool 4 (“Add model ready datasets to Pro map”) is an optional display step and is not required for processing. Provide the latest MGIS geodatabase, DEM, and watershed boundary, and specify an appropriate clipping buffer (e.g., 500-ft.) for importing the DEM. Note that for this project the clipping buffer was applied only to the DEM; no separate clipping buffer was specified when loading MGIS data into the project folder, since the script now automatically handles clipping of the MGIS feature network to the watershed. Manual verification of loaded features is recommended prior to running the Topology Correction and Attribute Correction tools. For this project, Model Ready feature classes were run through an additional Repair Geometry step manually using the Repair Geometry toolbox in ArcGIS Pro to remove any invalid features.

For Topology Correction, run Tool 0 (“Run all topology correction steps”) from the Topology Correction toolset to run all seven topology correction steps in order. Specify the desired feature snapping tolerance (e.g., 5-ft.) as an input before running.

For Attribute Correction, run Tool 1 (“Update attributes”) from the Attribute Correction toolset to run through all attribute correction steps.

Manually review final outputs prior to importing them into the hydraulic model. Review feature geometries and attributes, including the flag fields and Issues field in the output geodatabase. Feature revisions in the Manual Overrides geodatabase may be necessary to resolve issues that the automated process may not otherwise cover.



Appendix F – Waterbody Screening and Prioritization for Additional Data Collection

Technical Memorandum

Date: Monday, September 15, 2025

Project: 2-D Watershed-Wide Model

To: Brian Beck (MWCD)

From: HDR

Subject: Appendix F: Waterbody Screening and Prioritization for Additional Data Collection

Introduction

HDR is assisting the Minnehaha Creek Watershed District (MCWD) in developing a coupled surface water groundwater model to support near and long-term watershed planning. As part of Task 3B Non-pipe Stormwater Feature Development, limited information was available regarding how waterbodies outlet to downstream features. This memo documents the process to identify waterbodies which may have outlet control structures, prioritize those waterbodies for desktop review, identify data availability, and prioritize additional data collection. Data collection may include review and digitization of as-builts and/or performing field survey.

The memo outlines the process to determine where outlet control structures are located, what type of feature exists, and if there is a need to gather more data to describe the feature.

Structure Locations

Initial identification of structure locations were targeted larger frequently wet waterbodies. Multiple sources of surface waterbodies were used to develop a survey prioritization of the outlet features.

- LiDAR breaklines generated by the USGS through review of the LiDAR point cloud data. The features delineate the edge of water location at the time of LiDAR flights. As part of the LiDAR point to topographic surface generation these breaklines are used to hydro flatten the water surface. These lines were converted to polygons and oddities (islands, etc.) were removed.
- Surface waterbodies (non-wetlands) that were generated as part of Task 3A memo which identified 849 lake and pond features from the previously identified GIS datasets (Lake_GDB, LakeBathymetricOutlinesContoursDEM, LAKE_POLYGONS, 20240725_National_Hydrography, and 20240725_DNR_Hydrography).

These sources were merged and overlapping features were joined into a single aggregate feature. Each waterbody feature included the following attributes: LiDAR breakline surface area, total aggregated surface area, and the approximate drainage area as determined from ArcHydro processing. Figure 1 shows an example of an aggregate feature.

Waterbody features within the largest 200 LiDAR surface areas or within the largest 200 total aggregated surface area were selected for further analysis for a desktop review. This resulted in 256 waterbodies. Figure 2 shows the location of the initial 256 waterbodies prioritized for additional review. Lake Minnetonka was removed from this list as data are assumed to be available to represent Gray's Bay Dam, the outlet control structure.

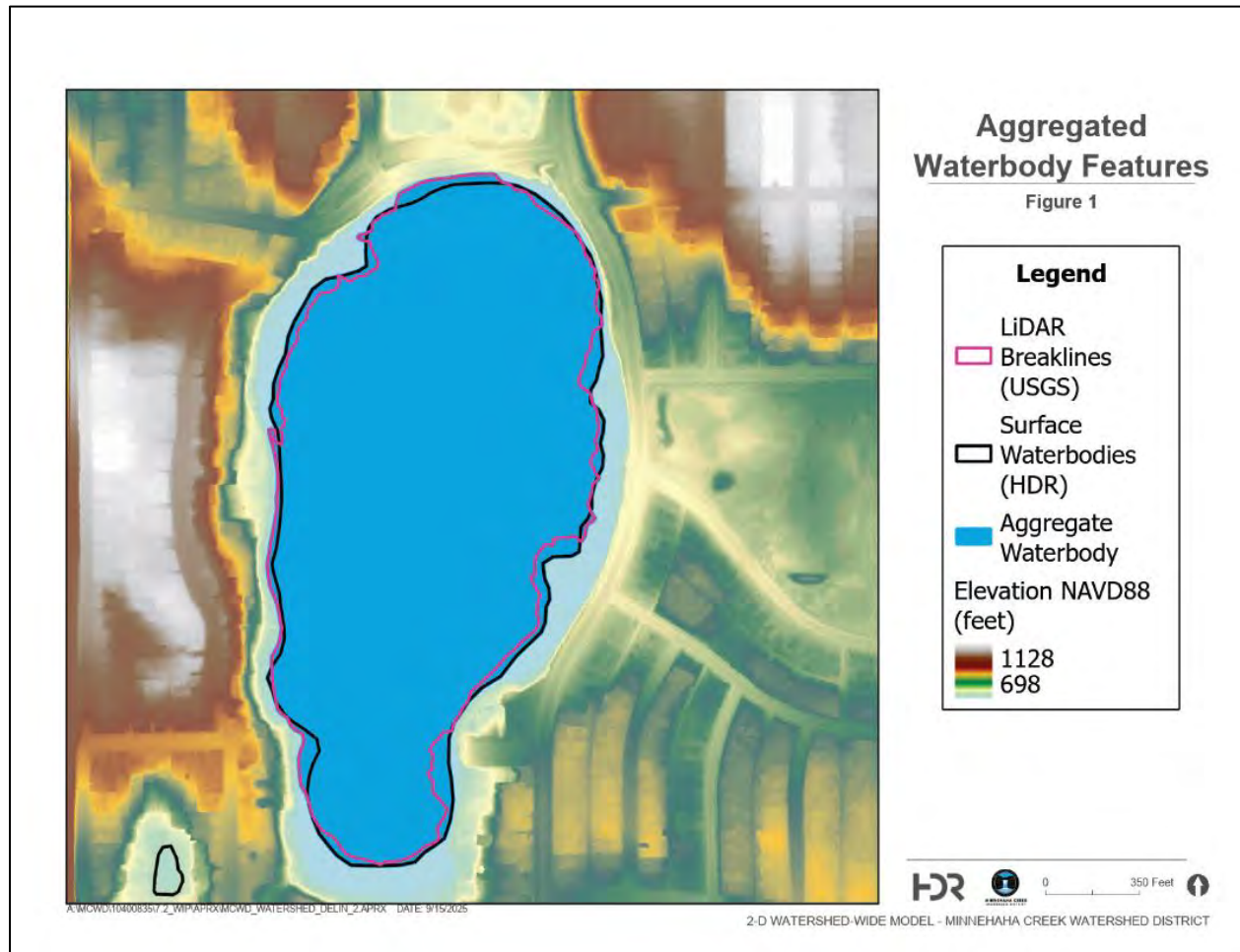


Figure 1. Aggregated Waterbody Features

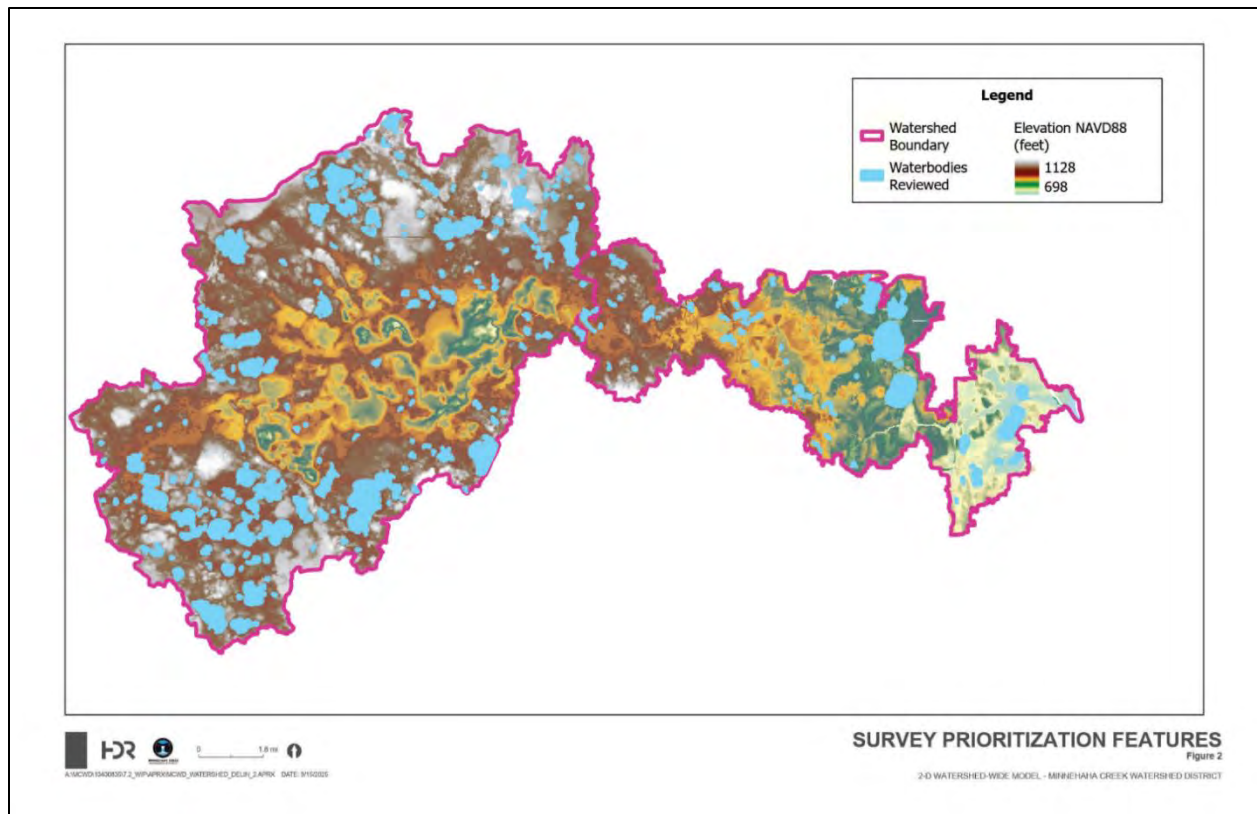


Figure 2. Waterbodies for initial data collection review

Existing Data Review

Each of the 256 features were individually screened via desktop review to determine if additional information would be required to represent the outlet within the StormWise model. The review included using LiDAR, aerial imagery, Pictometry (oblique aerial imagery), and the raw stormwater GIS datasets from the source municipality, county, or state. The raw datasets were reviewed as they often contained additional details which removed as part of the aggregation to a combined MGIS data schema. The desktop review documented the following at each feature:

- Likely location of the outlet/outfall
- Type of outlet
- Source of GIS data that was used to identify the outlet location
- If there is sufficient GIS data to represent the outlet structure in StormWise (e.g. elevation and diameter)
- If as-builts were noted in the GIS datasets
- Recommendation of survey or additional data request

The desktop screening of 256 features resulted in:

- Additional information required: 148 features

- o Request as-builts: 12
 - o Collecting field survey: 136
- Feature has sufficient data: 36
- Outlet was a channel or overland flow path not requiring additional information: 59

For those features requiring more information (155 total):

- Culverts or pipes: 113
- Outlet structures: 20
- Lift Stations: 4
- Unknown if pipe or structure present: 18 - Field investigation required to verify

Feature Data Requirements

Three main feature types were identified to control outflows from surface water bodies. Each feature type has specific data requirements for representation within stormwater modeling environments. Additional data collection (field survey or as-built review) will attempt to capture each of the below described feature characteristics:

- Culvert
 - o Entrance/exit configuration
 - o Upstream and downstream invert elevations
 - o Material
 - o Geometry: shape and dimensions
- Lift Stations
 - o Wet well geometry: dimensions and elevation
 - o Pump curve(s)
 - o Pumping set points for operation
 - o Outlet pipe geometry: material, size, shape, inverts
- Outlet control structures: Details for an example structure included in attachment
 - o Inlet pipe: inverts, diameter, material
 - o Outlet pipe: inverts, diameter, material
 - o Drop structure: invert, diameter
 - o Grate: elevation, diameter, description
 - o Notch, orifice, weir, or gate characteristics if present

Next Steps

This waterbody screening and prioritization is the first step at reviewing waterbodies and their respective outlet control structures or outfalls for additional data needs. It included a review of 256 frequently inundated areas and features described as lakes or ponds. Future efforts could expand the analysis to review more of the lake and pond features and/or include wetland features.

For those features with identified data needs (155) the following summarizes the approach to gather data:

- Culverts/pipes (113): MCWD is currently completing culvert survey on other culvert features in the watershed and intends to include these 113 into their data collection.
- Outlet structures (20): HDR survey team will collect data at identified outlet control structures.
- Lift Stations (4): Request for lift station operations will be made to the feature owner
- Unknown (18): Provided to MCWD for staff desktop review and potential field verification

Electronic Data Delivery

Waterbodies that were considered for review are provided as a geodatabase electronically along with this memorandum.

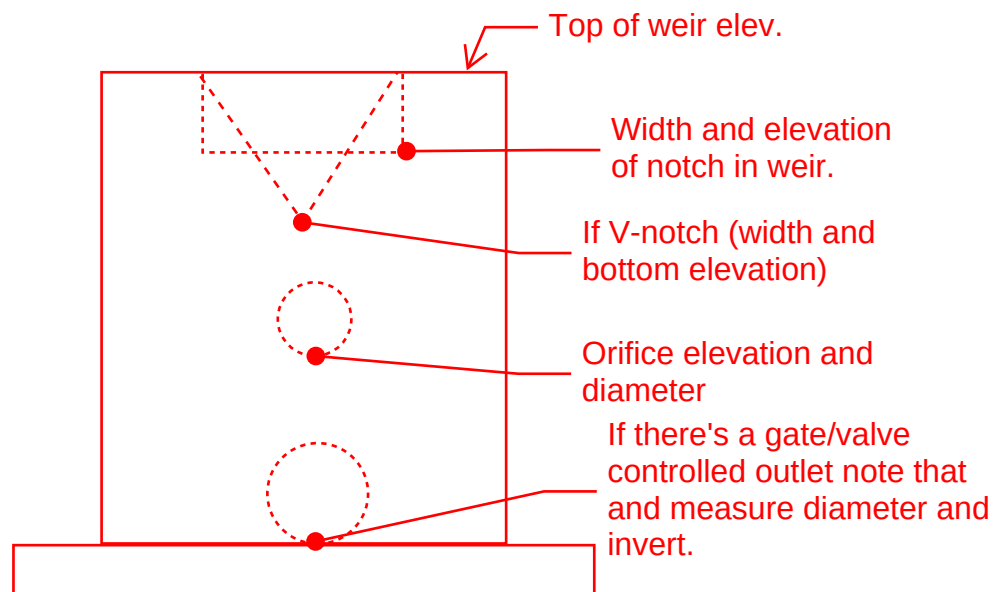
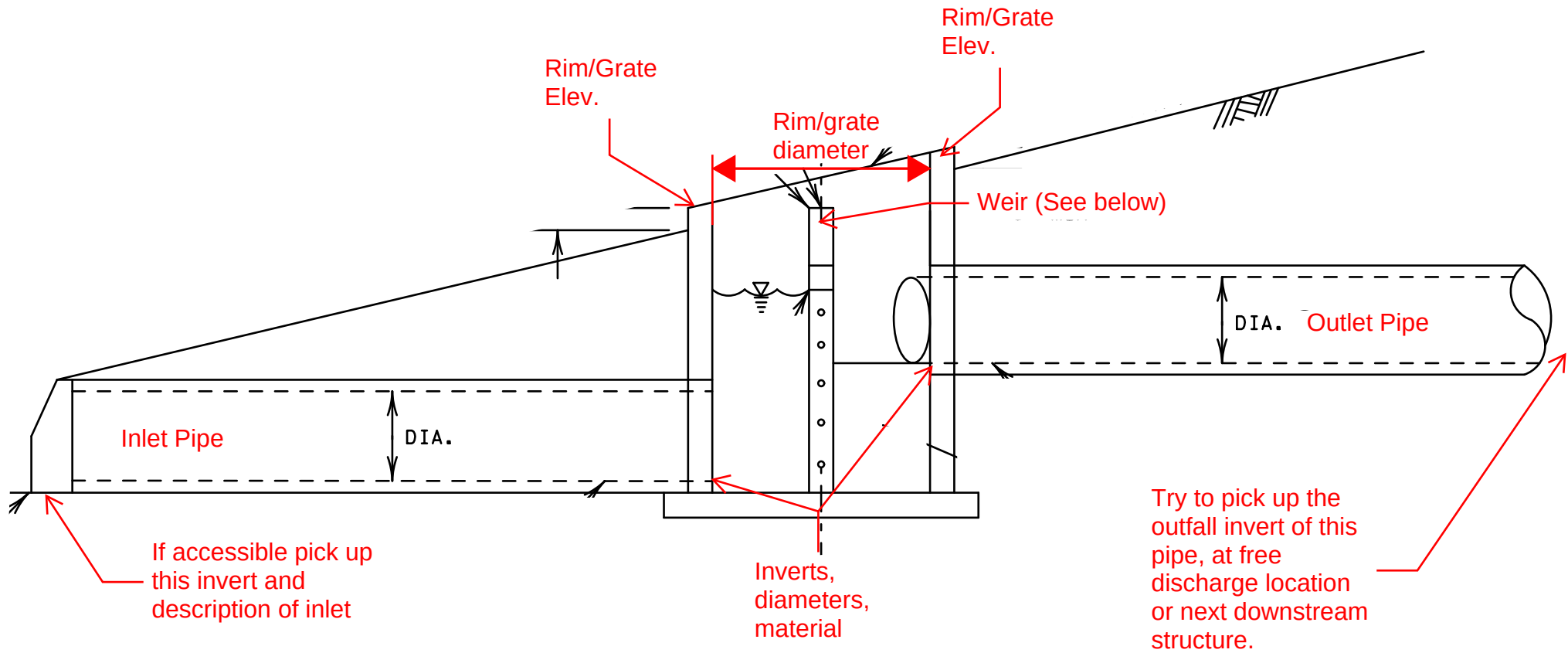
Geodatabase of all waterbodies considered for review and comments on each of the reviewed features: Survey_Prioritization.gdb

Attributes associated with the feature class include:

- Should Be Review – Identifies features in the largest 200 LiDAR surface areas or within the largest 200 total aggregated surface area for desktop review
- Outlet – Location of the outlet and the datasets that were used to identify the outlet
- Comments – Comments from desktop review containing additional pertinent information about the features
- Sizes and Elevations – Yes or “null”, Yes indicates there is enough information contained in the GIS dataset
- Survey Needed – 1 or “null”, 1 means survey or as-built information is likely needed
- Outlet Type – Observed outlet type
- LiDAR area – Calculated area from LiDAR breaklines representing open water
- Lake area – Calculated area for the Task 3 generated waterbodies

Attachment 1: Example Outlet Control Structure

Example Outlet Structure Configuration



Inlet Pipe:

U/S Invert, dia., material, end section description

D/S Invert, dia. material

Outlet pipe:

U/S Invert, dia., material

D/S Invert, dia., material, end section description

Structure Info:

Structure invert

Structure diameter

Grate:

Grate elevation (top and bottom if sloped)

Grate diameter

Grate Description (flat, sloped, beehive, other)

Weir:

Width/thickness

(If weir is made of stop logs make a note of that)

Notch:

Shape - Rectangular/V/Other

Width, invert elevation

Orifice:

Invert elevation, diameter

Gate or valve control?

Invert, diameter, type of valve



Upper Watershed Model Build and Calibration

Hydrologic and Hydraulic Modeling Report

Draft Final | September 2026



MINNEHAHA CREEK
WATERSHED DISTRICT

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Acronyms and Abbreviations

1D one-dimensional

2D two-dimensional

CAF Climate Action Framework

CCV channel control volume

cfs cubic feet per second

DCIA directly connected impervious area

ET evapotranspiration

HEC-RAS Hydrologic Engineering Center–River Analysis System

LiDAR light detection and ranging

MCWD Minnehaha Creek Watershed District

MGIS unified geographic information system schema

MNDNR Minnesota Department of Natural Resources

MNDOT Minnesota Department of Transportation

MSP Minneapolis–St. Paul

NAVD88 North American Vertical Datum of 1988

NRCS Natural Resources Conservation Service

NSE Nash–Sutcliffe efficiency

OF overland flow

PBIAS percent bias

PCV pond control volume

R² coefficient of determination

SSURGO Soil Survey Geographic Database

USGS U.S. Geological Survey

The lists of figures and tables cover the main report. Technical appendices retain the numbering used within each supporting memorandum.

1 Introduction

This report outlines the watershed model build and calibration for the Minnehaha Creek Upper Watershed. The watershed model was built using the StormWise (previously known as ICPR4) software and includes a two-dimensional (2D) surface mesh integrated with a 2D groundwater mesh. This documentation provides an overview of the watershed, describes data used and developed, explains model build decisions, describes each model element used to create the watershed model, and discusses calibration of the model to observed data. Detailed descriptions of data refinement and model build processes are appended to this report as separate technical memoranda.

1.1 Project Background

The Minnehaha Creek Watershed District (MCWD) experienced its wettest decade on record from 2010 to 2019 and severe drought in 2021 and 2022. The watershed, like much of the Midwest, is experiencing the extremes of flood and drought with increasing frequency, which directly impacts the water resources and the communities that depend on them. MCWD developed a Climate Action Framework (CAF) to guide the District's efforts to adapt to changing precipitation patterns and build long-term resilience (MCWD, 2022).

The CAF is built on three pillars: Understand and Predict vulnerabilities across the watershed, Convene and Plan with the MCWD's partners to develop a coordinated watershed adaptation strategy, and Implement, Measure, and Adapt projects and policies to the changing climatic conditions.

This watershed-wide model development is at the center of the CAF, enabling MCWD to effectively understand and predict water movement through a numerical tool capable of capturing the physical processes important to the watershed response to single rainfall events as well as extended simulation periods. The power of a model exists in its ability to explicitly understand the implications of change. Future applications of the model, beyond the scope of this project, will evaluate the impacts of future climate on flood risk and how projects, policies, and operational actions may alter those impacts.

HDR and MCWD (the Project Team) collaboratively developed the watershed-wide model through a shared understanding of model goals and a shared decision-making process. HDR developed the Lower Watershed model (downstream of Lake Minnetonka), while MCWD developed the Upper Watershed model (Lake Minnetonka and upstream). MCWD's Advisory Team reviewed the preliminary Lower Watershed model and provided suggestions for the final model build. The Advisory Team included technical staff from the software developer, Streamline Technologies, and faculty specializing in watershed modeling at Virginia Tech. Input from that review, along with additional model enhancements, informed the final Upper and Lower Watershed model builds and calibration to historical events.

1.2 Minnehaha Creek Watershed District

The Minnehaha Creek Watershed drains 178 square miles within the western Twin Cities metropolitan area, as shown in Figure 1-1. The watershed is divided into two distinct subbasins, the Upper Watershed and the Lower Watershed. The Upper Watershed drains 104 square miles of rural and suburban land to Lake Minnetonka, a 22-square-mile waterbody. Lake Minnetonka outlets through Grays Bay Dam operated by the MCWD into Minnehaha Creek. The Lower Watershed begins at Grays Bay Dam and drains approximately 52 square miles into Minnehaha Creek through the Minneapolis Chain of Lakes or

directly by means of stormwater conveyances or overland flow. Minnehaha Creek passes over Minnehaha Falls and then flows into the Mississippi River (MCWD 2017).

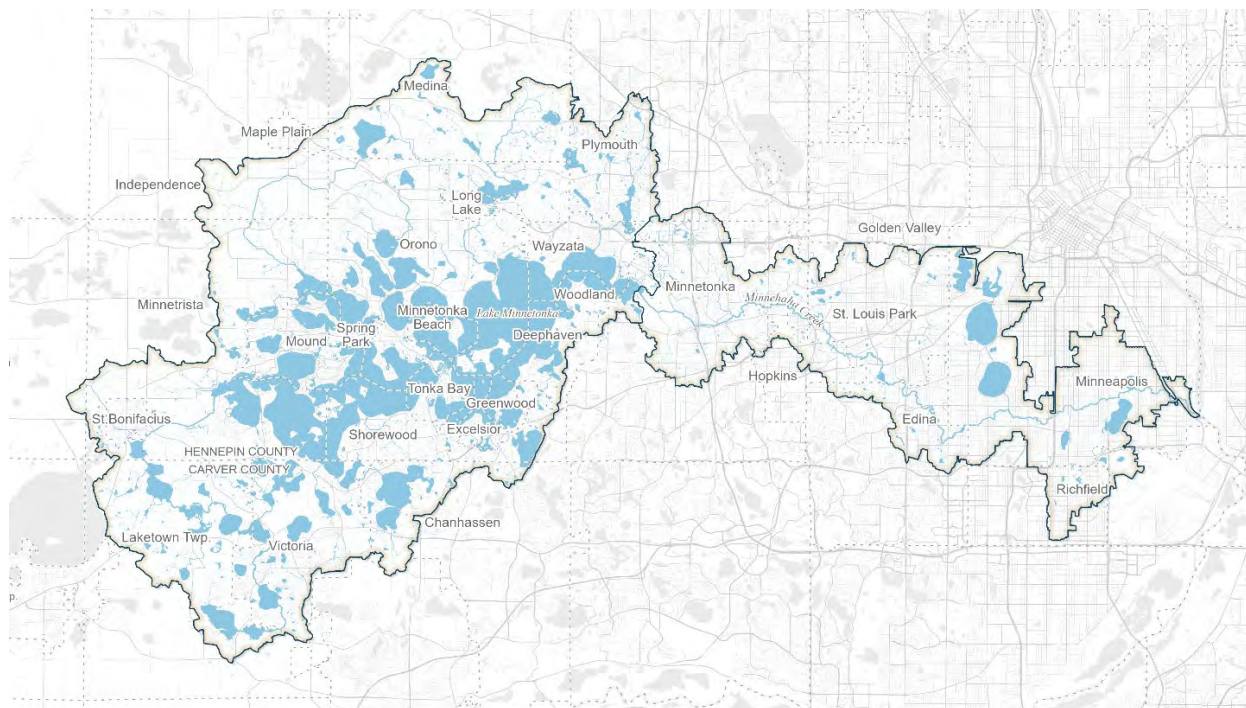


Figure 1-1. Minnehaha Creek Watershed

1.3 StormWise Software Selection

Prior to watershed-wide model development, MCWD completed a pilot 2D model build, comparing Infoworks ICM and StormWise software packages for function and applicability to represent the watershed response and meet MCWD's overall modeling goals (Kimley Horn 2023). Pilot models were created for two small subwatersheds of contrasting land use to represent the variability of land use and hydrologic dynamics of the watershed. Between the two platforms, StormWise aligned more closely with MCWD's climate planning needs. Both models have the capability to evaluate flood risk; however, StormWise is capable of integrating surface water and physically based groundwater methods into flood risk evaluations. This enables MCWD to evaluate the complex interactions between surface water and groundwater to more holistically understand flood and drought risk.

StormWise is a hydrologic and hydraulic modeling software that is commonly used for watershed and stormwater modeling in Florida, where interconnected ponds and groundwater interaction are important. In 2014, the software released the fully integrated one-dimensional/two-dimensional (1D/2D)-coupled surface water and groundwater components for the model with an emphasis on interaction between surficial groundwater and surface water bodies. For the Minnehaha Creek watershed model, StormWise, version 4.08.09, expert license (2D capabilities enabled) was used for the build and simulation. The software includes:

- Link-Node (1D) approach to describe stormwater inlet-pipe-manhole systems, which can also be used to represent simplified subbasin runoff response and pond/channel routing.

- 2D overland flow (OF), using a flexible triangular mesh with automated mesh generation based on geometric inputs. The 2D OF can be used to represent infiltration and surface runoff instead of the conventional subbasin approach.
- 2D saturated horizontal flow in the surficial aquifer between the ground surface and a confining layer, as shown in Figure 1-2.
- 2D OF and link-node components can be simulated independently or coupled with groundwater.

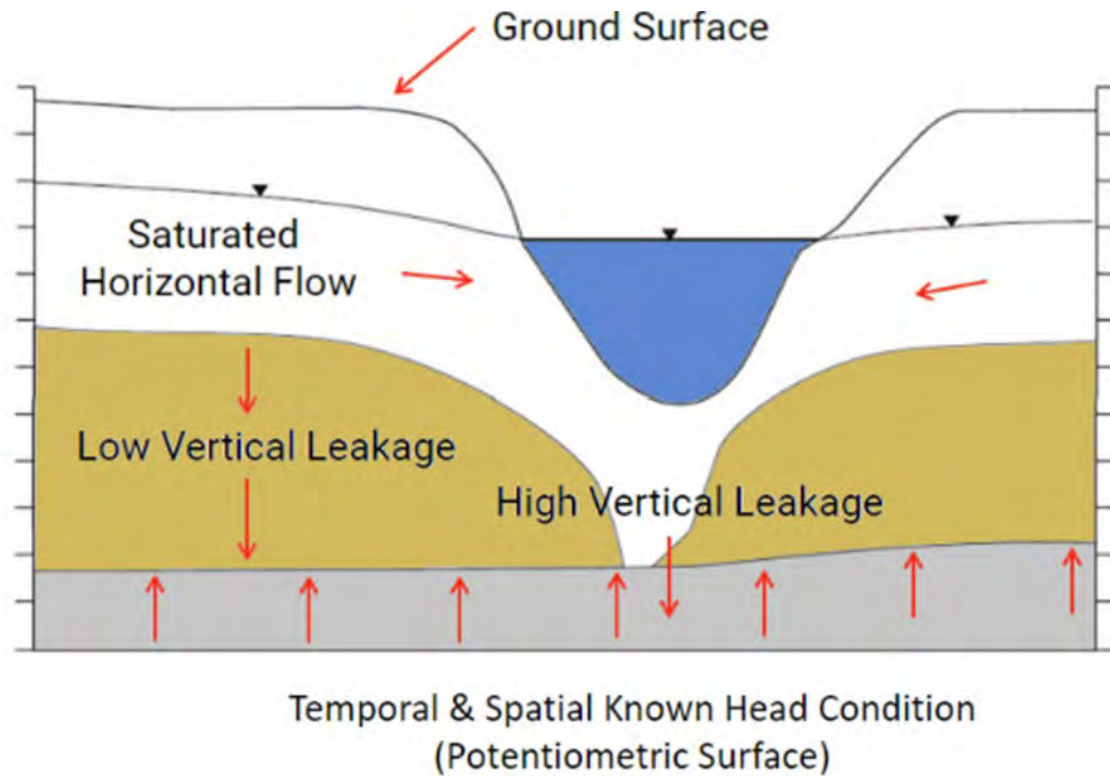


Figure 1-2. Saturated Horizontal Groundwater Flow (figure from Streamline 2024)

2 Watershed Model Build Decisions

The Minnehaha Creek Watershed was divided geographically between MCWD and HDR for the model build, but model build decision making was performed collaboratively. MCWD staff led the Upper Watershed model build and HDR staff led the Lower Watershed model build. This modeling report documents the specifics of the Upper Watershed model.

Modeling decisions were addressed through three methods: 1) workshop meetings at key model build stages, 2) emailed requests for input on model approach with recommendations from the modeling team that were reviewed and agreed upon by the group, and 3) additional unforeseen choices made along the way, which were discussed through biweekly meetings and verified with the larger group through detailed description and concurrence. Decisions are documented as part of this report, appended materials, and through summary notes of the model build workshops.

Alignment of the Project Team on directional decisions for the model build approach was completed through a series of five workshops. Workshop attendees included the Project Team and the Advisory Team.

Five workshops for this project consisted of the following:

- **Goal Setting and Prioritization:** Develop a shared understanding of model objectives and key decision areas to guide the upcoming model build process.
- **Surface Water Model Build:** Develop an approach to create the surface water components of the model through a discussion of the model domain and boundary conditions, 1D storm sewer integration, channel and storage area representation, and overland flow representation.
- **Surface Water Overland Flow:** Weigh the benefits and limitations of overland flow approaches with respect to MCWD goals through detailed discussion.
- **Groundwater Model Build:** Develop a shared understanding of groundwater specific goals, model domain and boundary conditions, and details of mesh generation and parameterization.
- **Calibration and Validation:** Develop a shared understanding of the typical watershed response, data availability, and calibration/validation approaches with the intent to select events and performance metrics for calibration/validation efforts.

Workshop notes are included as part of Appendix A.

2.1 Phased Model Build Approach

Due to the level of detail of this model build, a phased approach was used. Model detail was incrementally added in four key phases to improve build efficiency and minimize chances of unforeseen errors. Figure 2-1 provides an overview of the geometric features of each phase. After each phase of model build, the model was simulated to test potential issues, as described below.

- **Phase 1 Surface Mesh:** The first phase of model development focused on the 2D surface, or OF, mesh. The intent of this phase was to estimate the OF mesh resolution to confirm it aligns with the model intent. Model elements included in this phase included breakpoints, breaklines, 1D node interface points, and the existing ground surface. Issue identification targeted mesh generation inputs resulting in narrow triangles.

- **Phase 2 Control Volumes:** The second phase added channel control volumes (CCV) and pond control volumes (PCV). The intent of this phase was to include more detail within the OF region and to evaluate the quality of flow pattern representation within the watershed, which includes Lake Minnetonka, streams connecting smaller lakes and wetlands, and a number of other smaller surface waterbodies.
- **Phase 3 Storm Sewer Network:** The third phase added the full storm sewer network as 1D model elements. This includes inlets, manholes, pipes, weirs, culverts, and other miscellaneous storm sewer inputs. This phase looked for connectivity and consistency of the storm sewer system and additional mesh refinement required to integrate these elements. Potential errors of new narrow triangulation and missing storm sewer data were reviewed and resolved.
- **Phase 4 Groundwater:** The fourth phase was completed in two parts, adding vertical infiltration, and adding a horizontal groundwater model domain. These components were appended to the Phase 3 build. Here, the groundwater model domain was defined and split into computational regions, and the groundwater mesh was generated from a standard breakpoint pattern. Evaluation of the groundwater-only domain supported the troubleshooting of groundwater-only issues such as input surface (ground, bedrock, and water table) intersections and provided a resulting set of water table rasters used for final model initialization. Only the Phase 3 model with vertical infiltration was used for calibration to flood events. A completed four-phase model build was generated but not calibrated as part of this work; future efforts can use this generated model as a starting point for coupled surface water-groundwater calibration.

The following sections describe the complete model construction resulting from all four phases of model build, the decision workshops, input data and its pre-processing, and details of individual model element integration.

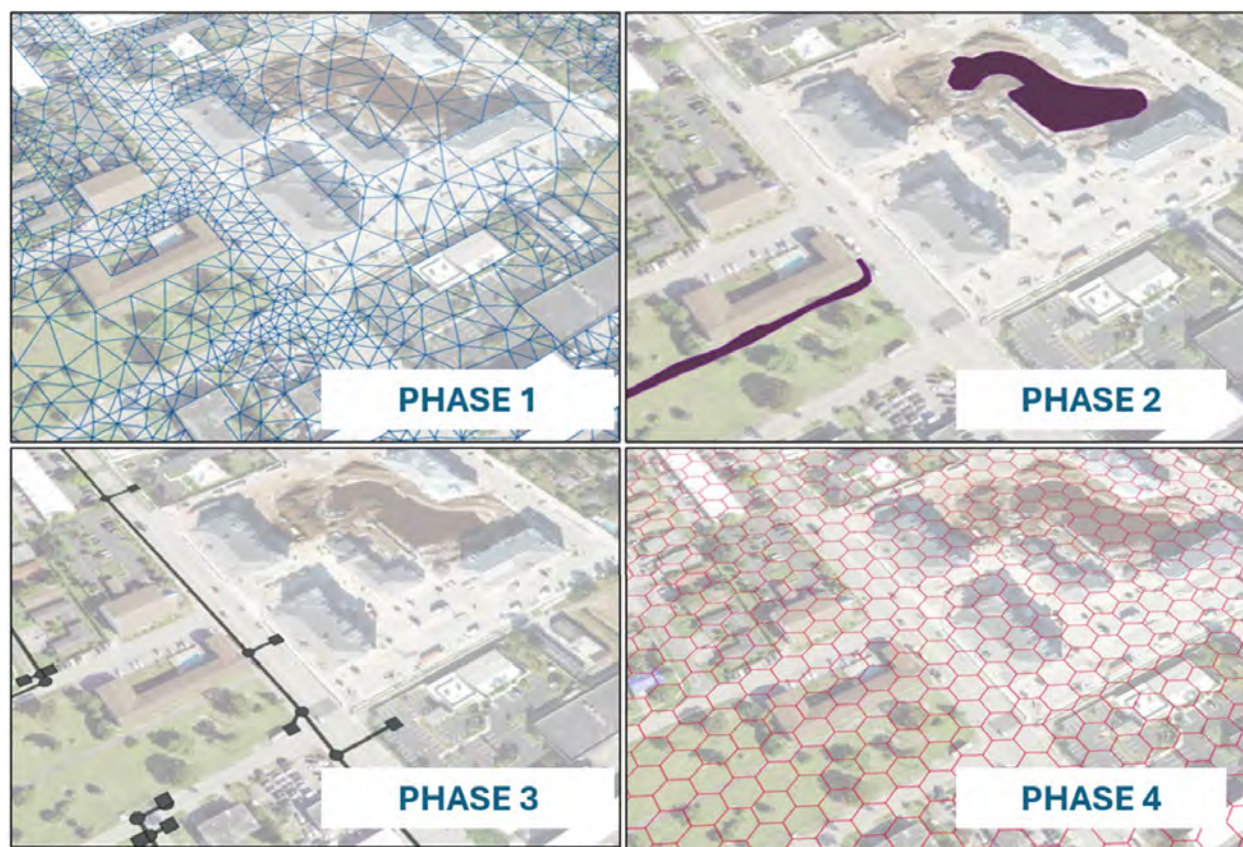


Figure 2-1. Phased Model Build Approach

2.2 Overview of Model Build Decisions

Overarching directional decisions were determined through the collaborative build workshops and follow-on technical discussions. This section provides an overview of these decisions for each modeling phase. The influences on the model build are described here and can be seen throughout the model build.

- **Phase 1 Surface Mesh:** MCWD has interest in identifying and understanding both local and regional flooding areas, to describe the groundwater/surface water interactions in a spatially meaningful way, and be capable of consistently evaluating policy and projects watershed wide. To meet MCWD's modeling objectives, 2D OF was used throughout the entire Upper Watershed in lieu of using 1D basins to generate infiltration and runoff. To support this intent, detailed breaklines were generated to support understanding of localized flow patterns, and due to the density of overland flow mesh geometry features and their influence on mesh element size and spacing, a systematic review of feature vertices was required to mitigate small triangles while retaining high level of model detail.
- **Phase 2 Control Volumes:** Surface storage is known to affect the watershed response in a meaningful way throughout the watershed; therefore, the built model needed to effectively capture the influence of these features. CCVs and PCVs can provide increased model efficiency and increased model accuracy. To support this intent, where applicable storage was explicitly represented by PCVs, bathymetric surfaces for many storage features were estimated to better

reflect the below-normal water storage conditions, outlet control structures were surveyed to better describe water levels, and CCVs were used to represent tributary channels and connections among lakes and wetlands in the Upper Watershed.

- **Phase 3 Storm Sewer Network:** All or most of the storm sewer infrastructure data were included in the model to effectively describe localized flooding and future effects of modified storm sewer conveyance. To support this intent, the existing Python scripts, which aggregate the municipal storm sewer data, were expanded to comprehensively check the datasets for redundancy, erroneous data, connectivity issues, and develop assumptions to fill all necessary attributes. These scripts could be used in the future for re-importing updated storm sewer data from municipalities. To develop a representative and efficient 2D mesh, 2D elements needed to align with localized flow pathways (e.g., in gutters) to reasonably characterize flow entering storm sewer inlets at a density sufficient to capture in-street flows versus out-of-street flows and inlets needed to be explicitly included in model development.
- **Phase 4 Groundwater:** Groundwater integration into this model build is critical to represent the dynamic nature of near surface groundwater movement and soil water storage relative to flood risk and long-term water balance. To meet this intent, the vertical layers method was selected to better estimate vertical and horizontal groundwater flow and continuous simulations will be used to effectively initialize the groundwater and soil water components.

2.3 Data Integration

Minnehaha Creek Watershed District overlays portions of more than 30 government entities, including municipalities, counties, park boards, and park districts. Each of these entities as well as MCWD maintains their own stormwater infrastructure data. A critical component of a successful model build and future use of these data is to aggregate, store, and manipulate these data in a transparent, repeatable manner. Data provided from each of the project partners, previously surveyed by MCWD, or aggregated through this project, are integrated into a unified geographic information system schema or “MGIS Formatted” geodatabase. These data are then reviewed for gaps and inconsistencies followed by correction of these data, where applicable. Where automated identification and correction of inconsistencies were not sufficient, manual overrides were identified and integrated at this stage. Stormwater infrastructure is then converted into a model-ready format. Here additional non-infrastructure data are included into the complete package of model-ready inputs. Figure 2-2 provides an overview of how and where various data sources enter the integration process. These steps are described in more detail throughout the report.

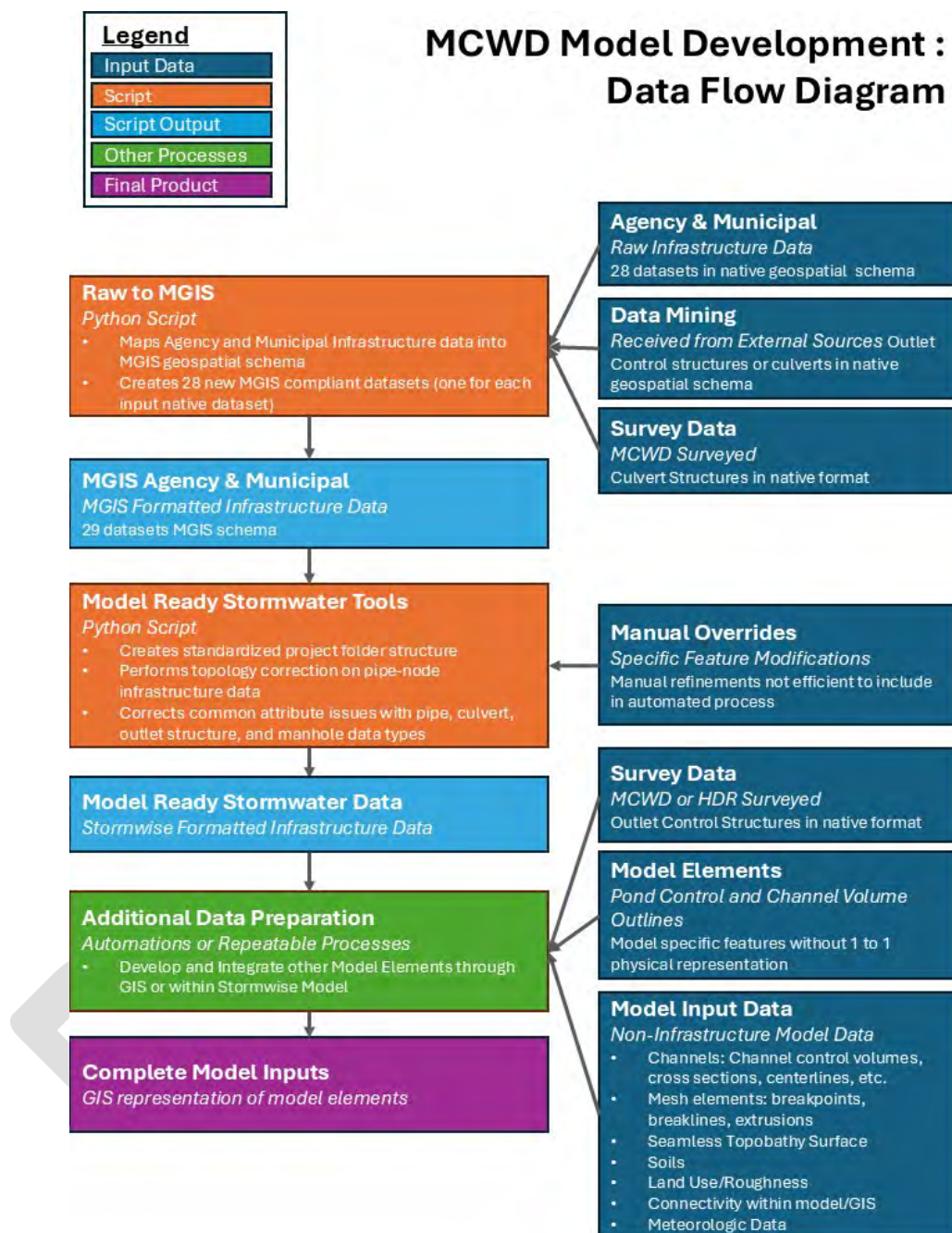


Figure 2-2. MCWD 2D Model Build Data Flow Diagram

3 Watershed Model Inputs

Development of the Upper Watershed model followed the four-phased approach that is described in Section 2.1. The following sections are arranged by model build phase with each section first discussing the data acquired and any preprocessing needed, while Section 4 provides a discussion of the model elements. Each build phase incrementally added detail to the previous phase often requiring iterative refinement to prior phase model features.

Refer to Appendix B for the Data Registry, which documents data sources and use in the model development. Appendix C (C-1 through C-13) provides details on how various elements were refined or developed as part of the model build. Note Appendix C is instructional and often requires the explanation found in this report for broader context.

3.1 Phase 1: Surface Mesh

Phase 1 required the input of a representative surface watershed boundary, seamless topographic-bathymetric ground surface, land cover, and mesh-generating elements (breaklines and break points).

3.1.1 Upper Watershed Boundary

It is important for the OF model domain to accurately represent the existing ground surface. Boundaries not in alignment with the topography could cause water ponding against the model domain or outflow inaccurately along the model edge. The Upper Watershed boundary was updated as part of this project. The general shape and extent were retained while local boundaries were refined to reflect drainage connectivity. The approach used ArcHydro processing to define boundaries that reflect the topography, which were manually reviewed with regard to the storm sewer network to determine which systems flow into or out of the watershed. The updated Upper Watershed Boundary vertices were coarsened to limit likelihood of small triangles as part of the OF mesh generation for use as a single OF region in the model.

Additional details of this process are provided in Appendix C-1, “Watershed Boundary Adjustment Process.”

3.1.2 Topography and Bathymetry

Topographic data for the model was generated from a combination of the best available (most recent) light detection and ranging (LiDAR) data, publicly available bathymetric data, survey data acquired by MCWD, and estimated bathymetry in critical waterbodies. Figure 3-1 shows the locations of bathymetric data development in the Upper Watershed.

- **LiDAR:** The most recent LiDAR data product for the region, collected in spring 2022, was processed at the original product resolution of 0.5 meter and is of U.S. Geological Survey (USGS) Quality Level 1 or better (USGS 2022). This is a high-quality dataset; however, LiDAR does not collect elevation data beneath the water surface and can have difficulty in densely vegetated areas.
- **Channel Bathymetry:** 2D models require a continuous surface for terrain development. To supplement the LiDAR surface, MCWD provided available surveyed channel cross sections for use in bathymetry surface development. Survey data along the creek was used to construct a

channel bathymetry surface through linear interpolation between cross sections. Bathymetric data was mosaicked with the LiDAR-based surface to create a new topographic surface that more accurately represents the channel bottom elevations.

- **Surface Waterbody Bathymetry:** StormWise model relies on accurate characterization of the stage-storage volume of potential water stored within the feature. Known bathymetry was mosaicked into the LiDAR surface for 190 features, including many of the largest waterbodies in the watershed. LiDAR classification of hydro-flattened waterbodies (2 acres or more) was used to identify 405 waterbodies within 1 mile of the watershed boundary (upper and lower). Empirical methods were used to estimate maximum waterbody depth and volume. Bathymetric contours were iteratively generated as interior buffers of the hydro-flattened waterbody at incremental depths to closely match the estimated depth-volume relationships. Interior buffers were converted to a depth raster which was subtracted from the hydro-flattened LiDAR surface to generate a continuous LiDAR-channel bathymetric surface.

Additional details of terrain and bathymetry development are provided in Appendix D, “Task 3b: Non-pipe Stormwater Feature Development Summary.”

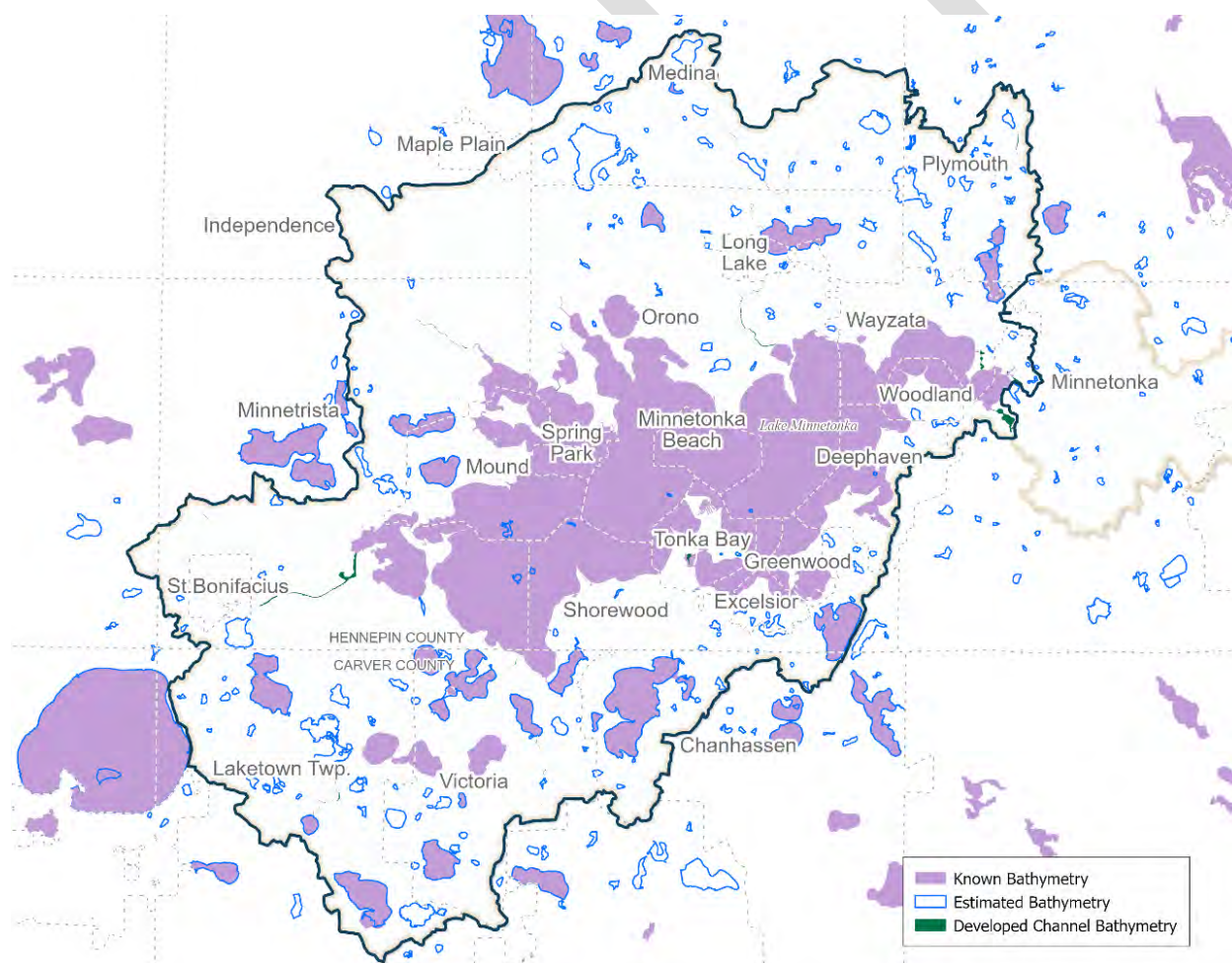


Figure 3-1. Upper Watershed Bathymetry Development

3.1.3 Land Cover

Land cover characteristics were used to describe roughness of overland flow (resistance to flow) and to define impervious surfaces for infiltration/direct runoff calculation. Through coordination with Moore Engineering, a blended land cover was selected to support future watershed planning efforts (Email Correspondence 3/16/2026). The blended land cover uses the following two primary products.

- Metropolitan Council Environmental Services (MCES) Generalized Land Use dataset (2020) is provided for the seven-county metro area and is developed through aerial photography, county-level parcel data, and field verification. It includes mixed-resolution polygons representing consistent land use areas. The coverage is updated every 5 to 7 years. This dataset provides added classification detail in developed areas. Therefore, the MCES (2020) product was selected to represent all areas identified as developed land cover.
- National Land Cover Dataset (NLCD 2024) provides national cover data classification at 30-meter resolution. It is based on satellite data and updated annually. In undeveloped spaces, NLCD provides additional classification detail that are not included in the MCES (2020) dataset. Therefore, where the MCES data (2020) identified undeveloped land use, the NLCD data (2024) was used.

Upper Watershed land cover includes developed areas, agricultural land, forests, wetlands, and open water. Table 3-1 lists the land cover classes and model codes used in the blended dataset. Figure 3-2 shows their spatial distribution. Additional details of the blending process are provided in Appendix C-3, “Land Cover Polygons Process.”

Table 3-1. Land Cover Classes and Model Codes

Land Cover Description	Model Code
Farmstead	111
Seasonal/Vacation	112
Single Family Detached	113
Single Family Attached	114
Multifamily	115
Manufactured Housing Park	116
Retail and Other Commercial	120
Office	130
Mixed Use Residential	141
Mixed Use Industrial	142
Mixed Use Commercial	143
Industrial or Utility	151
Institutional	160
Major Highway	201
Major Railway	202
Airport or Airstrip	203

Land Cover Description	Model Code
Open Water	11
Developed, Open Space	21
Developed, Low Intensity	22
Developed, Medium Intensity	23
Developed, High Intensity	24
Barren Land (Rock/Sand/Clay)	31
Deciduous Forest	41
Evergreen Forest	42
Mixed Forest	43
Shrub/Scrub	52
Herbaceous/Grasslands	71
Hay/Pasture	81
Cultivated Crops	82
Woody Wetlands	90
Emergent Herbaceous Wetlands	95

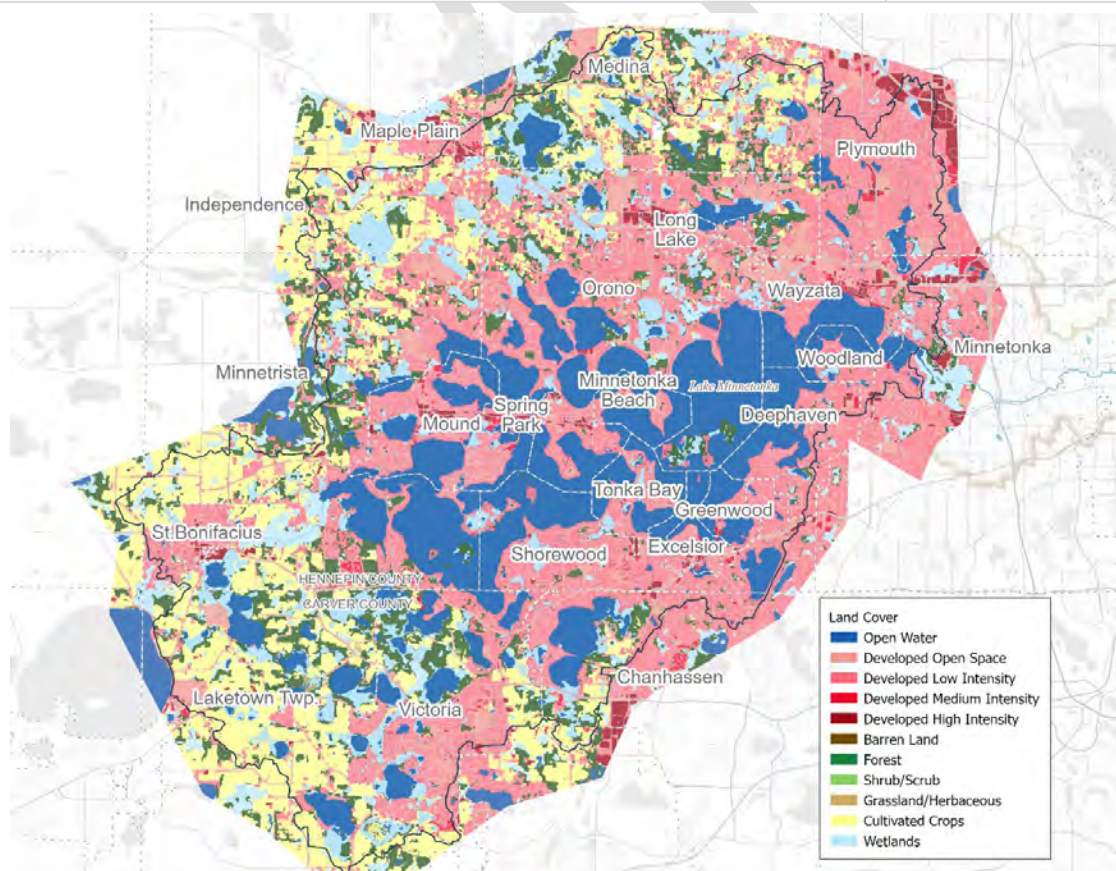


Figure 3-2. Upper Watershed Land Cover

3.1.4 Surface Roughness

StormWise implements a depth variable roughness approach that allows users to specify a shallow and deep flow roughness coefficient and a transition depth to change from shallow to deep flow.

Shallow flows that experience more frictional surface roughness have a higher value than deeper flows over those same surfaces. Roughness coefficients were selected using literature values and through coordination with the Advisory Team. Table 3-2 shows the selected roughness values for the model build.

Table 3-2. Manning's Roughness Coefficients

Land Cover	Shallow Flow Depth ² (feet)	Shallow Flow n	Deep Flow n ¹
Open Water	0.1	0.038 ²	0.038
Developed, Open Space ³	0.1	0.15 ¹	0.04
Developed, Low Intensity ⁴	0.1	0.15 ¹	0.09
Developed, Medium Intensity ⁵	0.1	0.15 ¹	0.12
Developed, High Intensity ⁶	0.1	0.15 ¹	0.16
Barren Land (Rock/Sand/Clay)	0.1	0.05 ²	0.027
Forest ⁷	0.1	0.4 ²	0.19
Shrub/Scrub	0.1	0.4 ²	0.11
Herbaceous/Grasslands	0.1	0.24 ²	0.04
Cultivated Crops ⁸	0.1	0.17 ²	0.10
Wetlands ⁹	0.1	0.15 ¹	0.07

Source:

¹ HEC RAS Manual (USACE 2025)

² NEH: sheet flow (USDA 2008)

³ Developed, Open Space includes farmstead, major highway, major railway, and airport or airstrip

⁴ Developed, Low Intensity includes single family detached, single family attached, manufactured housing park, and institutional

⁵ Developed, Medium Intensity includes multi-family

⁶ Developed, High Intensity includes retail and other commercial, office, mixed use residential, mixed used industrial, mixed-use commercial, and industrial or utility

⁷ Forest includes deciduous forest, evergreen forest, mixed forest, and seasonal/vacation

⁸ Cultivated Crops includes hay/pasture

⁹ Wetlands include woody and emergent herbaceous wetlands

3.1.5 Impervious

StormWise requires impervious percent and directly connected impervious percent as model inputs. This input describes the amount of impervious surface on the land for which infiltration will not occur; instead rainfall is directly converted into runoff. Impervious area was determined for each land classification using the NLCD (2024) Impervious layer. This layer provides impervious percent estimates at a 30-meter resolution over the entire watershed. For each blended land cover description, an average

impervious percent was determined watershed wide resulting in a single impervious percent value for each land cover description. These average impervious percent values were used as input to the model. Directly Connected Impervious Area (DCIA) are impervious areas that are connected to the stormwater drainage system, surface or subsurface, and are expected to respond faster and without infiltration losses.

Table 3-3 provides the model inputs; additional details of this process are provided in Appendix C-3, “Land Cover Polygons Process.” Note that calibration resulted in adjustments to the impervious percent; these are discussed in more detail in Section 5.4.

Table 3-3. Impervious and DCIA Model Inputs

Land Cover Description	Impervious %	DCIA %
Farmstead	18	9
Seasonal/Vacation	4	2
Single Family Detached	29	18
Single Family Attached	49	30
Multifamily	60	38
Manufactured Housing Park	48	39
Retail and Other Commercial	75	75
Office	68	68
Mixed Use Residential	75	43
Mixed Use Industrial	69	69
Mixed Use Commercial	78	78
Industrial or Utility	65	65
Institutional	47	35
Major Highway	60	45
Major Railway	62	46
Airport or Airstrip	63	32
Open Water	0	0
Developed, Open Space	11	0
Developed, Low Intensity	34	33
Developed, Medium Intensity	62	60
Developed, High Intensity	86	80
Barren Land (Rock/Sand/Clay)	0	0
Deciduous Forest	0	0
Evergreen Forest	0	0
Mixed Forest	0	0
Shrub/Scrub	0	0

Land Cover Description	Impervious %	DCIA %
Herbaceous/Grasslands	0	0
Hay/Pasture	0	0
Cultivated Crops	0	0
Woody Wetlands	0	0
Emergent Herbaceous Wetlands	0	0

3.1.6 Breaklines

Breaklines are used to define mesh element edges and are often used to define flow paths and ridgelines across the model surface. Breaklines were created using an automated process for this model and focused on describing critical flow paths within the watershed. Geospatial tools were used to create draft breaklines based on a flow accumulation threshold of 5,000 square feet in developed areas and 50,000 square feet in undeveloped areas. Flow paths in the urban spaces were often curblines that required a smaller accumulation threshold to adequately describe. The less developed areas had more natural drainage features that could be represented with a higher threshold. These draft lines were then modified to confirm parallel breaklines did not result in small triangles, minimize line vertices, and snap to other mesh elements, where necessary.

Additional details of this process are provided in Appendix C-4, “Surface Mesh.”

3.1.7 Breakpoints

Breakpoints are used to define mesh element vertices. These are typically generated on a regular grid pattern within StormWise to fill the space between other mesh generating elements. To better represent surface water-groundwater interactions and to improve inundation mapping along narrow channels, a denser breakpoint pattern was generated within CCVs and PCVs. Within CCVs, a 25-foot side length was used, and within PCVs, a 50-foot side length was used. A standard coarser breakpoint pattern was applied for the rest of the Upper Watershed area, as discussed in Section 4.1.

Additional details of this process are provided in Appendix C-4, “Surface Mesh.”

3.2 Phase 2: Control Volumes

Phase 2 required development of PCV model elements (boundary polygons, nodes, and connectivity), CCV model elements (boundary polygons, links, nodes, and cross sections), and rating curves for any creek or channel crossings that cannot be represented by a culvert. Pond and channel control volumes override the 2D mesh and simplify the hydraulics into a 1D representation. The Project Team intentionally located these features to maximize accuracy of the watershed response while improving model efficiency. PCVs were used to represent large frequently wet waterbodies, while CCVs were used to represent tributary channels and connections among lakes and wetlands in the Upper Watershed.

3.2.1 Pond Control Volumes

PCVs are polygons that simplify computations in portions of the 2D OF area using a 1D approximation of storage and connectivity. These features can result in increased numerical efficiency and, where appropriately implemented, can improve model accuracy. PCVs were used in the model for many of the

continuously wet waterbodies along with large wetland complexes. To represent these features in the model, a polygon outline (control volume) and a node (stage/area) are needed.

Polygons were created using closed contour lines that represented the approximate top-of-bank area of a waterbody. Where PCVs were adjacent to other PCVs or CCVs, their polygon edges were aligned and a 1D weir was added allowing water to exchange through the weir connection. These features were manually modified to contain pipe ends (inlet or outlet) that connect to the waterbody, and then these polygons were simplified to minimize the number of vertices. Stage/area nodes, a 1D model element, are associated with PCVs. Each stage/area node was placed within the PCV polygon and assigned to the corresponding PCV. Figure 3-3 shows the pond and channel control volumes included in the Upper Watershed model.

Additional details of this process are provided in Appendix C-5, “Pond Control Volumes.”

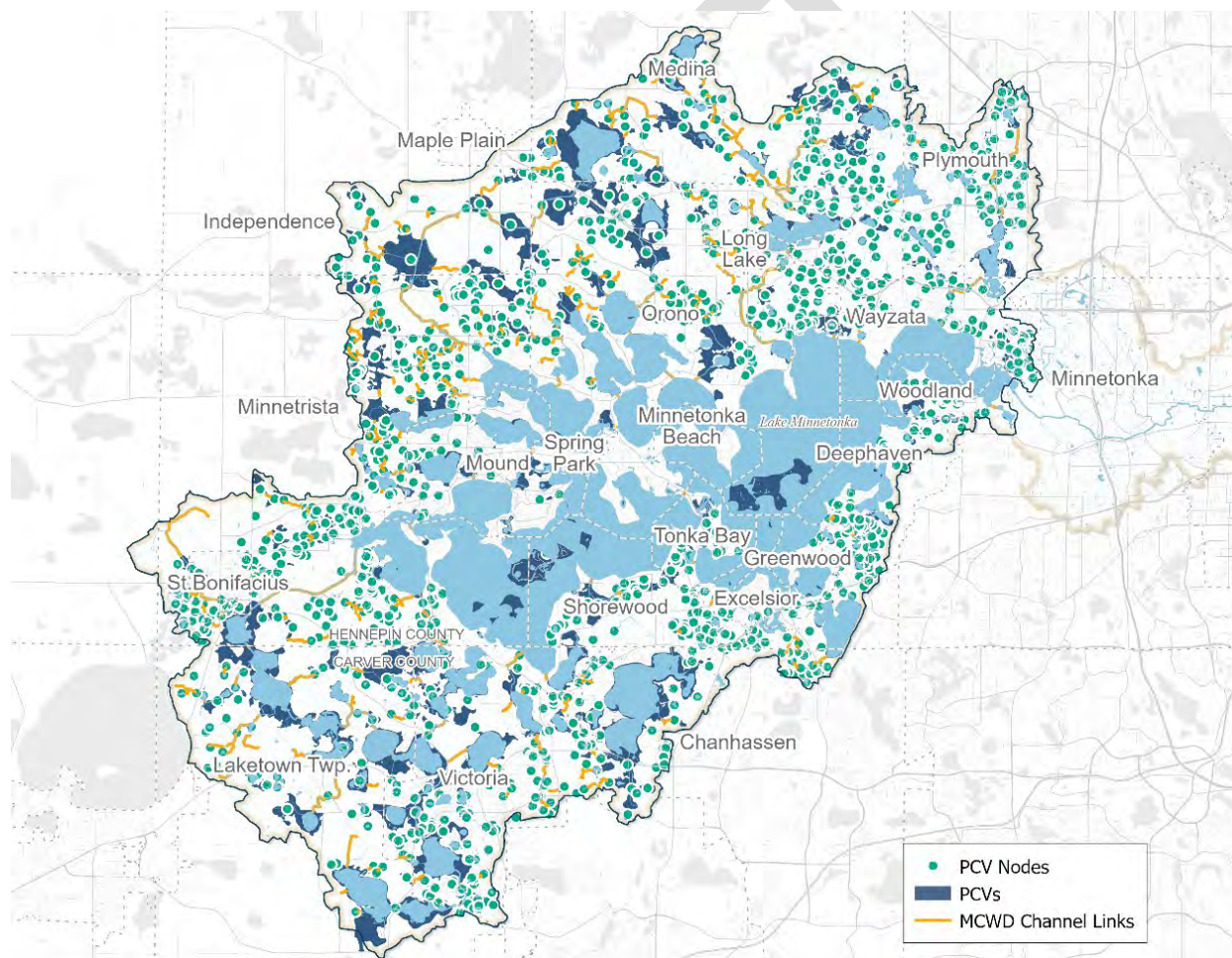


Figure 3-3. Upper Watershed Pond and Channel Control Volumes

3.2.2 Channel Control Volumes

CCVs are used to define areas of linear water features such as channels, rivers, and streams that can be represented with a 1D channel link. For this watershed model, tributary channels and connections among lakes and wetlands were represented as a series of 1D channel links, as shown in Figure 3-3. To

represent CCVs in the model, the following are needed: channel links, cross sections, polygons outlining incremental channel areas (control volumes), a channel node (stage/area node).

Channel links are the 1D elements that represent open-channel flow routing. Channel cross sections define the geometry used to estimate flow area and conveyance. Where survey data were available, cross sections were aligned with surveyed locations; elsewhere, channel geometry was interpolated or estimated. Stage/area nodes were generated at the intersection of cross sections and channel links. CCVs represent areas of 1D flow and were developed using contours to estimate top-of-bank areas aligned with the limits of the channel cross sections. Because CCVs act as mesh-generating features, vertices along the polygons were minimized or snapped to other mesh features.

Along with 1D channel links, the model requires OF channel features to define connectivity within the channel. These features are typically identical to the 1D channel link geometry. See Figure 3-3 for the location of CCVs.

Additional details of this process are provided in Appendix C-6, “Channel Control Volumes.”

3.2.3 Channel Crossings and Hydraulic Controls

Road crossings, culverts, bridges, and outlet-control structures can restrict flow, increase upstream water levels, and attenuate peak discharge. In the Upper Watershed model, these features are represented through the storm sewer network, surveyed outlet information, channel geometry, and applicable pipe or weir links. Where a bridge requires a more detailed hydraulic representation, a family of head-flow rating curves can be developed using the U.S. Army Corps of Engineers’ Hydrologic Engineering Center-River Analysis System (HEC-RAS) and imported into StormWise.

Appendix C-7 documents the Minnehaha Creek crossing assessment completed for the Lower Watershed portion of the watershed-wide project. Its structure inventory and tier classifications apply to that companion model. Upper Watershed crossing representation should be evaluated using the tributary-specific geometry and infrastructure included in this model.

3.3 Phase 3: Storm Sewer Network

Phase 3 required the input of the storm sewer infrastructure, which includes primarily inlets, pipes, manholes, outlets, and culverts. These are part of the 1D “link-node” modules of the software and are connected to the 2D OF through 1D node interface points. These interface points are typically storm inlets and establish a new mesh-generating element, which requires refinement of the OF 2D mesh to integrate these features and detailed review to remove small triangle edges.

3.3.1 Storm Sewer Infrastructure

MCWD overlaps numerous municipalities, counties, and other entities that own storm sewer infrastructure. Approximately 30 different storm sewer infrastructure datasets were aggregated and processed for use in the whole watershed model build (Upper and Lower). Figure 3-4 shows the pipe network throughout the watershed, including the following infrastructure features:

- 49,500 storm sewer conduits ranging in size from 6 to 120 inches
- 3,100 culverts ranging in size from 6 to 120 inches
- 33,400 inlets

- 7,000 outlets
- 19,100 manholes

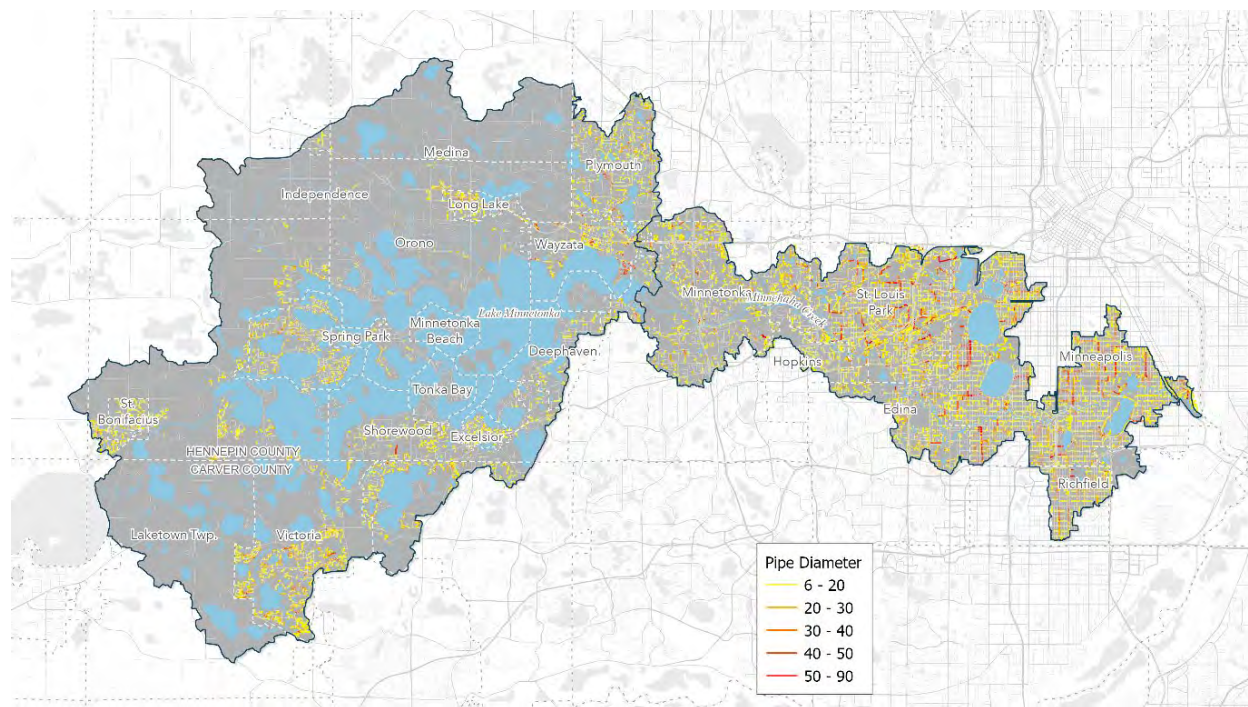


Figure 3-4. Watershed-wide storm sewer infrastructure

3.3.2 Storm Sewer Refinement

Major advancements were completed as part of the pilot project to aggregate, review, and refine these storm sewer datasets. Scripts developed for the MCWD watershed-wide model pilot study systematically re-formatted and consolidated storm sewer datasets from all constituent owners (state, county, city) into a unified geographic information system schema (MGIS) (Bolton and Menk, 2024). To support model development, data gaps and erroneous attributes were flagged and filled following a variety of methods depending on the gap type and available data. As part of this model build, the MCWD scripts were updated to fill gaps for all required missing attributes. The “Task 4 Script Documentation” Technical Memorandum describes modifications to the previously developed scripts and is included as Appendix E. Both an automated and manual approach were used to identify issues and address them. Where manual updates were completed, a tracking geodatabase was populated with the required updates, and this dataset was input into the scripts to perform the modifications in a systematic and repeatable manner.

Automated Procedures

Where automated procedures filled gaps in pipe and node features, a systematic review of municipal datasets was performed to determine appropriate default values for each attribute. Methods for filling data gaps varied by attribute and consisted of the following:

- Node (inlets, manholes) rim elevation: where rim elevations were more than 0.5 feet different compared to topographic surface elevations, rim elevations were replaced with the topographic surface elevation.

- Node (inlets, manholes) invert elevation: where node invert elevations were questionable (less than 700 feet, greater than 1,200 feet, or greater than the digital elevation model point elevation), invert elevations were set to null and filled in by subsequent steps of the script. Where nodes were connected to a pipe, pipe inverts were used to fill data gaps. Where pipe data were missing, the surface elevation and assumed cover depth was used to fill these data. Typical cover depth over the conduit was assumed to be 4.0 feet, based on review of the municipal datasets, and included a typical 6-inch pipe thickness for the top of the pipe. Two passes were used to fill data gaps for structures: an initial pass to fill data gaps based on initially available data, and a second pass to fill data gaps, based on assumed pipe invert elevations.
- Pipes (culverts, storm sewer) to/from nodes: populated from connected nodes or a buffered snapping procedure (snapping pipe ends to nodes within 5 feet). Where unable to snap, manual review was performed.
- Pipes (culverts, storm sewer) geometry (diameter, height, width, shape, material): where pipes were connected to other pipes, the average of those geometric fields were used to fill any data gaps. Where connecting pipe data were also missing or if pipes were at the upstream end of the network (having no other connecting pipes upstream), default values were applied instead. A manual review of the municipal datasets was performed to determine typical pipe attributes. Typical pipe diameters, shapes, and materials were found to be generally consistent across municipalities within the watershed; therefore, default values of 15 inches (diameter), circular (shape), and reinforced concrete (material) were applied in cases where the data gap-filling procedure required default assumptions.
- Pipes (culverts, storm sewer) length: where the attributed length is greater than +/- 20 percent of the geometric feature length or if not populated, the geometric feature length was used.
- Pipes (culverts, storm sewer) inverts: uses the same process as node inverts.

Further detailed discussion of the associated attribute fields and approach used to fill data gaps in the storm sewer infrastructure data is provided in Appendix C-8, "Storm Infrastructure Assumptions."

Manual Procedures

Manual procedures were implemented where decisions required human input or where clear repeatable automated processes would be onerous to implement given the number of features required to address. Two primary methods were used: a random sampling process (where many features required review) and a manual one-by-one review of each feature in question.

Random sampling was implemented where widespread redundancies in storm sewer data were identified in source datasets to the MGIS data aggregation workflow. This analysis selected a statistically significant sample of each potentially redundant dataset to review for potential omission from the aggregated dataset. The results of the random sampling analysis indicated that Hennepin County and Carver County data may be omitted without substantial loss of relevant data. Minnesota Department of Transportation (MNDOT) data also exhibited a high degree of redundancy and were omitted; however, further review of these data is recommended for potential inclusion in specific regions of the watershed area.

Manual review was performed for culvert features identified as potentially redundant with storm sewer pipes in the overall storm pipe dataset. Where manual procedures were required, manual updates were tracked as features in a manual overrides geodatabase for inclusion into the script process. The script was then updated to read the manual overrides geodatabase and incorporate the manual updates to make them repeatable. Manual modifications were required where professional judgement was needed to address a conflict such as pipe/node proximity conflicts, redundant datasets, or infrastructure around the model boundary.

Further detailed discussion of the random sampling analysis process and results is presented in Appendix C-9 “Storm Infrastructure Duplicative Dataset Evaluation Process.”

Automated Conversion to Model Ready

While StormWise allows several input dataset methods, for this model build, a .CSV input approach was implemented. A Python script developed by MCWD ingested complete model-ready storm infrastructure geodatabase features as well as PCVs and CCVs. The script removed features completely contained within PCVs and CCVs, updated the pipe links to/from nodes to the appropriate control volume feature, and converted each feature class into a set of .CSV files for import into StormWise. The .CSV storm sewer inputs are provided as part of an electronic delivery package delivered along with this report.

The CSV conversion workflow is summarized above. Appendix E documents the supporting storm sewer data-processing scripts and refinements.

3.3.3 Waterbody Outlet Survey Collection

Surface water storage in distributed waterbodies throughout the watershed has a significant impact on watershed response. Many of these features have limited information available to describe the outlet conditions and connectivity downstream. The Technical Memorandum, “Task 6: Waterbody Screening and Prioritization for Additional Data Collection,” describes the process to identify and prioritize survey data collection and is included as Appendix F.

A desktop analysis was performed on the largest 256 waterbodies watershed wide. Here the storm sewer infrastructure, LiDAR topography, and oblique aerial imagery was reviewed to identify potential gaps in data required to include outlet structures into the model. The desktop analysis identified 155 features with data needs to support model development, as described below:

- Culverts/pipes (113): MCWD to survey
- Outlet structures (20): HDR to survey
- Lift Stations (4): Data request to owner
- Unknown (18): MCWD to field verify

Surveyed culverts/pipes were integrated as an independent data pathway into the storm sewer infrastructure scripts. Lift stations and more complex survey data were integrated directly into the model. Figure 3-5 shows locations of outlet control structures that were directly integrated into the model based on survey data, as-builts, or the current MCWD XPSWMM model.

3.3.4 Lift Stations

Lift stations require, at a minimum, a maximum discharge capacity, pump-on and pump-off elevations, and upstream and downstream connectivity. Available municipal data, surveyed information, and reasonable assumptions were used to characterize these structures. Figure 3-5 shows lift stations and outlet-control features in the Upper Watershed.

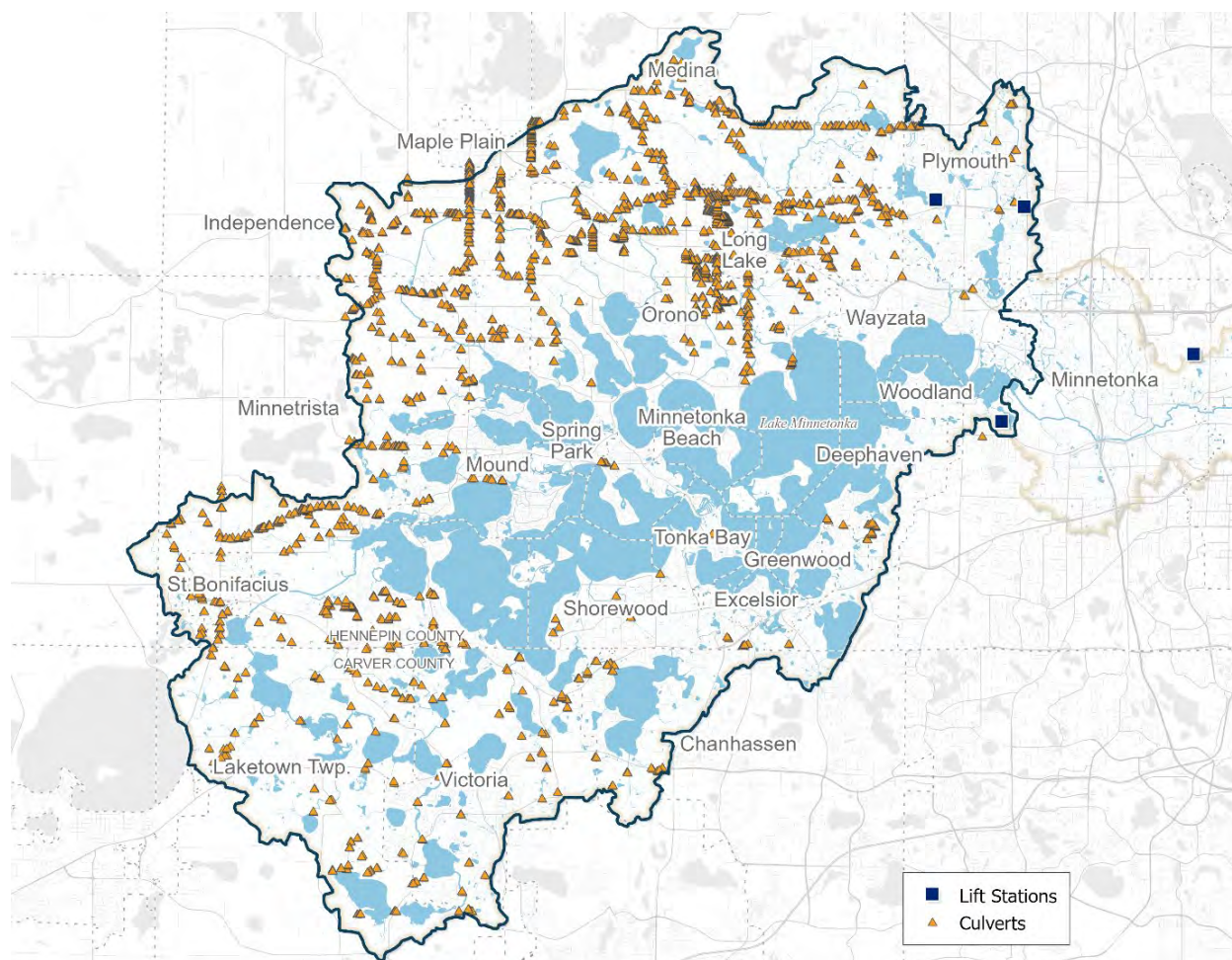


Figure 3-5. Lift Stations and Outlet Control Structures

3.4 Phase 4: Groundwater

Phase 4 required the input of a representative groundwater boundary, groundwater regions, soil spatial and vertical variability as well as parameters, a continuous confining layer, and mesh generating elements (break points).

3.4.1 Lateral Groundwater Boundary

Lateral groundwater boundaries were chosen to be different than, and typically outside of the surface water boundary. Lateral groundwater boundary extents were set to locations of known boundary conditions (head) to reduce the uncertainty of these inputs. Boundary points were defined at groundwater wells with available water table information, surface water bodies anticipated to be

perennially wet, or artificial points used to keep the groundwater boundary outside of the surface water boundary. The groundwater boundary and points to generate it are shown in Figure 3-6.

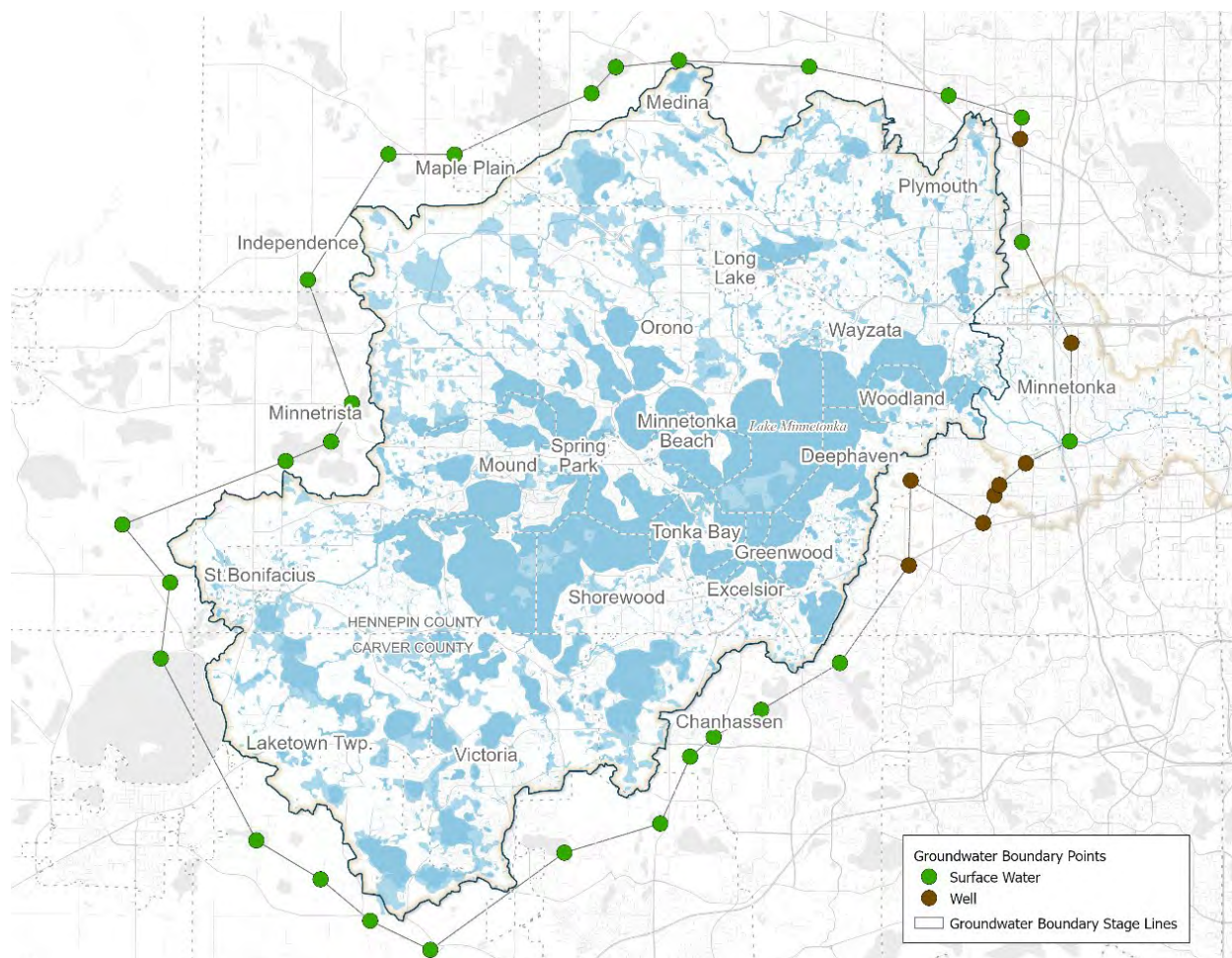


Figure 3-6. Upper Watershed Groundwater Boundary Development

3.4.2 Groundwater Regions

Unlike OF, the StormWise groundwater numerical solution does not lend itself to direct parallelization. Therefore, the mesh was decomposed into multiple groundwater regions to improve simulation performance. StormWise assumes groundwater regions have lateral no-flow boundaries, allowing them to be solved independently. This forces any lateral exchange along groundwater region boundaries to occur through vertical exchange to the surface OF flow region, then laterally into the adjacent groundwater region. Locations where the surface domain is frequently wet offer continuous connectivity between groundwater regions.

The Upper Watershed lateral groundwater boundary, as discussed in Section 3.4.1, was divided into six regions at locations that are continuously or frequently ponded, such as along Lake Minnetonka, Painter Creek centerline, Six Mile Creek centerline, and Long Lake Creek centerline. These boundaries are also groundwater mesh generating elements; therefore, the boundary vertices were coarsened to a minimum of 250-foot spacing to limit the likelihood of small triangles as part of groundwater mesh generation. The Upper Watershed groundwater regions are shown in Figure 3-7.

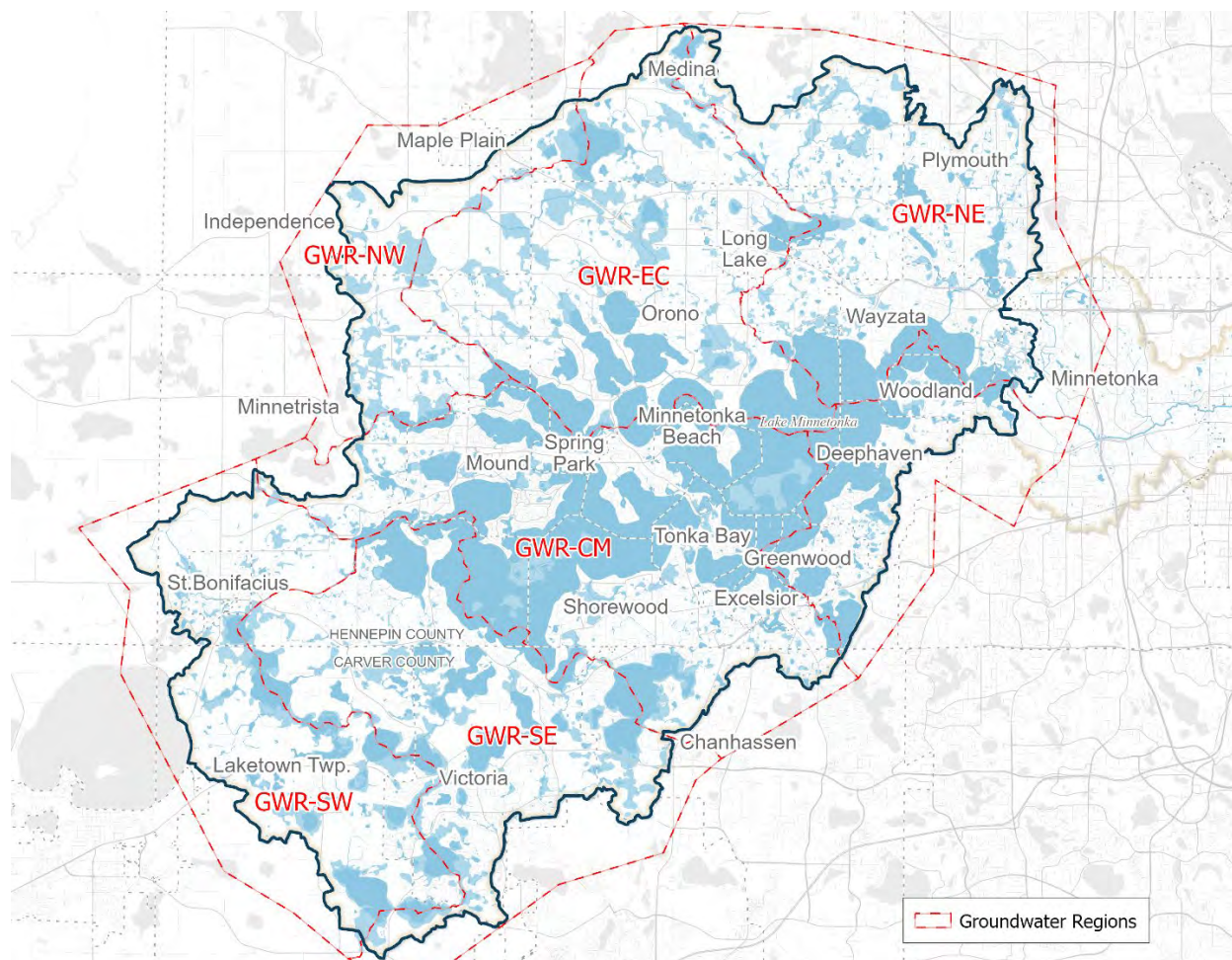


Figure 3-7. Upper Watershed Groundwater Regions

3.4.3 Confining Layer Boundary

StormWise requires a lower boundary of the groundwater domain to be the top of a confining layer. That surface is assumed to represent the top of bedrock and was based on the most recent available county geologic atlas data: the 2018 Hennepin County Geologic Atlas (Steenberg et al. 2018) and the 2009 Carver County Geologic Atlas (Bauer et al. 2009). Figure 3-8 shows the depth to bedrock for the Upper Watershed.

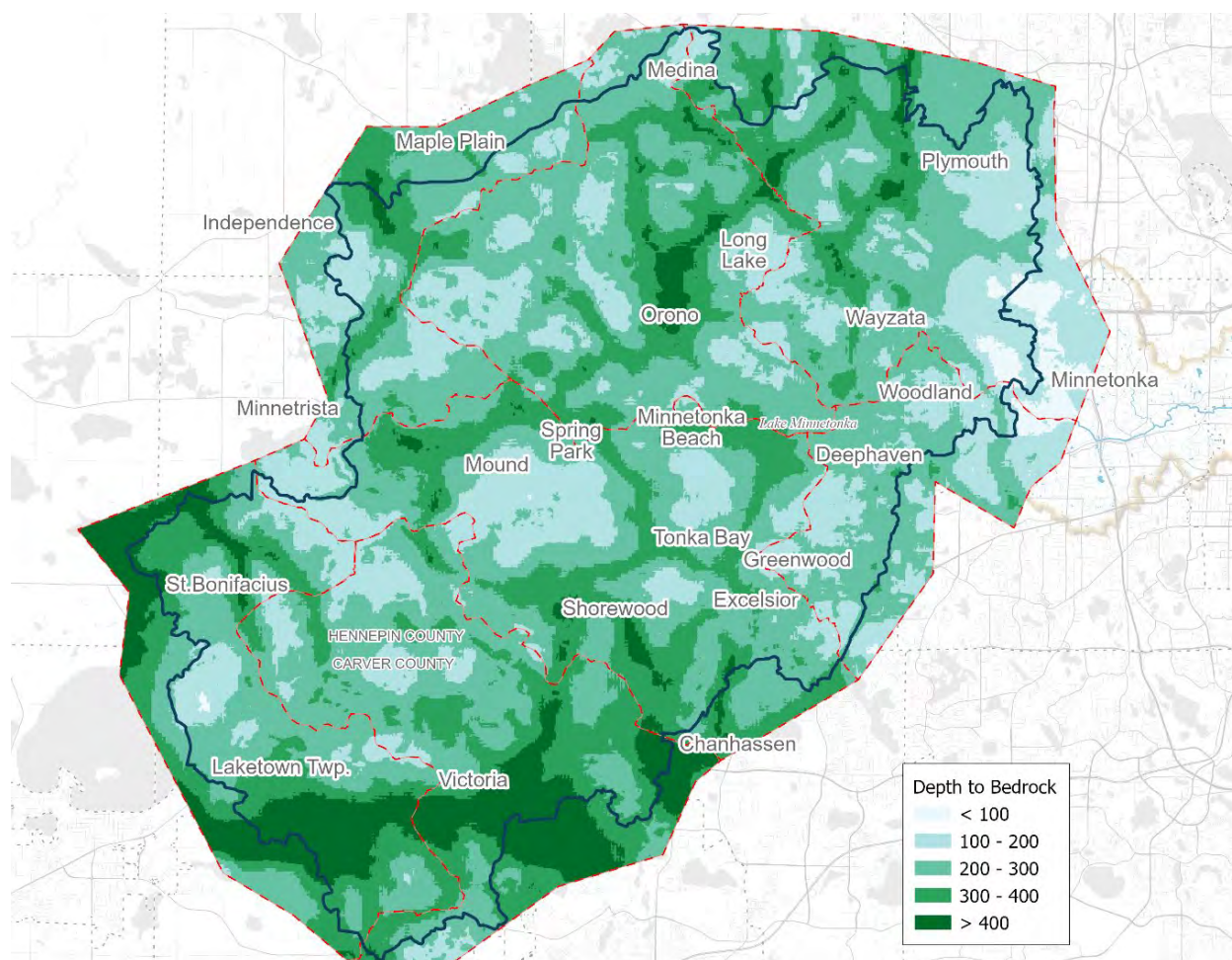


Figure 3-8. Upper Watershed Depth to Bedrock

3.4.4 Soils Spatial Data

The soil map layer is used heavily in the groundwater portion of the model for vertical and horizontal flow but is also used as part of the rainfall excess calculations at the surface. The Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) for Hennepin and Carver counties were acquired for model import. The “MUKEY” attribute for each soil polygon was used for reference and the various groundwater tables imported to the model all use this attribute.

Figure 3-9 shows the variability of soil conductivity in the Upper Watershed.

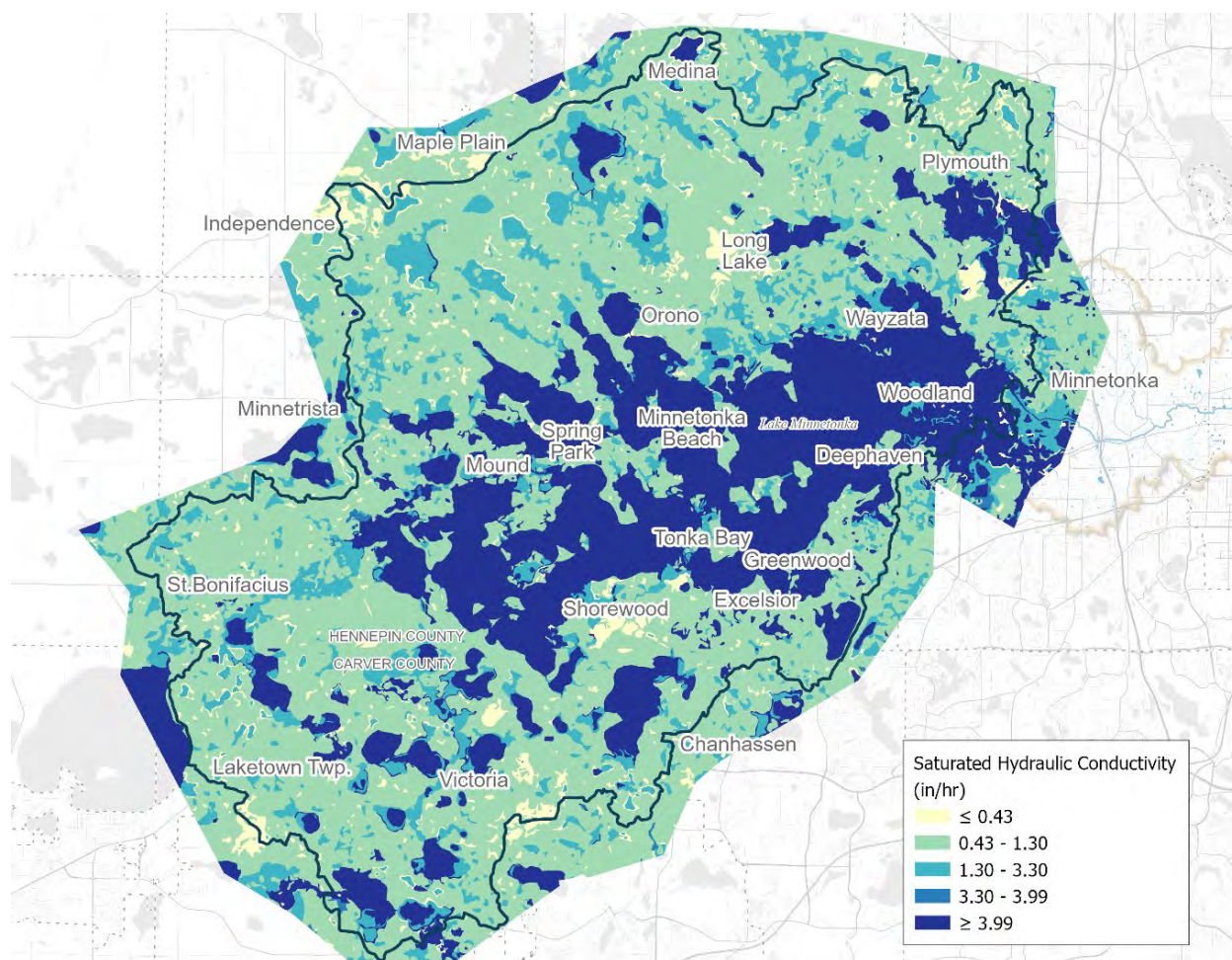


Figure 3-9. Upper Watershed Saturated Hydraulic Conductivity

3.4.5 Vadose Zone and Groundwater Soil Parameters

Associated look-up tables for the soil map layer include hydraulic conductivity, fillable porosity, and vertical layer tables. Look-up tables were developed using the vertical layer parameters from NRCS soils process outlined in the StormWise User's Manual (Streamline 2024). These look-up tables were generated for the entire watershed by Streamline in April 2025. These tables include the vertical layers tables, which have soil parameters for each depth horizon below the surface extracted from NRCS. Note that calibration resulted in adjustments to the infiltration rates; these are discussed in more detail in Section 5.4.

SSURGO survey data commonly is available up to 6 feet deep. For this model build, the bedrock surface was used as a confining layer, which in some cases, can be more than 100 feet below the ground surface. In these cases, the lowest soil horizon data was assumed to represent the soil information from the bottom of the surveyed soil column to the confining layer. In many cases, these lower depths of soil are assumed to be saturated. In saturated conditions, StormWise uses horizontal groundwater flow hydraulics and requires conductivity and fillable porosity tables. For each MUKEY, porosity was assumed to be the saturated moisture content of the lowest soil horizon. Hydraulic conductivity of the saturated zone was assumed to be 10x more conductive such that the horizontal hydraulic conductivity was 10x the vertical hydraulic conductivity of the lowest soil horizon in each MUKEY. Anisotropy was assumed to

be a compromise between sandy material with a horizontal to vertical hydraulic conductivity ratio of approximately 3x and clay/till materials of 100x- 500x (Tipping 2011).

3.4.6 Crop Coefficients

Groundwater simulations are inherently continuous simulations and for accurate estimation of water balance components, evapotranspiration is required. Evapotranspiration is input as a time series of reference evapotranspiration for an ideal cover condition and endless water supply. To adjust the reference evapotranspiration for specific land covers, representative crop coefficients and root depth values are provided to StormWise. Crop coefficients are applied as a scalar of the potential evapotranspiration and adjust for the seasonal growth stages of various agricultural plants and expanded to various vegetation and open water cover conditions. For each land cover condition, monthly crop coefficients were calculated based on average soil temperature data from 2009 to 2024. Monthly variations in crop coefficient are shown in Figure 3-10. Additional details of this process are provided in Appendix C-10, “Crop Coefficients.”

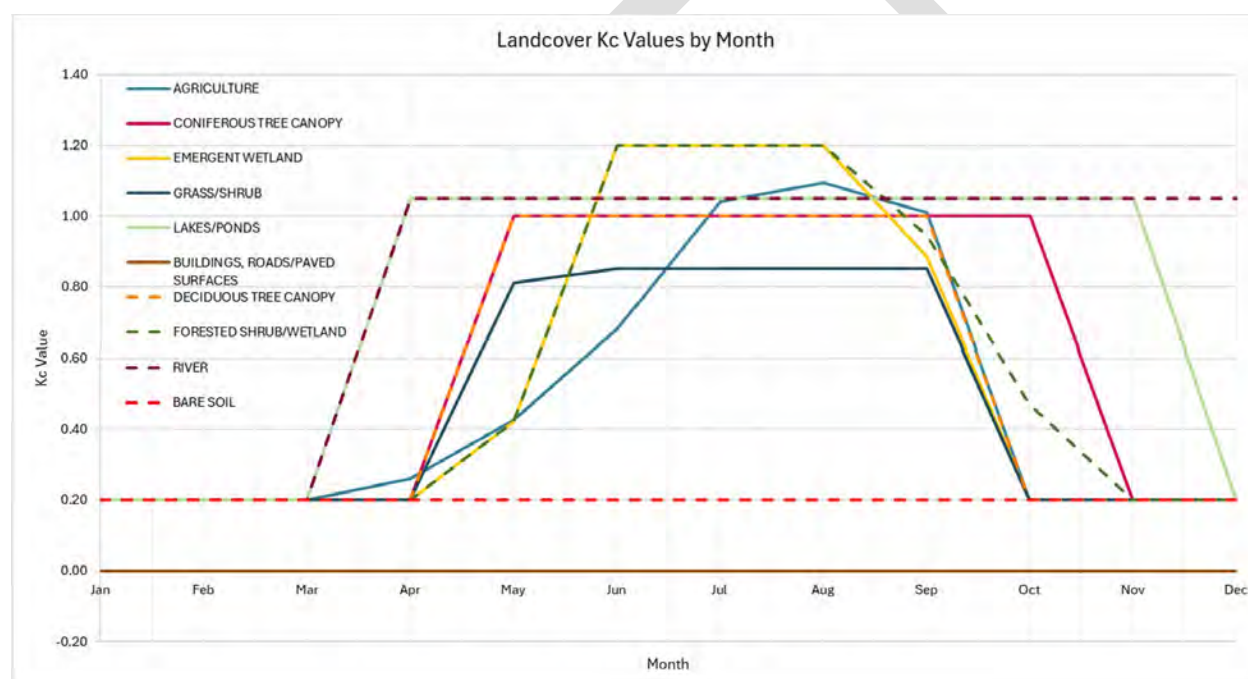


Figure 3-10. Crop Coefficient Annual Variability

3.5 Naming Convention

A standardized naming convention was created for watershed model elements that follows an AA- BBB- CCCCCC scheme. The first sequence (AA) signifies the model element type, such as “NC” for Node – Channel. The second sequence (BBB) signifies the area or sub-element, such as a municipality or subwatershed identifier. The third sequence (CCCCC) is a six-digit numeric that uniquely identifies the element. Prior to import into the model all elements were updated accordingly.

Naming conventions for model elements are detailed as part of “Naming Convention” memo provided in Appendix C-11.

4 Watershed Model Build

This section details each individual model element created or imported into the watershed model, its purpose, and the reasoning behind modeling decisions. Types of model elements are separated into five categories: map layers, surfaces, 1D elements, OF region elements, and groundwater region elements.

4.1 Phase 1: Surface Mesh

Phase 1 model build required importation of map layers, surfaces, tables, and OF region elements relevant to 2D OF. Each of the following items was imported into the model.

- OF: Upper Watershed boundary as discussed in Section 3.1. Through discussion, the Project Team decided that a single OF region would be used for the Upper Watershed. StormWise has optimized the OF region solver for surface hydrology and routing to take advantage of multi-core processors; therefore, a single OF region is used to represent the Upper Watershed.
- OF: Breaklines imported as shapefiles discussed in Section 3.1.
- Surface: Topographic and bathymetric surface with a buffer of 500 feet around the Upper Watershed surface boundary, as discussed in Section 3.1.
- Map Layer: Land cover polygons, as described in Section 3.1, were directly imported into StormWise. Land cover is used for rainfall excess calculations and assignment of surface roughness.
- Table: Manning's n values, or friction coefficients, to 1D and 2D computations, as described in Section 3.1. The land cover Map Layer is used to distribute roughness coefficients spatially.

StormWise computational mesh assumes flow occurs between nodes (or vertices) along the edge of each triangular element, making the location of vertices of high importance to align with drainage pathways. The initial surface mesh included breakpoints, vertices of breaklines, vertices of the OF boundary.

Breakpoints were the last 2D OF mesh element included in the model build. Within PCV and CCV, a denser breakpoint pattern was required and created as described in Section 3.1.7, these breakpoints were imported to the model. For the remaining areas of the OF, breakpoints were used to define the mesh density where not already specified by other geometric inputs. Breakpoints were assigned within the StormWise model using a 200-foot pattern in rural areas and 100-foot pattern, with 50-foot minimum distance from other mesh features, at the end of the build process. This prioritizes other mesh elements for defining the OF mesh, while keeping a maximum triangle size in areas lacking other elements.

The final mesh generation in the Upper Watershed was heavily dependent upon Phase 2 CCVs and PCVs, and Phase 3 storm sewer and culvert inlets and outlets. The remainder of this section discusses the final mesh, and each subsequent section describes how the mesh was refined to accommodate the newly added features. Final surface mesh nodes include breakpoints, vertices of breaklines, vertices of the OF boundary, vertices of the CCVs and PCVs, and all 1D node interface points. Thoughtful development of these input datasets is critical to generating a high-quality mesh with limited elongated triangle features known to cause model instabilities. CCVs, PCVs, and 1D node interface points are discussed in more detail later in these sections.

These inputs result in a triangle overland flow mesh with:

- 1,011,415 triangles with average area of 6,790 square feet (Minimum: 150 square feet)
- 1,519,324 individual links

Figure 4-1 shows an example of surface-mesh generation elements and the resulting mesh.

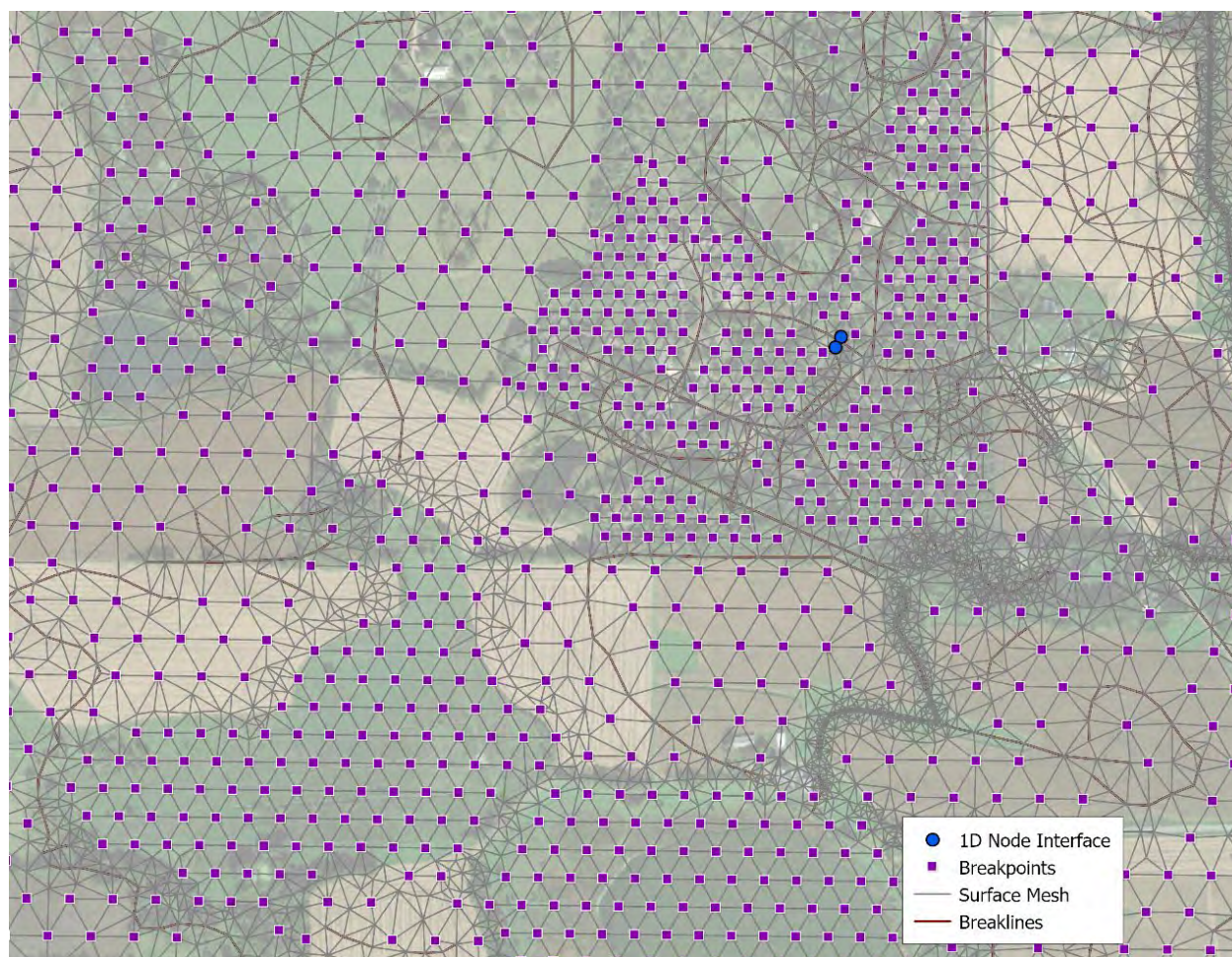


Figure 4-1. Surface Mesh Generation Elements and Resulting Mesh

Boundary conditions for the OF domain were defined to represent the Lake Minnetonka watershed and its outlet through Grays Bay Dam. The exterior boundary of the OF region generally follows the drainage area contributing to Lake Minnetonka and is represented as a no-flow boundary. The only surface-water outlet from the model domain is through the three modeled gates at Grays Bay Dam. A time/stage node was specified downstream of the dam using a time series of observed water-surface elevations to represent the downstream tailwater condition. Discharge through the dam gates is therefore simulated as part of the model rather than prescribed using historical dam-release records.

4.2 Phase 2: Control Volumes

Phase 2 model build required importation of 1D elements relevant to the PCVs and CCVs. Each of the following items was imported into the model.

- 2D: PCVs and associated stage/area nodes were imported as shapefiles. Stage/area tables were extracted directly from the existing ground surface, including bathymetry. See Section 3.2 for more details.
- 2D: CCVs, channel links, channel cross sections, and channel stage/area nodes were imported as shapefiles. See Section 3.2 for more details.
- 1D: Weir links associated with control structures throughout the Upper Watershed were manually digitized and associated geometric data was manually entered. See Section 3.2 for more details.

Stage/Area nodes are included anywhere a stage-area relationship is needed that is not captured in the 2D surface (CCV nodes, PCV nodes, storm sewer infrastructure nodes). A minimum amount of storage in all stage/area nodes is assigned within the Simulation Manager. Otherwise, stage/area tables are included at nodes to represent the amount of storage in a certain area. The storm sewer structures and channel nodes are not provided with unique stage/area tables. These nodes used the default minimum value as most of the volume being stored is already captured in the pipe and channel links themselves. For pond nodes, separate stage/area tables are included and are extracted directly from the provided ground surface.

2D Mesh Note: PCVs and CCVs act as mesh generating features. Here, the input features were simplified to limit vertex generation and the mesh was reconfigured to remove breaklines within a 10-foot proximity.

4.3 Phase 3: Storm Sewer Infrastructure

Phase 3 model build required importation of 1D elements relevant to the storm sewer infrastructure. All of the Phase 3 imports (geometric and attributes) were completed through .CSV imports generated through automated script, as discussed in Section 3.3. Each of the following items was imported into the model.

- 1D: Pipe links representing storm sewer pipes and culverts. Pipes can connect to either stage/area nodes or to the OF region directly. Some large culverts directly within Upper Watershed channels were also included as pipe links. Over 15,000 pipe links are included in the model, most of which are within the gravity storm sewer system.
- 1D: Weir links included at each inlet to the storm sewer that connects a subsurface stage/area node to the OF mesh node. For these inlet structure locations, a representative standard inlet grate size was selected and used to develop model weir characteristics. This approach improves estimates of inlet capacity and its effect on localized flooding. These weir links are located at a single point in space; therefore, they do not have spatial linework associated with them and are tabular only in the model. Over 8,000 weir links are included.
- 1D: Stage/area nodes representing manholes, inlets, and outlets as part of the subsurface system. The storm sewer structures are not provided with unique stage/area tables. These nodes used the default minimum value as most of the volume being stored is already captured in the pipe and channel links themselves.
- 1D: Node interface points connecting inlets and outlets of the storm sewer network to the OF surface.

The watershed model uses 1D node interface features to define the 2D mesh and provide the opportunity for a point on the 2D OF mesh to connect to other 1D features. Inlets and outlets were defined as 1D node interface points at locations of 1D/2D connectivity. For each inlet and outlet feature in the storm sewer data, a 1D node interface point is added with a naming convention that aligns with the stage/area part of the structure. Weir links are used to model the flow from the surface mesh (1D node interface) to the subsurface structure (stage/area node). Weir characteristics were developed based on the Neenah Foundry R-3067-V inlet (Neenah 2025) and were uniformly applied to each inlet weir link. See Appendix C-12, Neenah Foundry Catalog. In cases of culverts or cross-drains with open end treatments on either end of the pipe, 1D node interface features are used exclusively.

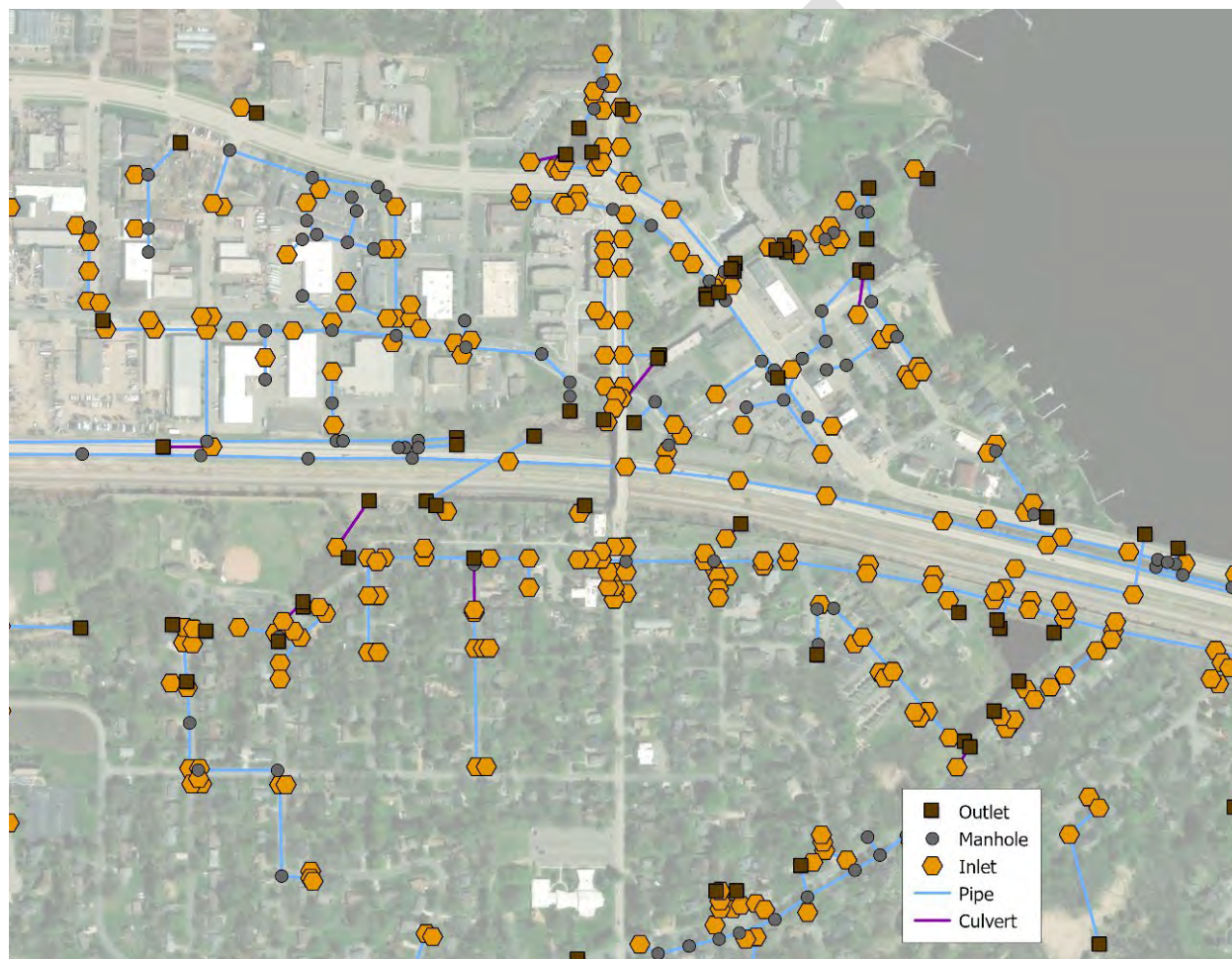


Figure 4-2. Detailed storm sewer infrastructure

2D Mesh Note: 1D node interface points act as mesh generating features. A systematic review of all mesh generation feature vertices was performed to limit proximity of vertices to more than 10 feet, with 10 feet being the preferred minimum triangle side length. Where closer than 10 feet, storm sewer inlets were combined and included with representative increases of inlet capacity, and parallel culverts were included as single pipe elements with multiple barrels.

4.4 Phase 4: Groundwater

Phase 4 model build required importation of map layers, surfaces, tables, and groundwater region elements relevant to 2D groundwater. This portion of the build represents the final Upper Watershed model. See Appendix C-13 Groundwater Model for more details. Each of the following items was imported into the model.

- Groundwater: Upper Watershed groundwater regions (six regions) were imported as shapefiles, as discussed in Section 3.4.
- Groundwater: Boundary stage lines between each lateral groundwater boundary vertex described in Section 3.4. These lines are used to define lateral head conditions as part of model simulations.
- Surface: Confining layer surface equal to a modified top of bedrock surface with a buffer of 500 feet around the Upper Watershed surface boundary was imported as a raster, as discussed in Section 3.4.
- Map Layer: Soils spatial data representing soil units throughout the watershed were imported as polygons with “MUKEY” identifiers used to relate soil parameters, as described in Section 3.4.
- Table: Vertical Layers tables describing the required input Green and Ampt vertical infiltration parameters were imported. The soils map layer was used to distribute these parameters spatially. These tables are described in Section 3.4.
- Table: 2D Conductivity tables for lateral movement of water in the groundwater domain were imported. These inputs are described in Section 3.4.
- Table: Crop Coefficients, as described in Section 3.4, were imported into the model. As of version StormWise 4.08.03, the “typical year” crop coefficient table option does not perform as intended, so monthly crop coefficients were created for a long period of record to mimic the typical year approach.

One additional surface is required to simulate groundwater, the initial water table. It was assumed that the water table was equal to the ground surface. Future simulations should consider long-term simulations to set more realistic water table conditions and export water tables for use as initial groundwater conditions. Note that the water table cannot be lower than the top of confining layer.

Similar to the OF flow mesh, StormWise groundwater computational mesh assumes flow occurs between nodes (or vertices) along the edge of each triangular element. The initial surface mesh included groundwater region boundaries and a standard breakpoint pattern. The groundwater regions use a simplified mesh, compared to the OF region and surface mesh. The standardized breakpoint pattern at 400-foot spacing was used in each groundwater region to define a maximum groundwater honeycomb cell size. Figure 4-3 shows the groundwater mesh.

Boundary stage lines were specified around the entire groundwater boundary with the exception at the most downstream limit (see Figure 3-7). The groundwater regions were drawn to align with known water features and locations of known head condition. Boundary stage lines replicated these boundary locations. The boundary stage lines use two boundary stage sets, which act as time/stage conditions, and the model interpolates between these two points linearly. For this watershed model build, static elevations representing the normal or observed water level were used. The groundwater regions extend

far enough past the OF region with the goal of reducing the reliance on boundary stage conditions to accurately predict groundwater levels in our Upper Watershed region.

Note that flood calibration was performed on the Upper Watershed model with vertical infiltration, but without 2D groundwater included. For the calibration model build groundwater specific elements were not required to be imported, these include the groundwater regions, groundwater boundary stage lines, the bedrock surface, and the initial water table. The completed coupled model as described in this section is included as part of the electronic delivery package.

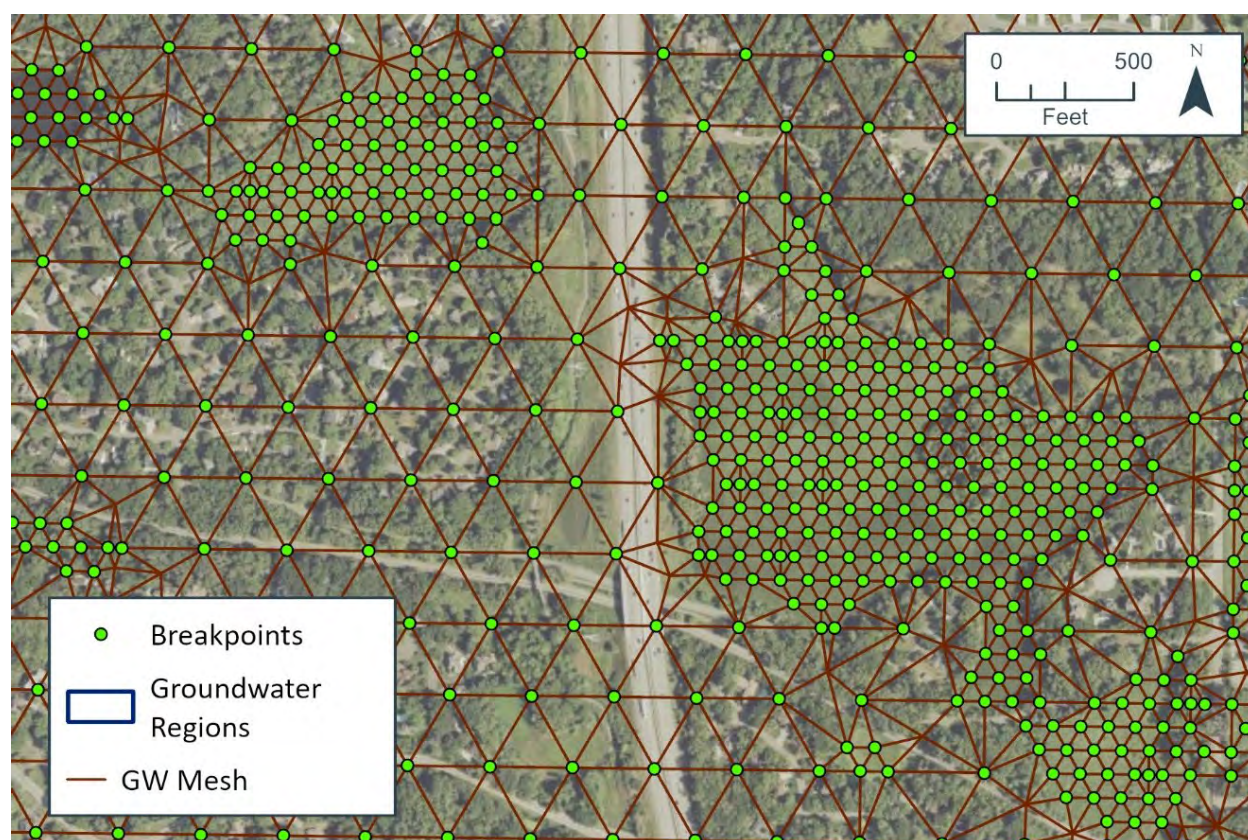


Figure 4-3. Groundwater Numerical Mesh

4.5 Simulation Parameters

Input simulation parameters were either selected as default parameters or through correspondence with the software developer Streamline. The Diffusive Wave equation set was selected for both 1D and 2D hydraulic calculations. This hydraulic solution removes local acceleration terms that become important where high velocity flows, hydraulic jumps, major flow reversals, and wave propagation are expected to occur. These hydraulic conditions were not expected to control the watershed-scale response represented by these simulations. The intent of this model is watershed scale planning, the hydraulic equations are used to route locally generated runoff (2D grid), and pipe/channel flows. If detailed hydraulics are of interest, future efforts should consider the energy and/or the momentum equations. Other selected simulation parameters are shown below.

- General
 - Minimum Calculation Times

- Hydrology: 60 seconds
- Surface Hydraulics: 0.01 second
- Groundwater: 14,400 seconds
- Maximum Calculation Times
 - Surface Hydraulics: 2.561 seconds
- Output Time
 - Hydrology: 60 minutes
 - Surface Hydraulics: 60 minutes (during active response periods)
 - Groundwater: 3600 minutes
- Tolerances and Options
 - Energy Switch (2D): Diffusive Wave
 - Energy Switch (1D): Diffusive Wave
 - Time Marching: FIREBALL
 - Default Dampening Threshold (1D and 2D): 0.09
 - Minimum Node Surface Area (2D): 700 square feet
 - dZ Tolerance: 0.0001
 - Link Optimizer Tolerance: 0.00001
- Simulation Times
 - 2025 Calibration Event:
 - Start: June 20, 2025
 - End: July 2, 2025
 - 2014 Validation Event:
 - Start: June 12, 2014
 - End: June 24, 2014
 - 100-year Event:
 - Start: June 12, 2014
 - End: June 24, 2014

4.5.1 Computer Setup and Runtime

The model workstation specifications and approximate processing times reported for the model build and simulations are listed below.

- Central processing unit (CPU): AMD Ryzen Threadripper 7970X, 32 cores / 64 threads
- Operating system (OS): Windows 11 w/ Remote Desktop Session Host Feature

- Configuration: 128 GB RAM; Gigabyte TRX50 AERO D motherboard; dual PCIe Gen5 NVMe solid-state drives configured as a striped volume for high-speed model input/output

Approximate model build time: 17.4 hours. Approximate model runtimes:

- 2025 calibration event (12 days simulation time): 29.0 hours
- 2014 validation event (12 days simulation time): 67.5 hours
- 100-year event: 70 hours

5 Model Calibration and Validation

The MCWD Upper Watershed model calibration focused on flooding and included calibration to one event and validation to a second event. To make the model calibration more efficient, the 2D groundwater components were removed. Inclusion of groundwater components allows the model to represent horizontal subsurface water movement, dynamic soil storage, surface water body storage, and exchange between the surface and subsurface. These processes are slow relative to the time scales of surface water rainfall/flood response. Omission of groundwater is anticipated to have only a limited impact on watershed conditions during and immediately after these flood-focused events. This section documents the data, decisions, and final calibration parameters and performance.

The Upper Watershed model calibration strategy is as follows:

- Develop initial conditions for each calibration event as described in Section 5.1.3.
- Conduct sensitivity simulations on the 2014 and 2025 events as described in Section 5.2.
- Develop initial calibration simulations based on sensitivity results.
- Review and compare performance metrics and flow hydrographs from initial calibration simulations.
- Adjust infiltration rate, moisture content, water table, and impervious percent to improve flow volume and timing. Iterated until adequate model performance was achieved.
- Adjust Manning's roughness and weir coefficients, where necessary, to improve stage observations and timing of response.

5.1 Calibration and Validation Data

For the MCWD Upper Watershed model, historical data served as initial conditions, boundary conditions, and as observed basis of comparison on which to assess model accuracy. Two events were selected one for calibration and one for validation as described below.

- Calibration Event: 2025 June
 - Major rainfall-driven response during June 25–26, with additional rainfall and runoff later in the calibration period.
 - Intense rainfall over less than 24-hour period, which stresses the urban drainage system resulting in significant local flood inundation.
 - Robust observation data available.
- Validation Event: 2014 June
 - Lake Minnetonka levels continued to rise through the late-June observation period.

- Abnormally high basin-wide precipitation for weeks leading up to watershed-wide response during wet period.
- Observation data limited to daily Grays Bay water level measurements and biweekly observations at major lakes.

5.1.1 Precipitation

Precipitation data from nearby rain gages was used as input to the model. Hennepin County West Mesonet was commissioned in 2017 providing a robust, dense network of rain gage data for more recent events. Figure 5-1 shows the rain gage locations relative to the Watershed, and Figure 5-2 and Figure 5-3 show the cumulative precipitation during the 2025 and 2014 events, respectively.

- Calibration Event: 2025 June
 - Source: Hennepin County West Mesonet. Six gage records are shown in Figure 5-2.
 - Cumulative precipitation shown in Figure 5-2 ranges from approximately 3.7 to 5.0 inches among the six gages through June 29.
 - Reporting interval: 5-minute
- Validation Event: 2014 June
 - Source: Minneapolis-St. Paul (MSP) weather station
 - Validation Period Total Precipitation: 8.85 inches
 - Reporting interval: 5-minute

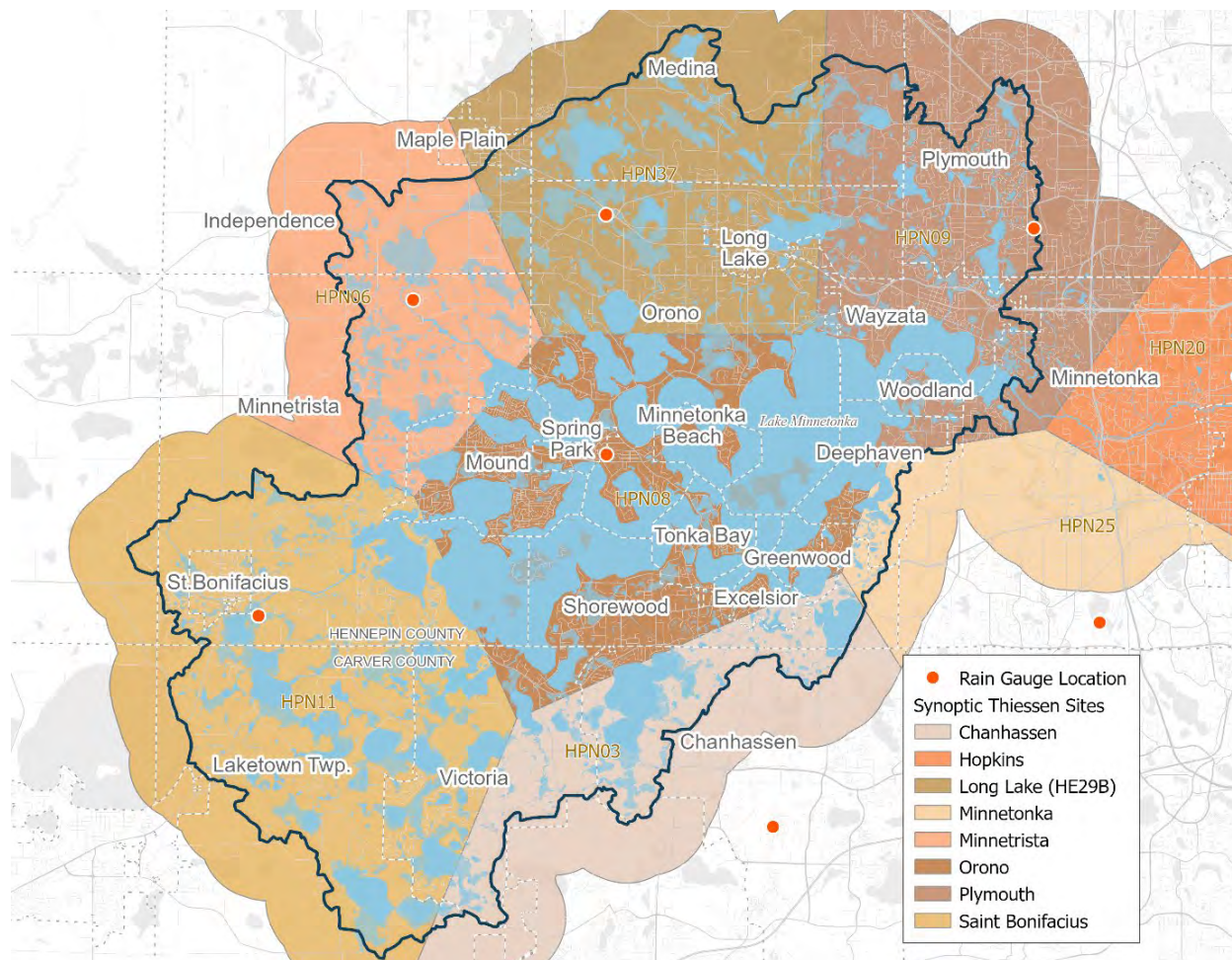


Figure 5-1. Rain Gage Locations

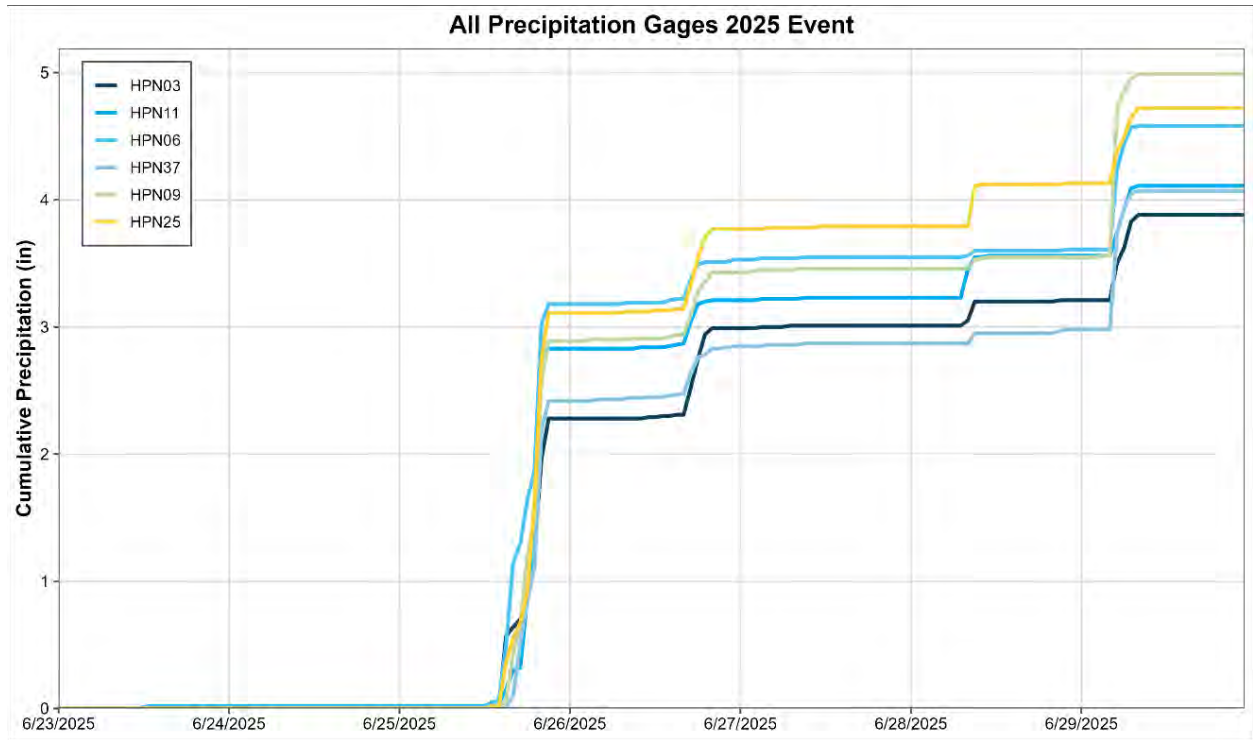


Figure 5-2. Cumulative Rainfall June 2025

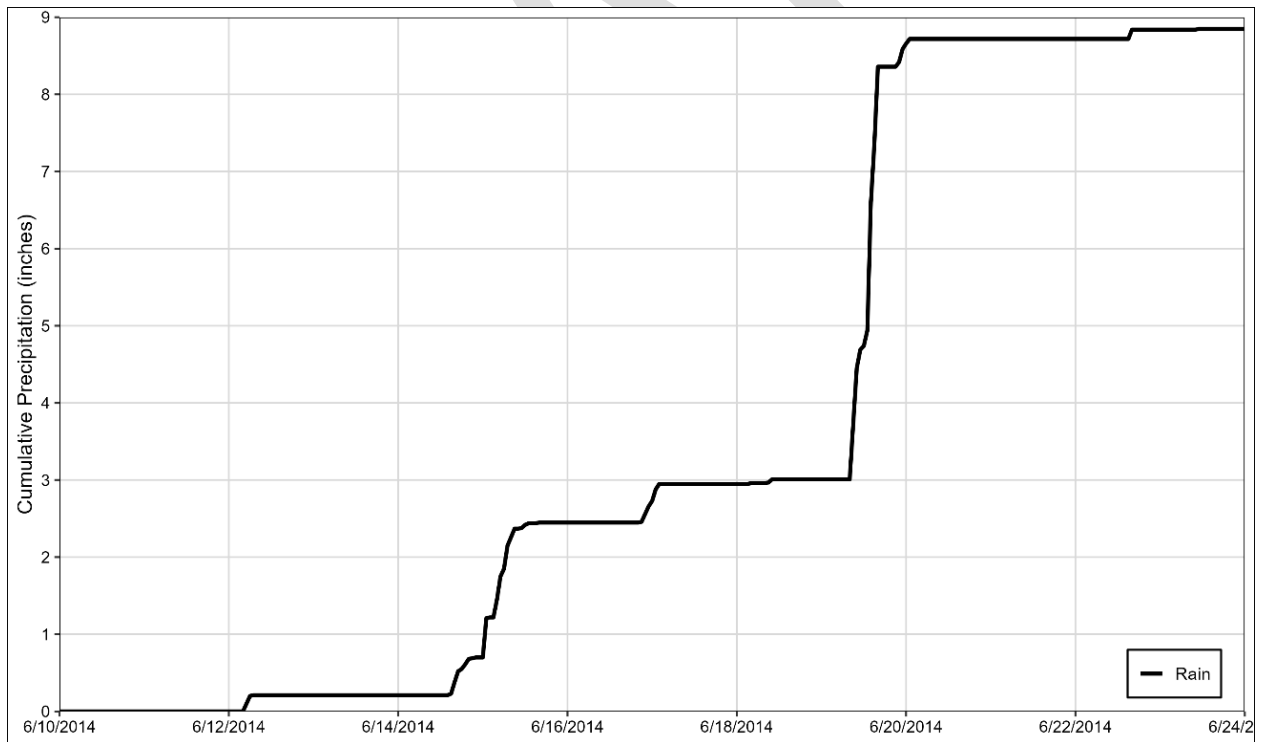


Figure 5-3. Cumulative Rainfall June 2014

5.1.2 Observation Data

Observed flow and stage data were available at major subwatershed outlets to Lake Minnetonka and at selected lakes. Figure 5-4 shows the monitoring locations. These data were collected by the USGS, MCWD, and Minnesota Department of Natural Resources (MNDNR). Section 5.1.4 describes the system response relative to these observations.

- Calibration Event: 2025 June
 - USGS Lake Stage:
 - 1 Location
 - Name: USGS-05289000 (Grays Bay Dam Above Outlet)
 - Temporal Reporting: 15 minute
 - MCWD Stage and Flow:
 - 6 Locations
 - Temporal Reporting: 5 minute
 - MCWD Stage Only:
 - 1 location
 - Temporal Reporting: 5 minute
 - MCWD Flow Only:
 - 1 location
 - Temporal Reporting: 5 minute
- Validation Event: 2014 June
 - MCWD Lake Minnetonka observations at Grays Bay Dam
 - 1 Location
 - Temporal Reporting: Daily
 - MNDNR Lake Levels
 - 11 lakes listed in the source observation inventory
 - Name: Christmas Lake, Church Lake, Dutch Lake, Gleason Lake, Lake Minnewashta, Zumbra Lake, Langdon Lake, Long Lake, Lydiard Lake, Mooney Lake, Wassermann Lake
 - Temporal Reporting: Bi-weekly

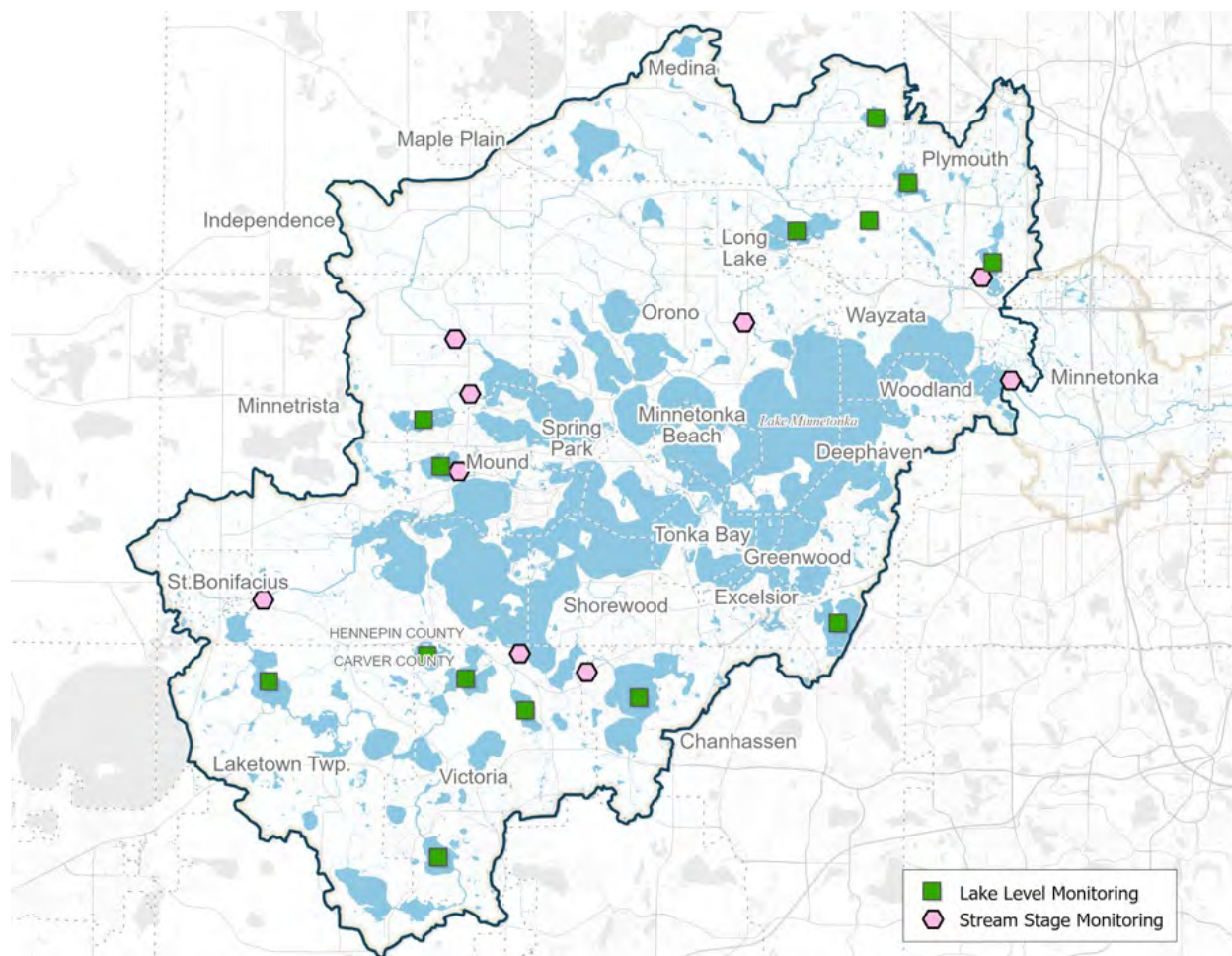


Figure 5-4. Upper Watershed Lake and Stream Monitoring Locations

5.1.3 Initial Conditions

The Minnehaha Creek Watershed has a substantial amount of storage volume available within nearly 1,500 lakes, ponds, and wetlands in addition to within the soil column. The process to develop required initial conditions is described below.

- Initial PCV Elevations
 - Initial PCV elevations reflect the amount of water that is contained in each defined waterbody prior to an event occurring.
 - Where observed data are available, the most recent MCWD or USGS measurement was used. This includes two locations shown in Table 5-1.
 - Where observed data are not available, the raw downloaded LiDAR elevations were reviewed. The downloaded LiDAR has a hydro-flattened water surface elevation, which provides an approximate normal pool elevation for waterbodies. The lowest LiDAR elevation in each PCV was used and was assumed to represent a normal water level condition.
 - Assigning initial water levels to nearly 1,500 lakes, wetlands, and ponds was a major challenge. Initial water levels were an important calibration consideration during the 2025 event.

- Where observed lake or wetland levels were unavailable, peak simulated levels from the 2025 event were used as initial conditions for the 2014 event.

Table 5-1. Initial Conditions for Lake Levels

Model ID	Lake Name	Initial Elevation (feet NAVD88)		
		6/12/2014	6/20/2025	100-year
PCV-017	Grays Bay	930.46	929.41	930.46
PCV-001268	Zumbra Lake	944.76	942.52	944.76

- **Initial Depth to Water Table**
 - Depth to water table is the location where the soil becomes completely saturated. It partially defines the amount of soil storage available.
 - Underneath all PCVs, the depth to water table was set to 0.0 feet (or at the ground surface), assuming the soil underneath a waterbody is typically saturated.
 - SSURGO provides estimated depth to water table for the soils. The water table depth populated by SSURGO was used in all soils not located beneath a wetland, lake, or pond (PCV).
- **Soil Initial Moisture Content**
 - Initial soil moisture content is the amount of soil pore space filled with water above the water table. It partially defines the amount of soil storage available.
 - Underneath all PCVs, the soil moisture content was set to the saturation moisture content, assuming the soil underneath a waterbody is typically saturated.
 - Moisture content in all other soils was based on SSURGO default values.

5.1.4 System Response

The Upper Watershed stream flows originate throughout the drainage area tributary to Lake Minnetonka. The watershed contains an interconnected network of lakes, wetlands, streams, and drainage systems that ultimately discharge to Lake Minnetonka. Major tributary systems include Six Mile Creek, Painter Creek, and Long Lake Creek, in addition to numerous smaller tributaries and direct drainage areas surrounding the lake. The large number of lakes and wetlands provides substantial hydrologic storage and attenuation of runoff as water moves through the watershed.

Land use within the Upper Watershed varies considerably, ranging from agricultural and lower-density residential development in the western portions of the watershed to more developed suburban areas surrounding Lake Minnetonka and within communities farther east. Correspondingly, the drainage network includes a mixture of natural channels, wetlands, agricultural drainage features, road crossings, storm sewer systems, and other constructed conveyance features. Lake Minnetonka serves as the primary receiving waterbody for the Upper Watershed and provides substantial storage before water leaves the watershed through the three gates at Grays Bay Dam. Consequently, hydrologic response within the Upper Watershed is strongly influenced by antecedent lake and wetland levels, available storage, precipitation conditions, and the hydraulic connectivity between the watershed's numerous lakes, wetlands, and tributary systems.

Figure 5-5 shows the rainfall and subsequent stream flow response for the 2025 event along the tributaries. Approximately 2.4 inches of rain fell on June 25, followed by another 0.4 to 0.5 inches on June 26. The timing and magnitude of the response varied across tributaries. Painter Creek responded rapidly, increasing from approximately 10 cfs to 135 cfs late on June 25 before declining to approximately 40 cfs on June 26. Six Mile Creek reached approximately 50 cfs on June 26, with several additional peaks over the following days. Flows at Gleason Lake, Lake Virginia Inlet, Schutz Lake, and Langdon Lake Outlet generally increased more gradually and had smaller peaks. These slower responses are consistent with water being stored and gradually released through the Upper Watershed's lakes and wetlands. Long Lake Outlet remained near zero throughout the period shown. Additional rainfall on June 29 brought total precipitation to approximately 4.1 inches and caused another increase in stream flows, with Painter Creek reaching approximately 65 cfs. Flows at several locations remained above pre-event conditions at the end of the period shown.

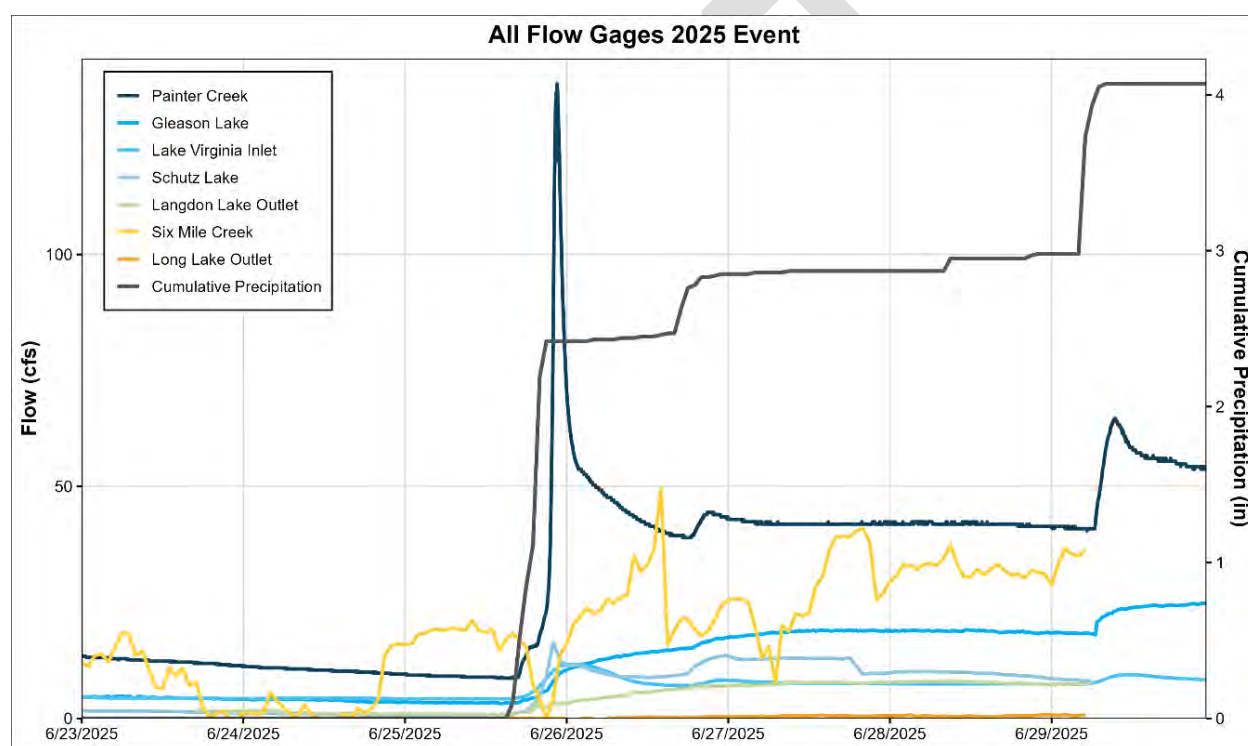


Figure 5-5. Upper Watershed Tributary Streamflow and Rainfall in June 2025

5.2 Sensitivity Analysis

A sensitivity analysis was conducted on the key uncertain parameters to understand the impact of the parameter value adjustments on the model results, and to help identify the ranges of values to be used for calibration simulations. The sensitivity results presented here are for the June 2025 event.

An uncalibrated simulation was conducted using the base parameterization approach, as discussed in the previously described methodology. These initial parameter estimates act as a reference for comparing the sensitivity simulation results, in addition to the observed streamflow data. The sensitivity simulations were run by adjusting the following parameters uniformly, one parameter per simulation, for the ranges listed below. Sensitivity ranges attempted to reflect the expected uncertainty in the input parameters; however, they do not encompass the upper and lower bounds of parameter adjustments.

The sensitivity simulations for 2025 events included the following:

- Impervious Percent:
 - Adjustment: +/- 1 standard deviation
 - Base imperviousness: assigned by land cover class.
 - Name: S1U and S1D
- Saturated Hydraulic Conductivity
 - Adjustment: +/- 1 log [standard deviation]
 - Name: S2U and S2D
- Initial Water Table Depth
 - Adjustment: +/- 1 standard deviation
 - Base average based on SSURGO: 2.4 feet
 - Name: S3U and S3D
- Initial Soil Water Content
 - Adjustment: +/- 30% (lower bound is approximate wilting point)
 - Base is the average SSURGO which is set to the field capacity: ~60% saturated (Moisture ContentInitial/MoistureContentSaturated)
 - S4U and S4D

The sensitivity results presented in Figures 5-6 and 5-7 show the effects of individual adjustments to hydraulic conductivity, initial water table depth, and initial soil water content during the June 2025 event.

Figure 5-6 and Figure 5-7 compare the uncalibrated simulation and sensitivity runs for hydraulic conductivity, initial water table depth, and initial soil water content with observed flow at Schutz Lake Creek and Painter Creek, respectively.

Before calibration, the model already reproduced the general timing of the rainfall-driven response at these locations. The simulations generated runoff and responded to the June 25–26 rainfall, indicating that the initial parameterization represented important components of watershed response. However, substantial differences remained in flow before rainfall, peak magnitude, and sustained flow following the event. These differences identified initial conditions as a priority for calibration, with initial soil water content producing the clearest separation among the sensitivity runs shown.

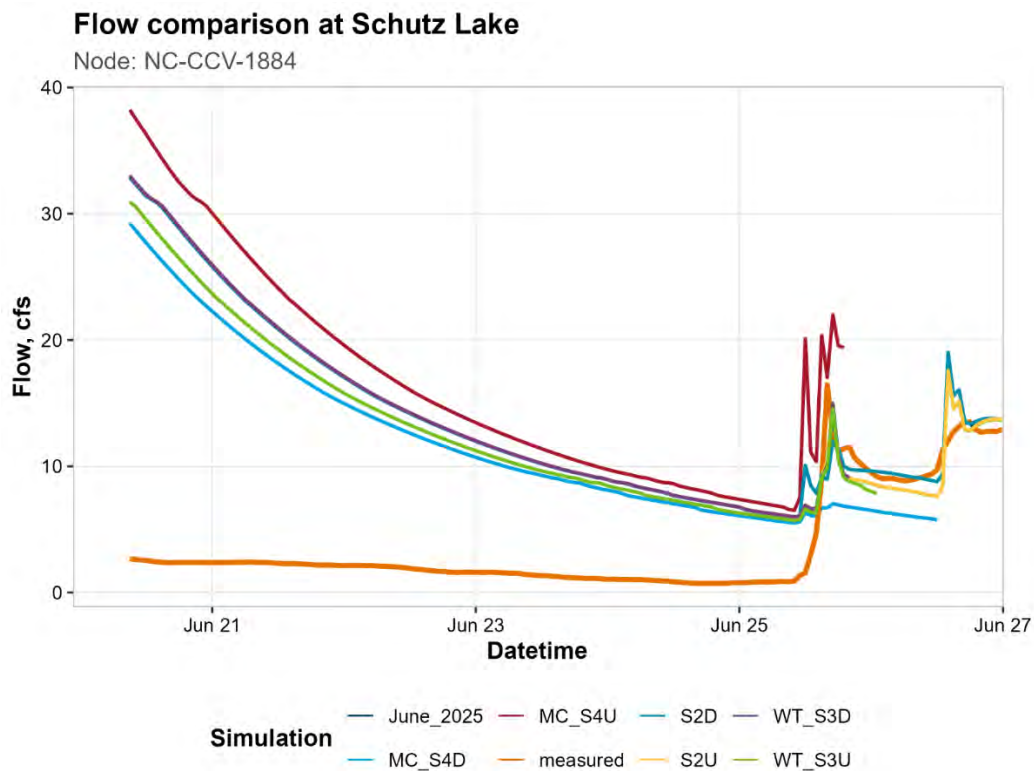


Figure 5-6. Schutz Lake Creek Sensitivity Analysis

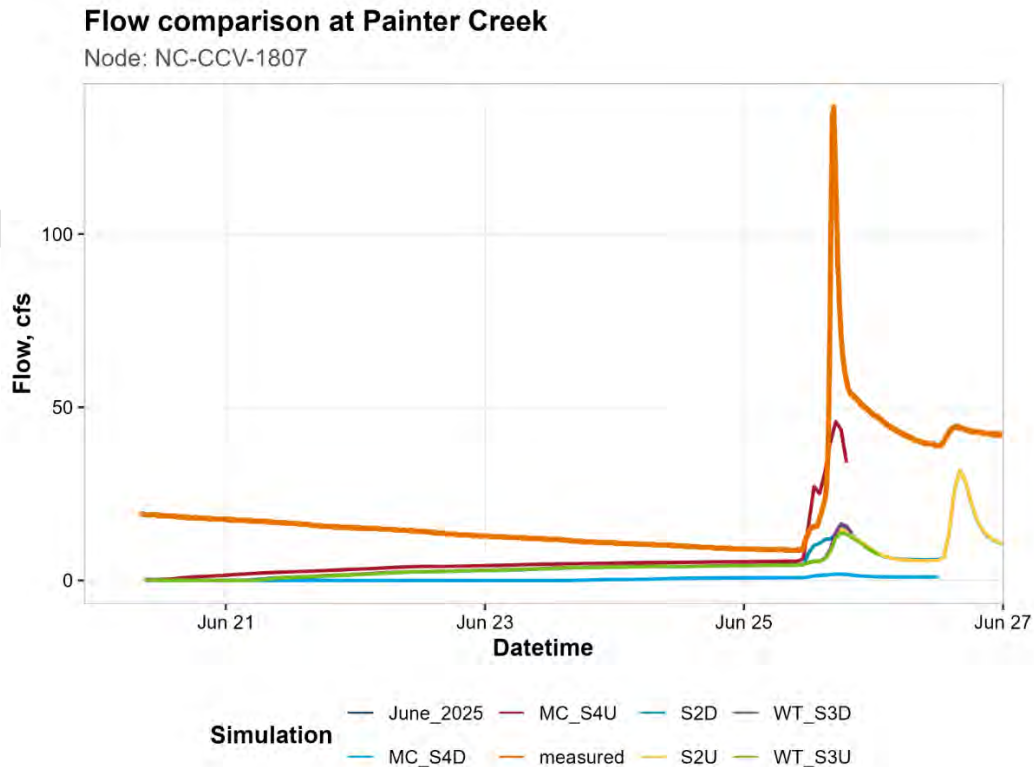


Figure 5-7. Painter Creek Sensitivity Analysis

5.3 Performance Metrics

Three performance metrics were used for calibrating and validating the Upper Watershed StormWise model. The performance metrics were selected with reference to Moriasi et al. (2015) to document the quality of calibration simulations with respect to the observed data (O is observed and P is predicted):

- Coefficient of determination (R^2) describes the strength of the linear relationship between simulated and observed data. Values range from 0 to 1, with values closer to 1 indicating a stronger linear relationship. R^2 can be sensitive to extreme values and does not independently demonstrate that simulated magnitudes are unbiased.

$$R^2 = \frac{\left[\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P}) \right]^2}{\left[\sum_{i=1}^n (O_i - \bar{O})^2 \right] \left[\sum_{i=1}^n (P_i - \bar{P})^2 \right]}$$

- Nash-Sutcliffe efficiency (NSE): NSE is a normalized statistic to determine the relative magnitude of the residual (error) variance compared to the measured data variance. This is a commonly used metric in hydrologic modeling; however, it can be overly sensitive to high extreme values. Values range from $-\infty$ to 1.0 with those closer to 1.0 indicating a better fit.

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2}$$

- Percent bias (PBIAS) measures the aggregate difference between simulated and observed values, expressed as a percentage of the observed total. This report uses the simulated-minus-observed convention: positive values indicate overprediction and negative values indicate underprediction. Values closer to zero indicate less aggregate bias. This sign convention is the reverse of the observed-minus-simulated convention used in some literature.

$$PBIAS = 100 \frac{\sum_{i=1}^n (P_i - O_i)}{\sum_{i=1}^n O_i}$$

Flow and stage hydrographs were also reviewed visually to evaluate timing, peaks, recession, and overall agreement. Simulated flow and stage were extracted at the link and node locations corresponding to each monitoring site. Table 5-2 summarizes the adopted performance categories. For stage, errors expressed in feet are particularly important because percentage bias calculated from absolute elevations can appear small even when water-level differences are substantial.

Table 5-2. Performance Metrics Target Values

Metric	Very Good	Good	Satisfactory	Not Satisfactory
R ²	R ² > 0.85	0.75 < R ² ≤ 0.85	0.60 < R ² ≤ 0.75	R ² ≤ 0.60
NSE	NSE > 0.80	0.70 < NSE ≤ 0.80	0.50 < NSE ≤ 0.70	NSE ≤ 0.50
PBIAS	< 5%	5% to < 10%	10% to ≤ 15%	> 15%

5.4 Calibration

Calibration of the June 2025 event focused on improving initial conditions and the representation of runoff, storage, and hydraulic connectivity. The sensitivity simulations generated a rainfall response but showed substantial differences in pre-event flow, peak magnitude, and sustained flow. The calibration workflow included the following refinements:

- Longer ramp up time prior to rainfall events allowing the creek and connected relevant waterbodies to stabilize.
- Rainfall time series inputs were updated from hourly to 5-minute increments to better describe short bursts of intense rainfall.
- Spatially distributed rainfall from nearby gages was used for the 2025 event to improve representation of storm variability.
- Grays Bay Dam was represented using the three modeled gates and an observed downstream stage boundary, as described in Section 4.1.

Imperviousness and directly connected impervious area (DCIA) were assigned by land cover class. Table 5-3 contains the imperviousness and DCIA calibration parameter set provided with the draft model documentation.

Future calibration efforts may benefit from increased granularity of input land cover data to better target the location and magnitude of impervious adjustments.

Table 5-3. Calibrated Impervious and DCIA Model Inputs

Land Cover Description	Impervious %	DCIA %
Farmstead	40	9
Seasonal/Vacation	14	2
Single Family Detached	47	18
Single Family Attached	67	30
Multifamily	78	38
Manufactured Housing Park	64	39
Retail and Other Commercial	92	75
Office	88	68
Mixed Use Residential	94	43
Mixed Use Industrial	89	69

Land Cover Description	Impervious %	DCIA %
Mixed Use Commercial	94	78
Industrial or Utility	89	65
Institutional	75	35
Major Highway	79	45
Major Railway	82	46
Airport or Airstrip	92	32
Open Water	0	0
Developed, Open Space	16	0
Developed, Low Intensity	42	33
Developed, Medium Intensity	70	60
Developed, High Intensity	89	80
Barren Land (Rock/Sand/Clay)	0	0
Deciduous Forest	0	0
Evergreen Forest	0	0
Mixed Forest	0	0
Shrub/Scrub	0	0
Herbaceous/Grasslands	0	0
Hay/Pasture	0	0
Cultivated Crops	0	0
Woody Wetlands	0	0
Emergent Herbaceous Wetlands	0	0

Statistical calibration results are summarized in Tables 5-4 and 5-5 for flow and stage, respectively. Figures 5-8 through 5-18 present the available June 2025 flow and stage hydrographs. The model represents flow reasonably well at several monitoring locations, while stage performance is more variable. The following observations summarize the available comparisons:

Gleason Lake

Simulated flow closely follows the overall observed response, with an NSE of 0.92 and a flow bias of approximately -4 percent. Simulated flow is lower than observed before rainfall and rises more rapidly during the initial response, but the magnitude and progression of the major flow increases are reasonably represented.

Simulated stage is shown without an observed stage series. Stage agreement therefore cannot be assessed from this figure.

Future model improvements should focus on the flow preceding rainfall and the rate of increase during the initial storm response.

Six Mile Creek

Simulated flow volume is reasonably consistent with observations, with a reported flow bias of approximately –6 percent. However, the simulated response is smoother than observed, with an NSE of 0.38 and an R^2 of 0.48.

Simulated flow remains near 10 cfs during periods when observed flow approaches zero, underestimates the brief observed peak on June 26, and increases more gradually following rainfall.

Periods of overprediction and underprediction contribute to the small overall bias. Future model improvements should focus on channel geometry and storage within connected lakes and wetlands to improve the timing and short-term variability of flow.

Painter Creek

Simulated flow responds rapidly to rainfall but substantially underestimates sustained flow. Before rainfall, simulated flow is nearly zero while observed flow remains approximately 9–20 cfs. Following storm peaks, observed flow remains approximately 40–55 cfs while simulated flow rapidly declines. The lack of sustained flow results in a flow bias of approximately –80 percent, despite an overestimated initial peak.

Simulated stage is generally lower than observed between rainfall events but briefly exceeds observations during storm peaks. The simulated maximum stage is approximately 2.21 feet above the observed maximum.

Future model improvements should prioritize groundwater contributions to sustained streamflow. Channel geometry, wetland storage, and runoff routing should also be reviewed to address the exaggerated peak response.

Schutz Lake and Schutz Lake Outlet

Simulated flow generally matches observations before rainfall and represents much of the elevated flow following the initial event, with an NSE of 0.75 and a flow bias of 16 percent.

Simulated peak flow exceeds observations, and the model produces a substantial June 29 response that is not present in the observed hydrograph.

Simulated stage shows a substantially larger response than observed. The simulated maximum is approximately 2.26 feet above the observed maximum, and levels remain elevated through much of the period following rainfall.

Future model improvements should prioritize channel surveys and local hydraulic controls. The comparatively stronger flow performance suggests that the relationship between flow and stage requires particular attention.

Lake Virginia

Simulated flow reasonably represents the initial storm peak and subsequent recession, with an NSE of 0.70 and a flow bias of approximately 5 percent. The simulated response to rainfall on June 29 is sharper and higher than observed.

Simulated stage is higher than observed before rainfall but underestimates the initial storm response and remains lower afterward. The simulated maximum stage is approximately 0.75 feet below the observed maximum.

Future model improvements should focus on channel geometry and local hydraulic controls. The change in the direction of the stage error indicates that a constant elevation adjustment would not resolve the discrepancy.

Dutch Lake

Simulated outlet flow generally underestimates observations, with a reported flow bias of approximately –68 percent.

Simulated stage at Dutch Lake Creek remains substantially above observations, with an average difference of approximately 4.14 feet.

Future model improvements should include channel surveys and verification of modeled channel elevations. Monitoring elevations, vertical datum, and the correspondence between modeled and monitored locations should also be confirmed.

Future data review should examine straight segments and abrupt changes in the observed records for gaps, interpolation, or documented changes in conditions before drawing conclusions about response timing.

Lake Minnetonka at Grays Bay

The stage statistics in Table 5-5 indicate an NSE of 0.76 and a simulated maximum stage approximately 0.15 feet below the observed maximum at Grays Bay. The calibration review indicates that simulated stage follows the broad sequence of observed water-level changes but underestimates later increases.

Future model improvements should focus on dam operations, release calculations, and the flow output used for comparison. Excessive modeled outflow could contribute to the lower simulated lake levels.

Zumbra Lake

Simulated stage reasonably represents the overall progression of rising lake levels, although the later response is larger than observed. The simulated maximum level is approximately 0.17 feet above the observed maximum.

Future model improvements should focus on the balance between inflow, lake storage, and outlet conveyance during successive rainfall events.

Common discrepancies and potential improvements are described below:

Uncertainty in channel geometry

Portions of the channel network rely on interpolated cross sections that may not capture local changes in channel width, bottom elevation, or controlling features.

Other channels, including those associated with Lake Virginia, Schutz Lake, and Dutch Lake Creek, were not surveyed. Differences between modeled and actual geometry are a likely contributor to some stage discrepancies and should be evaluated through targeted surveys.

Sensitivity of small channels to geometric differences

Relatively minor differences in channel width, depth, or bottom elevation can substantially change the stage required to convey a given flow. This provides a possible explanation for locations where flow is reasonably represented but stage is not.

The muted stage response at Lake Virginia and exaggerated response at Schutz Creek Outlet indicate that geometry and hydraulic controls should be reviewed individually at each location.

Missing groundwater contributions

In the current simulations, streamflow is supplied by surface-water contributions. Water that infiltrates into wetland soils does not subsequently return to the channel through groundwater discharge.

This limitation is particularly relevant to Painter Creek, where the model generates storm runoff but does not maintain observed flow between rainfall events or during the storm recession.

Incorporating and calibrating groundwater exchange is expected to improve the representation of these sustained contributions. The hydrographs support this as a working explanation, although they do not independently establish the source of all missing flow.

Table 5-4. Statistical Performance for Flow

Location	Difference (%)		R ²	NSE	PBIAS (%)
	Peak Flow	Total Volume			
Gleason Lake	7%	-4%	0.98	0.92	-4%
Lake Virginia Inlet	18%	5%	0.74	0.70	5%
Langdon Lake Outlet	-18%	-27%	0.86	0.68	-27%
Painter Creek	40%	-80%	0.25	-1.57	-80%
Schutz Lake	54%	16%	0.84	0.75	16%
Six Mile Creek	-50%	-6%	0.48	0.38	-5%

Table 5-5. Statistical Performance for Stage

Location	Difference (feet)	R ²	NSE	PBIAS (%)
	Peak Stage			
Grays Bay	-0.15	0.91	0.76	0.01%
Lake Virginia Outlet	-0.75	0.51	0.33	0.00%
Painter Creek	2.21	0.44	-4.03	0.08%
Schutz Creek Outlet	2.26	0.61	-8.39	-0.04%
Zumbra Lake	0.17	0.96	0.62	0.00%

Flow comparison at Gleason Lake

Node: PCV-000415 | Modeled variable: link_outflow_cfs | Simulated flows shifted forward 6 hours

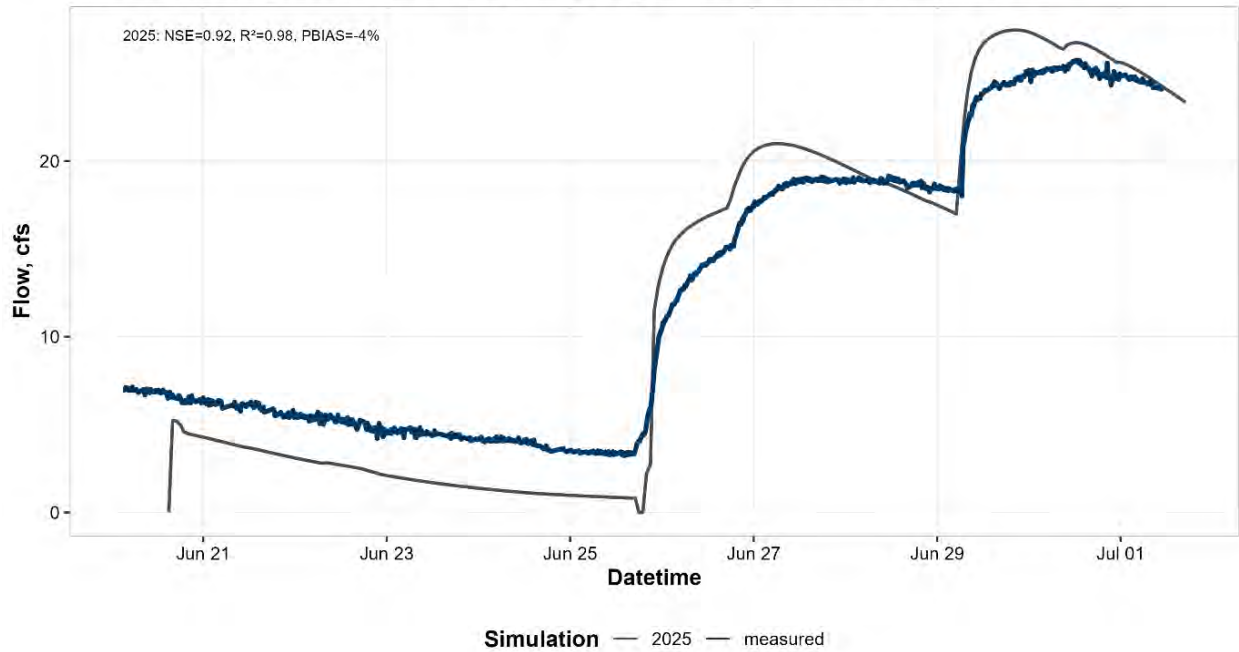


Figure 5-8. Gleason Lake Outlet 2025 Flow Calibration

Stage comparison at Gleason Lake Creek

Node: PCV-000415 | Modeled variable: stage_ft

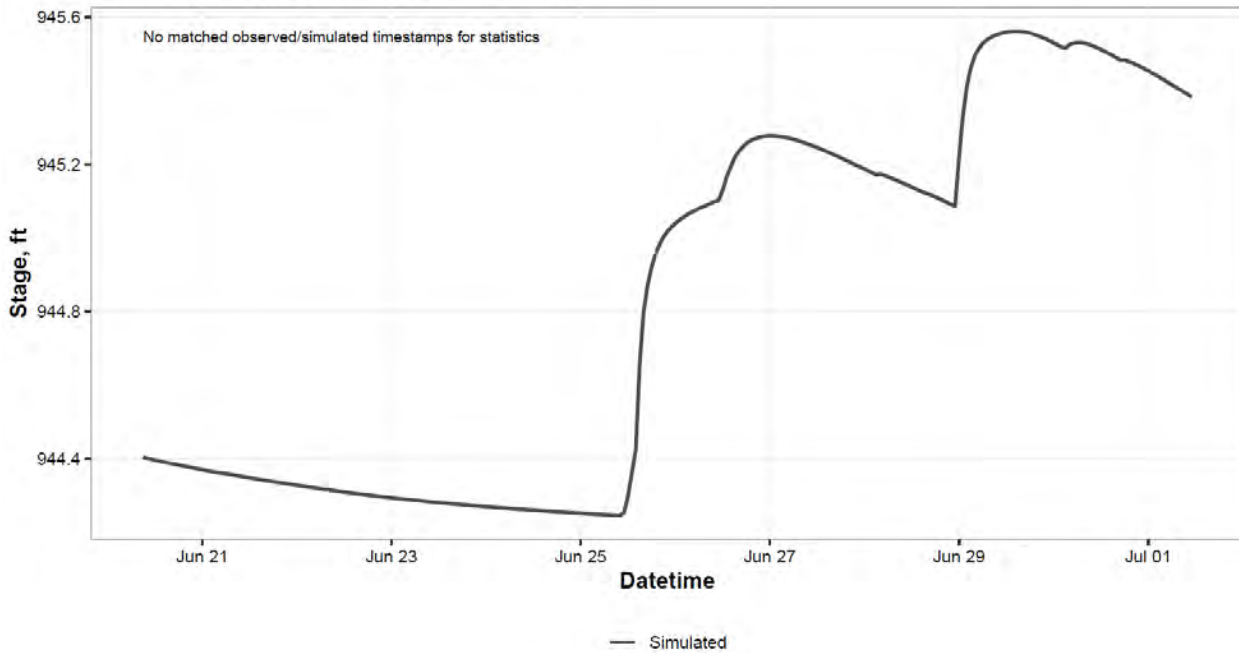


Figure 5-9. Gleason Lake 2025 Simulated Stage

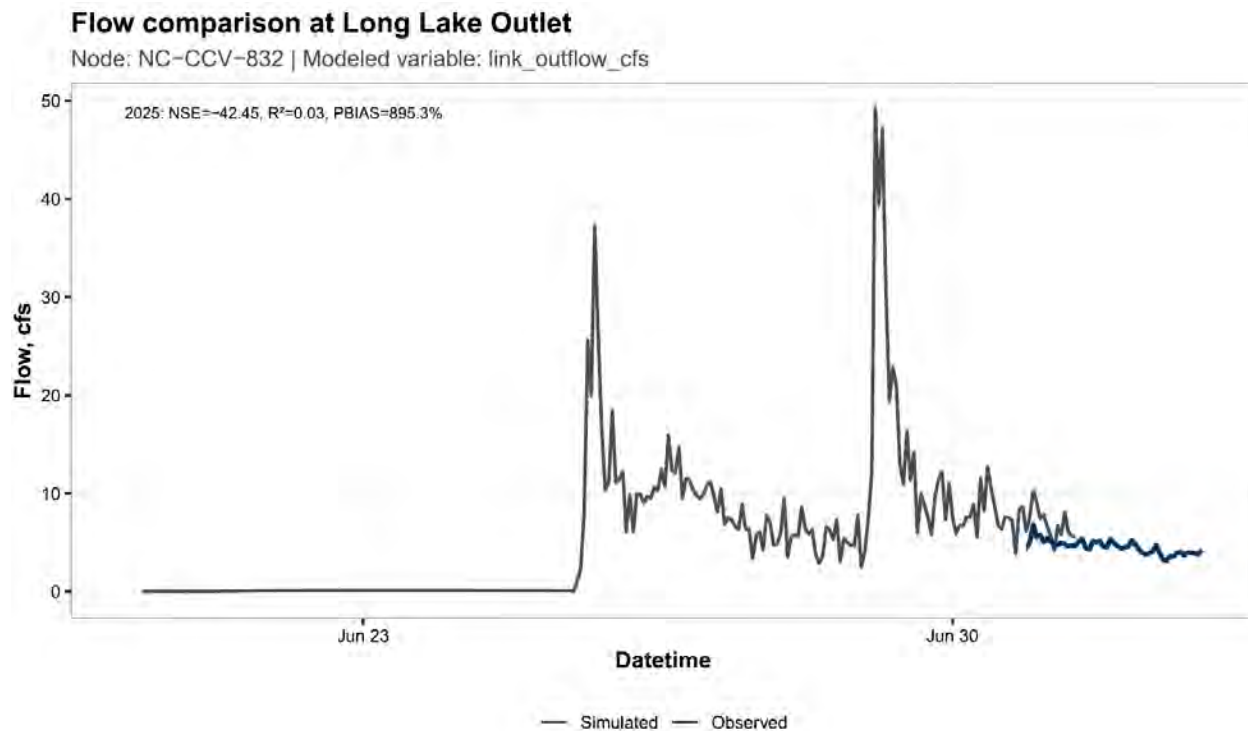


Figure 5-10. Long Lake Outlet 2025 Flow Calibration

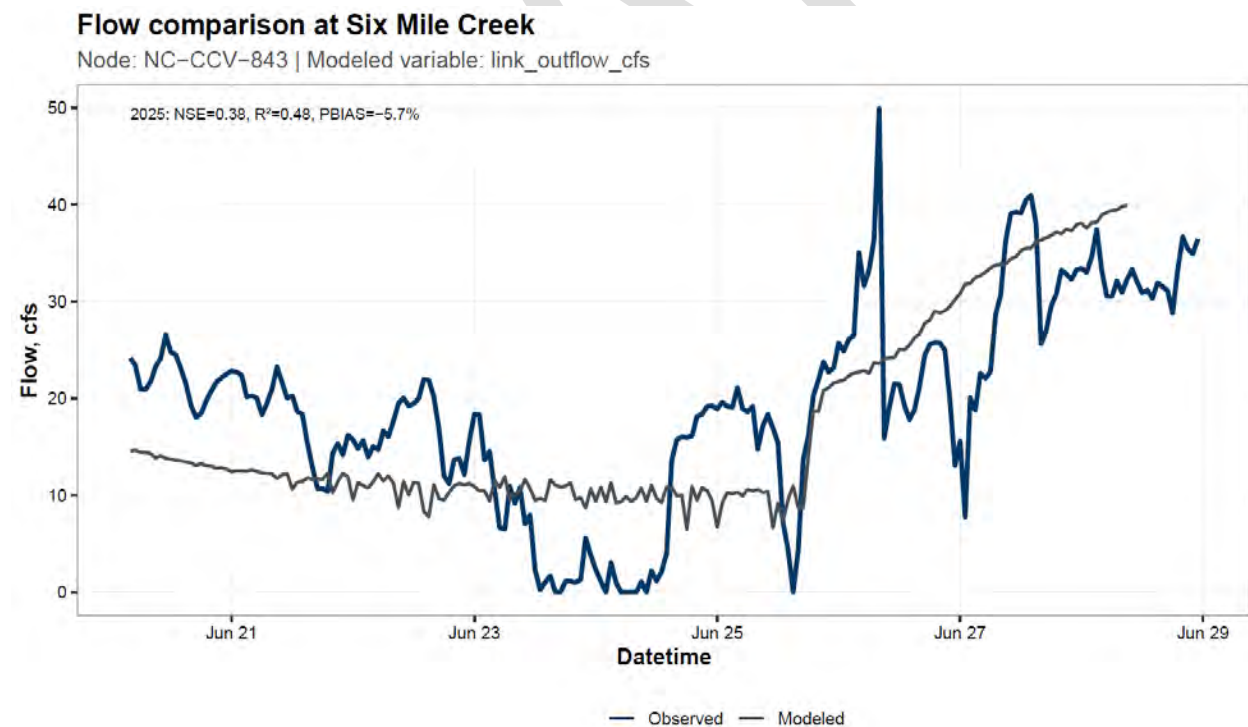


Figure 5-11. Six Mile Creek 2025 Flow Calibration

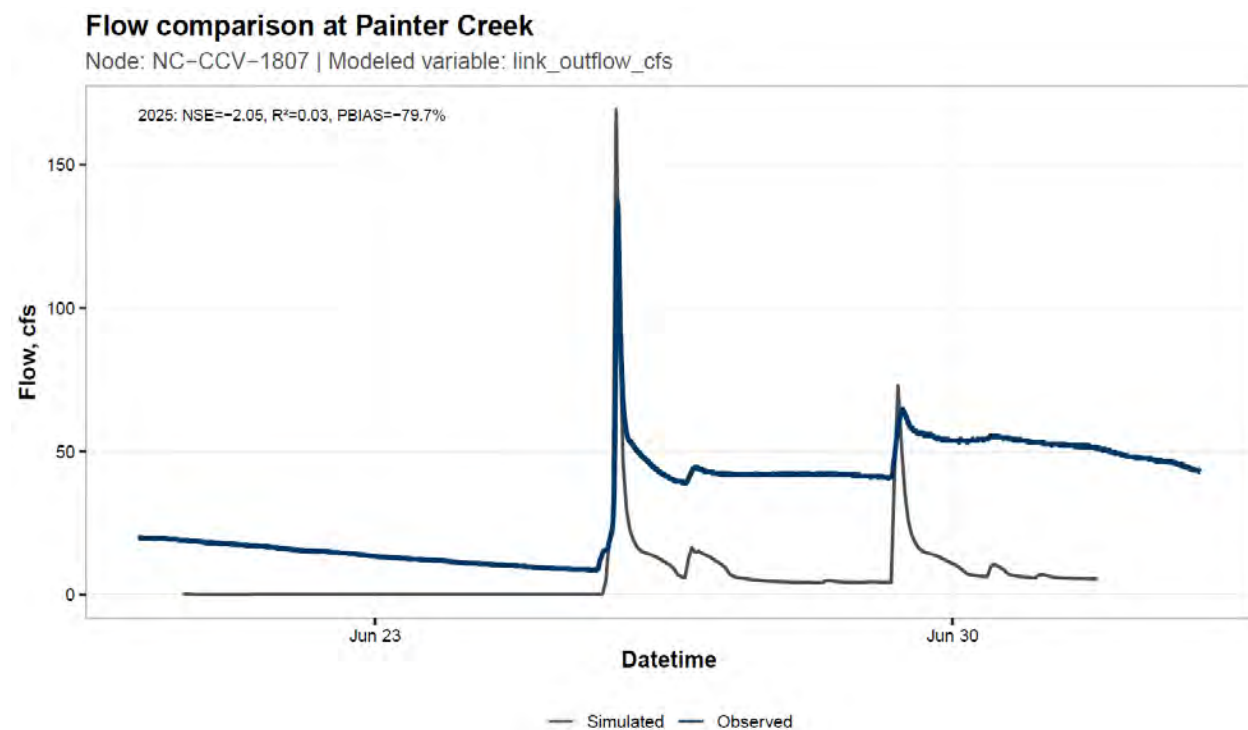


Figure 5-12. Painter Creek 2025 Flow Calibration

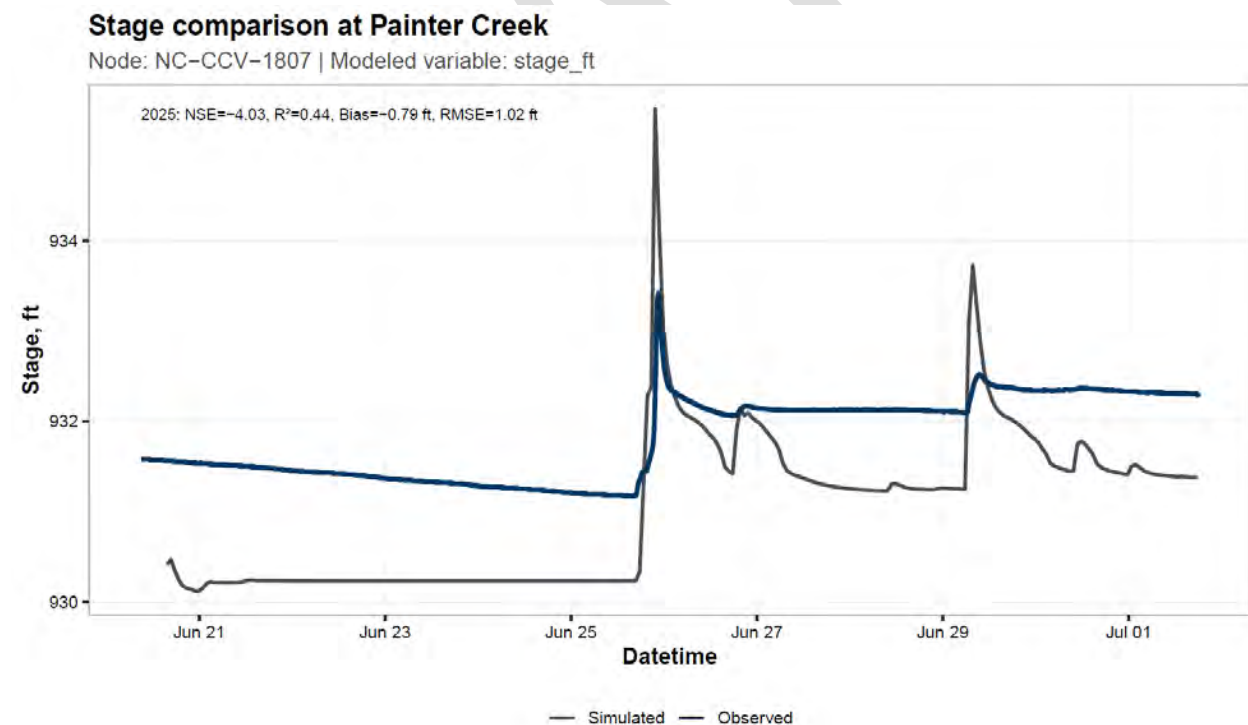


Figure 5-13. Painter Creek 2025 Stage Calibration

Flow comparison at Schutz Lake

Node: PCV-002887 | Modeled variable: link_outflow_cfs | Simulated flows shifted forward 6 hours

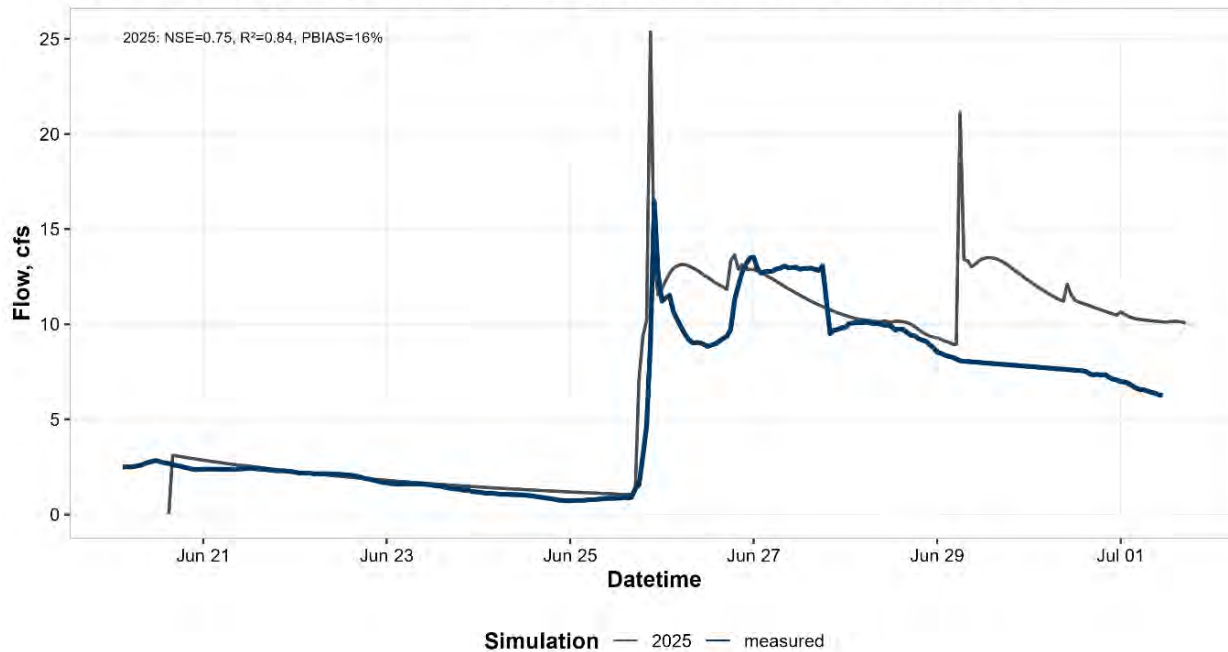


Figure 5-14. Schutz Lake 2025 Flow Calibration

Stage comparison at Schutz Creek Outlet

Node: PCV-002887 | Simulated stages shifted forward 6 hours

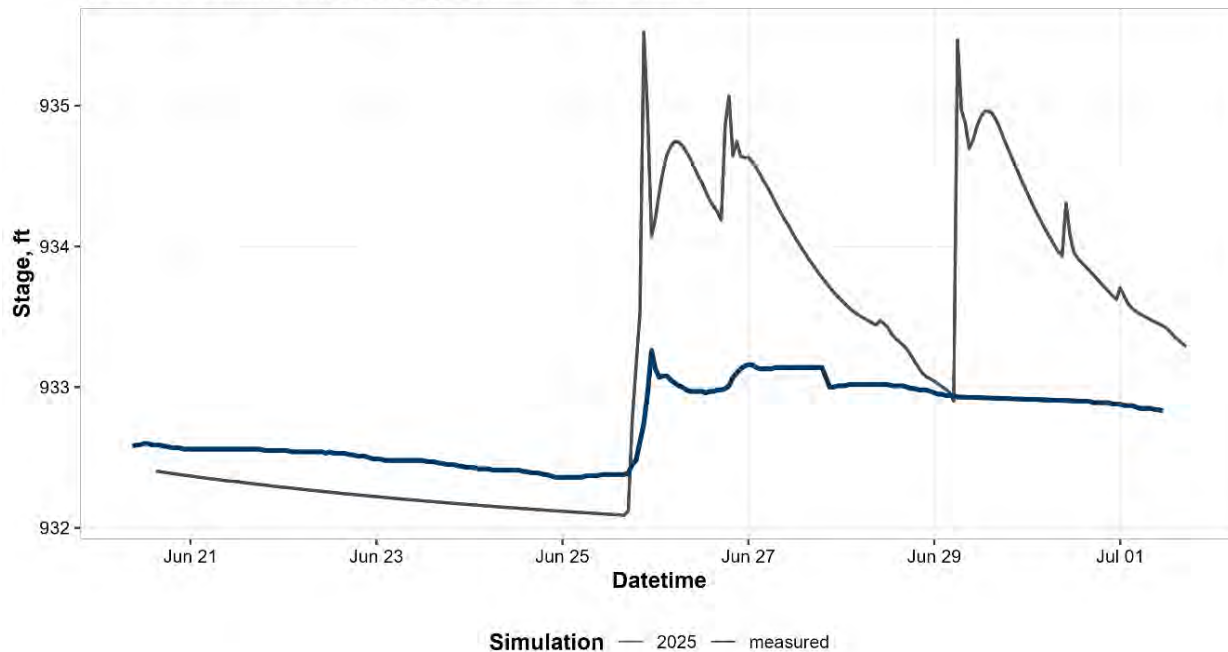


Figure 5-15. Schutz Lake Outlet 2025 Stage Calibration

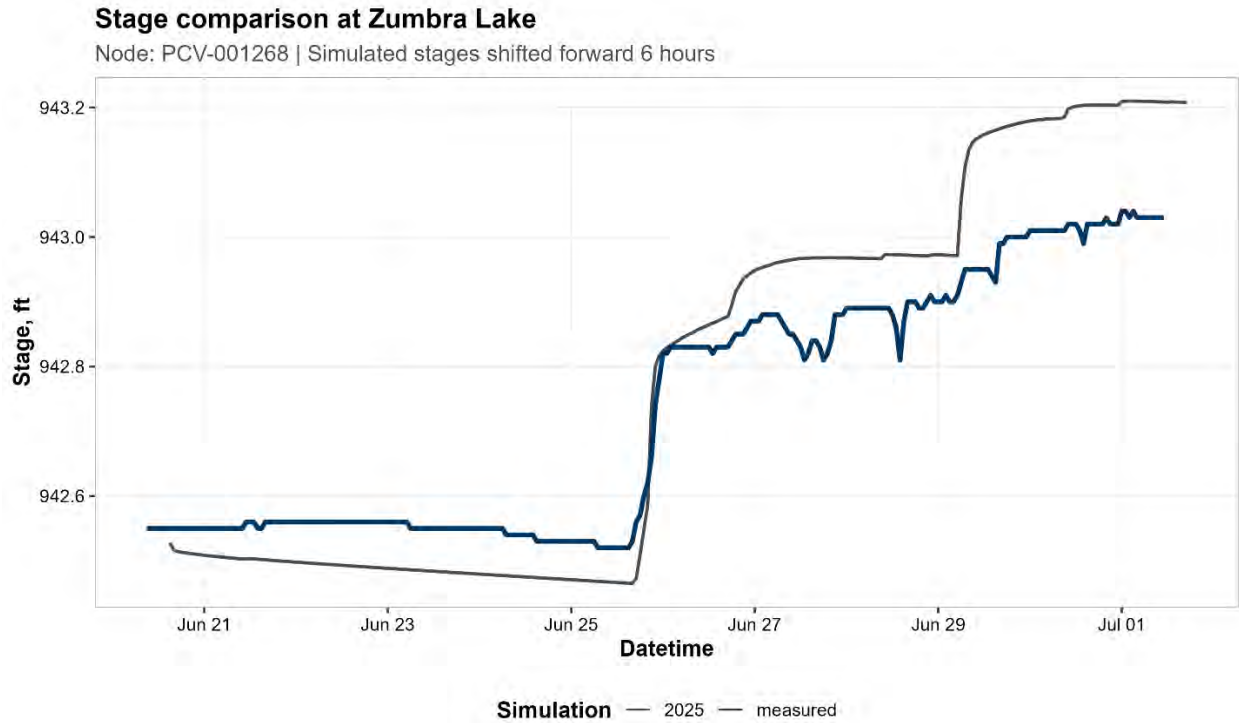


Figure 5-16. Zumbra Lake 2025 Lake Level Calibration

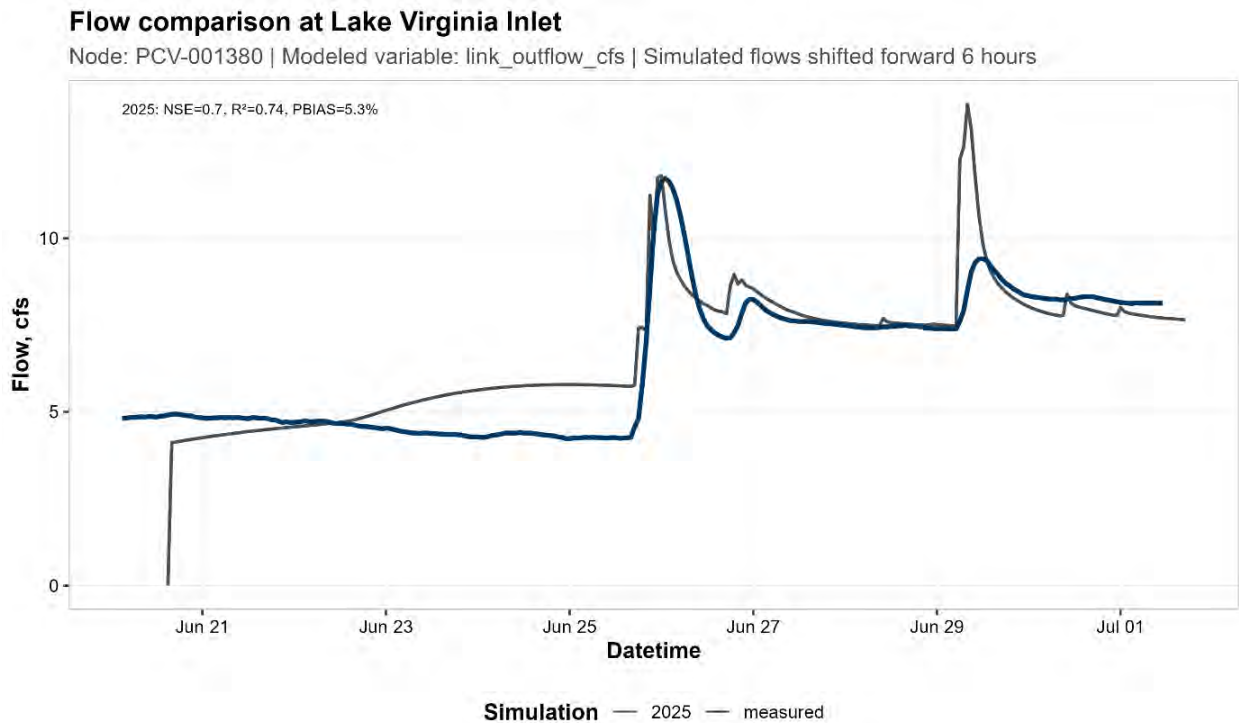


Figure 5-17. Lake Virginia Inlet 2025 Flow Calibration

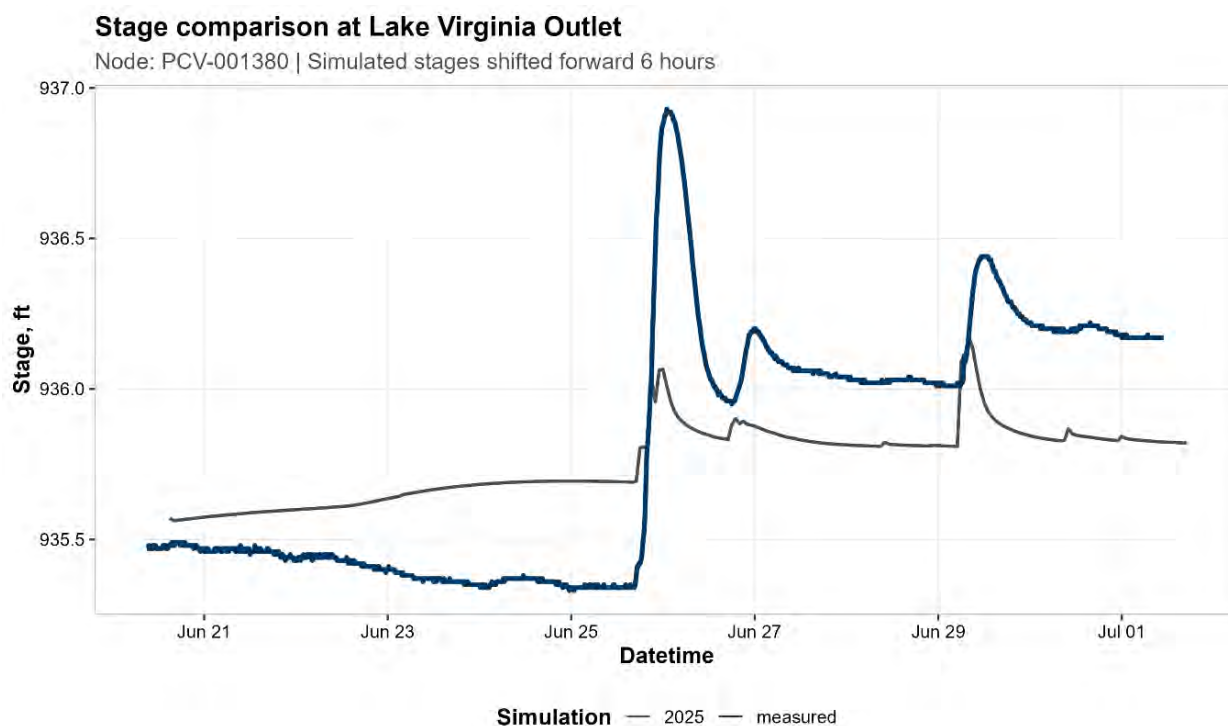


Figure 5-18. Lake Virginia Outlet 2025 Stage Calibration

5.5 Validation

The June 2014 event was used for model validation. Initial conditions were configured as described in Section 5.1.3. Beyond initial watershed conditions, no other modifications were made to the input parameters. Figure 5-19 compares simulated and observed Lake Minnetonka levels. Key observations are summarized below.

Available data for comparison

Observed Lake Minnetonka water levels at Grays Bay Dam were compared with simulated levels for the June 2014 event.

The spacing of the observations limits evaluation of the precise timing and rate of lake-level changes during the rapid rise.

Lake Minnetonka at Grays Bay Dam

Simulated lake levels reproduce the overall increase associated with the June 2014 event.

Simulated levels decline more rapidly than observations early in the simulation, falling approximately 0.2 feet below the observed trend before June 15. Agreement improves following the simulated rise on June 15.

The simulated rise on June 19–20 is sharper than the observed response. Simulated levels reach approximately 931.2 feet, compared with observed levels near 931.0 feet during the same period.

The displayed simulation ends around June 21, while observed levels continue rising to approximately 931.1 feet on June 23–24.

Future improvements should focus on initial lake and connected waterbody conditions, the timing and magnitude of watershed inflows, and dam releases.

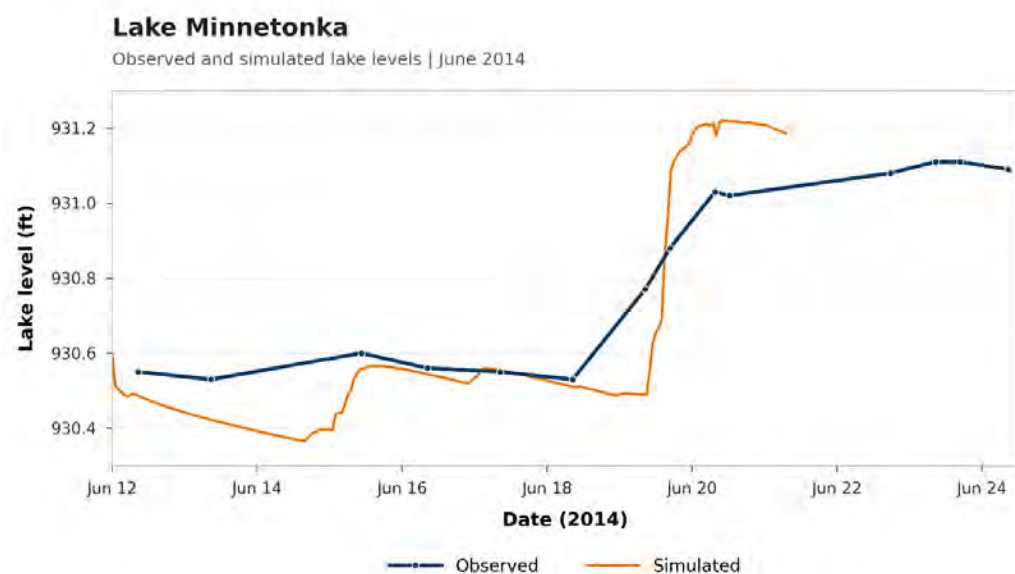


Figure 5-19. Lake Minnetonka at Grays Bay Dam 2014 Level Validation

6 100-Year Event Simulation

To support flood risk identification and future application of this model, a single 100-year 24-hour design storm event was developed. Characteristics for the event are summarized below.

- Rainfall was a 24-hour duration, 100-year frequency with 7.49 inches of total depth derived from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 (Perica et al. 2013) and applied an MSE3 temporal distribution.
- Soil initial moisture content was set to a wetter than normal condition of 80 percent saturated.
- The source design-event setup specifies a maximum dam-release assumption of 300 cfs.
- Initial lake level where observations available were set to the 95th percentile of all observed lake level data as shown in Table 5-1.

Figure 6-1 shows cumulative rainfall and the simulated Lake Minnetonka water level at Grays Bay Dam. The figure includes antecedent rainfall as well as the 7.49-inch, 24-hour design storm. The simulated peak lake level is approximately 931.4 feet. The draft cites a FEMA Flood Insurance Study (2016) 1-percent-annual-chance flood elevation of 931.5 feet at Grays Bay, approximately 0.1 foot higher than the simulated peak. Figure 6-2 shows an example of modeled inundation. Inundation extents may differ from municipal stormwater models for the reasons listed below:

- **Rain On Grid.** A 2D approach was applied for this model where a grid over the entire watershed converts rainfall into runoff, and routes it from its origin to the stormwater network and eventually to receiving channels and lakes. This approach accumulates runoff over the entire watershed. For this reason, the 100-year inundation limits have been masked at depths below 0.25 feet to better show areas of deeper accumulation. Other modeling approaches may route runoff through subbasins directly to an inlet or larger trunkline limiting the origins of the inundated area to the proximity of the subbasin outlet.
- **Inlets.** All pipes and inlets are included in the model. At each inlet, a standard catch basin style and size was assumed. Inlets can restrict the amount of flow entering into larger pipes and result in flows bypassing the inlet showing inundation near these areas. Other modeling approaches may assume there is no inlet and restrictions only occur within the pipe network increasing the amount of water able to enter the stormwater system.
- **Calibration.** Calibration was performed to an observed event. This provides confidence in the system's response to similar events. Calibration also required adjustments to some of the base parameters controlling runoff generation. Other modeling approaches may not have the benefit of observed data for calibration, and therefore, would use common engineering practices to select input model parameters.

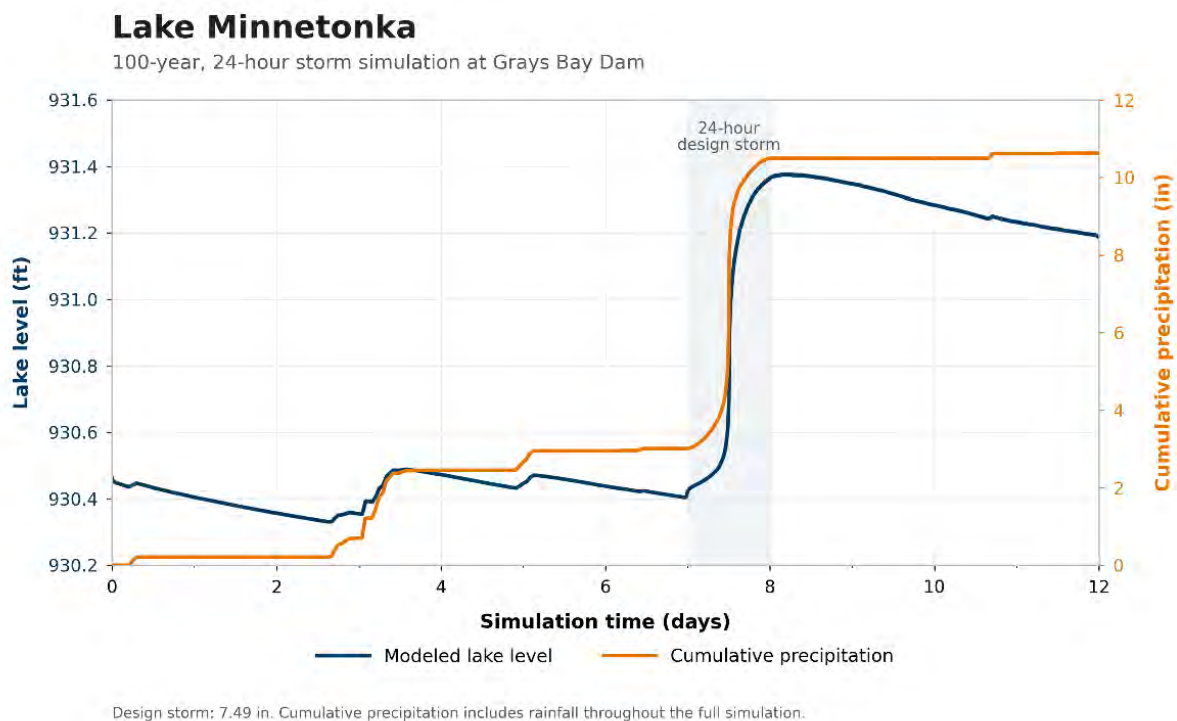


Figure 6-1. Design-Event Rainfall and Simulated Lake Minnetonka Water Level

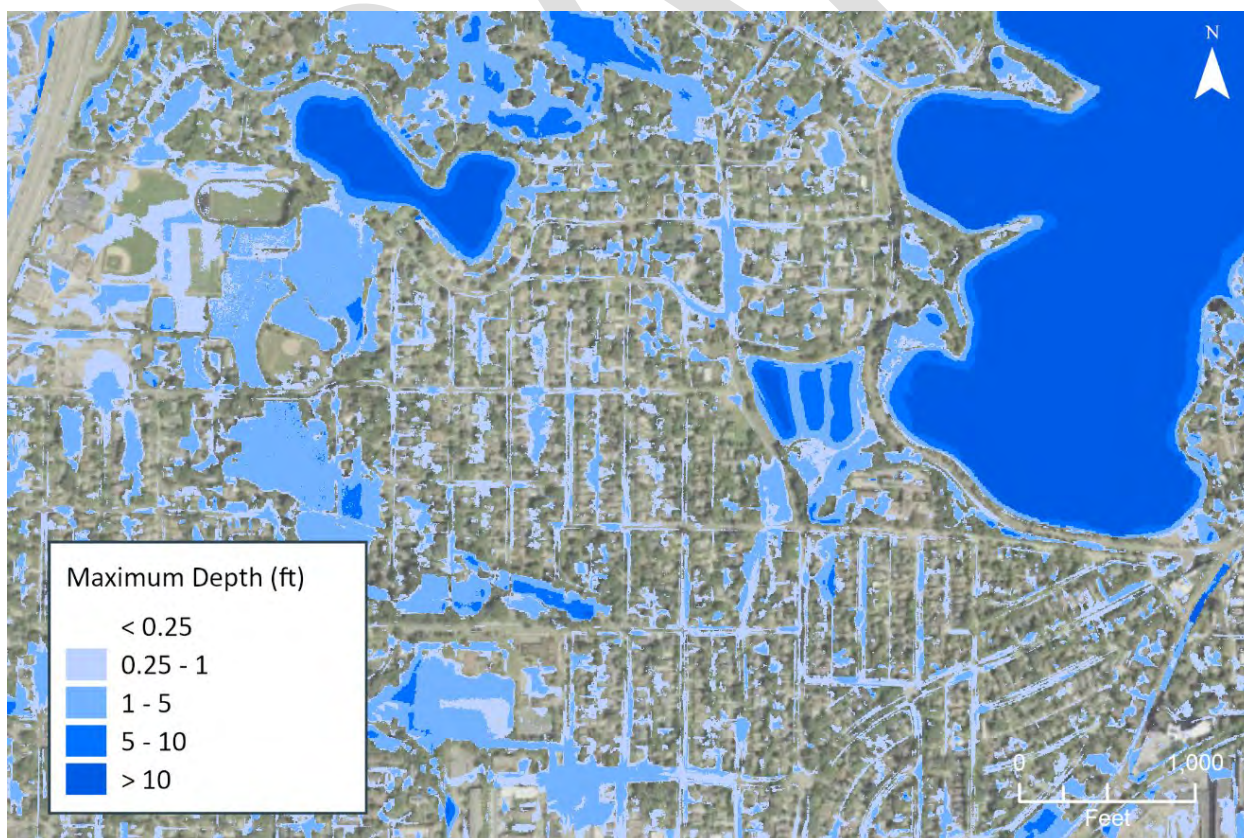


Figure 6-2. Example Inundation Limits from 100-year event

7 Recommendations

This report describes model development, calibration, and validation for the Upper Watershed of Minnehaha Creek. This model provides a quality and robust product useful for watershed planning purposes with the potential for a range of future applications. Future enhancements and improvements that could support expanded application of the model include:

- Expanded Flood Calibration Refinement
- Infiltration Measurements. Real measurements of infiltration across the watershed could help to hone the calibration adjustments in urban areas.
- Additional Event Calibration. Calibrate the Upper Watershed model to additional flood events. The combination of parameter adjustments to infiltration characteristics and initial conditions can be improved, helping to refine results of the current events, design storm events, and future applications of the model to flood conditions.
- Initial Condition Approach. Using additional calibration events to develop an approach to characterize soil wetness, water table depth, and initial lake and pond levels for other historical events or future event evaluations.
- Groundwater Calibration
- Evaluate Model Simplification for Groundwater Simulations. A calibrated, integrated surface water and groundwater model can support evaluation of watershed dynamics over multiple seasons or years. The reported event-model runtimes are substantial, so longer simulations may require a coarser 2D mesh, mapped basins, or other targeted simplifications that retain the processes relevant to the intended application.
- Develop Breakout Model. Develop a sub-watershed scale model with surface and subsurface observations. The sub-watershed scale model runs faster than the full model and will allow for more rapid evaluation of watershed response and parameters for a larger scale simulation. Results at the breakout model scale can give insights into local response which may be applicable to portions of the watershed scale modeling efforts.
- Model Set Up Refinement
- Evaluate additional Upper Watershed tributary crossings and hydraulic controls for integration or refinement, particularly where stage discrepancies indicate uncertainty in channel geometry or local restrictions.
- Storm sewer refinement. Storm sewer assumptions can be reviewed for refinement to conform with local design and implementation. Improving storm sewer information in the model, especially for larger pipes or areas conveying significant drainage area, may greatly improve model results in these areas.
- Storm sewer omissions. MNDOT dataset was omitted from storm sewer integration due to the amount of redundancy. However, up to 30 percent of this dataset may be unique to the MNDOT dataset and may benefit model drainage patterns.
- Lift station assumptions. Many of the lift stations include assumed maximum capacity and on/off elevations. Update these assumptions with information received from local partners.

8 Future Application

This watershed-wide model development is at the center of the CAF and is intended to be used as a numerical tool to describe the physical processes important to watershed response. Through this model build, the goals of model development were focused on describing both local and regional flooding conditions. To this end it includes a detailed representation of the watershed wide storm sewer infrastructure using the most current detailed topography and bathymetry, and numerical features intended to make the model simulations faster and more accurate. This detailed model development was paired with a targeted calibration and validation which refined the model inputs to better reproduce real events. Although some improvements have been noted throughout the above sections, the model is ready for application to support MCWD's current and future needs.

- **Watershed Planning.** Use the model as a tool to support 2027 Watershed Management Plan activities. The model can be used as a platform to bring people together around common goals and develop a shared understanding of some of the complex inter-related water challenges. It can be used to understand current and future flood risk and approaches to mitigate that risk.
- **Supporting Partners.** Model development included aggregation, review, and refinement of vast amounts of project partner data for incorporation into a detailed watershed wide understanding of the storage and conveyance system. These data and processes can be provided to project partners to meet shared goals. Project partners have varying investments with respect to stormwater planning. This model can support partners as is and be used to support their own planning purposes or provide a regional understanding of local project development.
- **Evaluate Projects.** Use as a watershed wide model or divide out key project areas for purposes of project siting, feasibility, and design.

9 Electronic Data Package

The electronic data package accompanies the model documentation and contains the Upper Watershed StormWise model, supporting GIS data, processing tables, and workflow documentation. Table 9-1 summarizes the data categories and their intended use. The technical appendices include shared watershed-wide methods and historical Lower Watershed examples; filenames in those original memoranda refer to their source workflows.

Table 9-1. Electronic Data Package

Data Category	Contents and Purpose
StormWise model	Upper Watershed event model and completed coupled surface water–groundwater model build.
Rainfall and boundary conditions	Event rainfall series, Grays Bay Dam operating inputs, downstream stage conditions, groundwater boundary-stage inputs, and reference evapotranspiration.
Surface model data	Upper Watershed boundaries, topography and bathymetry, land cover, building footprints, mesh inputs, and exported surface mesh.
Pond and channel control volumes	Control-volume polygons, nodes, stage/area data, channel links, cross sections, and applicable hydraulic-control inputs.
Storm sewer infrastructure	Processed pipes, culverts, inlets, manholes, outlets, manual overrides, and CSV files used for model import.
Groundwater model data	Six groundwater regions, boundary-stage inputs, groundwater meshes, confining-layer surface, soils, and initialization surfaces.
Parameter tables	Vertical layers, hydraulic conductivity, fillable porosity, imperviousness, roughness, crop coefficients, and related processing tables.
Supporting documentation	Data registry, processing spreadsheets, scripts, workflow diagrams, survey information, and the technical memoranda identified in the appendices.

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Appendix A – Workshop Notes

Appendix A-1: Workshop 1 Meeting Minutes

<i>Project:</i>	MCWD 2D Model Build		
<i>Subject:</i>	Workshop 1: Goal Setting and Prioritization		
<i>Date:</i>	Thursday, June 13, 2024		
<i>Location:</i>	HDR Office & Microsoft Teams Conference Room 5Y 1601 Utica Avenue South Suite 600 St. Louis Park, MN 55416-3400		
<i>Attendees:</i>	Brian Beck (MCWD) James Wisker (MCWD) Becky Christopher (MCWD) Rebecca Neal (MCWD) Kate Moran (MCWD) Siddharth Saksena (VT) F. Warren McKinnie (Streamline) Andrew Judd (HDR) Nick Thomas (HDR) Ryan Fucci (HDR) Alex Miller (HDR) Ken Trefzger (HDR)		

The following items were discussed during the kickoff meeting for the 2D Model Build project:

1. Introductions

2. Workshop Series Overview

- Goal of the workshop is to develop a shared understanding of model objectives and key decision areas to guide the upcoming model build process.
- This is the first of four workshops and is the broadest. The next workshops will get increasingly technical and cover the topics of Surface Water Model Build, Groundwater Model Build and Model Calibration/Validation and Maintenance.
- One common goal of the workshops is to develop guidance documentation for model development which can be carried forward past this project.

3. Prioritized Model Scenarios and Discussion (MCWD presentation)

- MCWD Past Model Prioritization
 - The District has internally discussed the overarching model 'objectives', and wanted to go one step further within this workshop to discuss 'scenarios' of future model use to help guide the model build discussion.
 - Previous efforts to prioritize what the model should do have identified primary and secondary objectives.
 - Primary objectives: Flood extent and duration, GW/SW Impacts, Policy regulation scenarios analysis, Regional BMP strategy evaluations
 - Secondary objectives: Short term flood forecasting, Water quality evaluations, Boundary conditions, FEMA flood maps

- Secondary objectives may already have tools that can fill the need. However, it is a bonus if a model can be developed that also accomplishes secondary objectives.
- Climate Modeling Approach. The district suggested the following model uses:
 - Use 1 - Evaluate extent and magnitude of impacts due to increased precipitation
 - Interim Step (not associated with modeling) Develop specific goals that would minimize or avoid impacts due to increased precipitation
 - Use 2 - Evaluate MCWD known and potential projects at regional or local scale to evaluate effectiveness relative to the goals developed
 - Use 3 - Evaluate policy solutions or high-level strategies such as volume managed or zoning requirements
 - Use 4 - Run scenarios that characterize impacts of subwatershed-based projects and watershed-wide policy impacts relative to goals
 - These initial goals may relate to surface water bodies. These water features are the downstream recipients of upstream changes. These are also the most visible features and those that may be most related to the watershed districts purview. Currently, all goals (regulations) are site-specific. Here, we are looking at regional goals for a water body. These look to be proactive and typically around developed areas. Instead of waiting for redevelopment, are there regional opportunities that can be had in advance?
- Evaluate Impact of Climate Change Examples
 - Develop subwatershed plans to define objectives at confluence/outfall points on the creek
 - What is the percent frequency of out of bank flooding (consequence - high resolution surface mesh)
 - Does the frequency of localized flooding increase due to climate change (consequence - high-resolution pipe network)? Cities have or may ask for this understanding. MCWD intends to meet with associated partners to see what issues are in specific areas and develop regional goals to address them.
 - Accurately characterizing outfalls to creek (flows, impact on flood levels) could be important locations for system response evaluation.
 - Understand how groundwater impacts existing and future BMPs and their storage capacity.
- Note on District's responsibility for flooding. Typically, the District is associated with creek flooding, sometimes MCWD also associated with localized (non-creek) flooding. A Working definition of localized flooding is flooding that is the

responsibility of Cities, not the watershed District, things on the grid, not visually associated with the Creek or surface water bodies.

- Part of climate action plan is to define what MCWD is responsible for and what their partners are responsible for so each can more appropriately focus on goals.
- In City of Minneapolis, they have set established levels of service
 - 100 -year storm away from buildings
 - 10 - year storm within stormsewer
- Current regulatory paradigm is based on permitting changes on the landscape, which have cascaded down from MS4 requirements. Current projects such as pipe conveyance are specifically designed to not hit regulatory requirements. Cities can upsize their systems without consent from the district.
- What happens when conveyance impacts are intra-community? Sometimes these questions fall outside of regulation.
- It would be useful to have a framework between the District and the communities for these types of regional questions.
- Evaluate management strategies
 - Where are management strategies needed based on localized and regional flooding
 - Understanding if infiltrating more helps augment base flow later on during drought conditions
- Evaluate Policy Solutions
 - Evaluate upper watershed development under current plans/rules (water budget)
 - What is impact on rule or zoning changes based on climate scenarios (water budget)
 - Does the outlet at Grays Bay Dam need to be re-evaluated relative to changing flow conditions?
 - Would BMP Requirements for permits be useful?
 - What watershed conditions are conducive to different strategies.
 - For instance, soils are much more permeable in the lower watershed, are there opportunities for infiltration? Whereas, in the upper watershed soils are less permeable. Focus on infiltration where soils are suitable (lower watershed), and surface storage/wetlands where they may not be (upper watershed). This focus can be both through potential policies and specific BMMP siting.
 - It would be beneficial to understand interaction between surface water and groundwater movement, specific to how these impact effectiveness of BMPs.
- Evaluate policy solutions and management strategies together.
- How important is flooding vs. drought management in these scenarios?

- Most people put an emphasis on flooding, however drought and water balance will be important and long-term runs will be needed to quantify these impacts. A metric may look like 7q10 to evaluate baseflow and how the biota reacts to that. There may be paired SW/GW benefits from surface storage resulting in increased baseflow, but this is to be determined/quantified.
- Drought may affect more people than floods at a high level, and the District doesn't get blamed for a lack of supply. However, when it rains a lot, the blame falls on the water management and engineering community as to why there isn't a solution.
- If there are management strategies that both help flood and drought conditions that would be ideal. Increases to conveyance may not be the best solution.

4. Model Build Drivers (HDR presentation)

- Data Management: Data resolution, quantity, and/or accuracy for model input.
 - This includes 1D geometrics, GIS spatial data, meteorologic data, calibration data, and storage space.
 - Relative to storage space. Stormwise identifies a difference between 'scenario' and 'simulation' that is important relative to model size. Scenarios require full copies of a model, simulations do not.
 - There could be opportunities to preemptively look at things like landuse and discretize pre- and post- scenarios with just swapping the lookup tables. In the worst case, the team would just need multiple scenarios.
 - We need a model that meets the goal, is technically sound, and is manageable.
 - The team needs to keep in mind that the goals need to be accomplished first, and then elements like model runtime can be evaluated.
- Outputs: Type, location, spatial resolution, and temporal frequency of model results.
 - There are opportunities to modify outputs in postprocessing scripts pending what information is useful.
 - Siddharth noted that there are potential ways to get time series for entire 2D mesh. Currently only available to certain users.
- Model Detail: Numerical resolution of model or number of model elements
- Simulation Duration: Length of modeled evaluation period
- Model Build Drivers linkage and summary
- Runtime: Function of Level of Detail and Simulation Duration
 - Siddharth recommends leveraging 1D as much as possible, not just because of speed but because of physics. A consistent known water surface elevation will help facilitate accurate

groundwater movement. Going to 1D doesn't sacrifice accuracy if used correctly, it may be a win-win for accuracy and runtime.

- Tiered numerical element resolution should be considered based on how important certain features are to physics and/or where known priority areas are located.
- Warren suggests thinking about opportunities where we can simulate certain areas as mapped basins (without overland flow).
- Brian suggests City/community feedback to point to areas where higher resolution may be beneficial.
- Quality of data may also set a limit on model build requirements. If data is lacking, then it may not make sense to characterize elements in certain ways if it doesn't lead to more accurate results.
- Siddharth built a model in City of MPLS - Takes 1h to run 1h or simulation. Siddharth has a project in Cleveland of about the same size, takes 7 days to a run a 1-year simulation.
- Caution should be taken if choosing a runtime independent of other considerations. Aim to balance a model build that leverages good development practices instead of thinking with a runtime goal in mind.
- Changes to the 2D model elements are easy once the physics are established correctly with 1D elements, and areas that need higher resolution.
- Should keep in mind the number of long-term vs. short-term runs and characterize which scenarios need to be long term vs. short term.
- Are the simplifications considered to limit model runtime or the level of effort to build the model?
- Discussion of how we manage scenarios
 - Future scenarios should consider using long term simulations to guide and/or initialize shorter term ones.
 - Longer term models set the baseline for various climate conditions: very dry years, moderately dry years, moderately wet years, very wet years (etc). Then shorter-term models can be initialized to evaluate specific conditions. Then we look at longer term again relative to changes
- The project has a beginning and end date, but the end product needs to exist for 15-20 years. The District wants to log items that need to be managed beyond the life of the project itself. Can this be accommodated in a log throughout project lifespan off to the side?

5. Key Areas of Focus

- Nick - being strategic about model is constructed.
- Andrew – Regional implications between partners will be critical to future model uses.
- Samantha - Meeting expectations of Cities and setting clear goals.

- Brian - Understanding the differences between areas with localized flooding and where lower resolution is needed.
- Becky – Targeting locations of volume control vs. rate control.
- Becca – Ensuring the model is adaptable to support unpredicted partner questions.
- Ryan – Tool could help facilitate regional discussions, outside of regulations.
- James – Assuming the technical decision making will be sound, the tool will bring people together on a quantitative understanding of the watershed. Strategies will differ between upper and lower watersheds.
- Kate - getting the physics down, understanding where to prioritize detail.
- Warren – Be thoughtful in model build planning to minimize rework/lost time.
- Siddharth – Focus on getting the mass balance right throughout entire model.
- Alex – technical: groundwater regions and boundary conditions, general: build a model that can easily be run with different scenarios/simulations
- Ken - model within a timeframe that can answer one or two key things, show value of model to folks that you're trying to show.

Action Items

- Send Warren the specs on the PC setup
- Send Warren copy of presentation
- HDR to develop a long-term project log that exists beyond the scope of the project itself
- MCWD to assign scenarios into long term vs short term simulations buckets to see if this is critical in model development.

Appendix A-2: Workshop 2 Meeting Minutes

<i>Project:</i>	MCWD 2D Model Build	
<i>Subject:</i>	Workshop 2: Surface Water Model Build	
<i>Date:</i>	Wednesday, August 07, 2024	
<i>Location:</i>	HDR Office Conference Room 6A 1601 Utica Avenue South Suite 600 St. Louis Park, MN 55416-3400	
<i>Attendees:</i>	Brian Beck (MCWD) James Wisker (MCWD) Becky Christopher (MCWD) Rebecca Neal (MCWD) Kate Moran (MCWD) Siddharth Saksena (VT) - Virtual F. Warren McKinnie (Streamline) - Virtual	Andrew Judd (HDR) Nick Thomas (HDR) Ryan Fucci (HDR) Alex Miller (HDR) Leah Botting (HDR) Ken Trefzger (HDR) - Virtual

1. Introductions to New Members (9:00 - 9:10 am)

2. Workshop 2 Overview (9:10 – 9:30 am)

- Workshop 1 summary:
 - The model needs to show the watershed under current and future climate conditions, including both wet and dry scenarios.
 - The model will be used to plan and evaluate future policy and strategies.
 - MCWD noted the additional goal of stakeholder acceptance of the model and the importance of keeping the acceptance component in mind as the project moves forward.
- Objectives of workshop 2:
 - Develop an approach to create the surface water components of the model by stepping through a series of specific technical issues and discuss modeling choices as they align with district objectives.

3. Lessons Learned from Pilot Study (9:30 – 9:50 am)

- MCWD assessed a few different models.
 - Many of the issues in the pilot model weren't technical issues but rather incremental choices made by the modeling team diverging with the overall modeling goals over time. As a result, the watershed wide model build (this project) was structured with an emphasis on active communication and continued alignment relative to the District's goals.

- Outcomes:
 - Diverging goals resulted in a model that was calibrated to other models rather than observed data.
 - Diverging goals also resulted automation of the entire model build process rather than automation of a build process for stormwater infrastructure data specifically (District's Intent).
 - Model built entirely in 2D which had significant impacts on surface water-groundwater connectivity and model runtimes.
 - Models matched localized flooding modeling but couldn't effectively characterize streamflow.
 - Model did not integrate real or assumed channel bathymetry and relied upon hydroflattened surface
 - Calibration performed to other models rather than to observed data
- Takeaways:
 - Leverage expertise of similar model builds.
 - Goal oriented model build: Make sure the model answers the questions needed.
 - Communicate often: If issues arise in reaching stated goals, communicate to policy planning.
- Additional notes from Pilot Study discussion
 - Include detail where needed in the model (flooding in populated areas).
 - Use 1D channels, they improve computational efficiency and accuracy of SW/GW connectivity and channel conveyance. Need to account for bathymetry below hydroflattened water surface by creating a merged topo-bathy DEM. LiDAR only based DEMs aren't ideal for 2D channels because it typically includes the water surface and not the channel bottom.
 - Use bathymetry where it exists. When only using the stage-volume data, there was a 0.5 ft discrepancy between observed and simulated stages
 - MCWD advisors found improvements in model by, changing from the Green-Ampt to vertical layers from SSURGO and creating multiple groundwater regions.
 - 12,000-15,000 groundwater nodes for each groundwater region.
 - Siddharth mentioned that he prepared a report on the pilot study concerning the items that he did. He will send a copy of this report.
 - Pending intended use of the model there may be benefit in multiple models with varying detail to support answering different questions. For this project a single model will be developed, but future application may consider more than one.

Watershed overview of surface water features

- Setting the stage to show the watershed characteristics

- Surface water storage features: 20% of the watershed is represented in surface storage features.
 - Most data are from DNR and MCWD wetland survey.
 - DNR has bathymetry for many of the larger lakes, MCWD has bathymetry for a lot of the smaller water bodies.
 - Some DNR data intersects with MCWD data.
 - There are streams/channels/ditches in the watershed that aren't included in the DNR data.
 - 800 water bodies and 6,000 individual wetland features.
 - DNR stream information shows 52 miles of streams; 22 are Minnehaha Creek.
 - Wetlands are mostly in the upper watershed.
 - MCWD measured cross sections for Minnehaha Creek last year and gave data to HDR. They are open to collecting more data if needed. Gaps in cross section locations are typically at locations of recent built projects which have project specific data.
 - Consider how to merge the surface and bathymetry and cross section data.
 - It is important to be as detailed as possible when building the 1D channels, as they are difficult to edit if any changes arise. 2D meshes are easy to change but 1D features are not. If the 1D stage storage volume does not match the DEM, it can cause issues with the transfer to the groundwater region.
 - Search the data archives before MCWD goes back in the field. There is a GIS layer that is more inclusive (Interfluve).
 - The model needs to characterize the portions of Minnehaha Creek that run through lakes.
 - Need to identify the minimum threshold for surface water bodies to include.
 - Interfluve performed analysis of stream ordering in the District, available online, this information should be downloaded and reviewed for integration into the modeling effort.
 - MCWD has some wetland bathymetry developed through vegetation surveys
- Storm sewer pipes:
 - There are more pipe infrastructure data in the lower watershed; missing data in Edina, Orono, and Medina.
 - As part of a separate effort MCWD identified missing culvert locations and have begun to systematically collect those data for use in the model build.
 - The DNR data does not contain many manmade channels. Drawing in manmade channel links may be required.

4. Workshop 2: Surface Water Model Build (9:50 – 11:40 am)

a. Model Domain and Boundary Conditions

- Modeling tradeoffs

- Core needs: Model should be used for short- and long-term planning, in both flood and drought conditions, with reasonable run times.
 - Localized flooding will be captured; level of detail to be determined.
 - There is a tradeoff between level of detail and granularity of evaluation vs model runtime, model update, and model maintenance requirements.
- Boundary conditions: The hydrologic boundary that drains to the creek is slightly different from the administrative boundary.
 - Follow the hydrologic boundary.
 - Assume no flow leaving the boundaries.

b. 1D Storm Sewer Network

- Determine how to model the storm sewer network, including the level of modeling detail.
 - When determining level of detail, consider what element of the system is the limiting factor causing the flooding. For instance, are the inlets undersized and not able to allow all the water that enters the pipe, is the pipe undersized and not able to convey the flow downstream or is there a tailwater influence resulting in pipe backups.
 - If computational time becomes an issue, each model domain could be further subdivided.
 - One option is to have mapped basins entering into predefined locations along the pipe network such as inlets or manhole locations.
 - Con: flood inundation not mapped upstream of the location where water enters the 1D network.
 - Pro: limits 2D mesh, improves runtime, and depending on size of mapped basin most of the inundation may be post-processed from the model results at the inlet/manhole locations. Does not remove any input data resolution.
 - Consider modeling 2D mapped basins with 1D node outlets.
 - Blue spot method to identify the upstream limits of storm sewer inclusion proposed by Siddarth
 - Start with a 2D mesh over model area, identify blue spots (depressional areas of flooding that would be unrecognized if the pipe network was omitted), define “blue spot” as new mapped basin location with extended 1D network to assure that these flood-risk areas are accurately accounted for in the model.
 - Consider reaching out to individual communities to review these “blue spots” to confirm they have history of flooding and to increase early confidence in the model.
 - Include Groundwater in this analysis.
 - Consider using pond control volumes instead of mapped basins.
 - Pro: Allows visualization of flooding within model.

- Con: Omits lag time and assumes precipitation is immediately at the connection with the 1D network.
- Many urbanized communities are looking to upsize pipes. Consider how to model proposed upsizing of pipes.
 - Modeling mapped basins would allow upsizing pipes, but not the addition of grate inlets.
 - Start with 2D mesh, then make mapped basins for the areas that are not known to flood. For the areas that are known to flood and/or convey flow maintain the 2D mesh.
 - Brian noted most communities are targeting 12" diameter pipes and larger for upsizing. This could be considered to support identification of which conduits should be included in the model along with reviewing "blue spot" locations as described above.
- MCWD interested in reviewing q blue spot exercise with initial model setup/results with some of the downstream watershed communities (St. Louis Park, Edina, Mpls) to correlate their known flood areas with model flood areas (blue spots). HDR to create plan for model progression to "blue spot" identification. MCWD to create a plan for scheduling community involvement relative to project model schedule – likely between initial and final model build. Community involvement/engagement is important and may need to occur in parallel with continuation of the model build, calibration, and validation to deliver a final product on schedule.

c. Overland Flow

- Overland flow regions:
 - HDR presented preliminary overland flow regions for the lower watershed, which included approximately 50 individual regions.
 - Warren recommends breaking the lower watershed into less overland flow regions (3 max). Warren noted that having separate overland flow regions doesn't speed up the calculations because these can be done using parallel cores solving the finite volume equations. It's the groundwater regions that need to be run on the same processor because of the matrix it is solving. Siddharth and Warren recommended multiple overland regions if you want to see the volume of flow from the regions, otherwise, a single OF region may suffice.
 - The 2D mesh can be varied in the level of definition (coarser vs. finer mesh) to account for the different regions. More definition can be provided to an important area even if only 1 OF region is used.
- 2D elements such as breaklines and breakpoint patterns are defined in each overflow region. Re-specifying mesh generation parameters for many overland flow regions can become cumbersome if many overland flow regions are delineated.

- Wetlands and open sheet flow areas may not need mapped basins if it is more appropriate to use rain-on-grid. These areas will be defined during model build as-needed.

d. 1D vs. 2D Runoff, Storage, and Channels

- The mapped basin approach will not sacrifice resolution.
- Siddharth suggests pond control volumes for wetlands.
- How to capture Lake Minnetonka in the model:
 - Use separate pond control volumes connected by bridges.
 - Level pool for each pond control volume.
- We could have a depth storage curve for surface water bodies but without bathymetry, the groundwater interactions may be inaccurately modeled.
- Where there isn't good bathymetry Warren recommended editing the terrain so the bottom of the pond is at least 5 feet below the elevation that the water will never get below. In features anticipated to always be wet, the terrain needs to remain wet through the full run period. Need a good understanding of wetlands' live storage and outlets.
 - Siddharth: There are online high-resolution datasets that can help determine whether a wetland is wet or dry.
- Can include pond control volumes to represent stormwater treatment facilities within mapped basins.
 - If water pools on the surface for extended periods, a pond control volume would accurately handle seepage into the ground.
- How far upstream to include 1D channels vs overland flow pathways:
 - Treat the channel as a 1D control volume if the control volume can easily be delineated. If not, use a break line in the DEM.
 - Not including 1D channels might end up being more work.
 - Siddharth recommends using 1D channels where the range of flows is contained within the 1D channel section.
- Fine scale models often are delineated to go to swales instead of impervious areas, but this model will not be that detailed.

5. Workshop Outcomes:

Technical topics where decisions were made during the workshop:

- Model domain: It was decided that the model domain will be the watershed's hydrologic boundary.
- Bathymetry: Integrate bathymetric data with LiDAR into a continuous topo-bathy dataset instead of using just stage storage data at a storage feature (i.e. pond/wetland).
- 1D Channels: Use 1D channels far enough upstream to where the topographic data makes it difficult to define a channel.

- 1D Pond Control Volumes: Use 1D Pond Control Volumes in all continuously wet storage features (lakes, ponds, wetlands).
- Lake Minnetonka: The separate portions of Lake Minnetonka will be modeled as separate pond control volumes connected by bridges, culverts, or simple channels. Exact split was not defined.

Technical topics where a direction was identified, but specific decisions were not made within the workshop – these will be further reviewed with the technical team after the approach is advanced:

- 1D vs. 2D modeling: a blue spot identification approach was identified to support selection of 1D storm sewer extents, and locations of localized flooding. Additionally, this information would support selection of mapped basin vs. 2D overland flow areas and whether pond control volumes would be valuable to map inundation in these areas.
- Overland flow regions: It was suggested that the lower watershed use a limited number of overland flow regions, with Warren suggesting 3 or less may be a reasonable starting point.

Technical topics that have been identified but ongoing discussion will be required with the technical team:

- Minimum water body size: through Task 3 progression HDR and MCWD will determine the minimum size threshold for which water bodies to include in the model.
- Bathymetry: Define best method to identify and merge bathymetry with cross section data.
- Localized flooding: Create methods for identifying/verifying the locations of localized flooding.

Action Items:

- HDR
 - o Advance and review plan for “blue spot” exercise.
- MCWD
 - o Develop plan for engaging partner communities to identify localized flooding locations where more refined modeling may be of interest.
- Siddharth:
 - o Send a copy of the pilot study report.

Appendix A-3 Workshop 2a Meeting Notes

Short Term Evaluation

Instructions

1. Review Surface Water Model Approach Pros and Cons MS Word Document
2. In below two matrices, characterize how well each surface water model approach would perform relative to each of the objectives. Use one of three classifications: negative, neutral, or positive. Include a text description justifying each classification.
3. Prepare to discuss at the workshop 12/17/2024
4. Provide matrix spreadsheet to HDR (nicholas.thomas@hdrinc.com) prior to workshop for documentation purposes.

Definitions

Local Flooding: Flooding due to conveyance limitations in storm sewer network

Regional Flooding: Flooding on receiving waterbodies (Example: Minnehaha Creek, Six Mile Creek, Lake Minnetonka)

Evaluation Matrix

Characterization of flood extent and duration using *NOAA Atlas 14 precipitation events and future precipitation event based scenarios*.

Objectives	Surface Water Model Approach		
	Mostly Mapped Basins	Mostly 2D Rain on Grid	Hybrid
Capability to identify and understand local flooding areas <i>See local flooding definition</i>	OVERALL - Neutral MCWD - Near-Neutral/Negative . May miss some flooding in areas where there are many small pipes. Challenges with processing/visualizing information. SS - Neutral . Doesn't account for water getting 'stuck' within a node. Challenges determining where flooding occurs within node if it is flooding. Fairly easy to change areas to 2D/Hybrid once this is implemented. Suggested development of Mapped Basins regardless of approach. WM - HDR - Neutral , delineated subbasins may have additional value to stakeholders.	OVERALL - Positive WM - Positive . Still requires thoughtful placement of model elements, 2D isn't a solve-all. Saves model setup time compared to Mapped Basins. SS - more difficult to change from 2D to Mapped basin once a model area is built. HDR - Positive , ease of evaluation/interpretation of results. Requires need to include denser 1D network, related to laterals, etc.	OVERALL - Neutral HDR - Neutral/Negative , introduces subjectivity, inherit model complexity and inconsistency, difficult to manage explain choices to stakeholders MCWD - Neutral/Negative - Hybrid regions may be necessary depending on lack of data. SS - WM - Positive . Should include clear definitions of what is mapped basins vs. what is 2D. ie 2D in non-dendritic areas and known flooding areas.
Capability to identify and understand regional flooding areas <i>See regional flooding definition</i>	OVERALL - Positive MCWD - Positive , lower watershed does not include much surface storage; regional flooding is driven by 1D conveyance SS - ease of calibration if data is available. WM - Neutral , requires more care when defining river channels. HDR - Positive , stage area nodes can be cut directly from surfaces, compared to a 2-d approach that is limited by cell-size.	OVERALL - Positive MCWD - Positive SS - difficult to calibrate unless fine resolution data is available. If lake-governed water level causes water to dynamically seep out into urban areas a 2D model will be able to more easily identify this. WM - Positive , Advantage for when riverine flooding flows out of bank. HDR - Neutral ,	OVERALL - Neutral MCWD - Neutral SS - Positive , simple 1D hydrology for feeding basins to provide flow conditions, ~50% runtime efficiency increases compared to fully 2d approach. WM - HDR - Neutral , concerns with stakeholder interpretation of why certain areas are different than others, added time to define hybrid approach.
Evaluate regional policy or stormwater practice implementation <i>Examples: policy regulation scenarios, regional application of best management practices, changes in pipe size or intake structure</i>	OVERALL - Positive MCWD - SS - Positive/Neutral , may require additional postprocessing to help <i>identify</i> policy changes. WM - Positive Requires postprocessing for impacted structure evaluation. HDR - Easiest to iterate scenarios where there are changes in storage. May require less post-processing for evaluation of structures impacted.	OVERALL - Positive MCWD - SS - Positive , May be able to more easily and rapidly identify <i>why</i> things are happening beyond just <i>that</i> things are happening, when compared to Mapped Basins. WM - Positive . Requires postprocessing for impacted structure evaluation. HDR - Although small scale, 2D would allow for better analysis of improvements to curblines.	OVERALL - Positive MCWD - SS - Positive WM - Positive HDR -
Evaluate planned individual regional scale projects <i>Examples: regional detention, wetland complex, new housing development</i>	OVERALL - Positive MCWD - Positive . Easiest to use in undeveloped areas. Easiest to incorporate large development scenarios SS - Neutral . The impact of changes on the results may be magnified compared to 2D approach, since things are lumped. WM - Positive , easiest (but not by much) to incorporate regional scale projects due to the nature of the computational network. HDR - Positive Ease of incorporating design iterations.	OVERALL - Positive MCWD - Positive . May lead to better results in urban areas. SS - Positive WM - Neutral , need to be mindful of changes to computational network when comparing pre/post scenarios. Difficulties using the subset-extract tool. HDR - Neutral Advantages to detailed design, but may be cumbersome during design iterations.	OVERALL - Neutral MCWD - SS - WM - HDR - Neutral
Describing groundwater/surface water interaction <i>Examples: Impact of groundwater on initial and continuous surface storage, impact of groundwater on baseflow conditions</i>	OVERALL - Negative MCWD - Negative SS - Negative WM - Neutral . Requires more effort than 2d HDR - Negative . In known areas of interest, 2D would be used.	OVERALL - Positive MCWD - Positive SS - Positive WM - Positive HDR - Positive . Excels at GW/SW interaction	OVERALL - Neutral MCWD - Neutral SS - Positive WM - Neutral HDR - Neutral

Lower focus compared to regional policy

*MCWD is based on Brian Beck, did not confer with Becky/Kate.

Long Term Evaluation

Instructions

1. Review Surface Water Model Approach Pros and Cons MS Word Document
2. In below two matrices, characterize how well each surface water model approach would perform relative to each of the objectives. Use one of three classifications: negative, neutral, or positive. Include a text description justifying each classification.
3. Prepare to discuss at the workshop 12/17/2024
4. Provide matrix spreadsheet to HDR (nicholas.thomas@hdrinc.com) prior to workshop for documentation purposes.

Definitions

Local Flooding: Flooding due to conveyance limitations in storm sewer network

Regional Flooding: Flooding on receiving waterbodies (Example: Minnehaha Creek, Six Mile Creek, Lake Minnetonka)

Evaluation Matrix

Characterization of flood extent and duration using long term historic precipitation and future climate projections.

Objectives	Surface Water Model Approach		
	Mostly Mapped Basins	Mostly 2D Rain on Grid	Hybrid
Capability to identify and understand local flooding areas <i>See local flooding definition</i>		MCWD - 2nd Phase model will be a regional/long-term model, after localized flooding is understood. Exacerbates the runtime, questions how much benefit this has. Infiltration in the lower watershed becomes more important. SS - may want to look at simplifications to 2d areas during long-term model.	
Capability to identify and understand regional flooding areas <i>See regional flooding definition</i>			
Evaluate regional policy or stormwater practice implementation <i>Examples: policy regulation scenarios, regional application of best management practices, changes in pipe size or intake structure</i>			
Evaluate planned individual regional scale projects <i>Examples: regional detention, wetland complex, new housing development</i>			
Describing groundwater/surface water interaction <i>Examples: Impact of groundwater on initial and continuous surface storage, impact of ground on baseflow conditions</i>			

Appendix A-4: Workshop 3 Meeting Minutes

<i>Project:</i>	MCWD 2D Model Build	
<i>Subject:</i>	Workshop 3: Groundwater Model Build	
<i>Date:</i>	Thursday, August 08, 2024	
<i>Location:</i>	HDR Office Conference Room 6A 1601 Utica Avenue South Suite 600 St. Louis Park, MN 55416-3400	
<i>Attendees:</i>	Brian Beck (MCWD) James Wisker (MCWD) Becky Christopher (MCWD) Rebecca Neal (MCWD) Siddharth Saksena (VT) - Virtual F. Warren McKinnie (Streamline) - Virtual Kelton Barr ()	Andrew Judd (HDR) Nick Thomas (HDR) Ryan Fucci (HDR) Alex Miller (HDR) Cody Barrett (HDR) Ken Trefzger (HDR) - Virtual Amber Ritchie (HDR) - Virtual

1. Introductions to New Members (9:00 - 9:10 am)

2. Workshop 3 Overview (9:10 – 9:20 am)

Workshop 1 Review:

- Our goal is to develop a watershed model that represents short and long-term conditions well and serves as an effective planning tool for the future.
 - Long-term analysis: Understand water balance, including surface and groundwater interactions, under wet or dry cycles.
 - Short-term analysis: Evaluate the impact of specific rainfall events on flooding and stormwater infrastructure performance.
- Watershed model applications: Evaluate future policies or projects at a watershed or localized scale, assess impacts of changes (climate, operations, land-use), and gain stakeholder acceptance.
- A key connection of Workshop 1 (Goal Setting and Prioritization) to Workshop 3 (Groundwater Model Build) is appropriate characterization of the groundwater/surface water interactions and the model's ability to represent low flow drought conditions.

Workshop 3 Objectives:

- Discuss and develop framework for decision making throughout the model build process.
- Priorities for the Groundwater elements of the model
 - The groundwater elements can reproduce watershed water balance
 - Regional & localized variability can be captured by the model

- It's unclear at this point how well we'll be able to predict localized flooding on a property/parcel scale due to groundwater

3. Lessons Learned from Pilot Study (9:20 – 9:40 am)

- A set value below the DEM is not a good way to approximate the initial water table elevation
 - o Leverage known water table elevations such as lakes/monitoring wells whenever possible
 - o Water table results from a simulation without rainfall can be reimported as a more stabilized initial condition.
- Depth to bedrock and confining layers in the glacial material above the bedrock will impact how much storage space is available for the surficial aquifer

4. Workshop 3: Groundwater Model Build (9:40 – 10:40 am)

Watershed overview of groundwater features

- Subsurface dynamics vary between the upper and lower watersheds
 - o Upper watershed: Many of the quaternary deposits in the upper watershed are made up of thick fine-grained tills acting as aquitards, resulting in limited connectivity to the deeper layers including connectivity to the bedrock. Significant municipal water supply pumping does occur within the bedrock layers beneath the upper watershed (Prairie du Chein and Jordan). In the upper watershed, water table changes and vertical fluxes occur over long timescales and seasonal changes are muted.
 - o Lower watershed: Prevalence of coarse-grained layers in the quaternary deposits result in more infiltration and vertical water transfer. Seasonal changes in water table can be observed.
 - o Some of the bedrock aquifers (Platteville formation) limit vertical movement of water but are highly transmissive laterally and are colloquially noted as "aquitardifers".
 - o Portions of Minnehaha Creek are gaining and other portions are losing
- Modeling Considerations
 - o Bedrock and composition and thickness of overlying quaternary deposits can help indicate flow rates through layers.
 - o Watershed locations with increased prevalence and thickness of near surface sand layers, indicating increased SW/GW connectivity, should include a deeper groundwater model domain which may consist of multiple coarse and fine-grained layers. Where fine-grained tills are thick and vertical water movement is limited, we may be able to simplify the modeling approach.
 - o There is not anticipated to be a significant amount of conductivity between the upper and lower watershed groundwater.
 - o Tritium concentration can guide "age of water" and time-of-travel assumptions.
 - o Groundwater modeling should focus on the surficial aquifer.

- o Surface water cells and groundwater mesh dynamically communicate, integrating where infiltration occurs due to land use variability, and where ground water emerges due to rising water tables. and other effects.

General Discussion

- This modeling is important as it allows the District to shift from narrative-based discussions to data and model-driven groundwater analysis.
- The team should document trade-offs in technical modeling decisions and communicate them in a way that non-technical people can easily understand. Consider creating an evaluation matrix for high-level decisions. Another option would be a summary document following the model build that provides a non-technical narrative of these decisions.
- Create a modelers log which tracks incremental decisions in the model build at a more granular scale than the guidance documentation.

2D Groundwater Modeling Introduction

- Groundwater mesh contains horizontal cells connecting the surface to model bottom
 - o Bedrock can be modeled with either homogeneous soil or discrete layers.
 - o Updated Hennepin County data and metadata can be utilized.
- Areas where higher model resolution is desired may be good locations for break out models and future evaluations:
 - o In historical channels and wetlands which have been developed over time, especially around the chain of lakes where groundwater has caused flooding.
 - o Where known perched groundwater tables exist. Some neighborhood-level data exists; more can be collected as needed.

Groundwater Model Lateral Extents

- Groundwater and surface water mesh domains don't always match.
 - o Lateral limits must be paired with a boundary condition
 - They may be influenced by the level of confidence in our assumptions.
- It would be valuable to locate the preliminary lateral extents outside of the surface watershed boundary. This allows for the lateral limits to be better aligned with locations of known boundary conditions (head, flux, no flow) and for uncertainty in these inputs to be located away from the area of interest (watershed).
- Known head conditions along the lateral extents from measured groundwater levels in wells and stages from surface water bodies would be appropriate boundary conditions.
 - o Siddarth: Using as many known points as possible will be helpful
 - o Kelton: Caution against using the Mississippi as a known point. It's much lower in elevation than most of the Minnehaha Creek Watershed. Groundwater is raised within the domain by the creek.
 - o Groundwater materials can be refined near Minnehaha Falls to mimic connectivity at this location.

- A realistic average head condition that can be applied across all simulations could be favorable to collecting historical data for every simulation. However, it may depend on the influence of boundary conditions heads to the model results. The boundary heads may need to vary within a simulation (e.g. seasonally) or between different simulation runs to capture initial conditions and system response within the simulation period appropriately.
- Interpolations can be made between known boundary condition head points.
 - o Siddarth: A function-based interpolation may be more representative than a linear interpolation. Include multipliers at each point that capture seasonal variability.
 - o Long-term well records should be analyzed to support multipliers by location. It won't capture all local fluctuations but will be better than large linear interpolations.

Groundwater Model Bottom Extents

- Timescale of simulations should be considered in the bottom extent decision.
 - o If we have future scenarios without localized flow systems, we might want to include some bedrock. If future scenarios are localized, we might want to go shallower.
- In the lower watershed, a combination of Platteville and lower till could be ok.
 - o Pilot study found that some mid-level sand layers are important for hydrogeology, it may be beneficial to include those.
- Siddarth: Abrupt changes between vertical layers could be a problem
 - o A 10' change between adjacent GW cells may work, but a 100' change would lead to errors.
- A confining till layer may be harder to identify and create within the model. It would come with additional uncertainties.
- In lower watershed where there's more permeability, we want to make sure its deep enough to capture the surface/groundwater interaction
 - o Kelton: The deeper the model extends, the more there is to consider.
 - Ex.) pumping from municipalities outside the domain.
- Metro model 3 may not be very useful as the surficial layers were intended to account for reasonable infiltration to support groundwater recharge rather than localized near surface flow systems.

Subsurface Representation: Capturing Surficial Layers

- Kelton: Through an MCES project in 2020, HDR and Kelton applied a process to capture quaternary layers. The subsurface characterization could use the same approach
 - o Took metadata about 3D info in aquifers and aquitards
 - o Assess downward flow (based on thickness of material, hydraulic gradient, and conductivity)
 - o Calculate aggregate vertical permeability
 - o Calculate overall vertical permeability and time of travel
 - Can calibrate time of travel result with tritium concentration in well data

- o Create a time-of-travel map for across watershed. We could apply same approach to the vertical model to characterize subsurface.
- Would homogenous system work? Do we need more discrete layers?
 - o SSURGO data only works for certain thickness and is assumed to be leveraged for the nearest surficial soils.
 - o Homogenous system:
 - Potentially improve runtimes but may less accurately capture GW flow
 - Minimal effect on short term flooding scenarios
 - Less complexity, but assumptions may lead to unrealistic response within the model.
 - o Discrete layers:
 - Groundwater finds a more realistic path of least resistance
 - More accurate for long-term scenarios
 - We may want multiple layers in lower quaternary layers
 - Siddarth: Stratify SSURGO layers as much as possible because there's methodology and data available. There are lots of options in infiltration zones
 - Delineating the creek and outside boundaries thoughtfully may help define discrete zones inside and shrink runtimes
 - o Siddarth: My current preference is to use homogenous zones for better surface water results. However, if we're more interested in groundwater levels long term, multiple layers may be better. Depends on what question we want to answer
 - o James: We care most about surficial aquifer layer in this project
 - o Kelton: Residence time is not the most important thing because head at the upper table will impact those times immediately.
 - o Brian: We need to come up with a rationale and document how we define the layers to best service the model goals
 - Test how much vertical layer refinement influences runtimes and decide on an approach from there

Subsurface Representation: Groundwater Flow Regions

- Groundwater flow regions to be delineated for optimal computational speed and physical representation
 - o Groundwater regions cannot communicate with each other except at location of surface ponding where water can exchange through the surface domain, or if a boundary condition is supplied.
 - o 12k-15k cells per region is suggested for computational efficiency.
 - o Upper watershed contains disconnected lakes
 - Warren: Using creek locations is a reasonable approximation for GW region divides. Since the groundwater regions can't communicate with each other it is valuable to look at water tables over time to see if there's a significant difference between them. If there is, you may decide to combine regions to make it more physically representative.

- Siddarth: Run a preliminary simulation run to see exported water table results from one simulation and import and new initial condition. Sometimes using smoothing between regions and starting the water table in a more realistic location can help alleviate large discrepancies between regions.
 - Brian: majority of creeks dry up in summer, so lakes may be best approximation.
- SSURGO ranges for subsurface parameters are acceptable
 - o Brian: There are permits which include additional infiltration/geotechnical data, but it is likely more work than it's worth
 - o Siddarth: SSURGO is my go-to and the best starting point.
 - o Warren: If there's no existing data source that's better, stay with SSURGO. You can always calibrate later. However, porosity in SSURGO is typically higher. That parameter may need to be modified in the model. Saturated conductivity and SSURGO conductivity values are usually the first parameters to adjust in calibration.
- Additional Closing Remarks:
 - o We didn't dig into data collection or assumptions on surface water (ponds and wetlands). Followup with technical advisory group as this moves forward.
 - o There will be more opportunities to collect data after the initial model build

5. Workshop Outcomes:

Technical topics where decisions were made during the workshop:

- Subsurface Initial Parameters: Use SSURGO data for near surface and Geologic Atlas Data, Homogeneous or Layered, from the HDR (2020) study.
- Groundwater Model Lateral Extent: Approach to include a groundwater domain that is larger than the surface domain was chosen. The location should be collocated with areas of known head (waterbodies or well locations with groundwater levels). The exact boundary requires refinement but a tentative was defined based on nearby waterbodies and wellpoints.
- Groundwater Model Lateral Boundary Condition: Use known head as lateral boundary points with interpolation between known head locations. Develop either longer term average or seasonally varying boundary condition depending on range of variability and influence on model results. Consider a non-linear function to interpolate between known head locations.
- Subsurface Representation (near surface): Upper quaternary or near surface soils will be represented using SSURGO layering and initial parameters.

Technical topics where a direction was identified, but specific decisions were not made within the workshop – these will be further reviewed with the technical team after the approach is advanced:

- Groundwater Model Lower Extent: Lower model domain should consider either bedrock or a confining till layer.

- Subsurface Representation (deeper): Lower quaternary soils may be layered based on Geologic Atlas Data or homogenized similar to the process applied by HDR (2020).
- Groundwater Flow Region Boundaries: Boundaries should be set along creeks, streams, lakes, and other features that are continuously wet or frequently wet. Exact locations have yet to be defined.

Technical topics that have been identified but ongoing discussion will be required with the technical team:

- Groundwater Model Lower Boundary Condition: It is anticipated that a seepage or flow loss boundary condition will be used for the lower boundary, but additional review is required to determine appropriate source of information and selected seepage rates.

Action Items:

- Documented in model outcomes. HDR to advance and review with technical team.

Appendix A-5 Workshop 4 Meeting Minutes

<i>Project:</i>	MCWD 2D Model Build	
<i>Subject:</i>	Workshop 4: Calibration and Validation	
<i>Date:</i>	Wednesday, April 09, 2025	
<i>Location:</i>	Virtual	
<i>Attendees:</i>	Brian Beck (MCWD) Siddharth Saksena (VT) F. Warren McKinnie (Streamline)	Andrew Judd (HDR) Nick Thomas (HDR) Alex Miller (HDR) Sam Brandt (HDR)

1. Introductions (1:00 - 1:05 pm)

2. Workshop Overview (1:05 – 1:15 pm)

Review of Workshops 1-3

- Recapped surface and groundwater model builds and methods
- Siddharth asks for confirmation HDR is still using 1D channels, Nick confirms

3. System Response Overview (1:15 – 1:30pm)

System Response/MCWD Overview from Brian

- Lower watershed largely lacks storage, wetlands filled in with development
 - Upper watershed has more wetlands/storage
- Soils in lower watershed generally allow for more infiltration and/or are developed and may not be reflective of the SSURGO classification
- Water Level Monitoring
 - Peaks are more intense as you travel down Minnehaha Creek
 - Brian notes that the upper portion of the lower watershed, just downstream from Gray's Bay Dam, still has notable wetlands which result in peak flow dampening
 - Wetland water levels show evapotranspiration is a driver of system response in summer months.
 - Uncalibrated hydrologic models have historically overestimated peaks and underestimated base flow
- Edina and Minneapolis have much higher runoff
 - Storage in Minnetonka and SLP seem to reduce storm peaks
 - A or B soils in lower watershed but lots of compaction
- MCWD has built both P8 and StormWise models that ended up having similar results, both requiring increased infiltration to improve water balance, baseflow, and peak flow representation.

Comments

- Siddharth notes that understanding future operation of the dam will be important
 - o Brian says operations plan is based on elevation level of the lake
- Brian has calculated continuous dam discharges going back to 2018 using lake levels and tailwater conditions.
- Siddharth asks how HDR will calculate ET – important for the upper watershed
 - o Brian has ET calcs based on real time data
 - o University of Minnesota has an ET reference used to check calcs
 - o Siddharth says satellite-based data for ET may be useful
 - o Project team will rely upon ET calculations validated with U of M measured data. Where anomalies exist or as a watershed wide model validation, satellite data may be used.
- Warren says that PCVs are crucial for calculating ET from lakes in mapped basin type surface water modeling

4. Calibration & Validation Approach (1:30 – 2:00 pm)

Calibration and Validation Definitions

Strategy Overview

- Warren says that SSURGO saturated conductivities tend to be too high compared to actual conditions
 - o May want to reference geotechnical logs local to the project
 - o Brian suggests finding or collecting data on representative soils within the watershed
 - o Initial models will be parameterized with SSURGO representative parameters with the anticipation they will be refined in calibration. Refinement will rely upon SSURGO noted parameter ranges and in-situ infiltration testing where available.
- Siddharth emphasizes the importance of having representative results for both high and low flow events
 - o Important to consider how parameters impact each other
 - o For large scale models, focus on making sure the physics and model connectivity are accurate then adjust model parameters at the end
- Warren underscores the importance of calibrating to both extremes and low flows
 - o He further suggested that related parameters should be adjusted together to avoid unrealistic inconsistencies in simulated results.
 - o 2D models typically are much faster to calibrate as they better reflect the physics

Sensitivity Analysis

- Nick notes that HDR will plan to consider related parameters in the calibration and potentially as part of the sensitivity analysis per previous discussion
- Warren says that porosity and hydraulic conductivity may be impacted by urban compaction/development
 - o Alex asks if HDR should set up map layers to account for this

- Warren says urban soils should generally be unclassified, could change the map zone to indicate urban areas
- o Initial model build will rely upon SSURGO classification and look to refine these inputs relative to urbanization as part of the calibration/validation task
- Warren says that for initial conditions, spin up (~1yr) the normal conditions before running
 - o Difficult to separate ground and surface water here
 - o Siddharth says HDR can simplify ground surface here for computational efficiency
- Nick asks if we are missing parameters from our list of considerations
 - o Siddharth says impervious percentage has a big impact on the runoff generation and is most relevant to a mapped basin approach since the 2D approach inherently describes the surface variability.

Calibration Process

- Nick asks for comments on the calibration process slide
 - o Warren says, for mapped basins additional calibration parameters may include the unit hydrograph and time of concentration
 - o Siddharth says the mass balance error should be reduced before moving into calibration (<5%, Warren shoots for <2-3%)
 - Mass balance error is evaluated at each node and on a model wide basis and accounts for all inflows, outflows, and storage in the model.
 - Nick confirms with Warren that this is driven by the numerical solution of the model and can be addressed through improved mesh generation (short sides) and connectivity of different model, amongst others.
 - o Siddharth asks what time window we plan to use for our calibration
 - Brian agrees with Nick that we cannot be particular about specific event at this time
 - Events should be selected based on specific goals for each event
 - Siddharth says HDR should aim for different types of representation, timescale is important as well
 - Andrew says that HDR may want to select events that can isolate the upper or lower watershed
 - Siddharth likes the idea of selecting an event that isolates the lower watershed

5. Data Type, Location, & Availability (2:00 – 2:30 pm)

Review of Data Availability

- Brian says that MCWD has added ~10 new sites since sending this data over last year (for surface water at least)
 - o Nick confirms that most new gages cover 2024/2025 so far

- o 8 or more of the stream stage sites have rating curves developed
 - In the lower watershed surface water graphic, the ones we have highlighted should have rating curves
 - Mill Pond in Edina has a weir which MCWD has used to estimate flow
 - Warren suggests if not matching observations well, reviewing model link results to determine if flows are backwater influenced.
- o Brian says that they have project specific pipe flow, particularly in the lower watershed which could be used to get a better understanding of runoff/response
- o Andrew asks if the MCWD gages will be maintained for the foreseeable future
 - Brian says not necessarily but likely at least as long as the project requires
- o Brian says we could potentially install level sensors to document how water levels differ across Lake Minnetonka
- Alex asks about overlap between calibration events and gages
 - o Nick says that HDR can vary which gages we are leveraging for calibration based on events
 - o Andrew says HDR should aim to hold 2-3 gages across calibrations with different events for consistency
 - o Siddharth says HDR should do some analysis on data from gages (flow and precipitation) to see if patterns/responses have changed during the period of record
 - o Siddharth warns that Atlas-14 only captures data through 2012 and won't be representative of more recent conditions
 - o Brian says we have both the driest and wettest period on record (within the last ~6 years) at many gages
- Siddharth says HDR should have different calibration quality criteria for surface water vs groundwater
- Brian says sediment cores have been collected for lake bottoms that can give an indication of sediment type
 - o University of Minnesota may have a repository of core data

6. Historical Events to Consider

Event Types to Consider

- Brian says HDR should consider how calibration and validation events are delineated. Calibration events should target a particular system response, where validation events may try to encompass all of the critical system response characteristics
- Warren asks if there are any events Brian wants to include, specifically
 - o 2014 flood of record, multiple large events in a row. Warren suggests including events like this which resonate with stakeholders.

- o Siddharth recommends including events that have caused nuisance flooding that may be muted if we only focused on the creek
- For calibration, team agrees that it is most effective to simulate upper and lower watershed responses and perform calibrations independently
- Andrew says HDR should consider spatial rainfall patterns when targeting events
- Nick asks if the same events should be chosen for the upper and lower watershed
 - o Siddharth says to consider doing an analysis of the rainfall time series for each cell to understand spatial-temporal variability
 - o Group generally concurs that the upper and lower do not need to use the same events
- Brian recommends also looking for events that have homogeneous coverage across the watershed but also may capture localized hot spots that could get larger watershed response and local nuisance responses.

7. Performance Metrics (2:30 – 2:40 pm)

Statistical Performance Metrics

- Warren recommends including root mean square error, mean error. Siddharth expands that these metrics may be normalized so events can be compared more readily to one another.
- Siddharth says that, for hourly scales these metrics may be correlated in time and bias metrics. “Very good” for a daily scale could be “good” for an hourly scale
- Should also look at the log-scale of the time series data to see low flows better
- Siddharth says that for the time series plot (Muddy Creek), if HDR includes multiple events in the time series, we may want to normalize response metrics to rainfall to compare the overall performance

8. Critical Items for Model Build (2:40 - 3:00 pm)

- Siddharth
 - o Likes the approach in general
 - o The more work we do in the build itself will make calibration easier in the end and that calibration only occurs at the very end
- Warren
 - o Storm selection will be important, recommends having a discussion over storm selection before diving too far into analysis
 - o We will probably be pleasantly surprised with the limited amount of calibration needed as we add more detail
- Andrew
 - o Reiterates that we will need to hone in on what calibration parameters we are using and identify where gaps exist in the data we need
- Alex

- o Echoes Siddharth's comments of having a solid model build before calibration
 - o Notes importance of run times on calibration durations and project schedule
- Sam
 - o Improving and untangling stormwater infrastructure data for input to model
- Brian
 - o Representation of storage in upper/lower watershed

Next Steps

- HDR will continue with the model build in close collaboration with MCWD and begin reviewing observed precipitation data relative to stream flow and groundwater response to identify a suite of events for calibration and validation.
- MCWD will provide:
 - o Stream level locations and data installed in 2024 and 2025
 - o Stream rating curves where available
 - o Lake bottom sediment core information
- Technical Advisory Team will be engaged as the model build and calibration/validation continue.



Appendix B – Data Registry

Included as part of the electronic delivery package.



Appendix C – Detailed Data Refinement

Memo

Date: Tuesday, August 04, 2026
Project: 2-D Watershed-Wide Model
To: MCWD
From: HDR
Subject: Appendix C-1: Watershed Boundary Adjustment Process

Introduction

This document details the development of a new lower watershed boundary for better representation of overland flow with respect to the DEM and stormwater infrastructure used in the MCWD 2D Watershed-Wide Model. The ArcHydro extension of ArcGIS Pro, paired with ArcHydro technical papers, was used to delineate storm inlet drainage areas which were aggregated into a final updated lower watershed boundary.

Updated Lower Watershed Delineation

Required Components

1. Watershed DEM
2. Stormwater infrastructure inlets
3. Stormwater infrastructure pipes, for reference
4. Watershed boundary polygon
5. Watershed boundary polyline

First, watershed sinks were identified using sink identification approach 1 in *ArcHydro: Identifying and Managing Sinks*. This workflow requires a watershed DEM and identifies sinks, or depressional areas, that exist in the topography.

1. Sink Evaluation
 - a. This step identifies potential sinks within the watershed. No minimum threshold was used as to have more sinks to select from in the step to follow.
 - i. Input: Watershed DEM
 - ii. Outputs: Sink Polygons, Sink Drainage Area
2. Sink Selection
 - a. Select sinks output from the previous step with an area greater than 100 ft². These sinks will be the base features for delineating watershed drainage areas.

Next, artificial sinks were created by buffering MGIS inlets. These steps utilized section 4.2.1 of *ArcHydro – Stormwater Preprocessing and Analyses*.

1. Buffer Inlets

- a. MGIS inlets contained by and within 500 ft outside of the initial watershed boundary were buffered to 10 ft.
2. Assign Hydro ID to Inlet Buffers
 - a. Run the buffered MGIS inlets through the assign Hydro ID tool.
3. Append Inlets to Sinks
 - a. ArcHydro only requires a HydroID field, so any fields not shared by the buffered inlet and selected sink feature classes can be deleted.
 - b. Run the append tool to combine the inlets and selected sinks into one feature class, now referred to as the sink feature class
4. Dissolve Sinks
 - a. To prevent overlapping sink polygons and, subsequently, grouped sink delineations, run the dissolve tool on the sink feature class.

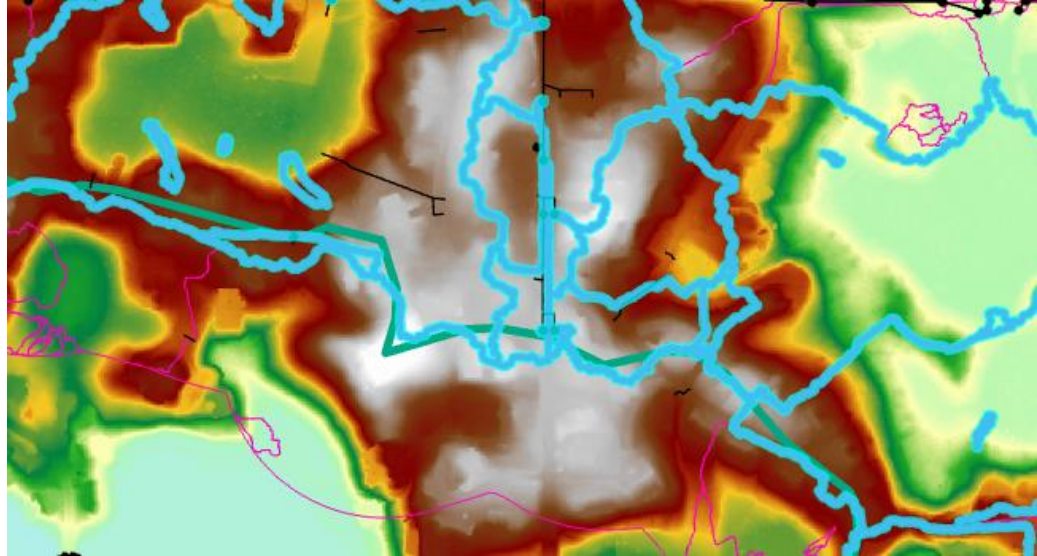
With the sink feature class created, use case 3 of *ArcHydro: Overview of Terrain Preprocessing Workflows* was used to delineate subwatersheds representing sink drainage areas.

1. Create Sink Structures
 - a. Inputs: Sink Polygon Feature Class, DEM
 - b. Output: Sink Polygons, Sink Polygon Raster, Sink Points, Sink Point Raster
2. Add DeepBurn Field to Sink Polygon Feature Class
 - a. Calculate Field
 - i. Field Name: DeepBurn
 - ii. Set DeepBurn = 650
3. Level DEM
 - a. Input: Sink Polygon Feature Class
 - b. Output: Leveled DEM
 - c. Input Fill Elevation Field: DeepBurn
4. Fill Sinks
 - a. Inputs: Leveled DEM, Sink Polygons
 - b. Output: Filled DEM
5. Flow Direction
 - a. Input: Filled DEM
 - b. Output: Flow Direction Raster
6. Adjust Flow Direction in Sinks
 - a. Inputs: Flow Direction Raster, Sink Point Raster, Sink Polygon Raster
 - b. Output: Sink Adjusted Flow Direction Raster
7. Sink Watershed Delineation
 - a. Inputs: Sink Adjusted Flow Direction Raster, Sink Point Raster, Sink Points
 - b. Outputs: Sink Watershed Raster, Sink Watersheds
8. Append Coastal Attachments
 - a. Inputs: Filled DEM, Sink Watershed Raster, Sink Watersheds

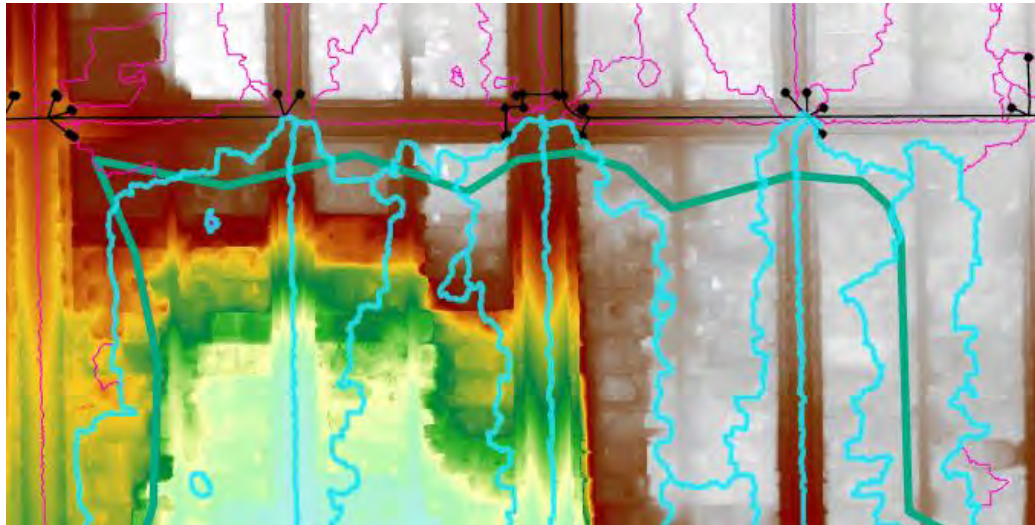
Next, the sink watershed delineation polygons were manually selected with respect to stormwater infrastructure and the existing watershed boundary. Here, stormwater infrastructure

was referenced as not to include inlets that drain outside of the watershed in the new watershed boundary's fringes. See below for examples.

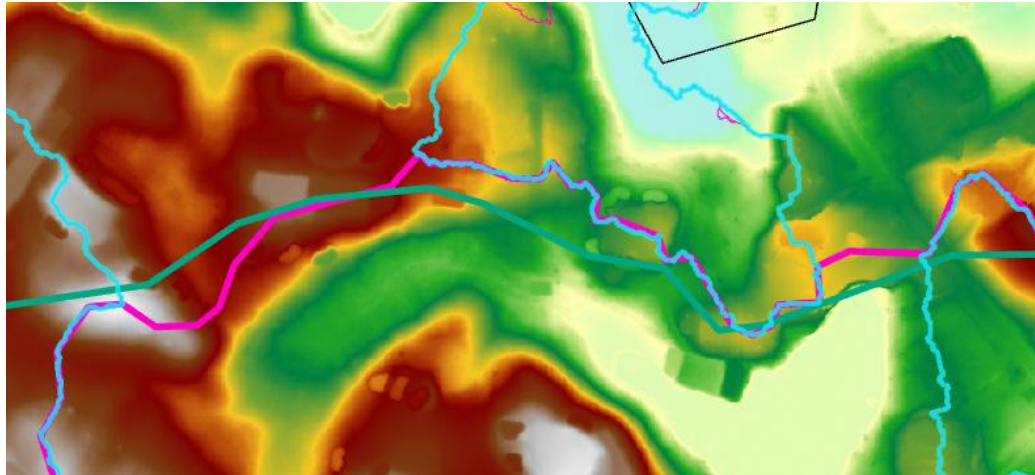
1. General Example (Existing Watershed Boundary = Green, Sink Delineations = Pink, Sink Delineations Selected for New Boundary = Light Blue, Stormwater Pipes/Inlets = Black)
 - a. The existing watershed boundary was referenced during the selection process. Where appropriate, delineations that coincided with the existing watershed boundary were selected.



2. Boundary Change Due to Stormwater Infrastructure (Existing Watershed Boundary = Green, Sink Delineations = Pink, Sink Delineations Selected for New Boundary = Light Blue, Stormwater Pipes/Inlets = Black)
 - a. As seen below, the right center polygon of which portions were included in the initial watershed boundary, was not selected. This is because the polygon drains to an inlet which transports water outside of the watershed.



3. Manual Splits to Sink Delineations (Existing Watershed Boundary = Green, Final Watershed Boundary = Pink, Existing Sink Delineations = Light Blue, Stormwater Pipes/Inlets = Black)
 - a. Where sink delineations connected with the outside of the existing watershed boundary, they were split by referencing the DEM and existing watershed boundary. These split polygons were then selected for use in the updated watershed boundary (see thick pink line below).



Finally, with sink delineations identified for use in the updated watershed boundary, merge all selected polygons. The result is a single polygon representing a watershed boundary that reflects both the DEM and stormwater infrastructure used for modeling.

1. Select all sink delineations representing the updated watershed boundary, including those on the interior.
2. Merge into one polygon
3. Run the Simplify Polygon tool on the new watershed boundary polygon
 - a. Simplification Algorithm: Retain Critical Bends (Wang-Muller)
 - b. Simplification Tolerance: 100ft
4. Run the Feature Vertices to Points tool on Simplify Polygon output
5. Run the Generate Near Table tool on the Feature Vertices to Points output
 - a. Search Radius: 25ft
6. Review and edit the watershed boundary so that it has no vertices within 25ft of one another
7. Generalize to 10ft
8. Visually review the simplified watershed boundary and confirm that it follows high points and does not create conflicts with stormwater infrastructure
9. Export to StormWise

References

- ESRI (Environmental Systems Research Institute). (2019, August). Arc Hydro: Overview of Terrain Preprocessing Workflows. Available online at: <https://www.esri.com/content/dam/esrisites/en-us/media/technical-papers/arc-hydro-overview-of-terrain-preprocessing-workflows.pdf>
- ESRI (Environmental Systems Research Institute). (2019, January). Arc Hydro: Stormwater Preprocessing and Analyses. Available online at: <https://downloads.esri.com/archydro/archydro/doc/Arc%20Hydro%20-%20Stormwater%20Processing.pdf>
- ESRI (Environmental Systems Research Institute). (2020, July). Arc Hydro: Identifying and Managing Sinks. Available online at: https://www.esri.com/content/dam/esrisites/en-us/media/technical-papers/arc-hydro-overview-of-terrain-preprocessing-workflows.pdf?srsId=AfmBOorGY2b6kAi-wmSyk67OHy5rSZfIU9JQBekoVT_rLHiJZ30snq7-

Memo

Date: Tuesday, August 04, 2026

Project: 2-D Watershed-Wide Model

To: MCWD

From: HDR

Subject: Appendix C-3: Land Cover Process

To represent roughness, imperviousness, and evapotranspiration of the surface within the StormWise model domain, a landcover raster is required. Through email coordination with Moore Engineering, it was decided that the watershed's land cover would be best represented with a blend of two land use datasets. The selected datasets were chosen as they receive periodic updates, allowing for future revisions with changing land cover. This document details the steps taken in ArcGIS Pro to develop this raster.

1. Required Components and Background
 - a. National Land Cover Database (NLCD)
 - i. Link: <https://www.usgs.gov/centers/eros/science/national-land-cover-database>
 - ii. Applied for non-developed land uses
 - b. Generalized Land Use (GLU)
 - i. Link: <https://gisdata.mn.gov/dataset/us-mn-state-metc-plan-general-Induse2020>
 - ii. Applied for developed land uses
 - c. Watershed boundary (upper and lower) buffered to two miles
2. GIS Polygon Processing
 - a. In ArcGIS Pro v.3.4, import the NLCD (raster) and GLU (polygon) datasets
 - b. For flexibility, clip each raster using the buffered watershed boundary
 - c. Convert the NLCD to a shapefile.
 - d. Perform a Union of the clipped NLCD polygons and GLU polygons providing a polygon describing the spatial and attribute variability of both input data sets.
 - e. Add an integer attribute to use as a land cover descriptor which will connect to model input tables describing land use characteristics.
 - f. Below attribute values were used for each the GLU and NLCD attributes. GLU highlighted in green (Agricultural, Park, Recreational, or Preserve, and Golf Course) were assumed to be non-developed areas where NLCD land cover descriptions were used.

GLU Description	Attribute Value
Agricultural	100
Farmstead	111
Seasonal/Vacation	112
Single Family Detached	113
Single Family Attached	114
Multifamily	115
Manufactured Housing Park	116
Retail and Other Commercial	120
Office	130
Mixed Use Residential	141
Mixed Use Industrial	142
Mixed Use Commercial	143
Industrial or Utility	151
Institutional	160
Park, Recreational, or Preserve	170
Golf Course	173
Major Highway	201
Major Railway	202
Airport or Airstrip	203
Undeveloped	210
Open Water	220

NLCD Description	Attribute Value
Open Water	11
Developed, Open Space	21
Developed, Low Intensity	22
Developed, Medium Intensity	23
Developed, High Intensity	24
Barren Land (Rock/Sand/Clay)	31
Deciduous Forest	41
Evergreen Forest	42
Mixed Forest	43
Shrub/Scrub	52
Herbaceous/Grasslands	71
Hay/Pasture	81
Cultivated Crops	82
Woody Wetlands	90
Emergent Herbaceous Wetlands	95

- g. Dissolve the shapefile based on the final classification attribute to simplify the resulting GIS file. This shapefile can be imported into the StormWise model.
- 3. Impervious Calculations
 - a. Impervious area is a required model input. Including impervious areas result in direct runoff generation without regard to soil infiltration. NLCD produces an impervious layer representing the percentage of land surface covered by impervious areas at a 30-meter resolution. Zonal Statistic to Table was run using the update land cover shapefile as a basis to run the statistics. The outputs are shown in the table below.
 - b. Directly Connected Impervious Areas (DCIAs) are a subset of total impervious areas and are a model input requirement. DCIA represents areas where impervious surfaces are directly connected to the storm system and would result in increased runoff production. Microsoft building footprints (2025) are continually updated polygon set of satellite derived building outlines. It was assumed in residential land uses that buildings would drain to pervious surface and therefore not be included as DCIA and all other impervious areas would be connected. In commercial and industrial areas the entire impervious area was assumed to be connected. See below table for input DCIA.

Land Cover Description	Land Cover Zone	Impervious %	DCIA %
Farmstead	111	18	9
Seasonal/Vacation	112	4	2
Single Family Detached	113	29	18
Single Family Attached	114	49	30
Multifamily	115	60	38
Manufactured Housing Park	116	48	39
Retail and Other Commercial	120	75	75
Office	130	68	68
Mixed Use Residential	141	75	43
Mixed Use Industrial	142	69	69
Mixed Use Commercial	143	78	78
Industrial or Utility	151	65	65
Institutional	160	47	35
Major Highway	201	60	45
Major Railway	202	62	46
Airport or Airstrip	203	63	32
Open Water	11	0	0
Developed, Open Space	21	11	0
Developed, Low Intensity	22	34	33
Developed, Medium Intensity	23	62	60
Developed, High Intensity	24	86	80
Barren Land (Rock/Sand/Clay)	31	0	0
Deciduous Forest	41	0	0
Evergreen Forest	42	0	0
Mixed Forest	43	0	0
Shrub/Scrub	52	0	0
Herbaceous/Grasslands	71	0	0
Hay/Pasture	81	0	0
Cultivated Crops	82	0	0
Woody Wetlands	90	0	0
Emergent Herbaceous Wetlands	95	0	0

Memo

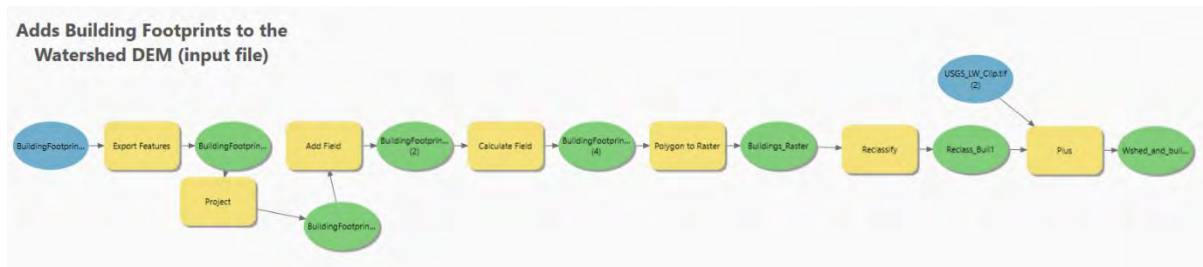
Date: Wednesday, March 05, 2025
Project: 2-D Watershed-Wide Model
To: MCWD
From: HDR
Subject: Appendix C-4: Surface Mesh

1. Required Components:

- a. Watershed boundary polygon
- b. Watershed boundary polyline
- c. Dem buffered to 500ft within watershed boundary
- d. Stormwater infrastructure inlets
- e. Channel Control Volumes (CCVs)
- f. Pond Control Volumes (PCVs)
- g. Groundwater region boundaries

2. Data Preparation

- a. Adjust base DEM to include Buildings. Using Microsoft building outlines, convert to raster and add 10 feet to the DEM at building footprint outlines.
 - i. This adjustment encourages the automated stream delineation procedure to avoid building footprints



- b. Create an accumulation weight raster to simplify breaklines in the upper third of the lower watershed and within parks/natural spaces. This is done with an accumulation weight raster that will force a higher accumulation threshold in these spaces.
 - i. Go through the area within the watershed boundary, creating polygons in the upper third of the lower watershed, defined as the area to the west of US-169, parks/large fields. These polygons will be referred to as natural spaces. In these natural spaces, less breakline detail is required to capture representative flowpaths than in the watershed's denser, more urban areas.
 - ii. Create a copy of the watershed boundary polygon.
 - iii. Run the Pairwise Erase tool on the watershed boundary polygon with the natural space polygons as the erase features
 - iv. Append the natural spaces to the erased watershed boundary polygon.
 - v. Create a field called "raster_weight" in the watershed/natural spaces polygon feature class.
 1. In this field, assign a value of 1 to the non-natural space polygon and a value of 0.1 to the natural space polygons. This

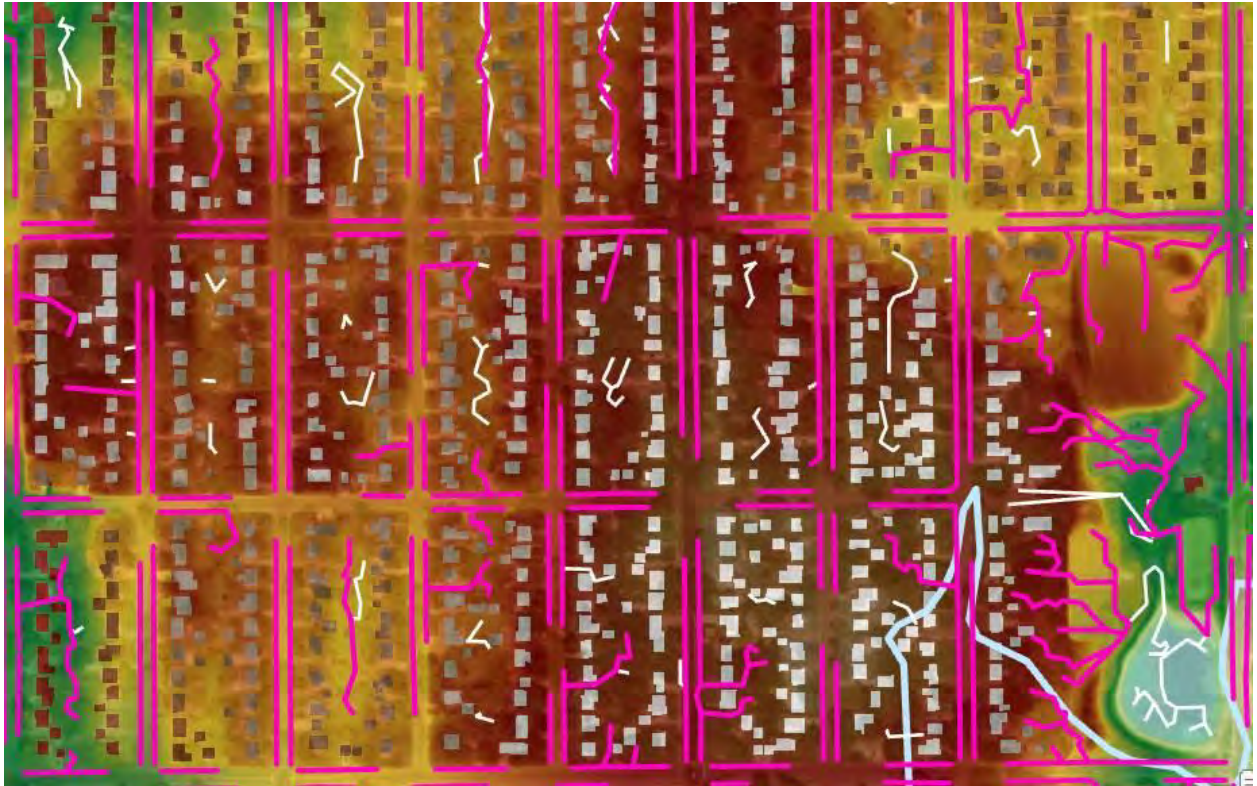
- vi. Run the Polygon to Raster tool on the polygons feature class
 1. Value field: raster_weight
 2. Cell size: 1.64
 - a. This is the cell size of the DEM to be used as input to the Derive Stream as Line tool

- [illegible]

- 2

- ii. 10 feet is the current target minimum (practical) mesh element size, some may necessarily be smaller
- e. End relevant breaklines within 10 ft of outlets
 - i. An automated procedure has been developed to snap delineated end points to inlets. DEM resolution is 0.5 m (1.6 ft). Selection of a tolerance of 10 ft resulting in snapping of auto-generated end points to the appropriate inlet point.

Manual Edits Example: pink lines are edited, and white lines are pre-edit



5. Snap Lines to Points - Automated breakline process results in flow paths that terminate at the raster cell center point where an inlet is located. However, the breakline does not end at the inlet point exactly. Without adjustment, stormwise would use breakline endpoints and the inlet points (as 1D-2D connections) and generate very small cells. HDR developed a simple script to snap the final breakline vertex to the inlet
 - a. Once manual edits of the breaklines are completed, use the provided Snap Lines to Points python script to snap breaklines to inlets
 - b. Create a unique ID field, in text, for the breaklines
 - c. Input Points Feature Class: Inlets
 - d. Input Lines Feature Class: Breaklines
 - e. Snapping Tolerance: 10ft
 - f. The script will create a new output feature class in the specified output folder
6. Generate a Stream Centerline Specific Breakline – The groundwater domain was divided into groundwater flow regions, north to south, at Minnehaha Creek.

- a. The groundwater flow region boundary, which was simplified from the stream centerline used for Channel Routing, was traced to generate a continuous feature from Gray's bay dam to the watershed outlet.
 - b. The polyline was split at the limits of each CCV.
 - c. Densify was used to create vertices along the channel segments at 25 foot increments.
7. Generate PCV and CCV Break Points in GIS
 - a. Open Watershed Boundary, Pond, and Channel Control Volume Outlines in GIS
 - b. Use the Generate Tessellation using the Triangle Shape type over the extent of the Watershed Boundary. This process will be completed for both the CCVs and PCVs using the below size inputs:
 - i. Pond Control Volumes: 1,500 sq ft size input (50 ft side length).
 - ii. Channel Control Volumes size: 312.5 sq ft size input (25 ft side length).
 - c. Convert Tessellations to Polylines using Polygon to Line tool
 - d. Convert Polylines to vertices using feature vertices to points tool
 - e. Select Vertices within PCVs (or CCVs), inverse selection, and delete all other vertices outside of the control volume.
 - f. Select vertices within 25 feet of the PCV (or CCV) boundary and delete.
 - g. Save the final breakpoints for CCVs and PVCs as shapefiles for import into Stormwise.
8. Data preparation for StormWise mesh generation
 - a. Select and delete breaklines within 25 ft of the watershed boundary if not done already
 - i. Mesh points close to the watershed boundary result in overly small mesh elements that may not be necessary.
 - b. Re-check breakline geometry to remove any unnecessary and or small branches, close parallel/sharp-angled lines, or endpoints/edges within 10ft of other mesh-generating features (inlets, outlets, PCVs, CCVs, watershed boundary)
 - i. Breakline vertices and edges will connect with both those of other breaklines and those of other mesh-generating features. Any breakline edge or vertex that isn't exactly coincident with another mesh-generating feature is likely to cause small vertices.
 - c. For the features in steps 5a-5c, add a field called "name" where each feature class has a unique character tag followed by numbers identifying individual features. HDR used the format "NI-XXX-000000" for inlets, and "OF-BKL-000000", giving each feature the same name length/format. See Naming Convention deliverable for more information. See specific formatting below
 - i. Inlets: "NI-XXX-000000"
 - ii. Breaklines: "OF-BKL-000000" + "0"
 - iii. These steps serve to make the data easier to work with in StormWise and cross reference in GIS.
 - d. HDR generated a simple Model Builder that takes in all mesh-generating features, converts polyline and polygon features to points, then buffers all mesh-generating points to $\frac{1}{2}$ the target distance and runs an intersection on this buffer. Here, a 5ft buffer was used so intersections of features <10ft from each other could be identified and corrected.



9. StormWise Mesh Generation

- a. Prepare GIS data for integration: Inlets, CCV break points, PCV break points, edited/snapped breaklines, watershed polygon feature class, all in "NAD 1983 (2011) StatePlane Minnesota South FIPS 2203 (US Feet" projection, for export to StormWise
- b. Add watershed raster to StormWise
- c. Select overland flow region and add watershed polygon shapefile
- d. Add Inlets shapefile to the "Breakpoint" feature class
- e. Add GIS generated break point patterns for Channel and Pond Control Volumes.
- f. Create breakpoint pattern for open areas using the "Create Overland Flow Graphic Element" button, pressing z, clicking on the map, and running with the standard inputs
 - i. Doing this for the entire watershed surpassed the computational limit of this function. For this reason, we split the watershed into three parts, creating polygons to be used as "fences" in StormWise. For this case, activate the fence for the area being processed and select the "use active fence" option before running. The polygons used for this are located in the shared GIS folder.



Memo

Date: Tuesday, August 04, 2026

Project: 2-D Watershed-Wide Model

To: MCWD

From: HDR

Subject: Appendix C-5: Pond Control Volumes

Introduction

This document details the development of pond control volumes (PCVs) for implementation into StormWise for the MCWD 2D watershed wide model build. Though several options were explored in the previously provided *Phase 2 Model Build – Pond Control Volume Options* document, the use of surface contours at elevations of anticipated uncontrolled overland flow was selected to derive PCVs. PCVs represent the entire polygon as a stage (elevation) storage relationship where the water surface is flat and water entering any part of the PCV is immediately available to discharge from an outlet point. Using a controlling elevation contour maintains most of the overland space as 2D flow while confining the 1D (stage-storage) hydraulics to occur only where the waterbody is anticipated act as a ponded feature. Here, ArcGIS Pro v3.3 was leveraged for PCV processing prior to exporting to StormWise. Using USGS LiDAR water body polygons as the basis for PCV creation, representative contours surrounding these polygons were selected for use as PCVs. These PCV outlines were further refined through the semi-automated process described in the following sections.

Pond Control Volume Development

First, contours were developed across the entire watershed. Contours representative of PCV area relative to the USGS LiDAR water body polygons were then selected. The following steps detail this process.

1. Contour (Spatial Analyst Tools)
 - a. The creation of dense contours allows for the selection of PCV outlines coincident with the stage of water bodies they represent. This was accomplished using Contour (Spatial Analyst Tools) in ArcGIS Pro
 - i. Input Raster: Watershed DEM
 - ii. Contour Interval: 1
 - iii. Output: 1ft Contours for the entire watershed
2. Contour Selection
 - a. Next, contours were selected surrounding the LiDAR water body polygons selected as PCV basis. The following rules were used to select representative

contours, helping mitigate small StormWise mesh elements and improving model functionality.

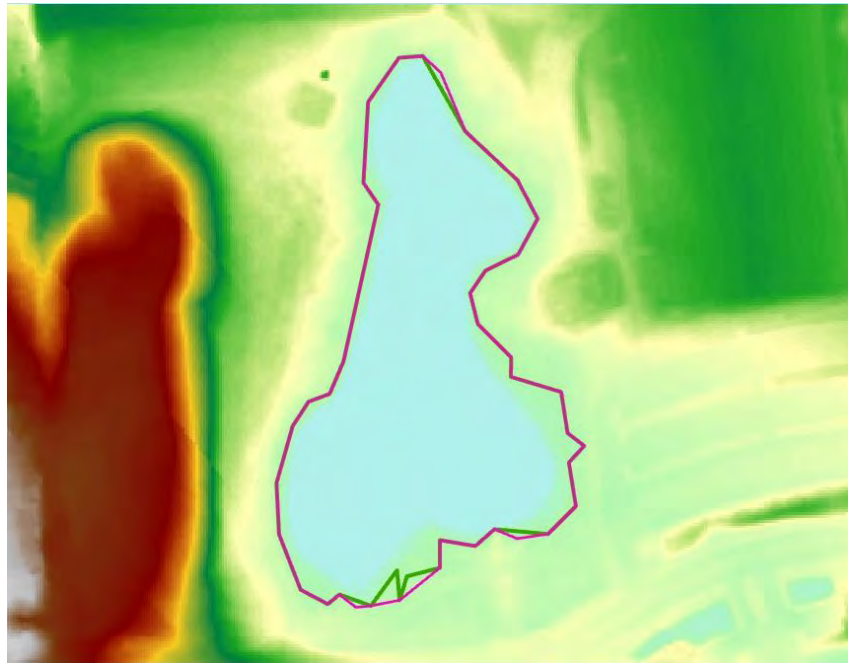
- i. Choose the highest elevation contour possible without overtopping to infrastructure (roads, homes, etc.)
- ii. Avoid having inlets less than 10ft from the outside of contours (for mesh generating purposes)
- b. Example (all contours light green, selected contour pink, LiDAR polygon blue)



Next, the selected PCV contours were edited as the vertices of the output contours are too dense. Exporting the selected contours to StormWise as PCVs as is would cause the generation of small mesh elements.

1. Generalize
 - a. Select all PCV contours identified in the previous step.
 - b. Use the point removal Generalization with 10 ft offset selected
2. Edit PCV Contours
 - a. The generalized contours must be manually reviewed and edited to confirm they are still representative of the boundary and transition between 1D and 2D hydraulics. In the generalization process, tight corners or deviation from the representative water body elevation may occur. Utilizing the Reshape tool in ArcGIS Pro, the following guidelines were used to make edits to generalized PCV contours.
 - i. Remove sharp corners or vertices <10ft apart generated by the generalization of small coves in the contour
 - ii. Confirm that generalized contours do not excessively deviate above/below the original contour

- b. Example (generalized contour green, generalized and edited contour pink)



3. Where pond control volumes are close and separated by a berm, make edges coincident and connect in Stormwise with a weir
 - a. This will simplify the model mesh for computational efficiency.
4. Run a check of inlet/outlet proximity to pond control volumes. Where <10ft from one another, adjust the PCV feature to encompass the outlet/inlet

Next, a node must be created for each PCV for implementation in StormWise.

1. Feature to Point
 - a. Run Feature to Point on the PCV polygon feature class with the centroid option selected.
2. Adjust Centroids
 - a. Some centroids may fall outside of PCV polygons depending on geometry. Review PCV centroids and move centroids inside of PCV boundaries where necessary.

Finally, assign names to each PCV and Node, assigning each PCV's node to a "Node_Name" field within the PCV feature's attribute table. See Naming Convention deliverable for more information.



Memo

Date: Tuesday, August 04, 2026

Project: MCWD 2-D Watershed-Wide Model Build

To: MCWD

From: HDR

Subject: Appendix C-6: Channel Control Volumes

Introduction

This document details the development of bank lines, channel control volume polygons, channel links, and channel nodes for implementation into a watershed-scale StormWise model for the lower Minnehaha Creek Watershed. The following processes used both HEC-RAS (version 6.5) and ArcGIS Pro.

HEC-RAS Processing

HEC-RAS was used to develop cross sections, which could also be completed in GIS software. Using the cross sections and centerline, edge lines are generated. Edge lines connect cross section end points following an offset from the centerline, these are the precursor to the channel control volumes.

1. This process began with the bathymetry development of a HEC-RAS model of Minnehaha Creek. The following features are required for cross-section and edge line development:
 - a. Channel centerline
 - b. Survey/cross-section locations
 - c. Terrain
2. Cross sections were created within a HEC-RAS geometry following the steps below.
 - a. Place cross-sections at:
 - i. Surveyed cross-section locations. Confirms the model is using observed data where it is available
 - ii. Upstream and downstream of bridge, culvert, or hydraulic structure crossings. Integrating pipe culverts, bridges, or weirs requires upstream and downstream bounding cross sections. Even if structures are not

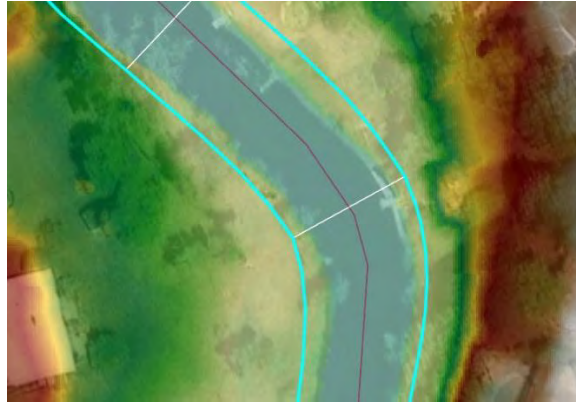
included as part of this model, the cross sections are available for future refinement.

- iii. Locations of hydraulic change (width, depth, slope, major meanders). Captures conveyance and hydraulic losses appropriately within the system.
 - b. Cross sections should extend past the edge of the low-flow channel bank. In channel flows are intended to be described by 1-D elements for improved hydraulic representation and model efficiency.
 - c. Add new cross sections so that spacing is less than 500 feet between cross sections. Water surface elevation variation and appropriate connectivity to the storm sewer network is a function of cross section and node placement. Closer spacing allows for improved streamwise description of water surface elevation changes and exchange with the 2D mesh nodes along channel banks.
 - d. Extend cross sections to encompass smaller coves (or off-channel pockets of backwater); larger coves will be accounted for in StormWise and do not need to be encompassed by the edge lines
3. Update edge lines to new cross sections
 4. Export edge lines and cross sections as a shapefile for use in ArcPro

ArcGIS Pro Processing

ArcPro is used to refine generated cross sections, centerline, and edge lines for integration into a Stormwise model. Note: Though not modeled in HEC-RAS, several channel control volumes were added in addition to those along Minnehaha Creek, to connect two pond control volumes, for example.

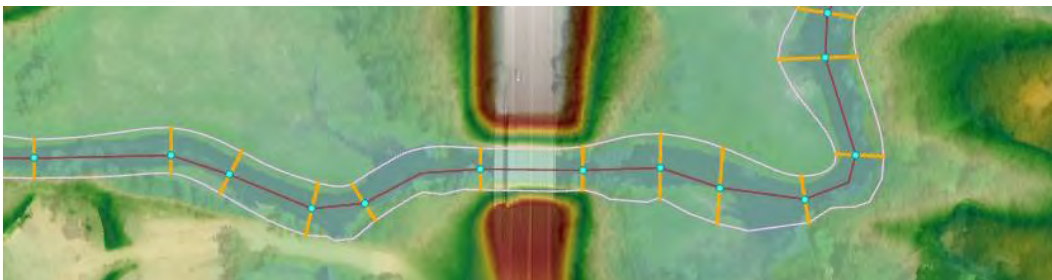
1. Import edge lines, cross sections, centerline, and terrain
2. Use the generalize tool to generalize the edge lines to 10 feet to limit small 2D cell faces. Adjust edge lines so they do not cross into the stream or through obvious low points. Edge lines should be representative of the creek bank lines. If they cross into the stream or through obvious low points, the model will misrepresent flow in and out of the channel. Edge lines were automatically generated within HEC-RAS based on cross section end points; between cross sections, bank lines may be located in less desirable places these locations should be reviewed in more detail.
3. Example (Edge Lines: selected in bright blue, Channel Centerline: brown, Channel Cross Sections: white)



4. Channel node locations were set at the location of the intersection between each channel cross-section and channel centerline. Use the intersect tool with the channel cross sections and the channel centerline as input and output, respectively. Nodes represent the computational points within the channel control volume and each require upstream and downstream cross sections.
 - a. General pattern (Channel Centerline: brown, Edge Lines: light pink, Channel Cross Sections: orange, Channel Nodes: selected in bright blue)



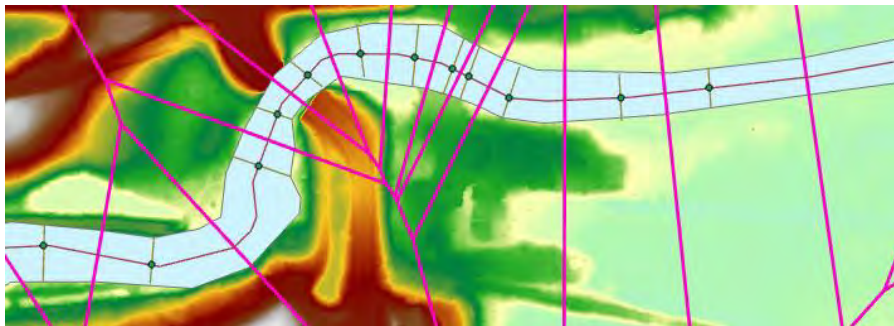
- b. At bridges



5. Channel links connect each node and were created using the Split Line at Point tool, split the channel centerline with the channel nodes.

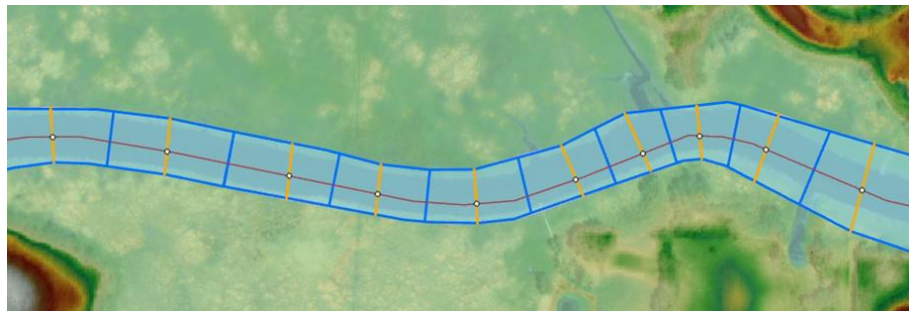
6. Polygons of the channel were generated using the Polygons from Polylines – XTools Pro tool. Using the adjusted channel edge lines, connect the end points with polylines and run the tool to generate a polygon of the channel.
7. Each channel node will have a respective polygon called a channel control volume polygon. This requires splitting of the entire channel polygon into many smaller polygons. To automate this, the Thiessen Polygons – XTools Pro tool was used with the channel nodes as inputs. Once generated, pan through the entire channel and adjust the Thiessen polygon output where necessary so each polygon will have a node when the Thiessen polygon output is used to split the entire channel polygon.

- a. Thiessen Polygon Output: pink

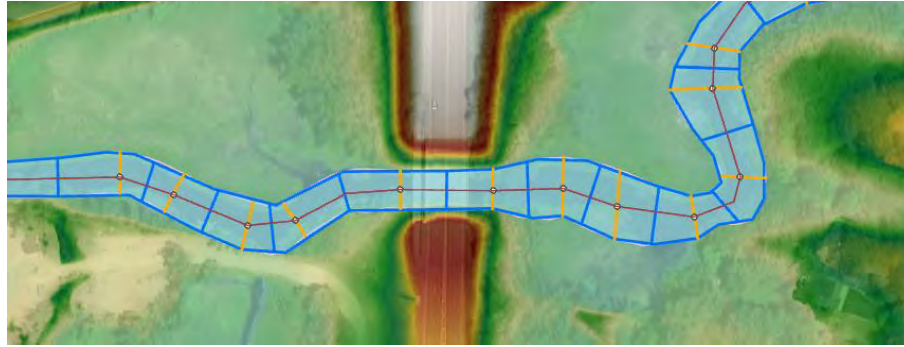


8. Run the Split Polygons tool with the entire channel polygon as the input feature and the Thiessen polygon output as the split features. The result should be one polygon for each channel node.

- a. General example (Channel Control Volume Polygons: blue, Channel Cross Sections: orange, Channel Nodes: white, Channel Centerline: brown)



- b. At Bridges



9. Where the channel crosses through major, static water bodies, create Pond Control Volumes (PCVs). Channel Control Volume Polygons and all other features can be deleted from these areas. PCVs represent surface water storage in StormWise and improve the representation of interactions between the channel and storage areas. “Phase 2 Model Build – Pond Control Volumes” describes the process to generate PCVs in detail. In general:
10. Identify water bodies and or low-lying areas the channel passes through. See example below.

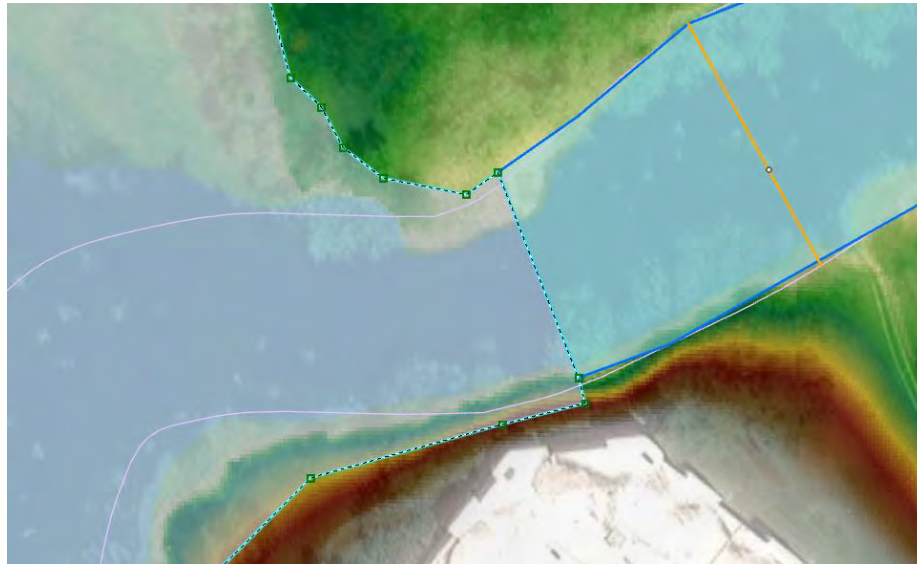


- a. Using DEM as reference, construct polygons representing bank lines of water bodies/low-lying areas. These polygons will be referred to as PCVs. The edges of PCVs must coincide with channel control volume polygon edges (not cross sections). Generalize the PCV polygon to 10ft to avoid small mesh elements when imported to StormWise. Confirm PCV and channel control volume polygon edges are still coincident See below.

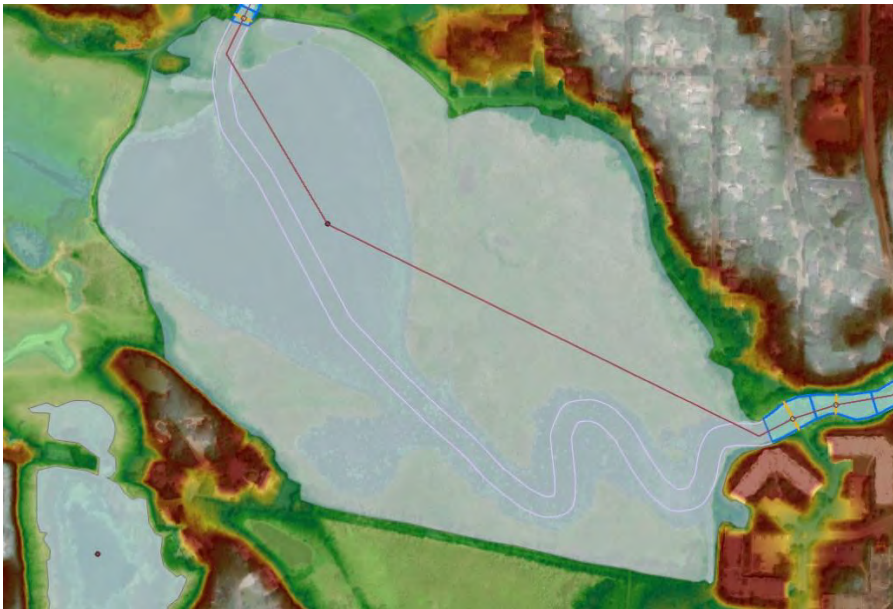
Entire PCV (in light purple)



Coincident edges



- b. Create a node in the center of the PCV and connect the upstream and downstream channel node to this new node with new links.



11. Add fields/populate fields for input to StormWise. This process references the channel nodes to their associated channel control volume polygon. See the provided Naming Convention deliverable for the detailed naming convention used.

a. Channel Nodes

- i. Add and populate a "NAME" field

b. Channel Control Volume Polygons

- i. Add and populate a "NAME" field
- ii. Create a field called "NODENAME". Use the "Spatial Join (Analysis Tools)" tool to assign channel node "NAME" field to each associated channel control volume polygon's "NODENAME" field.

c. Cross Sections

- i. Add and populate a "NAME" field

d. Channel Links

- i. Add and populate a "NAME" field
- ii. Add a field "FROM_NODE"
- iii. Add a field "TO_NODE"
- iv. Use the "Features to Points (Xtools Pro)" tool's "End of Line" function for the "TO_NODE" field. Repeat the following steps with the tool's "Start of Line" tool for the "FROM_NODE" field.



12. Spatial join the channel nodes to the Xtools Pro nodes. Join the channel nodes' "NAME" field to the Xtools pro nodes.
13. Spatial join the Xtools Pro nodes to the channel links feature class. Copy the node name column from this output into the relevant "FROM_NODE" and "TO_NODE" field of the original channel links feature class.
14. Package the channel nodes, channel control volume polygons, cross sections, channel links, and Pond Control Volume Outlines, as shapefiles, for export to StormWise.



Memo

Date: Tuesday, August 04, 2026

Project: 10400835 – MCWD 2D Model Development

To: MCWD

From: HDR

Subject: Appendix C-7: Minnehaha Creek Crossing Data Summary

As part of HDR’s ongoing development of the Minnehaha Creek Watershed District (MCWD) Stormwise 2D model, over 90 bridges along the Minnehaha Creek (Creek) have been identified for potential inclusion into the model. In addition, HDR has reviewed existing 1D models containing previously developed bridge geometry and supporting documentation from various stakeholders throughout the Creek. HDR intends to leverage this data to expedite creation of the 2D model and improve its accuracy where possible. For details and data on tier one crossings implemented in StormWise, see Electronic Data Package Item C-7: Minnehaha Creek Crossing Data Summary. Due to the large number of crossings along the Creek, bridges were sorted into various “Tiers” based on their hydraulic impact to peak water surface elevations (WSEs) as documented in the effective FEMA Flood Insurance Study (FIS). The geometry data source (HEC-RAS or XPSWMM) was also considered since bridges modeled in HEC-RAS generate headwater and tailwater rating curves that can be directly imported into Stormwise. However, bridge data sourced solely from XPSWMM must first be recreated in HEC-RAS before being implemented into Stormwise. Table 1 summarizes findings from the bridge geometry data review.

Table 1. Bridge Structure Data Summary

Data Source	Bridge Tier				Total
	1	2	3	Outdated	
HEC-RAS (Various Sources)	15	34	2	3	56
XPSWMM (MCWD Model)	0	20	16	3	38
					94

Tier 1: Critical Crossings with significant impact (1' or greater) to WSE of Minnehaha Creek

Tier 2: Crossings impacting (<1') WSE and/or structure within the 500-year Annual chance Flood

Tier 3: All remaining crossings

Outdated: Bridge was reconstructed after model data was generated



- Tier 1 represents structures with significant impact (deemed 1' or greater) to the Creek's peak WSE in either the 100-year or 500-year annual chance flood events and will be initially included in the Stormwise 2D model.
- Tier 2 represents structures with an impact of <1' to the peak 100 or 500-year WSE, or a structure with a low chord located below the 500-year annual chance flood. These structures, while not critical, should be next in-line for inclusion into the 2D model.
- Tier 3 structures have no apparent impact to the 100-year or 500-year peak WSE, do not have a low chord below the 500-year WSE, and are considered the least critical for inclusion into the 2D model.

A large portion of the bridge models and supporting documentation reviewed by HDR was generated between 2001-2003 as part of the initial Hennepin County FIS that was made effective on September 2nd, 2004. Since then, several bridges along the Creek have been reconstructed (identified via MnDOT Bridge GIS Portal), and an updated FIS was made effective on November 4th, 2016. Table 2 lists the reconstructed bridges and their corresponding tier.

Table 2. Bridges Reconstructed along Minnehaha Creek since 2003

Bridge	Tier	Year Reconstructed
Lyndale Ave	1	2011
28th Avenue South	2	2020
Portland Ave	2	2006
West 37th St	2	2017
I-35W	3	2008
BNSF Railway	3	2007

It's likely that any bridge reconstruction prior to 2016 has a corresponding HEC-RAS model that is up to date and part of the effective FIS. This project may benefit from current HEC-RAS models for all the outdated tier 1-2 bridge crossings, as well as any HEC-RAS models that can be used in lieu of the tier 2 XPSWMM based data to facilitate a more efficient and congruent modeling process. These bridges can be integrated as part of this project or in future refinements to the watershed wide model.

Model Implementation:

In StormWise, the default method for connecting channel nodes is through standard channel links. However, for Tier 1 hydraulic structures identified in the study, bridge rating curve links, weir links, and culvert links were utilized to more accurately represent the geometry and hydraulic behavior of these structures. Using available as-builts, each Tier 1 structure was reviewed and assigned the link type that best represented its geometry. HEC-RAS bridge rating curves were input for bridge rating curves, where relevant input values were selected for culvert and weir links using feature geometry. See the provided spreadsheet documenting StormWise inputs used for each feature represented as a culvert or weir link. Table 3 lists the number of

Figure 2. Hiawatha Avenue Weir (Weir Link)

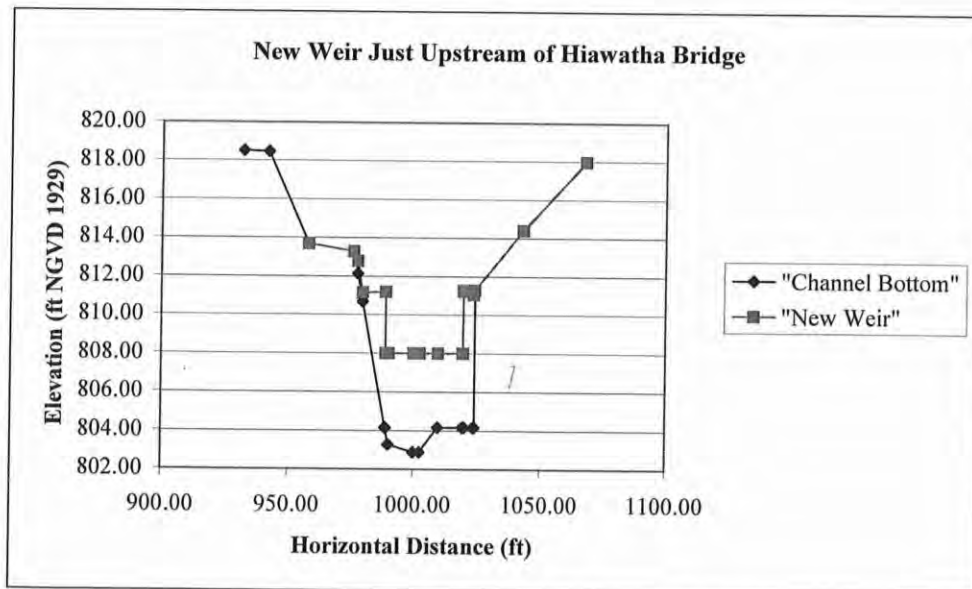
New Weir Just Upstream of Hiawatha Avenue Bridge

HEC-2 = Archpxl.dat RS = 11.3

Horizontal Distance		Elevation-BOTTOM		Elevation-TOP	
metric (m)	english (ft)	metric (m)	english (ft)	metric (m)	english (ft)
284.10	932.09	249.48	818.50		
287.10	941.93	249.47	818.47		
292.00	958.01	248.01	813.68	248.01	813.68
297.50	976.05	247.89	813.29	247.89	813.29
298.00	977.69	247.54	812.14	247.74	812.80
298.62	979.72	247.10	810.70	247.24	811.15
301.42	988.91	245.11	804.17	247.25	811.19
301.43	988.94	245.10	804.13	246.28	808.01
301.80	990.16	244.84	803.28	246.28	808.01
304.80	1000.00	244.72	802.89	246.28	808.01
305.59	1002.59	244.72	802.89	246.28	808.01
307.80	1009.84	245.11	804.17	246.28	808.01
310.74	1019.49	245.11	804.17	246.28	808.01
310.78	1019.62	245.11	804.17	247.27	811.25
310.90	1020.01	245.11	804.17	247.26	811.22
311.97	1023.52	245.11	804.17	247.21	811.06
312.10	1023.95	245.11	804.17	247.28	811.29
312.10	1023.95	247.28	811.29	247.28	811.29
317.90	1042.98	248.23	814.40	248.23	814.40
325.50	1067.91	249.32	817.98	249.32	817.98

Sta 52+91

swmm cross section highlighted



Memo

Date: Tuesday, August 04, 2026
Project: 2-D Watershed-Wide Model
To: MCWD
From: HDR
Subject: Appendix C-8: Storm Infrastructure Assumptions

Scripts developed as part of the MCWD watershed-wide model pilot study systematically re-formatted and consolidated storm sewer datasets from all overlapping owners (state, county, city) into a single GIS schema (MGIS). To support model development, data gaps and erroneous attributes were flagged and populated based on a variety of methods depending on the gap type and available data. The intent of this document is to review previously developed assumptions and refine them where necessary. Where data are unavailable or erroneous, gap filling methods will be generated for storm sewer infrastructure on a source-by-source basis.

The MGIS to Model Ready Scripting (script) is divided into three parts: “Project Folder Set Up”, “Topology Correction”, and “Attribute Correction”. This memo focuses on “Attribute Correction”.

Update Structure Attributes

This section will define current script assumptions and gap fill approaches for Structures which include manholes, inlets, and outlets. For aspects which require refinement a process to refine will be described. “pipes” include pipes and culverts.

- 1a – Fix Structure Rim
 - o *Existing script:* Update structure with rim elevation from digital elevation model (DEM)
 - o *Refinement:* Update script to flag and replace if rim elevations > 0.5' different from DEM. Review flags to confirm appropriate application of acceptable difference
- 1b – Fix Structure Invert Elevation
 - o *Existing script:* Updates structure invert elevations. If invert elevation is null, connected pipes are checked for invert values. The lowest invert value of all connected pipes are used, if any. If invert is populated, but <= 50, it is assumed as a measure down (depth value) and subtracted from the rim elevation or from them DEM if rim is not populated.
 - o *Refinement:* Existing logic was retained as a first pass, with an added check for excessively high structure invert elevations. Here, the script checks a structure's invert elevation against that point's DEM elevation. If the structure invert elevation is higher than the point's DEM elevation, the invert elevation is set to null and replaced with existing logic. In addition, a second pass was added to the script following the update of pipe attributes to update structure invert elevation based on assumed pipe inverts.

- 1c – Fix Structure Combination Field
 - o *Note:* Script comments indicate this script “Sets combination style to “Yes” if it is null (for inlets only)”; however, based on review of the code, the logic may be applied to all structures rather than just the inlets. Verification is recommended.
- 1d – Fix Structure Grate Size (inlets only)
 - o *Existing script:* Adjusts inlet grate length and width to assumed values if null. (length =36, width = 24)
 - o *Refinement:* Updated script to adjust inlet grate length and width to updated assumed values if null based on most typical values in dataset (length =2.75 ft [33 inches], width = 1.26 ft [15.125 ft])
- 1e – Fix Structure Outlet Length Width (outlets only)
 - o *Existing script:* Adjusts outlet length and width to mean of connected pipe sizes (if available) or else an assumed value of 24
 - o *Refinement:* None, maintain current approach
- 1f – Fix Outlet Type (outlets only)
 - o *Existing script:* Changes outlet type to assumed value of “Pipe” if null
 - o *Refinement:* None, maintain current approach

2-Update Pipe Attributes

This section will define current script assumptions and gap fill approaches for Pipes which include pipes and culverts. For aspects which require refinement a process to refine will be described.

- 1a – Add To/From Nodes
 - o *Existing script:* Populates the Node From and Node To fields for pipes based on connected structures.
 - o *Refinement:* None, maintain current approach
- 1b – Fix Pipe Size
 - o *Existing script:*
 - Adjusts pipe size parameter. If size is populated with value < 0 or == 999, size is set to null.
 - If value is < 6, value will be assumed as feet and converted to inches (note: HDR reviewed the MGIS pipe size data by source and validated this assumption to be appropriate).
 - If no value found, pipe size will be determined from mean of upstream and downstream pipes (if available), otherwise set to 24. Uses closest pipe size from the following list when determining mean pipe size:
 STANDARD_PIPE_SIZES = [6.0, 8.0, 9.0, 10.0, 12.0, 14.0, 15.0, 16.0, 17.0, 18.0, 20.0, 21.0, 22.0, 24.0, 25.0, 26.0, 27.0, 28.0, 29.0, 30.0, 31.0, 32.0, 33.0, 35.0, 36.0, 39.0, 41.0, 42.0, 43.0, 44.0, 45.0, 48.0, 50.0, 51.0, 54.0, 55.0, 57.0, 58.0, 58.5, 59.0, 60.0, 65.0, 66.0, 69.0, 71.0, 72.0, 73.0, 78.0, 80.0, 84.0, 88.0, 90.0, 95.0, 96.0, 102.0, 117.0, 120.0, 121.0]

- o *Refinement:*
 - Script adjusts pipe size parameter. If size is populated with value < 0 or == 999, size is set to null.
 - If no size value is found and the pipe is connected to another pipe upstream, the missing pipe size will be determined from the mean of upstream and downstream pipe sizes (if available).
 - If mean of upstream and downstream pipe sizes is not available or if the pipe is not connected to another pipe upstream, an assumed pipe size of 15 inches will be used.
 - Justification for the 15 inches default pipe size assumption is provided in Section 3 of this memo.
- 1c – Fix Pipe Material
 - o *Existing script:* Adjusts pipe material. Material is checked from connecting pipes first, otherwise set to Unknown.
 - o *Refinement:* HDR reviewed material distributions for MGIS pipe data by source (without clipping to the watershed). In addition to checking connecting pipes for material, a default pipe material of reinforced concrete will be used to populate missing values. Justification for this assumption is provided in Section 3 of this memo. Roughness coefficients will be defined in the model based on pipe material and will not be stored in the model ready dataset.
- 1d – Fix Pipe Shape
 - o *Existing script:* Changes pipe shape to assumed value of “Circular” if null
 - o *Refinement:* None, maintain current approach
- 1e – Fix Pipe Width
 - o *Existing script:*
 - The intention of the existing script is to populate an assumed pipe width and height if the pipe is not circular. However, HDR identified a bug in the existing script causing the assumed pipe width and height to be populated for circular pipes only (skipping non-circular pipes).
 - The intention of this part of the script is to update the width field for non-circular pipes to be equal to the pipe diameter field, if available, or else set it to 24.
 - o *Refinement:*
 - Script logic was corrected to apply the pipe width and height assumptions for non-circular pipes.
 - Script logic was updated to apply a default uniform width/height assumption of 18 inches for arched pipes and non-circular pipes (including non-arched).
 - In addition to updating the script, non-circular, non-arched pipes missing height and width values were manually reviewed, and width and height values were manually assigned using surrounding features.
- 1f – Fix Pipe Length
 - o *Existing script:* Checks pipe length in the attribute field. If attribute pipe length differs from geometry pipe length by more than 20%, or if the attribute pipe length is null, it

populates the attribute pipe length with the geometry shape length. Otherwise, it keeps whatever is in the pipe attribute field.

- o *Refinement:* None, maintain current approach
- 1g – Fix Pipe Inverts
 - o *Existing script:* Updates missing pipe upstream and downstream invert elevations from DEM (for culverts) or from adjacent structure inverts (for pipes).
 - o *Refinement:* Existing script approach was refined to estimate pipe inverts based on DEM if upstream and downstream pipe invert elevations are not available. If pipe is a culvert or pipe endpoint is an outlet, assume the invert is equal to the DEM elevation. If the pipe is not a culvert and the pipe endpoint is either a manhole or an inlet, assume the invert from an assumed cover depth (4 ft.) offset from DEM. Justification for the 4 ft. default pipe cover assumption is provided in Section 3.
- 1h – Fix Pipe Slope
 - o *Existing script:* Updates pipe slope if length, upstream and downstream invert are populated. (calculates slope based on attribute pipe length, not the geometry shape length). If slope is negative, it flags this as an issue in the Issues field.
 - o *Refinement:* None, maintain current approach

3- Update Pipe Attributes Check Results

1b – Fix Pipe Size

Summary:

Presently, the MGIS to MR script sets a default pipe diameter of 24” to features missing pipe diameter data. To validate or replace this default diameter, the pipe diameter distribution was explored both on a source-by-source and entire dataset basis.

Results:

MGIS Pipe Diameter Distribution, Not Including Null or Zero Values

Source	Count	Average Pipe Diameter (ft)	Median Pipe Diameter (ft)
ChanhassenData	8,452	17.50	15
DeephavenData	N/A	N/A	N/A
EdinaData	7,655	17.32	15
ExcelsiorData	605	14.40	12
GoldenValleyData	216	18.60	12
GreenwoodData	38	15.21	12
HopkinsData	N/A	N/A	N/A
LongLakeData	559	17.56	15
MaplePlainData	226	N/A	N/A
MedinaData	947	16.41	15
MinnetonkaData	12,931	17.29	15

Source	Count	Average Pipe Diameter (ft)	Median Pipe Diameter (ft)
MinnetristaData	1,533	15.10	15
Mound	1,464	13.82	12
MplsData	41,696	20.04	15
PlymouthData_Updated	12,952	18.47	15
RichfieldData	4,806	19.18	15
ShorewoodData	1,598	14.09	12
SpringParkData	31	13.97	12
StBoniData	412	11.16	12
StLouisParkData	8,867	15.75	12
VictoriaData	2,971	17.23	15
WayzataData	1,805	13.81	12
Entire Dataset	109,764	18.19	15

Conclusion:

As the median pipe diameter across the entire dataset is 15", HDR recommends replacing the existing default pipe diameter of 24" with a default pipe diameter of 15"

1c – Fix Pipe Material

Summary:

The distribution of pipe material was explored both on a source-by-source and entire dataset basis. For clarity, the provided results include only the most common material for each source.

Results:

Most Common Pipe Material for Each Data Source, not Including Null Values

Source	Pipe Material	Count	Percentage
ChanhassenData	Reinforced Concrete	7,672	74.60%
DeephavenData	Steel	1	100.00%
EdinaData	Reinforced Concrete	5,869	65.83%
ExcelsiorData	Reinforced Concrete	129	82.69%
GoldenValleyData	Reinforced Concrete	179	83.64%
HopkinsData	Unknown	776	100.00%
LongLakeData	Reinforced Concrete	488	87.46%
MedinaData	Reinforced Concrete	889	93.88%
MplsData	Reinforced Concrete	31,510	63.20%
MinnetonkaData	Reinforced Concrete	10,226	80.25%
MinnetristaData	Reinforced Concrete	1,398	92.09%
Mound	Reinforced Concrete	998	92.07%
PlymouthData_Updated	Polyvinyl Chloride	54	75.00%
RichfieldData	Reinforced Concrete	4,903	95.59%

Source	Pipe Material	Count	Percentage
ShorewoodData	Reinforced Concrete	134	77.91%
StLouisParkData	Reinforced Concrete	8,203	94.34%
VictoriaData	Unknown	192	98.46%
WayzataData	Reinforced Concrete	976	54.07%
Entire Dataset	Reinforced Concrete	73,574	71.35%

Conclusion:

Hopkins and Victoria have very limited pipe material information as indicated by the percentage of “Unknown” material features. Deephaven and Plymouth, while having different most common pipe materials than the other sources, have relatively few features. With the most common material across the entire dataset being reinforced concrete, HDR recommends a default material of reinforced concrete for all features missing material data.

1g – Fix Pipe Inverts

Summary:

To populate missing invert elevation data, three methods for invert estimation were considered including (1) calculating inverts based on cover depth relative to the DEM, (1) calculating inverts based on minimum pipe slope, and (3) flagging pipes for manual review and refinement. The project team concluded that the cover depth approach would best represent invert elevations where missing. To explore the distribution of cover depth on both a source-by-source and entire dataset basis, the approximate cover depth was calculated for pipes with existing invert elevations and pipe diameters. To calculate approximate cover depths, a typical 6 inch pipe wall thickness was assumed for the top of the pipe. This check utilized the model ready pipe dataset as the script populates missing invert elevations with manhole invert elevations.

Results:

Distribution of Calculated Cover Depth

Source	Count	Average Cover Depth (ft)	Standard Deviation	Median Cover Depth (ft)
ChanhassenData	7,516	4.26	3.03	3.45
EdinaData	6,990	4.35	2.82	3.69
ExcelsiorData	40	2.47	2.16	2.11
GoldenValleyData	108	3.60	2.18	3.09
HopkinsData	20	3.23	1.18	2.69
MinnetonkaData	9,871	3.87	2.81	3.19
MinnetristaData	4	2.32	0.86	2.40
Mound	984	3.55	2.38	3.13
MplsData	37,875	5.26	4.25	4.46
PlymouthData_Updated	12,100	4.06	2.60	3.46

Source	Count	Average Cover Depth (ft)	Standard Deviation	Median Cover Depth (ft)
RichfieldData	4,204	4.39	3.04	3.75
ShorewoodData	39	3.10	1.30	3.09
StLouisParkData	43	3.88	2.24	3.45
VictoriaData	17	10.10	10.37	7.45
WayzataData	3	0.89	0.42	1.10
Total	79,822	4.66	3.62	3.89

Conclusion:

With a median cover depth of 3.89 ft across the entire dataset, HDR recommends a uniform default cover depth of 4.0 ft be used for the calculation of missing invert elevations. This depth is consistent with local design standards and aligns with the findings of this check.

Memo

Date: Tuesday, August 04, 2026

Project: 2-D Watershed-Wide Model

To: Brian Beck (MCWD)

From: HDR

Subject: Appendix C-9: Storm Infrastructure Duplicative Dataset Evaluation Process

Introduction

As part of the development of a 2D watershed model for the Minnehaha Creek Watershed District (MCWD or District), the District provided HDR with a package of twenty-eight (28) storm sewer infrastructure datasets from agency and municipal sources across the region. These datasets were consolidated into the standardized MetroGIS (MGIS) format for use in model development. Upon review of the consolidated MGIS dataset, HDR noted that several of the original storm sewer datasets contain closely overlapping features and may be redundant. Any redundant data must be reviewed and removed prior to integration into the 2D model.

Due to the significant number of storm sewer features across the entire watershed, it would be impractical to manually review all individual features to identify redundancies for the 2D model. Additionally, while various GIS spatial analyses were considered to identify redundancies, HDR concluded that using a spatial analysis approach across the entire watershed scale for this dataset could introduce other unintentional errors and omissions in the 2D model.

Therefore, to address these redundancies efficiently across the entire watershed scale, HDR developed a random sampling process to review closely overlapping datasets and evaluate the potential impacts of omitting them. HDR's initial data review identified Hennepin County, Carver County, and MNDOT sources as potentially redundant. These datasets were reviewed as part of the random sampling process to evaluate their overall redundancy and make statistically significant conclusions on whether to omit them from the 2D model.

In addition, HDR identified other potential redundancies when comparing the culvert feature class (cPipes) to the storm sewer pipe feature class (pipes). In this instance, with just 385 potentially redundant pipes identified, the entire population of overlapping features was manually reviewed rather than utilizing a general random sampling approach.

Following this approach, HDR recommends omitting datasets that are found to be at least 80% redundant as determined through a random sampling statistical analysis with a 90% confidence level and 5% margin of error. This recommendation was used as the basis for the analysis and conclusions described in this memorandum.

Analysis Approach

The analysis approach is described in the following steps.

1. Identify datasets for review which may have substantial overlap with other data sources
 - a. MNDOT, Hennepin County, and Carver County storm sewer pipes
 - b. Culvert features
2. Perform a random sampling of a statistically significant number of storm sewer pipes across the entire watershed to evaluate data sources for potential redundancy and omission
 - a. Overlapping MNDOT features
 - i. MNDOT – Pipes (4,641)
 - ii. MNDOT – Inlets (4,257)
 - iii. For a population of 4,641 features, approximately 160-360 features from the **MNDOT dataset** are required in the random sample for statistical significance (assuming 5% margin of error)
 1. 80% Confidence Level = 159
 2. 85% Confidence Level = 199
 3. 90% Confidence Level = 258
 4. 95% Confidence Level = 355
 - b. Overlapping Hennepin County features
 - i. Hennepin County – Pipes (4,072)
 - ii. Hennepin County – Inlets (3,621)
 - iii. For a population of 4,072 features, approximately 160-360 features from the **Hennepin County dataset** are required in the random sample for statistical significance (assuming 5% margin of error)
 1. 80% Confidence Level = 158
 2. 85% Confidence Level = 198
 3. 90% Confidence Level = 256
 4. 95% Confidence Level = 352
 - c. Overlapping Carver County Features
 - i. Carver County – Pipes (228)
 - ii. Carver County – Inlets (141)
 - iii. For a population of 228 features, approximately 95-145 features from the **Carver County dataset** are required in the random sample for statistical significance (assuming 5% margin of error)
 1. 80% Confidence Level = 96
 2. 85% Confidence Level = 109
 3. 90% Confidence Level = 125
 4. 95% Confidence Level = 144
 - d. To evaluate all four MNDOT/Hennepin County datasets with 80–95% confidence, a total of approximately 640 to 1,440 randomly sampled features across all datasets would be required (e.g., 160–360 samples per dataset).

3. Selected storm sewer pipes were sampled randomly from all overlapping features. The random sample was then verified to confirm that a representative number of random features were sampled from each overlapping municipality.
 - a. Culvert features were identified for review by using “select by location,” and 385 MGIS culverts were identified as being within 10 feet of MGIS pipes. Due to the relatively small number of features, all (385) were manually reviewed following the process outlined below.
4. Each random sampling also included an evaluation of features adjacent to the randomly selected features. For each sampling, a visual buffer was applied including features within a roughly 50-100 ft. radius of the randomly selected feature to identify potential redundancies.
5. With each random sampling, a determination was made whether the features in the duplicate datasets inside the visual buffer area are redundant (yes/no) using a comparison of feature geometry, attribute completeness, and attribute quality. The following checks were used to determine potential feature redundancy.
 - a. Geometry – is the feature a direct geospatial copy? If not, is the feature visually similar via connectivity or orientation but offset from the comparison feature?
 - b. Attribute Completeness/Quality – are the primary attribute fields complete? If so, are the attributes reasonable?
 - i. Pipes/Culverts (in order of priority)
 1. Inverts
 2. Diameter
 3. Material
 4. Slope (where inverts are missing)
6. The result of each random sample determination was recorded in a point feature class as a single point (one for each visual buffer area) along with any relevant notes from the review explaining the selected result
 - a. Fields included for random sample point feature class
 - i. Unique ID
 - ii. Redundancy_Check (Y/N)
 - iii. Notes
 - iv. Municipality
7. Since missing inlet points can be regenerated through the “MGIS to Model Ready” script process, a separate random sampling analysis was not performed for inlets. Instead, determinations on inclusion or omission of a source’s inlets were made based on the quality of that source’s pipe data.
8. Based on the random sampling analysis, a final determination was made whether to omit the dataset or evaluate the dataset further
 - a. If more than 80% of the features within the random sampling are identified as redundant based on this random sampling, then the dataset may be omitted from future processing (this determination should be made separately for each of the four feature classes)

- b. If less than 80% of the features within the random sampling are identified as redundant based on the random sampling, further evaluation of the individual datasets may be warranted.

Results

The following section summarizes the results of the duplicative dataset evaluation for pipes and inlets in Hennepin County, Carver County, MNDOT as well as for MGIS culverts. A random sample analysis was performed for pipe data in Hennepin County, Carver County, and MNDOT. Determinations on the inclusion or omission of a source's inlets were made based on the quality of that source's pipe data.

1. Hennepin County Inlets/Pipes

- a. Pipes:

Hennepin County Randomly Sampled Subset Distribution Check

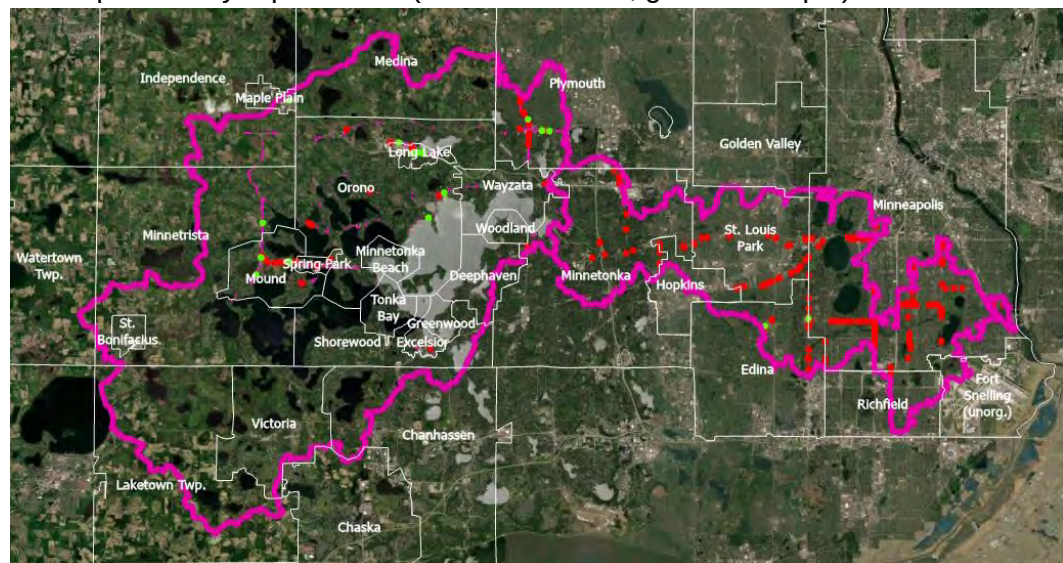
Municipality Intersected	All Intersections		Randomly Sampled Subset	
	Count	Percentage (of 3921)	Count	Percentage (of 260)
Edina	287	7.32%	23	8.85%
Golden Valley	0	0.00%	0	0.00%
Minnetonka	444	11.32%	20	7.69%
Hopkins	105	2.68%	5	1.92%
MNDOT	332	8.47%	24	9.23%
Minneapolis	2014	51.36%	140	53.85%
Plymouth	348	8.88%	24	9.23%
Richfield	23	0.59%	2	0.77%
Saint Louis Park	539	13.75%	34	13.08%
Wayzata	6	0.15%	1	0.38%
Victoria	0	0.00%	0	0.00%
Saint Bonifacius	0	0.00%	0	0.00%
Spring Park	93	2.37%	5	1.92%
Shorewood	0	0.00%	0	0.00%
Mound	194	4.95%	13	5.00%
Minnetrista	41	1.05%	1	0.38%
Medina	0	0.00%	0	0.00%
Maple Plain	7	0.18%	1	0.38%
Long Lake	134	3.42%	8	3.08%
Greenwood	0	0.00%	0	0.00%
Excelsior	16	0.41%	1	0.38%
Deephaven	0	0.00%	0	0.00%

Municipality Intersected	All Intersections		Randomly Sampled Subset	
	Count	Percentage (of 3921)	Count	Percentage (of 260)
Chanhassen	0	0.00%	0	0.00%
Carver	0	0.00%	0	0.00%
Null	203	5.18%	11	4.23%

Hennepin County Pipe Review Results

Area	Approx. % Unique	Approx. % Redundant
Entire Watershed	10.0%	90.0%
Upper Watershed	34.5%	65.5%
Lower Watershed	1.0%	99.0%

Hennepin County Pipe Subset (red = redundant, green = unique)



Hennepin County Pipe Review Results by Municipality

Data Source	Total Number of Features Intersecting	Number of Features	Approx. % Unique	Approx. % Redundant
Edina	287	23	8.7%	91.3%
Minnetonka	444	20	0.0%	100.0%
Hopkins	105	5	0.0%	100.0%
MNDOT	332	24	16.7%	83.3%
Minneapolis	2014	140	0.7%	99.3%
Plymouth	348	24	12.5%	87.5%
Richfield	23	2	0.0%	100.0%

Data Source	Total Number of Features Intersecting	Number of Features	Approx. % Unique	Approx. % Redundant
Saint Louis Park	539	34	0.0%	100.0%
Wayzata	6	1	0.0%	100.0%
Spring Park	93	5	0.0%	100.0%
Mound	194	13	23.1%	76.9%
Minnetrista	41	1	100.0%	0.0%
Maple Plain	7	1	100.0%	0.0%
Long Lake	134	8	62.5%	37.5%
Excelsior	16	1	0.0%	100.0%
Null	203	11	36.4%	63.6%

- b. **Hennepin County Recommendations:** With approximately 90% of the Hennepin County pipe network identified as redundant, it is recommended that the Hennepin County pipes and inlets be omitted in the watershed. The random sampling procedure indicates that omitting the pipe network would have a limited effect on the model quality.

2. MNDOT Inlets/Pipes

- a. Pipes:

MNDOT Randomly Sampled Subset Distribution Check

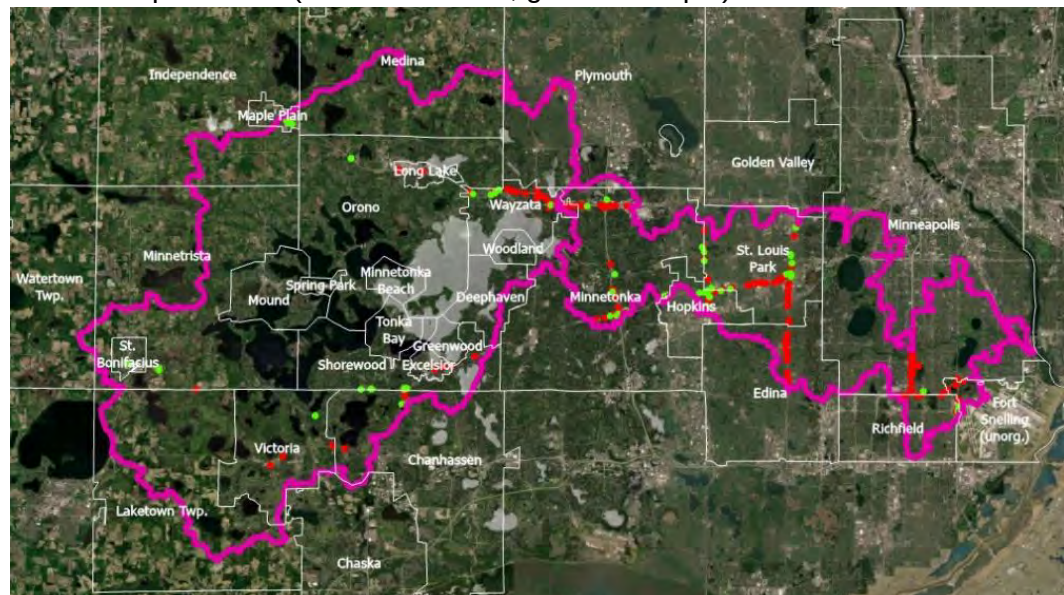
Municipality Intersected	All Intersections		Randomly Sampled Subset	
	Count	Percentage (of 4271)	Count	Percentage (of 260)
Edina	339	7.94%	20	7.69%
Golden Valley	53	1.24%	2	0.77%
Minnetonka	867	20.30%	52	20.00%
Hopkins	248	5.81%	21	8.08%
Hennepin County	1162	27.21%	68	26.15%
Minneapolis	999	23.39%	58	22.31%
Plymouth	18	0.42%	1	0.38%
Richfield	492	11.52%	32	12.31%
Saint Louis Park	1000	23.41%	56	21.54%
Wayzata	563	13.18%	36	13.85%
Victoria	82	1.92%	4	1.54%
Saint Bonifacius	34	0.80%	1	0.38%
Spring Park	0	0.00%	0	0.00%

Municipality Intersected	All Intersections		Randomly Sampled Subset	
	Count	Percentage (of 4271)	Count	Percentage (of 260)
Shorewood	129	3.02%	12	4.62%
Mound	0	0.00%	0	0.00%
Minnetrista	29	0.68%	2	0.77%
Medina	0	0.00%	0	0.00%
Maple Plain	41	0.96%	4	1.54%
Long Lake	187	4.38%	4	1.54%
Greenwood	73	1.71%	2	0.77%
Excelsior	161	3.77%	3	1.15%
Deephaven	0	0.00%	0	0.00%
Chanhassen	113	2.65%	12	4.62%
Carver	10	0.23%	1	0.38%
Null	81	1.90%	3	1.15%

MNDOT Pipe Review Results

Area	Approx. % Unique	Approx. % Redundant
Entire Watershed	29.9%	70.1%
Upper Watershed	48.1%	51.9%
Lower Watershed	23.2%	76.8%

MNDOT Pipe Subset (red = redundant, green = unique)



MNDOT Pipe Review Results by Municipality

Data Source	Total Number of Features Intersecting	Number of Features in Sample	Approx. % Unique	Approx. % Redundant
Edina	339	20	0.0%	100.0%
Golden Valley	53	2	50.0%	50.0%
Minnetonka	867	52	30.8%	69.2%
Hopkins	248	21	66.7%	33.3%
Hennepin County	1162	68	17.6%	82.4%
Minneapolis	999	58	1.7%	98.3%
Plymouth	18	1	0.0%	100.0%
Richfield	492	32	12.5%	87.5%
Saint Louis Park	1000	56	26.8%	73.2%
Wayzata	563	36	19.4%	80.6%
Victoria	82	4	25.0%	75.0%
St Bonifacius	34	1	100.0%	0.0%
Shorewood	129	12	41.7%	58.3%
Minnetrista	29	2	50.0%	50.0%
Medina	41	4	100.0%	0.0%
Long Lake	187	4	25.0%	75.0%
Greenwood	73	2	0.0%	100.0%
Excelsior	161	3	0.0%	100.0%
Chanhassen	113	12	33.3%	66.7%
Carver	10	1	0.0%	100.0%
Null	81	3	33.3%	66.7%

- b. **MNDOT Recommendations:** With approximately 70.1% of the MNDOT pipe dataset identified as redundant, omission of the entire dataset is not recommended. Further assessment of the dataset, however, identified municipalities that are potentially redundant with respect to the MNDOT pipe dataset as seen above. Per this further assessment, it is recommended that MNDOT data intersecting Edina, Minneapolis, Plymouth, Richfield, Wayzata, Greenwood, Excelsior, and Carver be reviewed for assessment of removal. It is recommended that MNDOT inlets intersecting with these municipalities be omitted as well.
- c. **4/25/2025 Update:** After further discussion with MCWD, it was decided to omit MNDOT pipes and inlets to facilitate the initial model build. Further evaluation whether to incorporate these omitted MNDOT features may be beneficial following the model build and calibration.

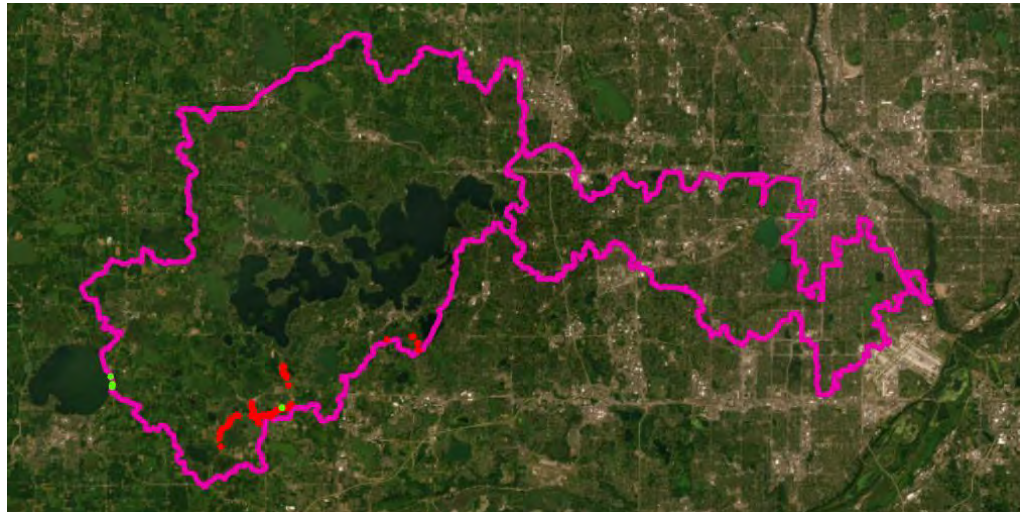
3. Carver County Inlets/Pipes

a. Pipes:

Carver County Pipe Review Results

Area	Approx. % Unique	Approx. % Redundant
Entire Watershed	8.0%	92.0%

Carver County Pipe Subset (red = redundant, green = unique)



Carver County Pipe Review Results by Municipality

Data Source	Number of Features	Approx. % Unique	Approx. % Redundant
Chanhassen	8	0.0%	100.0%
Golden Valley	109	1.8%	98.2%
None	8	100%	0%

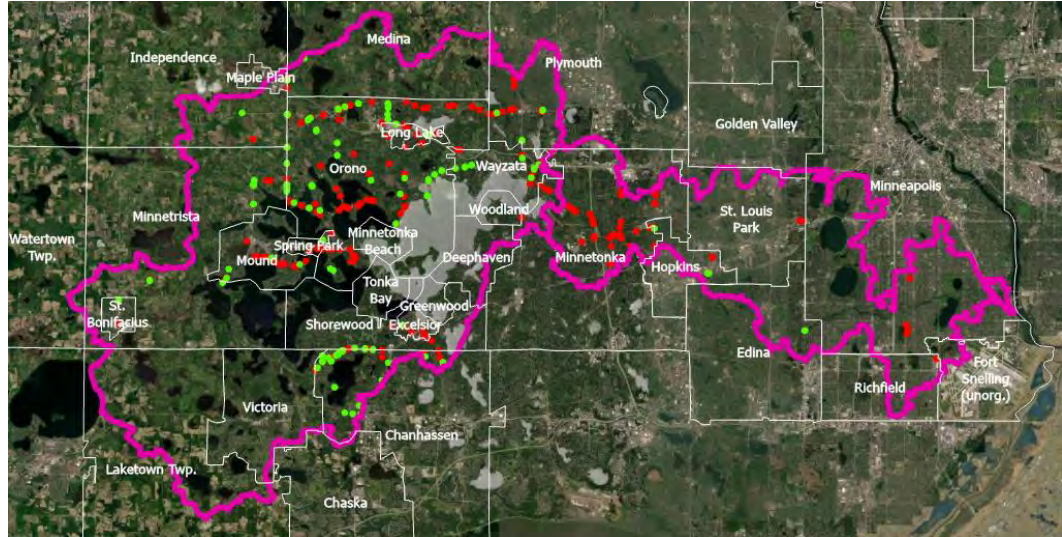
b. Carver County Recommendations:

With the redundancy of the Carver County pipe representative sample determined to be 92%, it is recommended that the dataset be omitted. In line with previous recommendations, it is also recommended that Carver County inlets be omitted.

4. MGIS Culverts

- a. 385/2109 (18.3%) of culverts were identified as intersecting MGIS pipes. Of these intersecting culverts, 282/385 (73.2%) were identified as redundant.

Intersecting Culvert Subset (red = redundant, green = unique)



- b. **MGIS Culverts Recommendations:** It is recommended that all 282 culverts identified as redundant be removed from the dataset.

Conclusions

Redundancy in storm sewer and culvert pipes were identified in source datasets to the MGIS data aggregation workflow. This analysis selected a sample of each potentially redundant dataset to review for potential omission from the aggregated dataset. The results indicate that Hennepin County and Carver County Data may be omitted without substantial loss of relevant data. MNDOT data may require additional review and omission from particular regions of the watershed area. MGIS culverts manually identified as redundant should be omitted from the final dataset.

Memo

Date: Tuesday, August 04, 2026

Project: 2-D Watershed-Wide Model

To: MCWD

From: HDR

Subject: Appendix C-10: Crop Coefficients

Note: With the update to land cover selection 03/2026, the previously developed crop coefficient and root depth values were adapted to the new selection. As such, all existing sections (sections 1-8) have been left unchanged, with additional sections added to reflect later work.

1.0 Introduction

To represent evapotranspiration in StormWise, an input table containing crop coefficients and rooting depths for each land cover type is required. StormWise requires each land cover type in this table to have crop coefficient values and rooting depths for each modeled day, month, and year. For this project, a land cover raster containing 11 land cover types is used and the corresponding input table was developed for an average year. The single crop coefficient approach from Chapter 6 of the Food and Agricultural Organization publication 56 (FAO 56), “Crop evapotranspiration—Guidelines for computing crop water requirements,” was used to calculate crop coefficients (K_c) for each land cover type present (FAO 1998). Here, evapotranspiration under standard conditions, ET_c , is calculated for each land cover type as the product of reference evapotranspiration, ET_0 , and a crop coefficient, K_c , developed for each land cover type. Reference evapotranspiration, ET_0 , data for the modeled Minnehaha Creek Watershed has been provided to HDR from MCWD. This document outlines the development of crop coefficients and, if applicable, rooting depths for each of the following land cover types present in the land cover raster. For detailed calculations, see Electronic Data Package Item C-10: Crop Coefficients.

- Agriculture
- Bare soil
- Coniferous tree canopy
- Deciduous tree canopy
- Emergent wetland
- Forested shrub/wetland
- Grass/shrub
- Lakes/ponds
- River
- Buildings
- Roads/paved surfaces

2.0 Crop Coefficient Background

In FAO 56 Chapter 6, Table 11 provides general lengths for the four distinct growing stages; initial, developing, mid-season, and late-season (L_{ini} , L_{dev} , L_{mid} , and L_{late}) for various land cover types, climates, and locations. Similarly, Table 12 of FAO 56 Chapter 6 provides reference initial, mid-season, and end-of-season crop K_c values ($K_{c\ ini}$, $K_{c\ mid}$, and $K_{c\ end}$). For each of the land cover types present in the watershed, representative growing stages and K_c values were extracted from Tables 11 and 12, respectively.

To properly relate the FAO reference values to the seasonal behavior of the land cover types in the Minnehaha Creek Watershed, growing season start and end dates are required for each land cover type. Using the middle of each month as the reference date (D_{ref}), the average monthly K_c for each land cover type was calculated using the following logic.

Definitions:

- $D_{initial} = \text{growing season start date} + L_{ini}$
- $D_{developing} = D_{initial} + L_{dev}$
- $D_{mid-season} = D_{developing} + L_{mid}$
- $D_{late-season} = D_{mid-season} + L_{late}$
- If $D_{late-season} < D_{freeze}$ then $D_{late-season} = \text{growing season end date}$

K_c Calculation:

- If $D_{ref} \leq D_{initial}$
 - o $K_c = K_{c\ ini}$
 - o For the initial period, K_c equals $K_{c\ ini}$
- If $D_{initial} < D_{ref} < D_{developing}$
 - o $K_c = (((D_{ref} - D_{initial}) / (D_{developing} - D_{initial})) * (K_{c\ mid} - K_{c\ ini})) + K_{c\ ini}$
 - o During the development period, K_c linearly increases from $K_{c\ ini}$ to $K_{c\ mid}$
- If $D_{developing} < D_{ref} < D_{mid-season}$
 - o $K_c = K_{c\ mid}$
 - o During the midseason period, K_c equals $K_{c\ mid}$
- If $D_{mid-season} < D_{ref} < D_{late-season}$
 - o $K_c = (((D_{ref} - D_{mid-season}) / (D_{late-season} - D_{mid-season})) * (K_{c\ late} - K_{c\ mid})) + K_{c\ mid}$
 - o During the late season period, K_c linearly decreases from $K_{c\ mid}$ to $K_{c\ late}$

ET_c Calculation:

- $ET_c = K_c * ET_0$
- This calculation is completed using the K_c , which varies over a calendar year, determined for each land cover layer.

3.0 Developed Land Cover Types

Within the land cover raster used, both the buildings and the roads/paved surfaces categories are assumed to have 100 percent impervious coverage. Impervious areas do not allow covered soil to evaporate and generally represent surfaces with little or no vegetation. Under this analysis, areas with 100 percent impervious coverage are assumed to have no evaporation

potential. This means the year-round K_c value for both the buildings and the roads/paved surfaces category will be zero.

4.0 Agriculture Land Cover

To give more detail to the agriculture land cover type, the 2022 Hennepin County Census of Agriculture was leveraged. From this census, the top three crop types in Hennepin County were determined to be soybeans, hay, and corn. Using the reported acreage of these crops, the fraction of each was determined. Average monthly K_c values were determined for each of these three crops. Using the crop fractions, the K_c values for each of the three crops were weighed and used to calculate one representative agriculture category, aligning with the land cover raster used. See **Table 1** below.

Table 1. Hennepin County Crops with Fractions (USDA 2022)

Crop	Count (ac)	Fraction
Soybeans	7169	0.43499
Forage (hay)	4944	0.29998
Corn (grain)	4368	0.26503
TOTAL	16481	-

5.0 Growing Season Determination

Surface Water Growing Seasons

The growing seasons for the Lakes/ponds and River land cover types were determined using ice-in and -out data from the Minnesota Department of Natural Resources (MNDNR) (MNDNR 2025). Using the available data for lakes within the watershed, the median date at which the lakes were reported frozen and thawed were pulled as the growing season start and end, respectively. It was assumed that rivers experienced open water sooner than the lakes/ponds in the spring and later in the fall/winter, so a buffer of 15 days on either end of the lakes/ponds growing season was used to represent this. See **Table 2** for the median ice-in and -out dates of the lakes used.

Table 2. Median Ice-in and -out Dates Informing Lakes/Ponds Growing Season

Lake	Median Ice-In Date	Median Ice-Out Date
Minnetonka Lower	8-Dec	13-Apr
Minnetonka Upper	-	14-Apr
Christmas	3-Dec	12-Apr
Diamond	-	25-Mar
Nokomis	1-Dec	4-Apr
Hiawatha	-	5-Apr
Harriet	10-Dec	7-Apr
Bde Maka Ska	11-Dec	9-Apr
Lake of the Isles	29-Dec	7-Apr
Cedar Lake	-	9-Apr

AVERAGE	10-Dec	7-Apr
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Growing Seasons for Remaining Land Cover Types

For the following land cover categories, growing season was determined by soil temperature.

- Agriculture
 - o Soybeans
 - o Hay
 - o Corn
- Bare soil
- Coniferous tree canopy
- Deciduous tree canopy
- Emergent wetland
- Forested shrub/wetland
- Grass/shrub

Each of these land cover categories was assigned a benchmark soil temperature where planting/germination is expected; this is the growing season start date. Similarly, the growing season is expected to end once the soil temperature is at or below freezing. Where available, recommended growing season start soil temperatures for each of the land cover categories was used. Where not available, a default assumption of 50°F was assigned based on Pathak et. al, 2012. With these benchmarks determined, data from the National Oceanic and Atmospheric Administration's (NOAA) soil temperature maps by depth station MPXM5, located in Chanhassen was leveraged. The dataset contains daily soil temperature data from 2009-2024 and was used to assign a date to each of these benchmark soil temperatures (NOAA 2025). Here, the average spring date at which each soil temperature was met or exceeded was determined for each benchmark. See **Table 3** for a summary of growing seasons and sources for all land cover types present.

Table 3. Growing Season Soil Temperature and Dates for MCWD Land Cover Types

Land Cover Category	Growing Start				Growing End			
	Type	Date	Source - Type	Source - Date	Type	Date	Source - Type	Source - Date
AGRICULTURE - Corn	55° soil temp	17-May	(Nair)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
AGRICULTURE - Soybeans	55° soil temp	17-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
AGRICULTURE - Hay	43° soil temp	11-Apr	(Pathak, 2012)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
BARE SOIL	32° soil temp	15-Mar	Assumed	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
CONIFEROUS TREE CANOPY	50° soil temp	2-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (28F)	27-Oct	Assumed	(NCEI, 2024)
DECIDUOUS TREE CANOPY	50° soil temp	2-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
EMERGENT WETLAND	50° soil temp	2-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)
FORESTED SHRUB/WETLAND	50° soil temp	2-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (28F)	27-Oct	Assumed	(NCEI, 2024)
GRASS/SHRUB	50° soil temp	2-May	(Pathak, 2012)	(NOAA, 2025)	Freeze (32F)	16-Oct	Assumed	(NCEI, 2024)

8.0 Rooting Depth

Specific root depth values were assigned to each of the land cover categories, where documentation was available. Where documentation was not available, a default root depth value of 3.0ft, StormWise’s default root depth, was assigned. Root depths were assigned for months within the land cover categories’ respective growing seasons only. Additionally, the root depths were assumed to be constant over each land cover type’s growing season. See Table 6 for the selected rooting depths for each land cover layer.

Table 6. Selected Rooting Depths by Land Cover Type

Class Names	Rooting Depth (ft)	Source
AGRICULTURE - Corn	3.00	FAO56 Annex 3 (FAO, 1998)
AGRICULTURE - Soybeans	2.00	FAO56 Annex 3 (FAO, 1998)
AGRICULTURE - Hay	1.50	(NRCS)
BARE SOIL	3.00	Assumed, StormWise
CONIFEROUS TREE CANOPY	3.00	Assumed, StormWise
DECIDUOUS TREE CANOPY	3.00	Assumed, StormWise
EMERGENT WETLAND	3.00	Assumed, StormWise
FORESTED SHRUB/WETLAND	3.00	Assumed, StormWise
GRASS/SHRUB	3.00	Assumed, StormWise
LAKES/PONDS	3.00	Assumed, StormWise
RIVER	3.00	Assumed, StormWise
BUILDINGS	-	-
ROADS/PAVED SURFACES	-	-

As was done with the K_c values for the agriculture land cover type, rooting depths for the corn, soybean, and hay crop types were weighed by acreage to create a representative rooting depth in the agriculture type land cover layer. See Table 7 for the rooting depth values for the corn, soybean, and hay components of the agriculture type land cover layer.

Table 7. Rooting Depths for Corn, Soybeans, and Hay by Month

[illegible]

Table 8. Rooting Depths for the Watershed Model Land Cover Raster Categories by Month

Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AGRICULTURE	0	0	0	0.45	0.45	2.12	2.12	2.12	2.12	2.12	0	0
BARE SOIL	0	0	0	0	0	0	0	0	0	0	0	0
CONIFEROUS TREE CANOPY	0	0	0	0	3	3	3	3	3	3	0	0
DECIDUOUS TREE CANOPY	0	0	0	0	3	3	3	3	3	3	0	0
EMERGENT WETLAND	0	0	0	0	3	3	3	3	3	3	0	0
FORESTED SHRUB/WETLAND	0	0	0	0	3	3	3	3	3	3	0	0
GRASS/SHRUB	0	0	0	0	3	3	3	3	3	3	0	0
LAKES/PONDS	0	0	0	3	3	3	3	3	3	3	3	0
RIVER	0	0	0	3	3	3	3	3	3	3	3	3
BUILDINGS	-	-	-	-	-	-	-	-	-	-	-	-
ROADS/PAVED SURFACES	-	-	-	-	-	-	-	-	-	-	-	-

9.0 Updated Land Cover Selection

Per discussions with the project team, updated land cover selections were made during the month 03/2026, to provide more flexibility in implementing future land cover changes. For this, two land cover datasets, the Metropolitan Council's Generalized Land Use (GLU) set and the USGS' National Land Cover Database (NLCD) were blended. Here, selected land cover types from the GLU set were replaced by values from the NLCD. See below for a definition of each set's land cover types and replacements made.

Generalized Land Use (GLU):

- Agricultural – Replaced with NLCD
- Farmstead
- Seasonal/Vacation
- Single Family Detached
- Single Family Attached
- Multifamily
- Manufactured Housing Park
- Retail and Other Commercial
- Office
- Mixed Use Residential
- Mixed Use Industrial
- Mixed Use Commercial
- Industrial or Utility
- Institutional
- Park, Recreational, or Preserve – Replaced with NLCD

- Golf Course – Replaced with NLCD
- Major Highway
- Major Railway
- Airport or Airstrip
- Undeveloped – Replaced with NLCD
- Open Water – Replaced with NLCD

National Land Cover Database (NLCD):

- Open Water
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land (Rock/Sand/Clay)
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrub/Scrub
- Herbaceous/Grasslands
- Hay/Pasture
- Cultivated Crops
- Woody Wetlands
- Emergent Herbaceous Wetlands

With the framework developed, all GLU zones defined by “Replaced with NLCD” above were removed, and the NLCD zones for these locations were appended. In raster form and as imported to StormWise, the GLU values are defined by a three-digit code and the NLCD values by a two-digit code. See the following section for a key.

10.0 TCMA to New Land Cover Conversion

To generate new values for both crop coefficients and rooting depths based on the new land cover types, a combination of direct and blended TCMA values was used based on land cover type alignment. For blended values, a combination of impervious and grass/shrub TCMA values was used, weighted by the GLU/NLCD layer’s impervious percentage. See Table 9 for a key including numeric code, source, impervious percentage, label, and TCMA value used for each new land use category.

$$K_{c \text{ blended}} = \%_{\text{impervious}} * K_{c \text{ impervious}} + (1 - \%_{\text{impervious}}) * K_{c \text{ grass/shrub}}$$

Table 9. New Land Use Selections Key

Code	Source	Impervious %	Label	TCMA Value Used
111	GLU	17.8	Farmstead	Blended
112	GLU	4.0	Seasonal/Vacation	DECIDUOUS TREE CANOPY
113	GLU	28.7	Single Family Detached	Blended
114	GLU	48.9	Single Family Attached	Blended
115	GLU	59.9	Multifamily	Blended
116	GLU	47.7	Manufactured Housing Park	Blended
120	GLU	74.6	Retail and Other Commercial	Blended
130	GLU	67.9	Office	Blended
141	GLU	74.6	Mixed Use Residential	Blended
142	GLU	69.1	Mixed Use Industrial	Blended
143	GLU	77.5	Mixed Use Commercial	Blended
151	GLU	65.0	Industrial or Utility	Blended
160	GLU	47.1	Institutional	Blended
201	GLU	59.7	Major Highway	Blended
202	GLU	61.6	Major Railway	Blended
203	GLU	63.4	Airport or Airstrip	Blended
11	NLCD	0	Open Water	LAKES/PONDS
21	NLCD	10.7	Developed, Open Space	Blended
22	NLCD	33.8	Developed, Low Intensity	Blended
23	NLCD	62.2	Developed, Medium Intensity	Blended
24	NLCD	85.6	Developed, High Intensity	Blended
31	NLCD	0	Barren Land (Rock/Sand/Clay)	BARE SOIL
41	NLCD	0	Deciduous Forest	DECIDUOUS TREE CANOPY
42	NLCD	0	Evergreen Forest	CONIFEROUS TREE CANOPY
43	NLCD	0	Mixed Forest	DECIDUOUS TREE CANOPY
52	NLCD	0	Shrub/Scrub	GRASS/SHRUB
71	NLCD	0	Herbaceous/Grasslands	GRASS/SHRUB
81	NLCD	0	Hay/Pasture	AGRICULTURE
82	NLCD	0	Cultivated Crops	AGRICULTURE
90	NLCD	0	Woody Wetlands	FORESTED SHRUB/WETLAND
95	NLCD	0	Emergent Herbaceous Wetlands	EMERGENT WETLAND

With TCMA to new land use assignments made, new Kc and rooting depth values were generated. See Tables 10 and 11 for these values, respectively.

Table 10. Kc Values for the Updated Land Cover Raster Categories by Month

Code	Label	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
111	Farmstead	0.16	0.16	0.16	0.16	0.67	0.70	0.70	0.70	0.70	0.16	0.16	0.16
112	Seasonal/Vacation	0.20	0.20	0.20	0.20	1.00	1.00	1.00	1.00	1.00	0.20	0.20	0.20
113	Single Family Detached	0.14	0.14	0.14	0.14	0.58	0.61	0.61	0.61	0.61	0.14	0.14	0.14
114	Single Family Attached	0.10	0.10	0.10	0.10	0.41	0.43	0.43	0.43	0.43	0.10	0.10	0.10
115	Multifamily	0.08	0.08	0.08	0.08	0.32	0.34	0.34	0.34	0.34	0.08	0.08	0.08
116	Manufactured Housing Park	0.10	0.10	0.10	0.10	0.42	0.44	0.44	0.44	0.44	0.10	0.10	0.10
120	Retail and Other Commercial	0.05	0.05	0.05	0.05	0.21	0.22	0.22	0.22	0.22	0.05	0.05	0.05
130	Office	0.06	0.06	0.06	0.06	0.26	0.27	0.27	0.27	0.27	0.06	0.06	0.06
141	Mixed Use Residential	0.05	0.05	0.05	0.05	0.21	0.22	0.22	0.22	0.22	0.05	0.05	0.05
142	Mixed Use Industrial	0.06	0.06	0.06	0.06	0.25	0.26	0.26	0.26	0.26	0.06	0.06	0.06
143	Mixed Use Commercial	0.04	0.04	0.04	0.04	0.18	0.19	0.19	0.19	0.19	0.04	0.04	0.04
151	Industrial or Utility	0.07	0.07	0.07	0.07	0.28	0.30	0.30	0.30	0.30	0.07	0.07	0.07
160	Institutional	0.11	0.11	0.11	0.11	0.43	0.45	0.45	0.45	0.45	0.11	0.11	0.11
201	Major Highway	0.08	0.08	0.08	0.08	0.33	0.34	0.34	0.34	0.34	0.08	0.08	0.08
202	Major Railway	0.08	0.08	0.08	0.08	0.31	0.33	0.33	0.33	0.33	0.08	0.08	0.08
203	Airport or Airstrip	0.07	0.07	0.07	0.07	0.30	0.31	0.31	0.31	0.31	0.07	0.07	0.07
11	Open Water	0.20	0.20	0.20	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	0.20
21	Developed, Open Space	0.18	0.18	0.18	0.18	0.72	0.76	0.76	0.76	0.76	0.18	0.18	0.18
22	Developed, Low Intensity	0.13	0.13	0.13	0.13	0.54	0.56	0.56	0.56	0.56	0.13	0.13	0.13
23	Developed, Medium Intensity	0.08	0.08	0.08	0.08	0.31	0.32	0.32	0.32	0.32	0.08	0.08	0.08
24	Developed, High Intensity	0.03	0.03	0.03	0.03	0.12	0.12	0.12	0.12	0.12	0.03	0.03	0.03
31	Barren Land (Rock/Sand/Clay)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
41	Deciduous Forest	0.20	0.20	0.20	0.20	1.00	1.00	1.00	1.00	1.00	0.20	0.20	0.20
42	Evergreen Forest	0.20	0.20	0.20	0.20	1.00	1.00	1.00	1.00	1.00	1.00	0.20	0.20
43	Mixed Forest	0.20	0.20	0.20	0.20	1.00	1.00	1.00	1.00	1.00	0.20	0.20	0.20
52	Shrub/Scrub	0.20	0.20	0.20	0.20	0.81	0.85	0.85	0.85	0.85	0.20	0.20	0.20
71	Herbaceous/Grasslands	0.20	0.20	0.20	0.20	0.81	0.85	0.85	0.85	0.85	0.20	0.20	0.20
81	Hay/Pasture	0.20	0.20	0.20	0.26	0.42	0.68	1.04	1.09	1.01	0.20	0.20	0.20
82	Cultivated Crops	0.20	0.20	0.20	0.26	0.42	0.68	1.04	1.09	1.01	0.20	0.20	0.20
90	Woody Wetlands	0.20	0.20	0.20	0.20	0.42	1.20	1.20	1.20	0.94	0.47	0.20	0.20
95	Emergent Herbaceous Wetlands	0.20	0.20	0.20	0.20	0.42	1.20	1.20	1.20	0.88	0.20	0.20	0.20

Table 10. Rooting Depth Values for the Updated Land Cover Raster Categories by Month

Code	Label	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
111	Farmstead	0	0	0	0	0	3	3	3	3	3	0	0
112	Seasonal/ Vacation	0	0	0	0	3	3	3	3	3	3	0	0
113	Single Family Detached	0	0	0	0	0	3	3	3	3	3	0	0
114	Single Family Attached	0	0	0	0	0	3	3	3	3	3	0	0
115	Multifamily	0	0	0	0	0	3	3	3	3	3	0	0
116	Manufactured Housing Park	0	0	0	0	0	3	3	3	3	3	0	0
120	Retail and Other Commercial	0	0	0	0	0	3	3	3	3	3	0	0
130	Office	0	0	0	0	0	3	3	3	3	3	0	0
141	Mixed Use Residential	0	0	0	0	0	3	3	3	3	3	0	0
142	Mixed Use Industrial	0	0	0	0	0	3	3	3	3	3	0	0
143	Mixed Use Commercial	0	0	0	0	0	3	3	3	3	3	0	0
151	Industrial or Utility	0	0	0	0	0	3	3	3	3	3	0	0
160	Institutional	0	0	0	0	0	3	3	3	3	3	0	0
201	Major Highway	0	0	0	0	0	3	3	3	3	3	0	0
202	Major Railway	0	0	0	0	0	3	3	3	3	3	0	0
203	Airport or Airstrip	0	0	0	0	0	3	3	3	3	3	0	0
11	Open Water	0	0	0	0	0	3	3	3	3	3	0	0
21	Developed, Open Space	0	0	0	0	0	3	3	3	3	3	0	0
22	Developed, Low Intensity	0	0	0	0	0	3	3	3	3	3	0	0
23	Developed, Medium Intensity	0	0	0	0	0	3	3	3	3	3	0	0
24	Developed, High Intensity	0	0	0	0	0	3	3	3	3	3	0	0
31	Barren Land (Rock/Sand/ Clay)	0	0	3	3	3	3	3	3	3	3	0	0
41	Deciduous Forest	0	0	0	0	3	3	3	3	3	3	0	0
42	Evergreen Forest	0	0	0	0	3	3	3	3	3	3	0	0
43	Mixed Forest	0	0	0	0	3	3	3	3	3	3	0	0
52	Shrub/Scrub	0	0	0	0	3	3	3	3	3	3	0	0
71	Herbaceous/ Grasslands	0	0	0	0	3	3	3	3	3	3	0	0
81	Hay/Pasture	0	0	0	0.45	0.45	2.12	2.12	2.12	2.12	2.12	0	0
82	Cultivated Crops	0	0	0	0.45	0.45	2.12	2.12	2.12	2.12	2.12	0	0
90	Woody Wetlands	0	0	0	0	3	3	3	3	3	3	0	0
95	Emergent Herbaceous Wetlands	0	0	0	0	3	3	3	3	3	3	0	0

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ELECTRONIC DATA PACKAGE ITEM C-10: Crop Coefficients

Memo

Date: Tuesday, August 04, 2026
Project: 2-D Watershed-Wide Model
To: MCWD
From: HDR
Subject: Appendix C-11: Naming Convention

1.0 - Introduction

This document outlines the naming convention used for model elements in the 2-D watershed-wide model developed for the Minnehaha Creek Watershed District. Each feature's name follows the following general convention: AA-BBB-CCCCC. The naming convention includes overall type (AA), subtype (BBB), and six digits for a unique identifier (CCCCC).

2.0 – Overland Flow Features

Overland flow features follow the naming conventions described in Table 1. Where relevant, the subtype was related to the municipality from which the feature was sourced - see Table 2. The unique identifier field assigned (six-digit integer string, CCCCC) is unique within each feature type but may not be unique in the context of all model elements.

Table 1. Naming Convention for Overland Flow Features

Category	Feature Type	Overall Type for Naming Convention	Subtype for Naming Convention*
Nodes	Storm Sewer Manhole	"NM"	Municipality Code
	Storm Sewer Inlet	"NI"	Municipality Code
	Storm Sewer Outlets	"NO"	Municipality Code
	Pond Control Volume Node	"NP"	"PCV"
	Channel Control Volume Node	"NC"	"CCV"
	Tailwater or Time/Stage Node	"NT"	Varies
Links	Pipes/Culverts	"LP"	Municipality Code
	Weirs	"LW"	Varies

Category	Feature Type	Overall Type for Naming Convention	Subtype for Naming Convention*
	Channels	"LC"	"MC"
	Rating Curves	"LR"	"MC"
	Drop Structures	"LD"	Varies
Cross Sections	Channel	"XC"	"MC"
	Weir	"XW"	Varies
Misc. Overland Flow Region	Region Boundary	"LW"	-
	Breakpoints	"OF"	"BKP"
	Breaklines		"BKL"
	Pond Control Volume		"PCV"
	Channel Control Volume		"CCV"
	Channel Feature		"CCF"
	Boundary Stage Lines		"BSL"
	Simplification		"SIM"
	1D Node Interface – Building Centroids	"1D"	"BLD"

*Features with "Varies" in the subtype field have either not yet been utilized or may span multiple subtypes. Weir links, for example, have been developed as a part of the channel control volume system, but also represent inlet and storm sewer infrastructure connections.

Table 2. Municipality Codes Used for Relevant Overland Flow Feature Subtypes

Municipality	Subtype Code
Carver County	"CVC"
Chanhassen	"CHA"
Deephaven	"DEE"
Edina	"EDI"
Excelsior	"EXC"
Golden Valley	"GVA"
Greenwood	"GRN"
Hennepin County	"HCN"

Municipality	Subtype Code
Hopkins	"HOP"
Independence	"IND"
Long Lake	"LLK"
Maple Plain	"MAP"
Medina	"MED"
Minnetonka	"MTK"
Minnetrista	"MTR"
MnDOT	"DOT"
Mound	"MOU"
Minneapolis	"MPL"
Orono	"ORO"
Plymouth	"PLY"
Richfield	"RFD"
Shorewood	"SHW"
Spring Park	"SPK"
Saint Bonifacius	"SBO"
Saint Louis Park	"SLP"
Three Rivers	"TRV"
Victoria	"VIC"
Wayzata	"WYZ"

3.0 – Groundwater Features

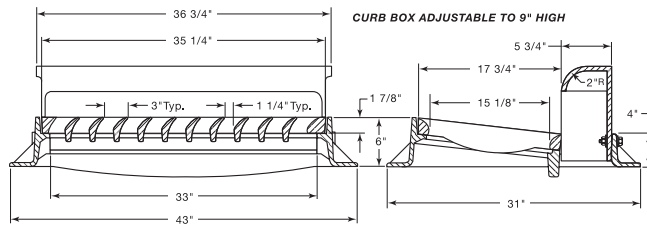
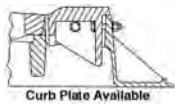
- Regions (4)
 - "GW-NE", "GW-SE", "GW-SW", "GW-NW"
- Breakpoints
 - GW-BKP-000000
- Boundary Stage Lines:
 - GW-BSL-000000

4.0 – Examples

- Feature: Storm Sewer Manhole from Minneapolis Dataset
 - Model Name: NM-MPL-000001
- Feature: Minnehaha Creek Channel Cross Section
 - Model Name: XC-MC-000001
- Feature: Channel Control Volume
 - Model Name: OF-CCV-000001
- Feature: Groundwater Boundary Stage Line
 - Model Name: GW-BSL-000001

R-3067-V Combination Inlet Frame, Grate, Curb Box

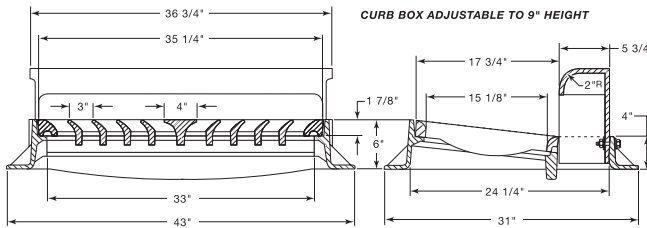
Heavy Duty



CATALOG NUMBER	GRATE TYPE	SQ. FT. OPEN	WEIR PERIMETER LINEAL FEET
R-3067-V	V	2.4	5.8

R-3067-VB Combination Inlet Frame, Grate, Curb Box

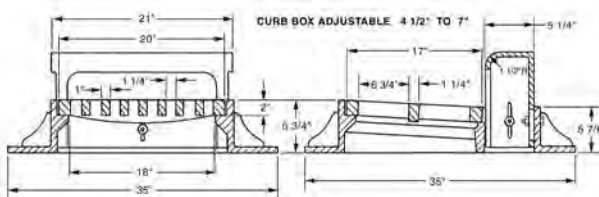
Heavy Duty



CATALOG NUMBER	GRATE TYPE	SQ. FT. OPEN	WEIR PERIMETER LINEAL FEET
R-3067-VB	V	2.7	5.8

R-3070 Combination Inlet Frame, Grate, Curb Box

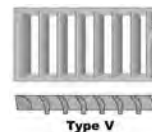
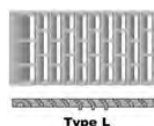
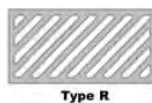
Heavy Duty



Standard Grate (shown): Type A

Alternate Grate(s):

CATALOG NUMBER	GRATE TYPE	SQ. FT. OPEN	WEIR PERIMETER LINEAL FEET
R-3070	A	0.9	4.5
R-3070	L	0.8	4.5
R-3070	R	0.9	4.5
R-3070	V	1.3	4.5



Available Curb Boxes: 1-1/2" Radius Open (standard), 1-1/2" Radius Barred, 3" Radius Open
Enviro-Curb Boxes available, see p. 129.

Memo

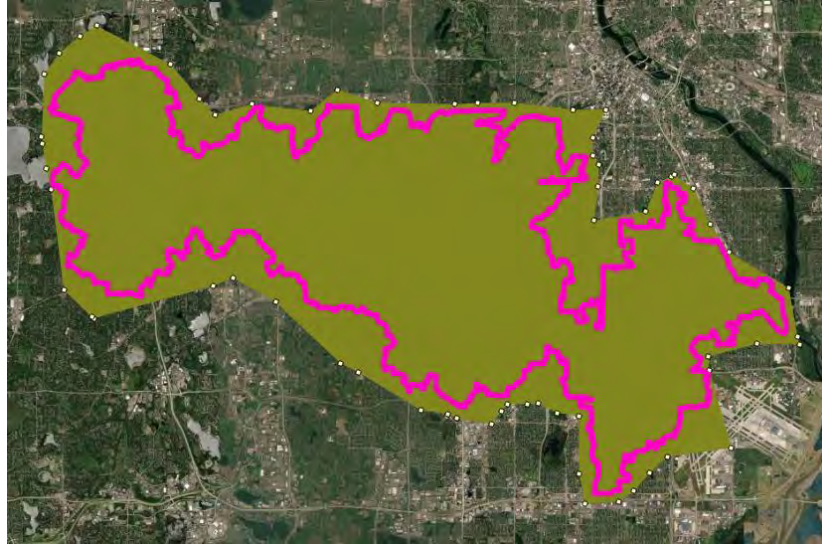
Date: Wednesday, June 04, 2025
Project: 2-D Watershed-Wide Model
To: MCWD
From: HDR
Subject: Appendix C-13: Groundwater Model

This document outlines the groundwater modeling workflow in StormWise, which uses GIS preprocessing to define groundwater regions and boundary conditions. Through structured data inputs like vertical soil layers, ET rates, porosity, and conductivity, StormWise simulates subsurface flow and its interaction with surface water features across the watershed. Model setup includes importing region shapes, boundary stage lines, and associated tables to support accurate hydrologic representation.

Preprocessing in ArcGIS

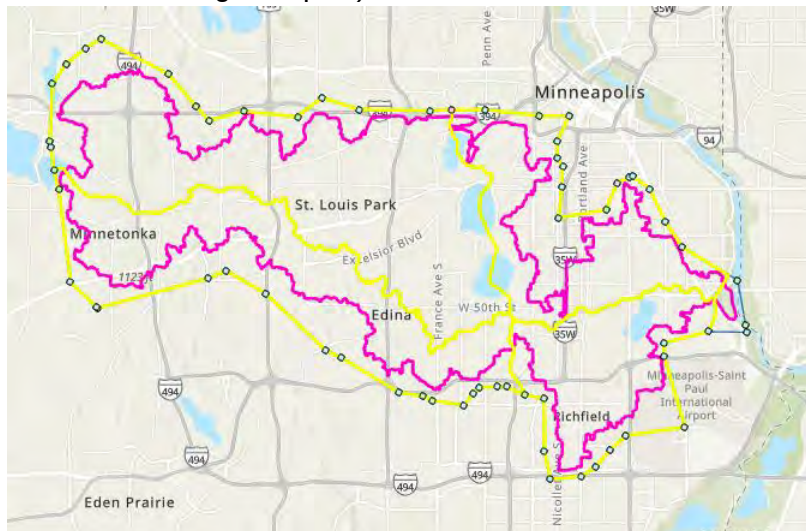
1. Required Components
 - a. Well locations with average static water table level from an external source
 - b. DEM with hydro-flattened water body surfaces
2. Select Groundwater Region Boundary Points
 - a. Identify wells and surface water bodies located outside of the model's overland flow region.
 - b. Place points in the center of the selected water bodies and at well locations in one feature class.
 - i. Each of these locations will serve as a vertex of the groundwater region polygon and provide static water table elevation values to be interpolated along the boundary stage lines.
 - c. In this point feature class, create the following fields and assign field values as described below:
 - i. Type
 1. Either "Well" or "Surface Water" depending on location type
 - ii. NAME
 1. See the provided Naming Convention deliverable.
 - iii. WaterEl
 1. Using the well source data, pull an average static water table elevation for each point. Here, the Minnesota Geological Survey's County Well Index was used to identify relevant wells and pull their static water elevations (MGS 2025).
 2. Use the Add Surface Information tool to calculate the z (elevation) value of each surface water body point, pulling hydro flattened water surface elevations from the DEM (ensure the DEM does not have bathymetry if using this method)
3. Draw Groundwater Region Boundary

- a. Connect all the selected groundwater region boundary points into a polygon bounding the model's overland flow region.
- b. Example: (groundwater region = green, well/surface water points = yellow, overland flow region = pink)

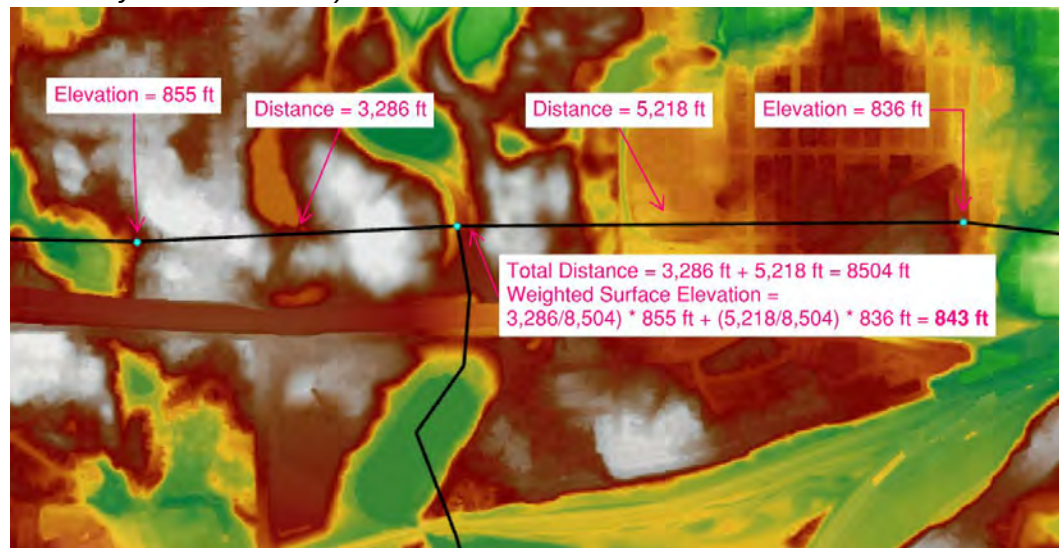


4. Split Groundwater Region Boundary

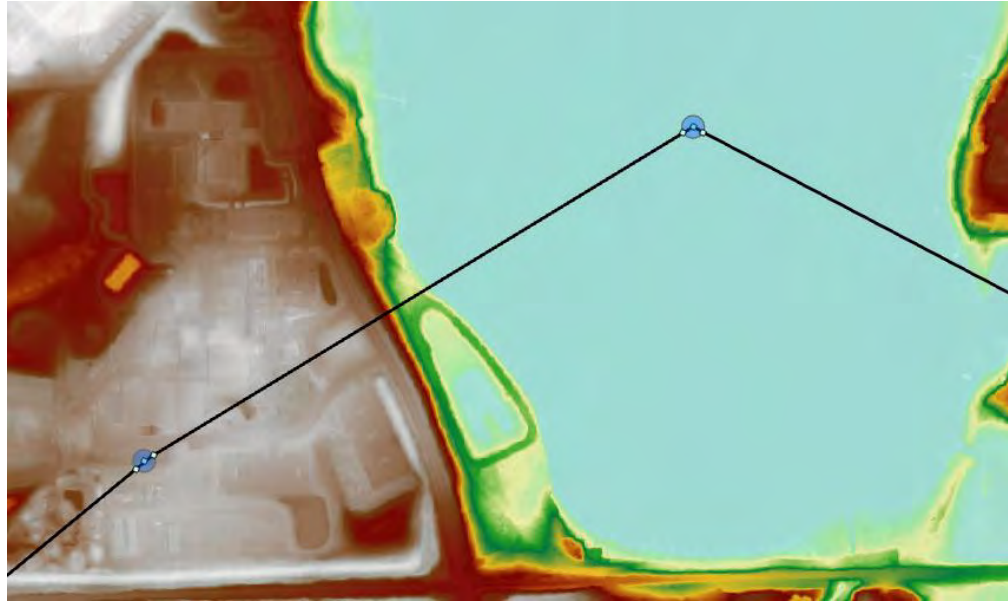
- a. The groundwater region boundary should be split into subregions, following surface water bodies within the region. In the example below, note that the groundwater subregion divides follow the chain of lakes from North to South and Minnehaha creek from East to West, dividing the groundwater region into four. It is best to place boundaries along paths of consistent/known water table elevation, hence the following of surface water features here. A fifth groundwater region was later added downstream of the Minnehaha Falls to cover a small amount of model area that acted independently from the main four regions.
- b. Example: (groundwater regions = green, well/surface water points = yellow, overland flow region = pink)



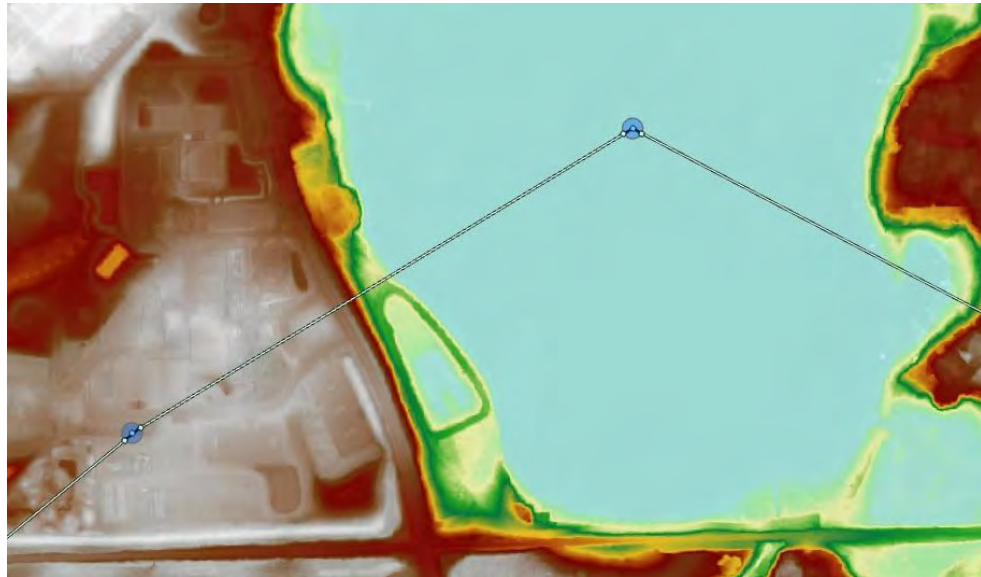
- c. In the groundwater region shapefile, assign unique names to each groundwater subregion in the NAME field
 - i. In the example above, the format “GW-XX” was used with XX = NE, NW, SE, SW, corresponding to the relative location of the subregion. The fifth, independent region was called “GW-FALLS” as this one does not connect to upstream groundwater regions and was included to cover a small area of OF region.
5. Ensure there is a point at each intersection between the groundwater boundary divisions and the outer groundwater boundary line. In the lower watershed, one point was added to the boundary point feature class to enforce this requirement.
 - a. In the NAME field of the additional point or points, assign a unique name per the model naming convention – see Naming Convention deliverable for details.
 - b. Interpolate the water elevation for the “WaterEI” field using the nearest neighboring groundwater boundary points. See the example below (groundwater boundary/divides = black)



6. Buffer each groundwater boundary point to 50ft
 - a. In StormWise, the groundwater boundary requires individual line segments with to and from nodes of known water surface elevation. Here, the water elevation along the line will be interpolated using these to and from nodes. These lines, however, cannot have coincident edges. Hence, a 50 ft buffer is used on the points to provide a 100 ft distance between the line segments on either side of a point.
7. Run the Intersect tool on the groundwater boundary and water level point buffers with the output set to point geometry. These will be start/end points of the groundwater boundary lines. See below. (buffer circles = blue, intersection points = teal, groundwater boundary = black)



8. Create lines along the groundwater region boundary, connecting the intersection points. These are called boundary stage lines. See below. (boundary stage lines = teal)



9. Add the following fields to the groundwater boundary stage lines
 - a. Groundwater_Region
 - i. Will be populated with the name of the one of the four groundwater regions it is representing
 - b. BDRY_Stage1
 - i. Will be populated with the name of one of the water level points the line is related to
 - c. BDRY_Stage2
 - i. Will be populated with the name of the other water level point the line is related to

10. Select each groundwater region individually, using that selection to select connected groundwater boundary stage lines and calculate the Groundwater_Region field = the name of the groundwater region used.
11. Using the Features to Points - XTools Pro tool or similar, generate a point at the start point of each groundwater boundary stage line. Use Spatial Join with a 70 ft distance to join the name of the water level point to this point. Next, use spatial join to join the name of the water level point field, from the Xtools Pro output, to the BDRY_Stage1 field of the groundwater boundary stage lines.
12. Repeat the above step, generating a point at the end of each boundary stage line and using spatial joins to pull the name of the other bounding point to the BDRY_Stage2 field of the groundwater boundary stage lines.
13. StormWise requires vertices on the groundwater boundary at groundwater boundary stage line endpoints. Select the groundwater boundary and, using the Edit Vertices tool, add vertices to the groundwater boundary at the intersection points generated in previous steps.
14. Split the groundwater boundary lines into separate feature classes by groundwater region they are connected to. StormWise will require a separate import of these lines to each of their respective groundwater regions.
15. Prepare groundwater region and boundary stage line shapefiles for export to StormWise.

Groundwater Tables

Each of the following tables has slightly different formatting requirements for import to StormWise. To populate these tables, HDR created dummy tables for each within StormWise, then exported them and filled out the correctly formatted, exported table with the relevant information. See StormWise Help for formatting and import requirements for specific datasets.

Boundary Stage Points

1. Background: Provides reference water level to boundary stage line endpoints for interpolation along the lines.
2. StormWise Location: 2D Features -> Groundwater -> Boundary Stage Points
3. Requirements:
 - a. CSV format of the ArcPro Groundwater Boundary Points table, described above, with name and water elevation values for each. See Electronic Data Package Item C-13.1.

Reference ET

1. Background: Provides information on time-varied ET rates for ET calculation for land cover layers.
2. StormWise Location: In project file structure -> Resources -> ReferenceET
3. Inputs:
 - a. Reference ET Rate (id^{-1} , mmd^{-1}) by year, month, day, and hour in text file format. See StormWise Help for formatting.
4. Approach:

- a. HDR was provided with reference ET data from MCWD. See Electronic Data Package Item C-13.2 for that used in StormWise.

Vertical Layers Table

1. Background: The vertical layers table contains an array of soil data for each soil type. This method allows for vertical discretization of the soil column into layers.
2. StormWise Location: Tables -> Rainfall Excess Methods -> Vertical Layers Sets
3. Inputs:
4. Approach:
 - a. HDR and MCWD coordinated with StormWise developers to have a vertical layers table developed for the model. StormWise developers developed the required vertical layers table in line with the “Tutorial - Vertical Layer Parameters from NRCS Soils” section of the StormWise help system (Streamline 2024). See Electronic Data Package Item C-13.3.

Impervious Set Data

1. Background: Provides imperviousness information for land cover map layer zones
2. StormWise Location: Tables -> Impervious Sets
3. Inputs: Imperviousness of values within land cover map layer
4. Approach:
 - a. In StormWise, use the extract option in the impervious set window to extract all land cover types from the map layer. (Note: land cover raster must be imported for this step) Here, Buildings, Lakes/Ponds, River, and Roads/Paved Surfaces were set to 100 percent imperviousness with 100 percent DCIA. All other land values were kept as zero. See Electronic Data Package Item C-13.4

Roughness Set

1. Background: Provides surface roughness information for land cover map layer zones
2. StormWise Location: Tables -> Roughness Sets
3. Inputs: Shallow flow roughness values, deep flow roughness values, and cutoff for depth for shallow/deep flow transition.
4. Approach:
 - a. Roughness values for land cover zones were populated with data from multiple references. See Electronic Data Package Item C-13.5

Crop Coefficient Set

1. Background: The Reference ET rate is scaled by coefficients from the Crop Coefficient Set that are specific to land cover map layer zones.
2. StormWise Location: Tables -> Evapotranspiration -> Crop Coefficient Sets
3. Inputs: Crop coefficient, root depth, irrigation rate, and irrigation efficiency by year, month, and day for each relevant land cover map layer zone.
4. Approach: See the provided Crop Coefficient spreadsheet and memo, Appendix and Electronic Data Package item B-7, for details on crop coefficient development.

Fillable Porosity Set

1. Background:

2. StormWise Location: Tables -> 2D Groundwater -> Fillable Porosity Sets
3. Inputs: Fillable porosity above and below ground for soil groups
4. Approach:
 - a. The below-ground fillable porosity for each soil type was represented as that soil type's "MC_Saturated" value from the vertical layers table. A uniform value of 1.0 was applied to each soil type to represent the above-ground fillable porosity. See Electronic Data Package item C-13.6.

Conductivity Set

1. Background:
2. StormWise Location: Tables -> 2D Groundwater -> Conductivity Sets
3. Inputs: Horizontal conductivity for soil groups
4. Approach:
 - a. The conductivity set was created using the saturated hydraulic conductivity from the bottom layer of each soil group in the vertical layers table. Multiply the saturated hydraulic conductivity from the vertical layers table by ten for each soil group. See Electronic Data Package item C-13.7

Groundwater Model Build

1. Create groundwater regions in StormWise representing each section of the groundwater region generated in the steps above.
2. Import each groundwater region's respective shape.
3. Generate a breakpoint pattern within each groundwater region using 250ft spacing and a 50ft buffer between other features.
4. Import the boundary stage line feature classes to their respective watershed region.
5. Import the boundary stage point set data to the groundwater boundary stage points under the 2D features tab.

References

Minnesota Geological Survey (MGS)

2025 County Well Index (CWI) - <https://cse.umn.edu/mgs/cwi>

Streamline Technologies

2024 Tutorial - Vertical Layer Parameters from NRCS Soils

ELECTRONIC DATA PACKAGE ITEM C-13.1 Boundary Stage Points

ELECTRONIC DATA PACKAGE ITEM C-13.2 Reference ET

ELECTRONIC DATA PACKAGE ITEM C-13.3 Vertical Layers Table

ELECTRONIC DATA PACKAGE ITEM C-13.4 Impervious Set

ELECTRONIC DATA PACKAGE ITEM C-13.5 Roughness Set

ELECTRONIC DATA PACKAGE ITEM C-10 Crop Coefficients

ELECTRONIC DATA PACKAGE ITEM C-13.6 Fillable Porosity Set

ELECTRONIC DATA PACKAGE ITEM C-13.7 Conductivity Set



Appendix D – Task 3B Report

Appendix D Task 3b Non-Pipe Stormwater Feature Development Summary

Date: September 22, 2025

Project: Minnehaha Creek 2-D Watershed-Wide Model

To: Brian Beck (MWCD)

From: HDR Inc.

Subject: Draft - Task 3b: Non-pipe Stormwater Feature Development Summary

Introduction

This memorandum describes steps taken to process Non-pipe Stormwater Feature (NPSF) data into model inputs for the initial model build (Task 5). The workflows described below are taken from the previously provided memorandum *Task 3a: Non-pipe Stormwater Feature Dataset Strategy Development REV1* dated January 9, 2025. Each workflow description includes a summary of steps used to carry out each workflow, as well as description of where the workflow diverged from the approach outlined in the Task 3a memo. Organization of the workflows and memo is as follows:

- Surface Water Bodies
 - Workflow 1 – Define Lake and Pond Extents
 - Workflow 2 – Associate Bathymetry to Lakes and Ponds
 - Workflow 3 – Define Wetland Extents
 - Workflow 4 – Associate Bathymetry to Wetlands
 - Workflow 5 – Create Seamless Surface
 - Workflow 6 – Develop Model Input
- Outlet Control Structures
 - Workflow 7 – Locate Outlet Control Structures
 - Workflow 8 – Associate Hydraulic Information to Outlet Control Structures
 - Workflow 9 – Develop Model Input for Outlet Control Structures
- Culverts
 - Workflow 10 – Locate Culverts
 - Workflow 11 – Associate Hydraulic Information for Culverts
 - Workflow 12 – Develop Model Input for Culverts

Surface Waterbodies

Surface waterbodies within the watershed include ponds, lakes, wetlands, artificial basins, and other depressed landforms. For representation in a StormWise model, surface waterbodies rely on accurate characterization of the stage-storage volume of potential water stored within the

feature this includes both above and below the normal water level. Many of these features will be represented by a Pond Control Volume (PCV), which are 1D representations of water storage, inflow, and outflow of a waterbody.

Previous workflows assumed all waterbodies would require augmentation of the topography to accurately characterize the surface water storage. The workflows applied for the preliminary model build, described below, identify all potential PCV locations and then target specific ones for bathymetry integration.

Workflow 1 – Define Lake and Pond Extents

This workflow identifies the extents of lakes and ponds within the model area. The proposed Task 3A memo method identified 849 lake and pond features from the previously identified GIS datasets (Lake_GDB, LakeBathymetricOutlinesContoursDEM, LAKE_POLYGONS, 20240725_National_Hydrography, and 20240725_DNR_Hydrography). These features often did not accurately align with the LiDAR depiction of the feature or the surrounding topography. In addition, a number of features were relatively small in surface area and were not clearly visible in the most recent LiDAR topography. This feature dataset is used to identify potential PCV locations. Due to the dated or inaccurate representation of the feature outline they were deemed inappropriate for use as outlines for bathymetry generation.

Another dataset, not previously defined in the Task 3A memo was instead used for bathymetry generation. Woolpert Inc. (2023) developed a Digital Elevation Model (DEM) based on more recently flown LiDAR data (2022). As part of the DEM processing breaklines were defined along the edge of water for Lakes-Ponds of larger than 2 acres in size which are used to hydro-flatten the water surface to a constant representative elevation. These breaklines accurately describe the land-water boundary within the DEM and were deemed the most applicable for bathymetry integration. Lake and Pond Extents were defined by the 'LiDARBreaklinePolygons_MCWD_1mi' which represents the 405 hydroflattened surfaces within 1 mile of the watershed boundary. This layer does not include Lake Minnetonka or its bays. Lake Minnetonka as defined by 'Lake_GDB' (provided by MCWD) was added to this layer to define the lake and pond extents.

Workflow 2 – Associate Bathymetry to Lakes and Ponds

This workflow assigns bathymetry, either observed or estimated, to the lake and pond extents identified in Workflow 1.

Assigning Known Bathymetry

Where bathymetry is known, it is assigned directly to the lake and pond extents identified in Workflow 1. Where there was overlap in known bathymetry sources for a given feature, the following order of preference was used:

- 'Lake_GDB'
- 'LakeBathymetricOutlinesContoursDEM'
- 'All Lakes Contours'

Estimating Waterbody Bathymetry

Where bathymetry is unknown, it is estimated prior to assigning it to each feature. The method used calculates an estimated maximum depth and volume, which is processed into bathymetric contours.

ESTIMATION OF MAXIMUM DEPTH

The Task 3a memo recommended a method for creating a relationship between pond area and maximum depth based on features with known bathymetry within the Big Woods Subsection Ecoregion (222Mb, Ecological Classification System, Minnesota DNR). This method did not result in a high-quality fit and therefore it was not used.

Instead, an empirical method from Heathcote et al. (2015) was used to estimate maximum waterbody depth based on the localized change in elevation. Localized change in elevation is determined from a buffer around each waterbody and the difference between mean buffer elevation and mean water surface elevation of the waterbody. Details of the calculations are included as part of the electronic submission package. Results of applying this approach to MCWD features are shown in Figure 1. To estimate maximum depth of features with unknown bathymetry, the following equation was used:

$$\log_{10} Z_{\max} = 0.35 + \log_{10} \text{elevation change}_{25} * 0.79$$

Where $Z_{\max}$ is the maximum depth (m) and $\text{elevation change}_{25}$ is the elevation change in the buffer at 25% of D the equivalent diameter. Where A is the waterbody surface area (m^2) and D is:

$$D = 2 * \sqrt{\frac{A}{\pi}}$$

Figure 2 provides a comparison between observed and estimated maximum waterbody depth for the 305 features in the Big Woods Subsection Ecoregion as they vary with surface area. In general the Heathcote et al. (2015) method provides a similar increasing trend in maximum water body depth with increasing surface area. However, the estimated maximum depths show less variability than the observed ones. Figure 3 provides additional context in that the Heathcote et al. (2015) provides less variation in maximum depth than was observed. The method tends to overestimate maximum depths for shallower features, and underestimate depths for larger features.

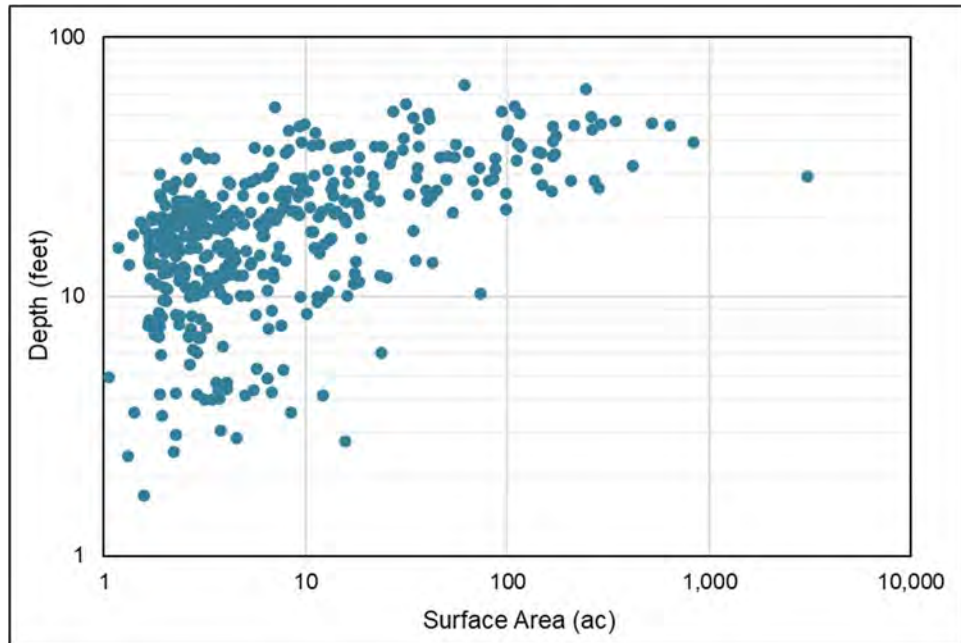


Figure 1. Unknown Waterbodies: Estimation of Maximum Depth as a Function of Waterbody Area

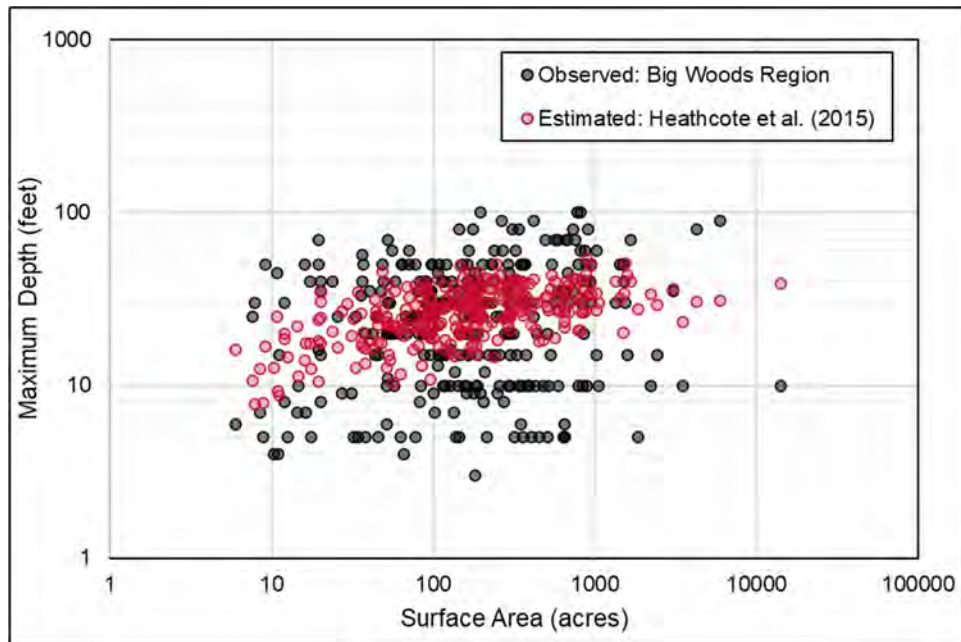


Figure 2. Big Woods Ecoregion Waterbodies: Observed and Estimated Maximum Depth as a Function of Waterbody Area

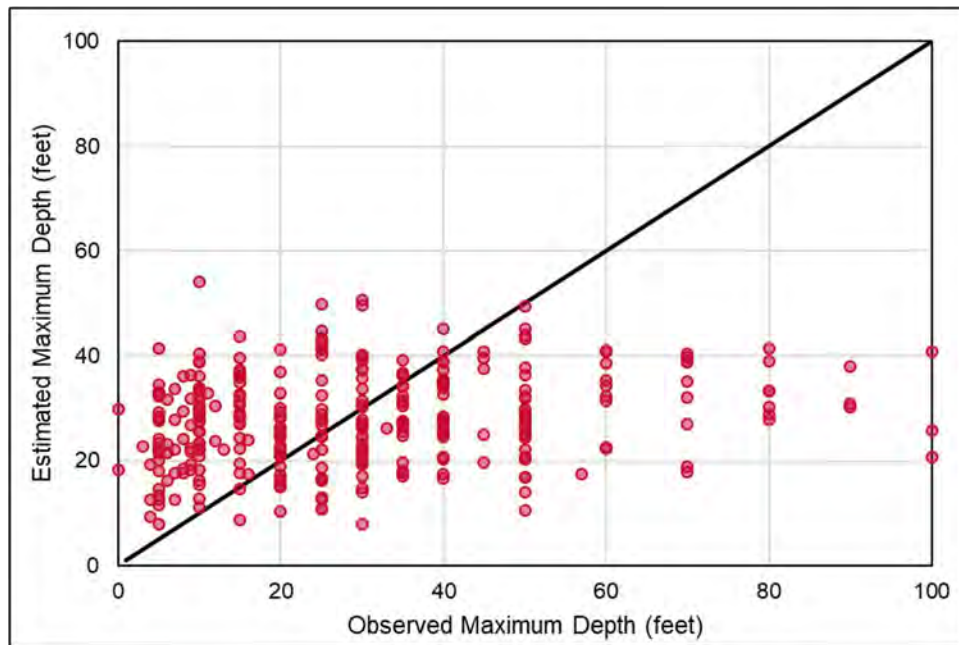


Figure 3. Big Woods Ecoregion Waterbodies: Observed vs. Estimated Maximum Depth

ESTIMATION OF WATERBODY VOLUME

Waterbody volume with unknown bathymetry was estimated using an empirical method by Delaney et al. (2022). Delaney et al. (2022) used the same approach as Heathcote et al. (2015) to calculate waterbody volume but focused on Minnesota waterbodies as input for the regression analysis. Both methods used the following equation:

$$\log_{10} V = c \log_{10} A + d \log_{10} DE_{25}$$

Where V is the water body volume (m^3), DE_{25} is the elevation change in the buffer at 25% of D the equivalent diameter, and c and d are empirical constants determined through regression analysis.

The Delaney et al. (2022) method was selected due since its parameters were developed encompassing the Minnehaha Creek Watershed. A comparison between Delaney et al. (2022) and Heathcote et al. (2015) methods applied to the MCWD waterbodies shows the Delaney method results in more storage volume for the same surface area and less variability (Figure 2). Details of the calculations are included as part of the electronic submission package.

Figure 5 shows the observed Big Woods Ecoregion volumes along with estimated ones from the Delaney et al. (2022) method. Although the Delaney et al. (2022) method refined the analysis to include waterbodies throughout central Minnesota, it always results in a higher estimate of waterbody volume than the observed data. Figure 6 shows a direct comparison of the observed volume as compared to the estimated one for the same waterbodies, which also shows the overprediction of waterbody volume. These relationships affect the below normal water level bathymetry, therefore during normal to high pool conditions are anticipated to have a limited impact on watershed response. However, during dry periods where the waterbodies may be

below normal pool conditions the total storage volume available is likely to be overestimated. This relationship should be considered for future refinement as part of the final model build.

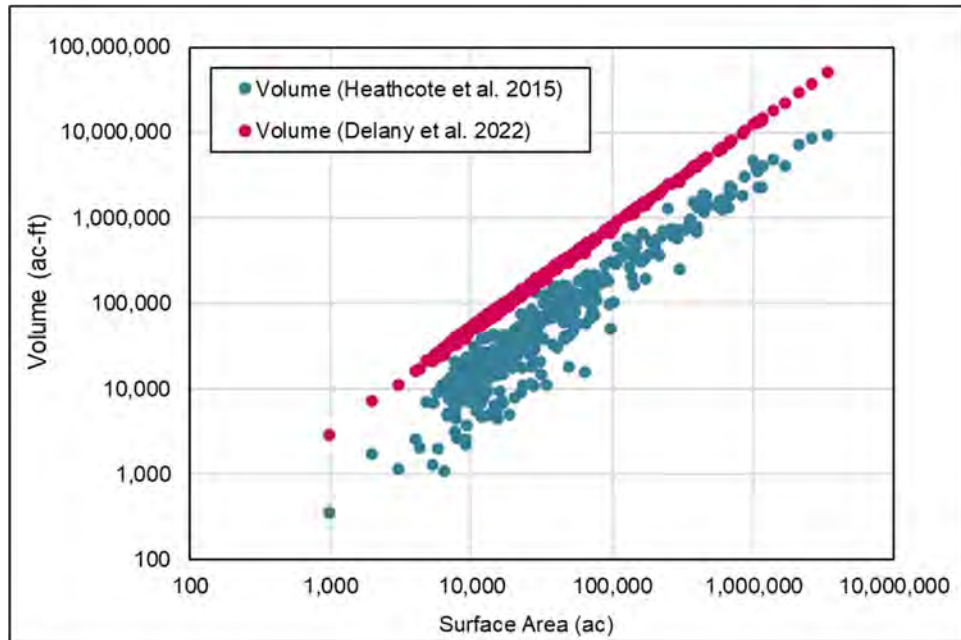


Figure 4. Unknown Waterbodies: Estimation of Volume as a Function of Waterbody Area

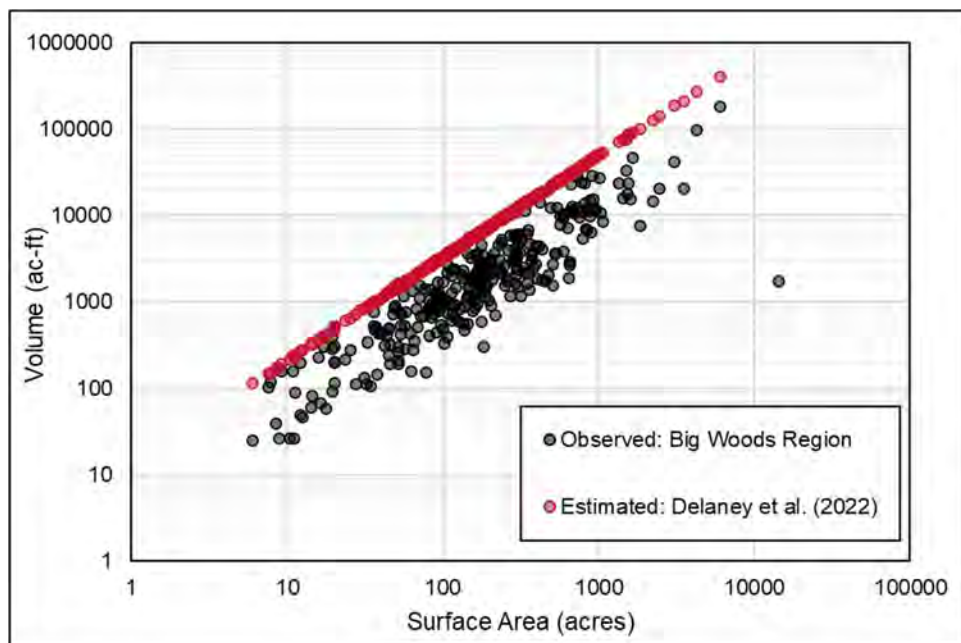


Figure 5. Big Woods Ecoregion Waterbodies: Observed and Estimated Maximum Depth for Big Woods Ecoregion Waterbodies Comparison of Estimated Volumes as a Function of Waterbody Area

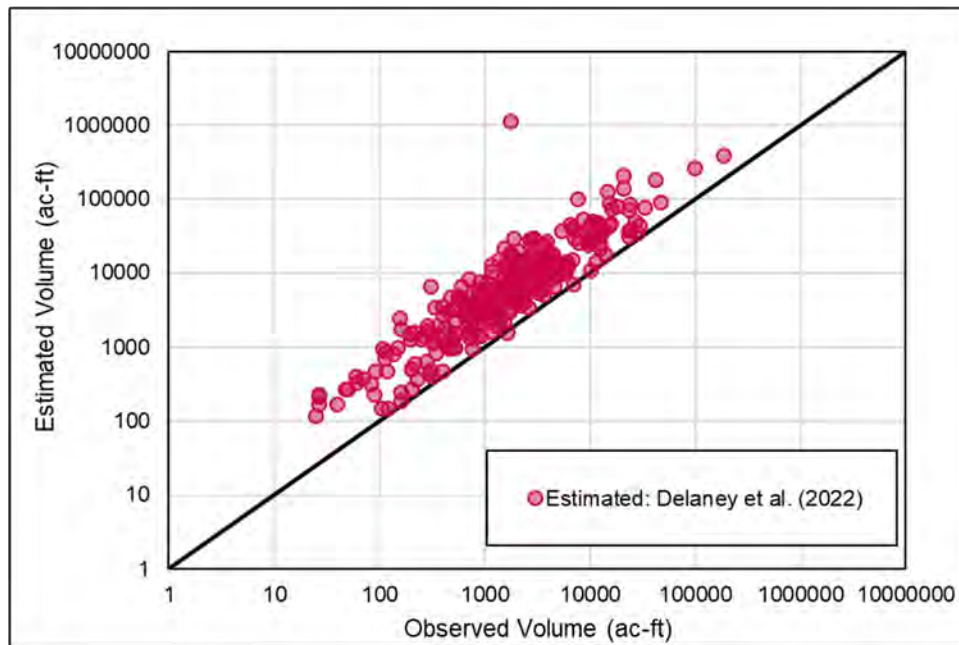


Figure 6. Comparison of Estimated Volumes as a Function of Area

VOLUME DISTRIBUTION OF KNOWN WATERBODIES

Storage volume versus depth characteristics were aggregated and summarized for regional waterbodies with known bathymetry. The resulting relationship is a normalized depth vs. normalized storage function and is used to validate the selected approach to distribute the storage volume along the depth for the estimate waterbodies. To determine the relationship between depth and volume for each feature with known bathymetry:

- Bathymetric contours were assigned to surface water bodies with known bathymetry within the Big Woods Subsection Ecoregion (Figure 7 - 222Mb, Ecological Classification System, Minnesota DNR). In areas where bathymetric contours traverse multiple features they were manually split. Figure 8 shows an example waterbody which includes set of contour lines with multiple closed contours at the same depth.

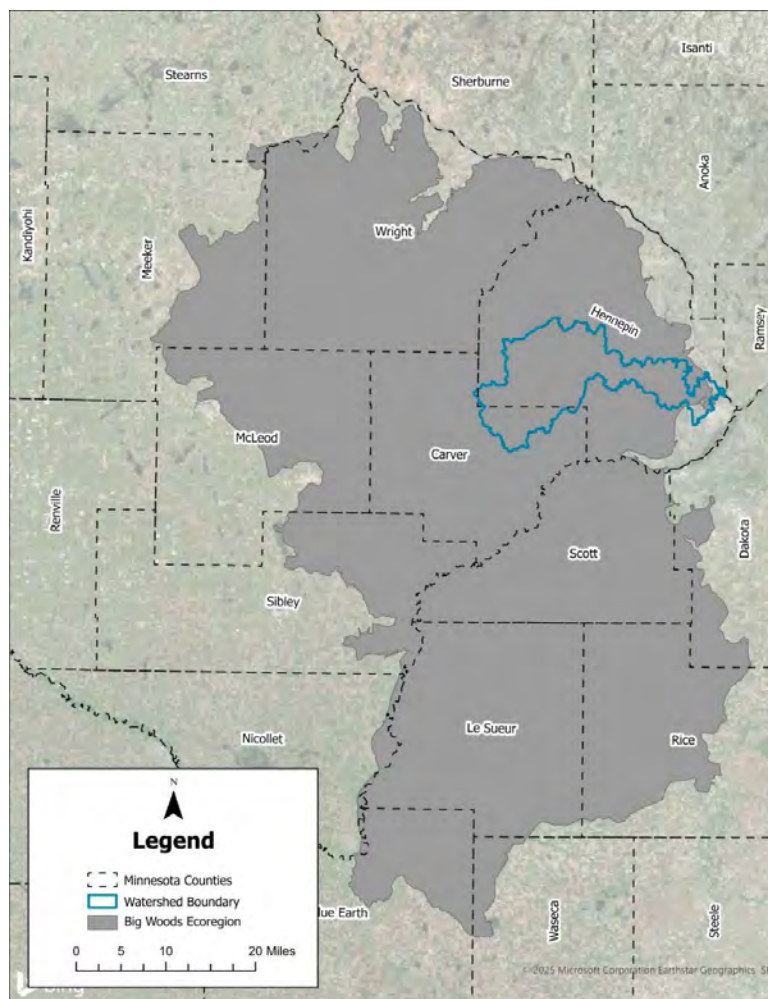


Figure 7. Big Woods Ecoregion (Grey), Compared to Watershed District Extents

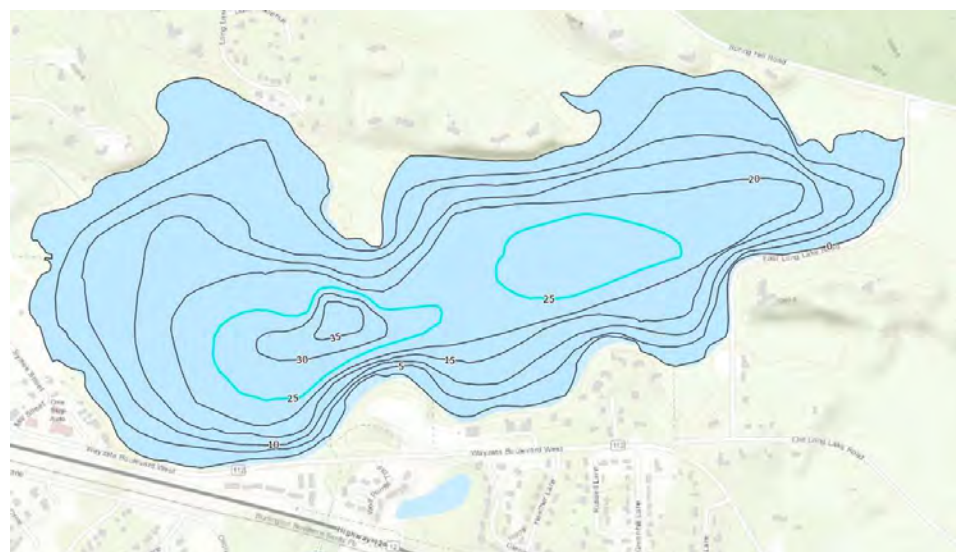


Figure 8. Lake with Multiple Closed Bathymetric Contours at the Same Depth

- Where contour polylines did not create complete polygons, polygons were completed and separate multi part features.
- Multipart features were separated.
- Using these modified bathymetric contour lines the area of each bathymetric contour was calculated.
- A depth volume relationship was created for each lake:
 - The total area of each contour within each lake was recorded. For lakes with multiple contour polylines at the same depth, the sum of their areas was used.
 - Incremental volumes between each contour interval were calculated and summed to create a total cumulative volume.
 - Cumulative volumes at each of 25th, 50th, 75th, 90th and 100th percentile depths for each waterbody were determined through linear interpolation.
 - Interpolated volumes were normalized by the total volume.
 - Figure 9 shows the 25th, 50th, 75th, 90th and 100 percent normalized depth vs the normalized volume. These data were used to validate the estimated volume distribution is reasonable.

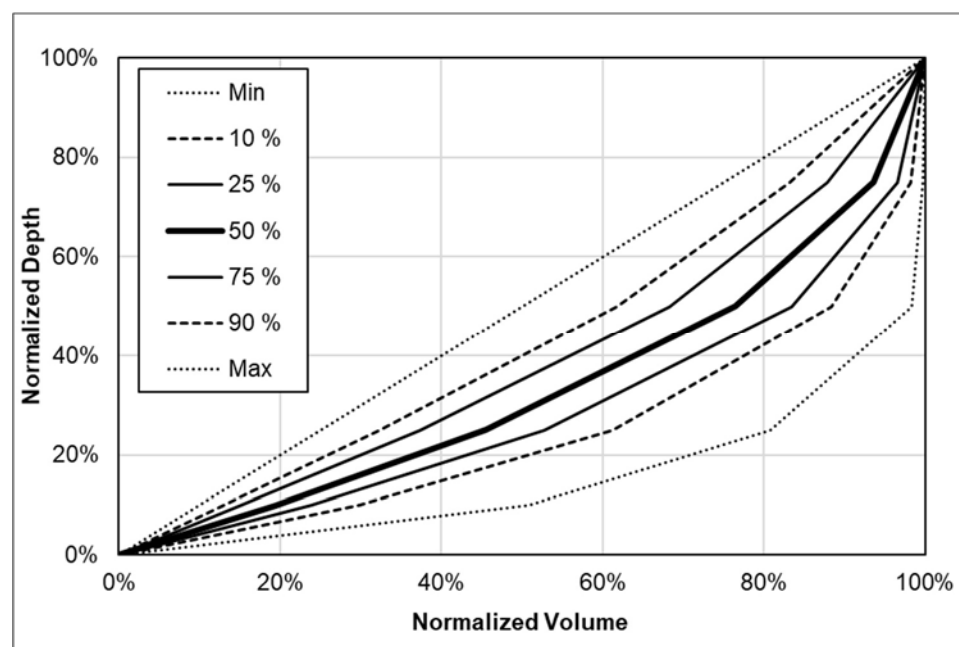


Figure 9. Normalized Lake Volume vs. Percentile Depth of Known Features

FITTING OF CONTOURS BASED ON CALCULATED WATERBODY DEPTH AND VOLUME

Distributing the storage volume of each water body over the maximum depth was intended to use the observed relationships of storage volume vs. depth from regional waterbodies as described in Task 3A memo. However, the combination of estimated maximum depth, estimated maximum volume, normalized vertical storage volume distribution and the known surface area did not result in reasonable vertical storage relationships. It is assumed the variability of approaches to calculate each input (depth, volume, distribution, surface area) did not result in compatible relationships.

Instead, distributions of the storage volume over the total depth were determined for each water body which maintained the maximum depth, total volume, and surface area. Areas of each incremental depth contour at the 25th, 50th, 75th, 90th and 100th percentile depths were estimated using the following steps:

- The 0th percentile depth, or water surface, was maintained from observed geospatial data.
- Each lower depth percentile (25th, 50th, 75th, and 100th) was assumed to have a smaller area than the contour interval above it. Each successively lower contour interval was calculated as the area of the above interval multiplied by a scalar value. The scalar was assumed to be constant for each waterbody and be applied to each incremental area such that:
 - $A_{25} = XA_0$ and $A_{50} = XA_{25}$ and $A_{75} = XA_{50}$ and $A_{100} = XA_{75}$
 - Or $A_{25} = XA_0$ and $A_{50} = X^2A_0$ and $A_{75} = X^3A_0$ and $A_{100} = X^4A_0$
 - Where $A_0, A_{25}, A_{50}, A_{75}, A_{100}$ is the contour area at 0th, 25th, 50th, 75th, and 100th percentile depth, respectively and X is the scalar.
- Scalar values were assumed to be less than 1.0 and more than 0.0 and were optimized to match the total volume. Where scalar values of more than 1.0 were required to match total volume, they were manually set to 0.95. Where scalar values of less than 0.0 were required to match total volume, they were manually set to 0.05. This method resulted in maintaining 97% of the estimated storage volume in all of the features.
 - Of the 405 waterbodies with estimated volume the scalar value was reduced to 0.95 for 37 features and increased to 0.05 for 1 feature.
- Figure 10 shows a comparison of the fitted vertical volume distribution to the observed ones. More than 50% of the fitted curves are within the observed vertical volume distribution. The median fitted curve closely aligns with the 90th percentile observed distribution. This results in more storage volume placed lower in the waterbody than expected from other regional waterbodies. This difference may result in increasing surface water groundwater connectivity at the waterbody locations.

More information is included in the 'Calc_Heathcote' spreadsheet included as part of this submission.

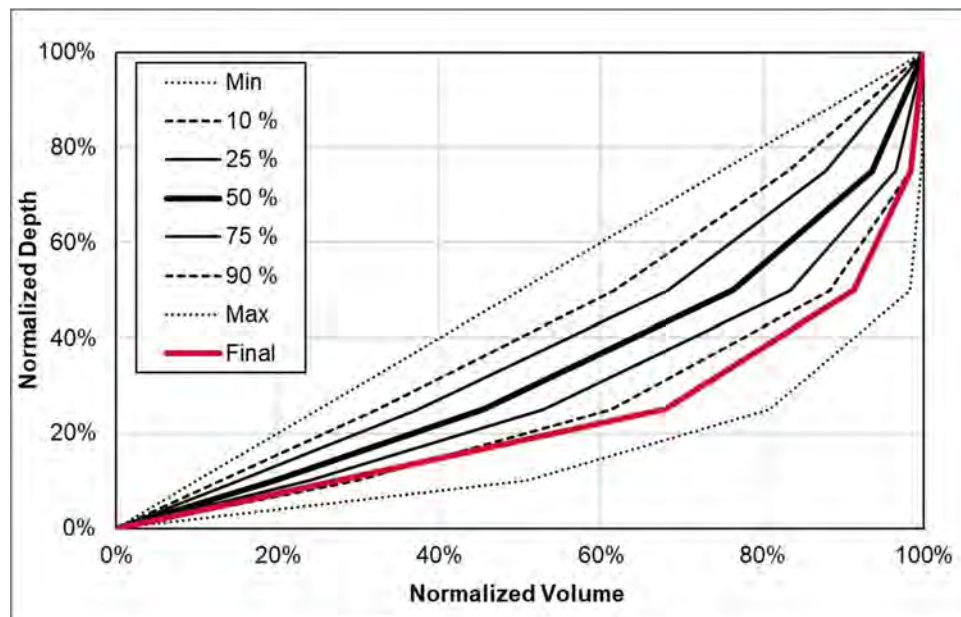


Figure 10. Comparison of Normalized Depth vs. Normalized Volume between Observed and Fitted Features

GEOSPATIAL CONTOUR CONVERSION

A GIS workflow was followed to take the estimated depths and areas associated with each estimated contour and convert them into geospatial features. The following steps were performed:

- Created negative (inward) buffers from each surface waterbody extent at 2-foot intervals.
- For each surface waterbody, found the closest match between each target area value and the area of these buffer polygons.
- Converted the selected buffer polygons to lines and assign the associated depth value to each contour.
- Figure 11 provides an example of estimated bathymetry surfaces blended into the LiDAR above water elevation data.

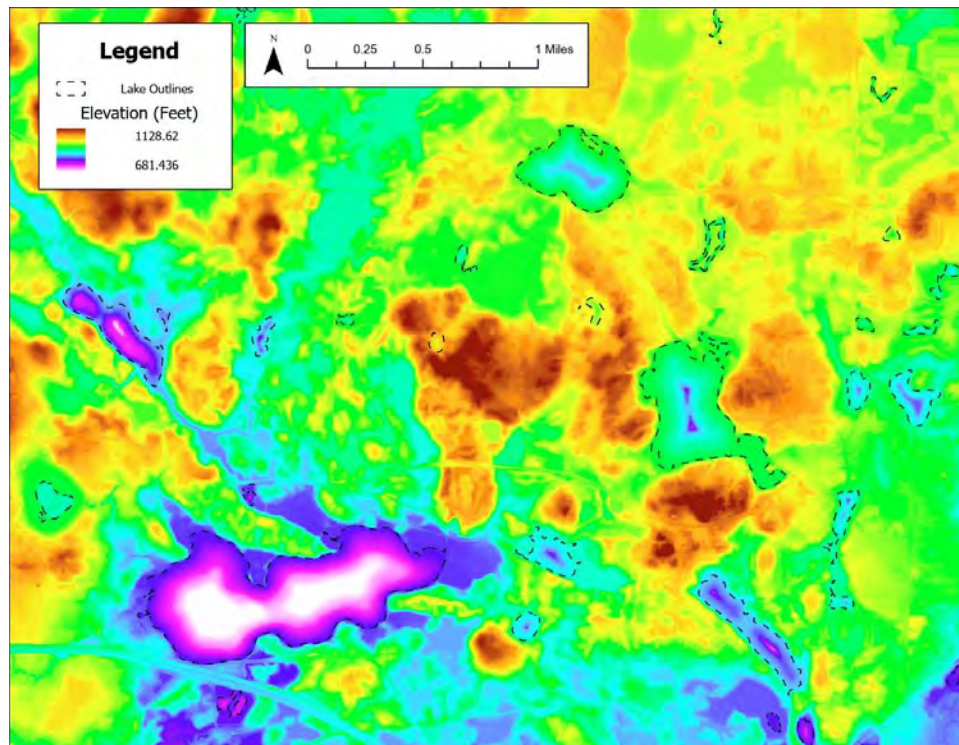


Figure 11. Sample Representation of LiDAR Modifications to Include Bathymetry Approximation

Workflow 3 – Define Wetland Extents

This workflow was to identify the extents of wetlands within the model area. Due to the output from this workflow not aligning with the LiDAR being used for the model build, the output is not intended to be used as part of the model build.

This workflow followed the process outlined in the Task 3a Memo, using features from:

- 'Lake_POLYGONS'
- 'MCWD Wetlands'

Workflow 4 – Associate Bathymetry to Wetlands

The intention of this workflow was to assign estimated bathymetry to wetland extents identified in Workflow 3. Due to the output from Workflow 3 not aligning with the LiDAR being used for the model build, the output is not recommended to be used as part of the model build.

To define the depth of the features:

- An 18-foot inward buffer (assumed 6:1 slope) was taken from the edge of each feature.
- A depth of 3 was assigned to this buffered feature, and a depth of 0 was assigned to the original edge of each feature.

Workflow 5 – Create Seamless Surface

Using data created in the above Workflows, a modified terrain that incorporates bathymetry was developed for use in the model.

The recommended model surface does not include modifications resulting from features identified in Workflows 3 and 4.

For bathymetries estimated as part of Workflows 2 and 4, it is necessary to convert depth contours to bathymetric surfaces:

- Create TIN surface based on depth contours
- Convert TIN surface to depth raster
- Create bathymetric raster by subtracting depth raster from 'Terrain_2024USGS_OPR.USGS_OPR_MN_CentralMissRiver_MCWD_FT.tif'
- Mask the newly created bathymetric raster by the feature extents developed as part of Workflows 1 and 3 (Workflow 3 unused).

Mosaic rasters in the following order, keeping information from the last raster on the list:

- LiDAR: 'Terrain_2024USGS_OPR.USGS_OPR_MN_CentralMissRiver_MCWD.tif'
- Estimated Wetlands: 'Workflow4_output.tif' (unused)
- Estimated Ponds/Lakes: 'Workflow2_output.tif'
- Lake Contours: 'Lake_bathymetric_elevation_modelElev.tif'
- Lake Rasters: 'lakeGDBElev.tif'

Workflow 6 – Develop Model Input

Generated surfaces from Workflow 5 are directly imported to the StormWise model. Each of the features with bathymetry estimated will be included in the model as PCVs. A future memorandum will provide details on the PCV generation process.

Outlet Control Structures

Water levels within many constructed surface waterbodies within the watershed are controlled by an outlet control structure. For the purposes of this memo, outlet control structures are defined as drop structures that control the water level of a surface waterbody and include a weir and pipe. These features are included in the model as attached to specific waterbodies PCVs and describe the stage-discharge relationships associated with these structures.

No outlet control structure data were available to support a preliminary model build. Many of these features are planned for survey and to be included as part of the final model build.

Workflow 7 – Locate Outlet Control Structures

Due to lack of existing data, no outlet control structures will be included in the initial model build.

Workflow 8 – Associate Hydraulic Information to Outlet Control Structures

Due to lack of existing data, no outlet control structures will be included in the initial model build.

Workflow 9 – Develop Model Input for Outlet Control Structures

Due to lack of existing data, no outlet control structures will be included in the initial model build.

Culverts

Culverts in a 2D model allow for the flow of water across topographic features that would otherwise be limited by topography as overland flow. Culverts can be represented as pipe links in StormWise, which are 1D hydraulic elements that connect nodes to one another with inputs including, inverts, length, shape, cross sectional dimensions, and roughness. Including these features allows for flow that may be artificially blocked by higher ground to flow through the elevated feature and downstream.

Culverts included as part of this memo have previously been identified as part of the model ready dataset or identified with previously surveyed data. Additional culverts are planned for survey and will be included as part of the final model build.

Workflow 10 – Locate Culverts

This workflow identifies location of culverts within the watershed. The starting culvert shapefile is “CulvertMR” in the “BMI Project Data” dataset provided by the District for use in the model. The CulvertMR shapefile includes line features of existing culverts. Additionally, culvert survey was supplied by MCWD, which had 4 point features (equating to 2 culvert features) representing culvert locations not identified by the above shapefile. These 2 culvert features were manually added. Culverts outside of the watershed were removed. Integration of culverts and the respective attributes are included as part of the model ready scripting assumptions. Future refinement of these assumptions may be made and documented in future memos.

Workflow 11 – Associate Hydraulic Information for Culverts

This workflow creates a new culvert shapefile with all required model inputs (shape/geometry, size, material/Manning’s N, invert elevations, inlet configuration/FHWA code). The information for these attributes was incorporated into a new shapefile of “CulvertMR_Updates_V1”.

Information was incorporated into this layer based on the following priority order:

- Information from MCWD survey (from ‘Culvert Survey’ shapefile)
- Existing GIS information (from ‘CulvertMR’ shapefile)
- Where culverts lacked existing GIS information and survey information, assumptions were incorporated as follows:
 - Missing shape: assumed circular
 - Missing size: assumed 18" (average pipe size)
 - Missing material: assumed concrete (0.012)
 - Missing invert elevation: assumed lowest elevation in LiDAR within 20' radius of invert

Data was associated with each feature based on the culvert ID from Workflow 10.

Workflow 12 – Develop Model Input for Culverts

As discussed in the Task 3a Memo, scripts developed as part of Task 4 were used to input the data into StormWise from the geospatial datasets created in Workflows 10 and 11.

The following tables were used to convert information into a format usable by StormWise. include Manning’s roughness coefficient, the values provided in **Error! Reference source not found.** were applied based on materials in existing GIS information and survey.

Table 1: Culvert Manning’s Roughness Coefficients

Material	Manning's coefficient
Concrete	0.012
Vitrified Clay	0.011
Metal/Steel	0.013
Corrugated Metal	0.024
Plastic	0.010
Other	0.011

No information was provided in GIS data source or survey on culvert inlet configuration. Federal Highway Administration (FHWA) culvert codes, as described in StormWise handbook, were used for inlet configurations. Assumptions on inlet configuration were made based on the size of the culvert and the culvert material, as described in **Error! Reference source not found..**

Table 2: Assigned FHWA Culvert Codes

Culvert Characteristics	FHWA Key	FHWA Description
Size: Large (greater than 48") Material: Concrete/Clay/Smooth Metal/Plastic	1	Circular Concrete, Square edge w/headwall
Size: Large (greater than 48") Material: Corrugated Metal	4	Circular CMP, Headwall
Size: Small (less than or equal to 48") Material: Concrete/Clay/Smooth Metal/Plastic	3	Circular Concrete, Groove end projecting

Size: Small (less than or equal to 48") Material: Corrugated Metal	6	Circular CMP, Projecting
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Summary

Transmitted alongside this memo are the following datasets to be used directly by the preliminary model:

- **LiDAR_Lakes_EST_Bathy** : Modified LiDAR to include lake and pond bathymetry
- **MCWD_LakePondExtents_MR20250731** : Lake and Pond extents considered for bathymetric modifications
- **MCWD_WetlandExtents_MR20250731** : Wetland extents considered for bathymetric modifications
- **MCWD_Culverts_MR20250731** : Model ready culvert data

Updates to these datasets as a result of data collection performed as part of Task 6 are expected to be incorporated into the final model build. Recommendations of options for these efforts were included in the Task 3a memo. Prioritization and execution of data collection and refinement efforts will be based on future project team consensus.

References

Delaney, C., Li, X., Holmberg, K., Wilson, B., Heathcote, A., Nieber, J. (2022). Estimating Lake Water Volume With Regression and Machine Learning Methods. *Front. Water* 4:886964. doi: 10.3389/frwa.2022.886964

Heathcote, A.J., del Giorgio, P.A., and Prairie, Y.T. (2015). Predicting bathymetric features of lakes from the topography of their surrounding landscape. *Can. J. Fish. Aquat. Sci.*

Woolpert Inc., 2023. "Lidar Mapping Report for the U.S. Geological Survey, MN Central Miss River 4 B22"



Appendix E – Task 4 Script Documentation

Memo

Date: 4/7/2026

Project: MCWD 2D Watershed-Wide Model

To: Brian Beck (MCWD)

From: Bryan Blaisdell, PE, GISP, CFM, Nick Thomas, PhD, PE

Subject: Appendix E - Task 4 Script Documentation

As part of the development of a 2D watershed model for the Minnehaha Creek Watershed District (MCWD or District), the District provided HDR with a package of stormwater data processing scripts for review and refinement. These scripts (referred to as “Raw to MGIS” and “MGIS to Model Ready”) were developed through previously completed efforts and automate several important data processing tasks required for stormwater hydraulic modeling, including (1) standardizing and consolidating stormwater utility data from municipal/agency datasets into a single, unified geodatabase as well as (2) identifying and correcting issues within the stormwater utility dataset’s geometry and attributes.

On December 13, 2024, HDR held a workshop meeting with the District to discuss potential script modifications for implementation. Script modifications were categorized as *Scope Requirements* (modifications required for the main project scope), *Potential Immediate Enhancements* (modifications to enhance the development of the 2D model within the project scope), and *Potential Long-Term Improvements* (modifications recommended for further consideration in future project phases).

The following memo documents the script modifications completed as part of the 2D watershed modeling project.

Process Overview

The MCWD stormwater data process consists of two tools: “Raw to MGIS” and “MGIS to Model Ready.” The “Raw to MGIS” script converts raw municipal stormwater utility data (including pipes, culverts, manholes, inlets, and outlets) to the unified MGIS geodatabase schema using configured field and value mapping tables. Once consolidated, features in the MGIS geodatabase are then input into the “MGIS to Model Ready” script, which converts the data from the MGIS schema to a simplified model-ready schema and identifies and corrects issues with the geometry and attributes.

Revisions to the “MGIS to Model Ready” script included the ability to apply specific feature updates from a Manual Overrides geodatabase and a Surveyed Features geodatabase, enabling manual database refinements to be incorporated directly into the automated workflow for repeatability. The manual override and survey import process allows for addition, exclusion, and replacement of specific features and attributes. A diagram of the full process workflow is shown in **Figure 1**.

As part of the manual override and survey import process, globally unique identifiers (GUIDs) were added to features in the raw municipality datasets to improve feature tracking and enable the automated feature replacement workflow. **GUIDs should be maintained and updated as needed in future changes to the raw municipal datasets to ensure workflow continuity.**

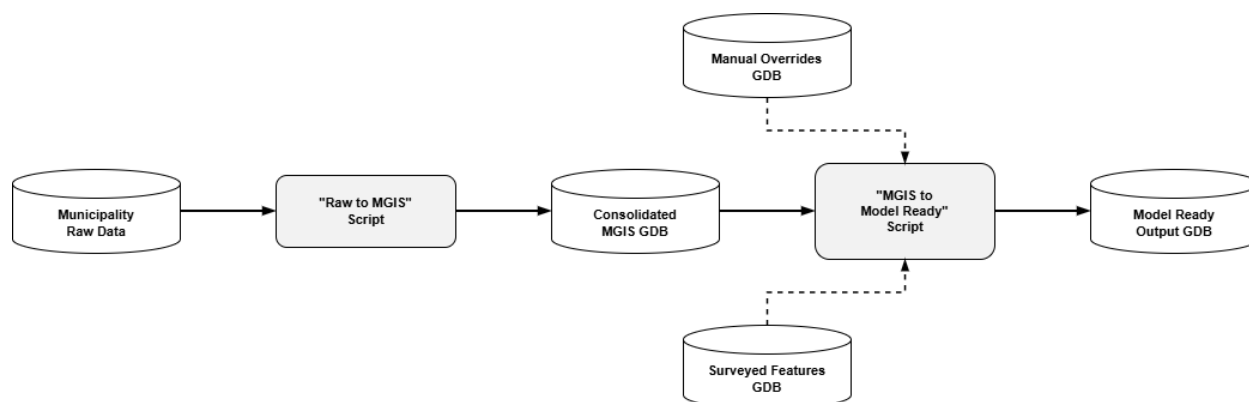


Figure 1: Full Process Workflow (Raw Data to Model Ready)

Modifications to the “Raw to MGIS” and “MGIS to Model Ready” tool package included the script files listed below (other supporting script files, `__init__.py`, `cursors.py`, `logger.py`, `testconfig.py`, and `tqdm_arcpy.py` were unchanged):

- **`_strings.py`** - String constants used for defining field names, file paths, source abbreviations, and other strings across the tool package
- **`core.py`** – “Raw to MGIS” processing (parsing raw data using mapping tables, applying field/value mapping, loading features into MGIS geodatabases)
- **`model_input.py`** – “MGIS to Model Ready” processing (geometry and attribute gap-filling and correction)
- **`utils.py`** - Shared utilities (including *ProjectInfo* class where input geodatabase names are defined)

In addition to these script files, the following input files were developed or updated to be incorporated into the workflow (“*Model Ready.lyrx*” was unchanged):

- ***ModelInputDatabase_Blank.gdb*** – Template geodatabase containing the empty Model Ready feature classes, domains, and schema used as the target for the MGIS to Model Ready process.
- ***MGIS_MSWGP_Manual_Overrides.gdb*** – Geodatabase containing manually added (A), excluded (E), or replaced (R) features. Each feature includes an OVERRIDE field (A/E/R) and is matched to the MGIS dataset by MGIS_GUID. Used by *load_mgis_data* to apply overrides during data loading.
- ***MGIS_MSWGP_Surveyed_Features.gdb*** – Geodatabase containing surveyed stormwater features with the same Add (A)/Exclude (E)/Replace (R) structure as the manual overrides GDB. Used by *load_mgis_data* to incorporate field-surveyed geometry and attributes during data loading.
- ***mappings.json*** – Configuration file defining the field mapping between MGIS and Model Ready feature classes. Updated to include Count and Structure_Type/PipeType field mappings for Inlets, Outlets, Pipes, and cPipes.

“Raw to MGIS” Script Updates

The “Raw to MGIS” process includes the following tools, each of which can be run separately:

1. Load Data
2. Load Data (Batch)
3. Load Data (Consolidated)

Each of the tools provides a different level of control over the “Raw to MGIS” process. For this project, only the new “Load Data (Consolidated)” tool was used (discussed below under “Consolidated Batch Processing to MGIS GDB”).

Path and Data Source Configuration (*_strings.py*)

- Path references to raw data (RAW_DATA_PATH), mapping tables (MAPPING_TABLES_PATH), and the MGIS geodatabase (MCWD_MSWGP), previously stored in the value and field mapping tables, were added to the *_strings.py* file to improve tool package portability. The value and field mapping tables were updated to store only relative file names, while the *_strings.py* file was updated to store absolute folder paths. **These paths should be updated to reflect the locations of the input files whenever the script location is moved.**
- Municipal data source abbreviations were added in the SOURCE_ABBREVIATIONS dictionary to standardize feature naming conventions in the “MGIS to Model Ready” script. Abbreviations use 3-letter codes (e.g., “EdinaData”: “EDI”, “MinnetonkaData”: “MTK”). Refer to *Feature Naming Convention* for more information on the updated feature naming convention.

Feature Type Classification (*core.py*, *_strings.py*)

- The script was updated to support new *type_field* and *type_value* parameters in the ValueMap mapping tables (“__ToolInfo” tab) to improve MGIS feature filtering and analysis. These parameters are optional and can be used to automatically assign a type attribute to features when imported into the MGIS geodatabase. The *type_value* parameter is used to assign a type attribute, while the *type_field* parameter specifies the target attribute for where the type attribute should be stored. For example, Deephaven gravity main features are assigned a type attribute of “GravityMain” in the “PIPE_DATAT” MGIS field to differentiate gravity mains from pressure mains.

Mapping Table Updates (**_FieldMap.xlsx*, **_ValueMap.xlsx*, *core.py*)

- Mapping tables were reviewed and updated for importing raw data into the MGIS geodatabase. Updates included mapping table corrections, adding *type_field* and *type_value* parameters, renaming files, and adding the MGIS_GUID field. A separate detailed changelog of specific mapping table changes is provided with the script files. In addition to these revisions, the “Raw to MGIS” script was updated to replace literal “<Null>” strings from the mapping tables with null values.

Raw Data Geodatabases

- Raw data geodatabases were updated to assign all input features a unique MGIS_GUID value. This unique GUID value is used in the manual override process added to the “MGIS to Model Ready” script. Refer to *Manual Override and Survey Data Integration* for more information.

Consolidated Batch Processing to MGIS GDB (core.py)

- A new consolidated batch processing workflow was added to enable execution of the “Raw to MGIS” Load Data process for all raw municipal datasets in a single run. The “Load Data (Consolidated)” process reads an input spreadsheet containing names of all raw data folders and MGIS GDBs, runs the existing “Raw to MGIS” workflow for each folder to create individual municipal datasets matching the MGIS schema, and then consolidates them into a single consolidated geodatabase (*MCWD_MSWG.P.gdb*) for later processing by the “MGIS to Model Ready” script.

“MGIS to Model Ready” Script Updates

Project Folder/Data Loading (*model_input.py*, *utils.py*)

The project folder/data loading process includes the following steps, each run separately:

1. Create Project Folder
2. Load MGIS data into project folder
3. Load MGIS datasets into model ready format
4. Add model ready datasets to Pro map
5. Import DEM to project

Manual Override and Survey Data Integration (*load_mgis_data*, *update_mgis_data*)

- The MGIS data loading process was updated to incorporate changes from the Manual Overrides and Surveyed Feature geodatabases into the Model Ready geodatabase. This approach combines the benefits of precise manual editing with the automated workflow. In parallel with the script development process, HDR performed extensive review of the stormwater data features, applying specific manual edits to the Manual Overrides geodatabase, which could not otherwise be captured by the automated process. The manual override and survey import process supports Add (A), Exclude (E), and Replace (R) operations:
 - o Add (A) – for adding new data such as features missing from the raw datasets or new surveyed features,
 - o Exclude (E) – for excluding data such as extraneous features contained in the raw datasets not required for modeling, and
 - o Replace (R) – for moving, editing, or replacing feature geometries or attributes.

The process requires each feature in the raw dataset to have its own GUID in the *MGIS_GUID* field; these GUIDs are carried throughout the “Raw to MGIS” and “MGIS to Model Ready” script processes. The “MGIS to Model Ready” script reads the manual override and survey import geodatabases and automatically updates the Model Ready geodatabase to capture the manual changes systematically with each tool run.

- The script was updated to automatically exclude MGIS features with inactive status values (e.g., ABANDONED, INACTIVE, FAILED, or REMOVED) from the Model Ready geodatabase.

Clipping Network to Watershed Boundary (*load_mgis_data*)

- The clipping logic for loading data was updated to include full pipe features overlapping the input watershed boundary, along with any structures connected to that pipe network. To achieve this,

feature classes are loaded in a specific order (lines before points) so that structures connected to pipes are captured.

Domain Validation (validate_domains)

- The Model Ready geodatabase uses domains to set valid attribute values for fields such as pipe material, pipe shape, and structure type. The domain validation process was improved to handle cases where the MGIS dataset contained an attribute value not matching the defined domains. The script was updated to check for invalid or empty values prior to appending them to the Model Ready geodatabase.

DEM Import (import_dem)

- The DEM Import process was improved to handle the following use cases: (1) when the user provides a project boundary with buffer, the DEM is clipped to the project boundary with buffer applied; (2) when the user provides a project boundary only, the DEM is clipped to the project boundary without a buffer; and (3) when a project buffer is not provided, the full DEM is used.

Topology Correction (model_input.py)

The Topology Correction process consists of the following steps (which may be run altogether or separately):

1. Flag or delete empty geometry
2. Split multipart geometries
3. Snap pipes to structures
4. Flag lines with same beginning and end vertex
5. Split at structures and intersections
6. Add artificial nodes
7. Remove disconnected nodes

Pipe Snapping (snap_pipe_ends)

- At the beginning of the project, HDR noted that the original script snapped structure points (manholes, inlets, outlets) to nearby pipe endpoints. This approach could potentially move points away from surveyed structure locations. Based on coordination between HDR and MCWD, the issue was addressed by Bolton & Menk and implemented into the updated “MGIS to Model Ready” script. In the updated snapping function, pipe endpoints are snapped to the nearest structure point within the specified tolerance. This preserves surveyed structure locations while adjusting pipe geometry to establish network connectivity.
- Additionally, the script was updated to round all feature coordinates to a specified grid tolerance (0.005 map units) to prevent snapping failures due to closely matching point coordinates that could not otherwise be differentiated at the spatial reference’s default XY resolution. The script generates a CSV snap log output recording the feature class, OID, vertex index, and snapping distance in feet for each snapped vertex.

Disconnected Feature Removal (remove_disconnected_nodes, flag_unsnapped_structures)

- The geometry validation process was updated to automatically remove orphaned structure points that do not intersect any pipe or culvert in the network from the dataset. Structures outside of the snapping tolerance that remain unsnapped after the snapping process are flagged by the script in

the Issues field (these may be reviewed manually when running geometry validation steps separately).

Attribute Validation (*model_input.py*)

The Attribute Validation process consists of a single step called “Update attributes” which runs all associated attribute correction subprocesses.

Feature Naming Convention (update_feature_name)

- The script was updated to generate a unique Model_ID for each feature based on a naming convention. The naming convention follows the format: {feature type prefix}-{source abbreviation}-{sequential unique identifier}. The feature type prefix identifies the feature type (e.g., NI for node inlet, NM for node manhole, NO for node outlet, and LP for line pipe or culvert), while the source abbreviation identifies the feature’s source municipality (e.g., EDI for Edina). An example ID for an inlet feature from the Edina dataset is NI-EDI-000001.

Missing Pipe Node Export (add_to_from_nodes)

- In instances where pipe endpoints do not have a connected structure, the missing pipe nodes are exported as a point shapefile (*missing_pipe_nodes.shp*) in the project folder. While most pipe endpoints should previously be automatically assigned a point through *add_artificial_nodes* in the Topology Correction step, there may be fringe cases where a pipe remains disconnected when the script assigns to/from node IDs during attribute validation. These missing pipe nodes can be reviewed manually and corrected as needed using the Manual Overrides process.

Multi-Pass Attribute Processing (process_features)

- To address circular dependencies when populating structure and pipe attributes, the attribute processing logic was updated for multiple sequential passes. For example, gaps in structure invert data can be estimated from the inverts of connected pipes, while pipe inverts can also be estimated from structure inverts. The script was updated based on the following logic order: (1) clearing invalid invert values for all features, (2) populating structure attributes from known pipe data, (3) processing pipe attributes and gap-filling missing inverts, and (4) reprocessing structures to fill any remaining gaps from pipes as estimated in step 3.

Invert Elevations (fix_pipe_inverts, clear_pipe_invalid_inverts, clear_structure_invalid_inverts)

- The script was updated to automatically clear invalid inverts outside the expected elevation range for the project area (700-1200 ft.) or above the DEM ground surface elevation. When calculating missing invert elevations for storm sewer pipes connected to manholes or inlets, inverts are estimated based on typical storm sewer installation depths; the script calculates missing inverts as equal to the DEM surface elevation minus a typical assumed 4-ft. cover depth minus the pipe diameter (converted to feet). For culvert pipes and pipes connected to outlets, missing inverts are assumed directly from the DEM elevation.

Rim Elevation (fix_structure_rim)

- The script was updated to replace structure rim elevations with the DEM elevation when the rim elevation differs from the DEM by more than 0.5-ft. Instances where the rim elevations were replaced are noted in the FLAG_Rim_Elevation flag field.

Pipe Attributes (fix_pipe_size, fix_pipe_material, fix_pipe_shape, fix_pipe_width_height, fix_pipe_slope)

- The default assumed pipe diameter was changed from 24-in. to 15-in. to be more representative of the typical storm sewer pipe size in the watershed. The script populates missing pipe diameters based on the mean size of connected upstream and downstream pipes. If upstream pipes exist, the script estimates the pipe's missing diameter as the mean of the connected pipe diameters. If there are no upstream pipes or no valid diameters from any connected pipes, the default pipe diameter of 15-in. is used (default assumptions are recorded in the FLAG_Diameter flag field).
- The default assumed pipe material was changed from "Unknown" to "Reinforced Concrete" to be more representative of the typical storm sewer pipe material in the watershed. Additionally, the script treats unknown or other material input values (e.g., "Unknown", "UNK", "Other", and "OTH") as null. Missing pipe materials are estimated from connected pipe materials where available, otherwise defaulting to Reinforced Concrete where unavailable.
- Pipe shape values were normalized for consistency. "Other" and "Round" pipe shape values are standardized to "Circular." For non-circular pipes, missing pipe width and height values are filled using an assumed 18-in. default. Additional notes are added to the FLAG_Width and FLAG_Height flag fields for arched pipes that may require manual review.
- Pipe slopes are automatically recalculated from the upstream invert, downstream invert, and pipe length attributes.

Inlet Type and Grate Size (fix_inlet_type_and_grate_size)

- The script was updated to classify inlets connected to culvert pipes as "Culvert" type without assigning a size and to classify inlets connected to storm sewer pipes as "Storm Inlet" filling missing size values with an assumed grate dimension of 2.75-ft. length × 1.26-ft. width.

Processing Workflow

The recommended workflow to run the "Raw to MGIS" and "MGIS to Model Ready" tools is described below:

Running "Raw to MGIS"

Before running the "Raw to MGIS" tool, verify that the raw municipal data geodatabases have been assigned MGIS_GUID values for all features and that the mapping tables (field maps and value maps) are updated and accurate. If input file locations have changed, update the file path references in *_strings.py* (RAW_DATA_PATH, MAPPING_TABLES_PATH). Prepare blank MGIS geodatabases where the outputs will be saved. To run the "Load Data (Consolidated)" tool, update the "Input Main Mapping Table" with the MGIS_GDB and Raw_Data_Folder names for all raw data sources to be processed. Next run the "Load Data (Consolidated)" tool, which will convert the data from the raw format to the MGIS schema and prepare the consolidated MGIS geodatabase (*MCWD_MSWGP.gdb*).

Running "MGIS to Model Ready"

Once the consolidated MGIS geodatabase is completed, prepare the Manual Overrides and Surveyed Features geodatabases. If input file locations have changed, update the file path references in *utils.py* (TEMPLATE_GDB, MANUAL_OVERRIDES_GDB, SURVEY_GDB, MAPPINGS_FILE).

For Data Loading, run Tool 1 (“Create Project Folder”), Tool 2 (“Load MGIS data into project folder”), Tool 3 (“Load MGIS datasets into model ready format”), and Tool 5 (“Import DEM to project”). Tool 4 (“Add model ready datasets to Pro map”) is an optional display step and is not required for processing. Provide the latest MGIS geodatabase, DEM, and watershed boundary, and specify an appropriate clipping buffer (e.g., 500-ft.) for importing the DEM. Note that for this project the clipping buffer was applied only to the DEM; no separate clipping buffer was specified when loading MGIS data into the project folder, since the script now automatically handles clipping of the MGIS feature network to the watershed. Manual verification of loaded features is recommended prior to running the Topology Correction and Attribute Correction tools. For this project, Model Ready feature classes were run through an additional Repair Geometry step manually using the Repair Geometry toolbox in ArcGIS Pro to remove any invalid features.

For Topology Correction, run Tool 0 (“Run all topology correction steps”) from the Topology Correction toolset to run all seven topology correction steps in order. Specify the desired feature snapping tolerance (e.g., 5-ft.) as an input before running.

For Attribute Correction, run Tool 1 (“Update attributes”) from the Attribute Correction toolset to run through all attribute correction steps.

Manually review final outputs prior to importing them into the hydraulic model. Review feature geometries and attributes, including the flag fields and Issues field in the output geodatabase. Feature revisions in the Manual Overrides geodatabase may be necessary to resolve issues that the automated process may not otherwise cover.



Appendix F – Waterbody Screening and Prioritization for Additional Data Collection

Technical Memorandum

Date: Monday, September 15, 2025

Project: 2-D Watershed-Wide Model

To: Brian Beck (MWCD)

From: HDR

Subject: Appendix F: Waterbody Screening and Prioritization for Additional Data Collection

Introduction

HDR is assisting the Minnehaha Creek Watershed District (MCWD) in developing a coupled surface water groundwater model to support near and long-term watershed planning. As part of Task 3B Non-pipe Stormwater Feature Development, limited information was available regarding how waterbodies outlet to downstream features. This memo documents the process to identify waterbodies which may have outlet control structures, prioritize those waterbodies for desktop review, identify data availability, and prioritize additional data collection. Data collection may include review and digitization of as-builts and/or performing field survey.

The memo outlines the process to determine where outlet control structures are located, what type of feature exists, and if there is a need to gather more data to describe the feature.

Structure Locations

Initial identification of structure locations were targeted larger frequently wet waterbodies. Multiple sources of surface waterbodies were used to develop a survey prioritization of the outlet features.

- LiDAR breaklines generated by the USGS through review of the LiDAR point cloud data. The features delineate the edge of water location at the time of LiDAR flights. As part of the LiDAR point to topographic surface generation these breaklines are used to hydro flatten the water surface. These lines were converted to polygons and oddities (islands, etc.) were removed.
- Surface waterbodies (non-wetlands) that were generated as part of Task 3A memo which identified 849 lake and pond features from the previously identified GIS datasets (Lake_GDB, LakeBathymetricOutlinesContoursDEM, LAKE_POLYGONS, 20240725_National_Hydrography, and 20240725_DNR_Hydrography).

These sources were merged and overlapping features were joined into a single aggregate feature. Each waterbody feature included the following attributes: LiDAR breakline surface area, total aggregated surface area, and the approximate drainage area as determined from ArcHydro processing. Figure 1 shows an example of an aggregate feature.

Waterbody features within the largest 200 LiDAR surface areas or within the largest 200 total aggregated surface area were selected for further analysis for a desktop review. This resulted in 256 waterbodies. Figure 2 shows the location of the initial 256 waterbodies prioritized for additional review. Lake Minnetonka was removed from this list as data are assumed to be available to represent Gray's Bay Dam, the outlet control structure.

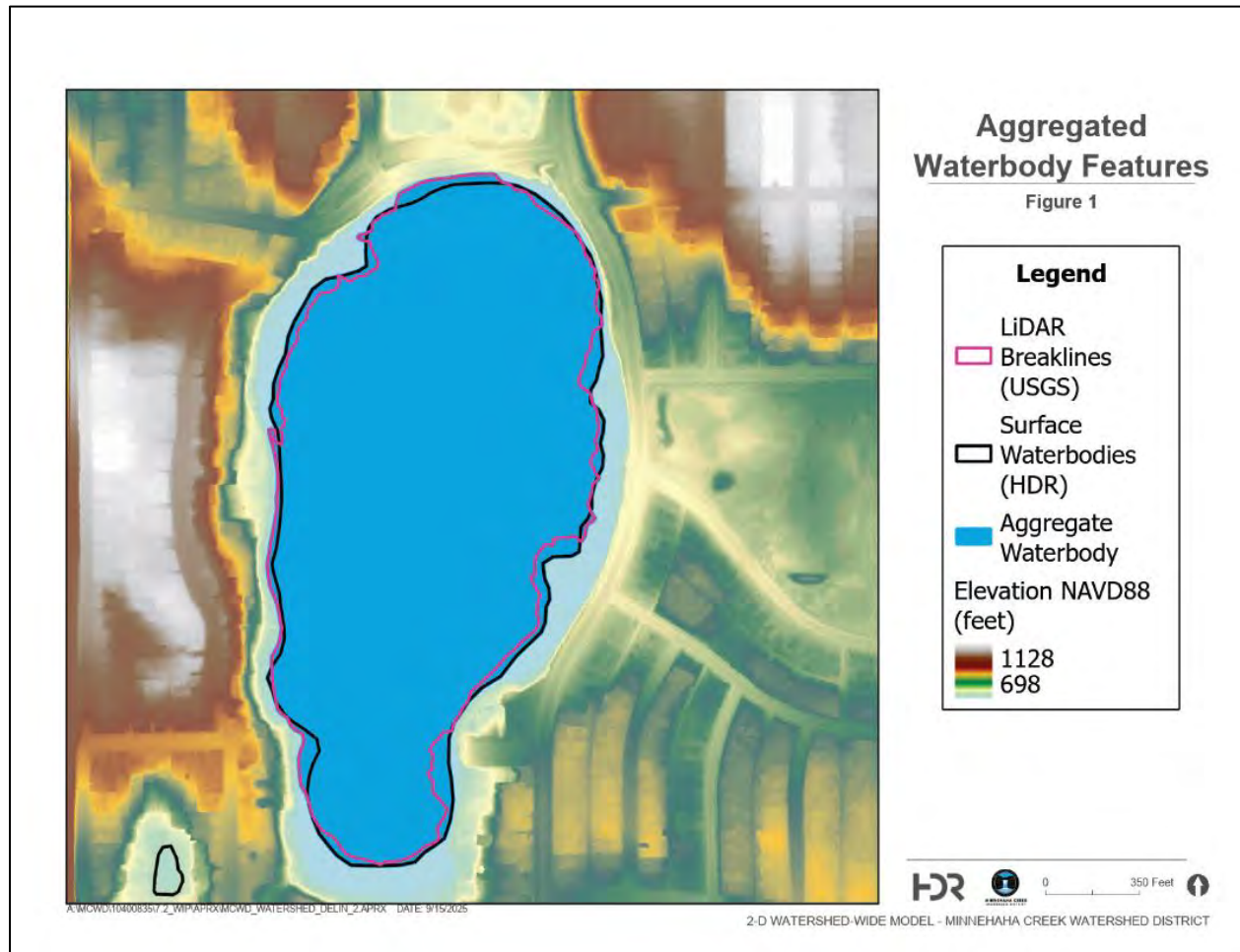


Figure 1. Aggregated Waterbody Features

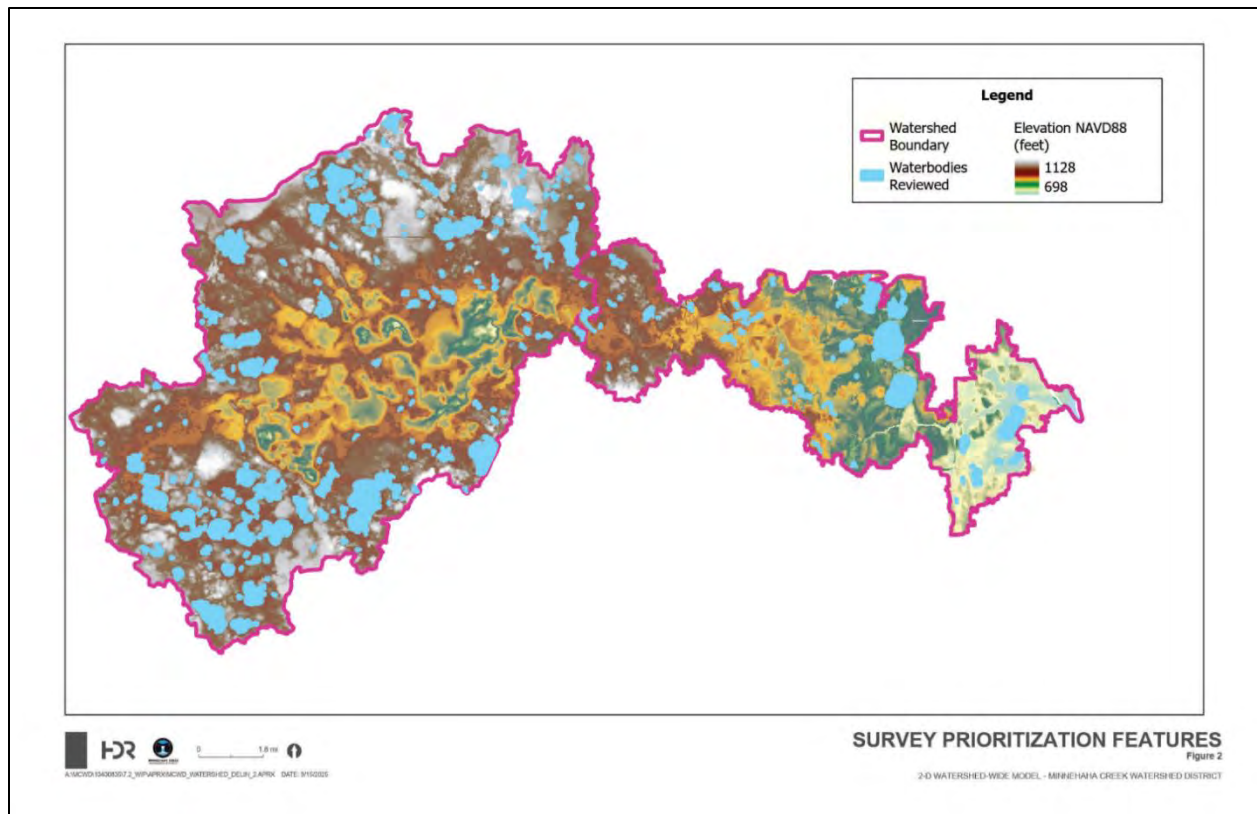


Figure 2. Waterbodies for initial data collection review

Existing Data Review

Each of the 256 features were individually screened via desktop review to determine if additional information would be required to represent the outlet within the StormWise model. The review included using LiDAR, aerial imagery, Pictometry (oblique aerial imagery), and the raw stormwater GIS datasets from the source municipality, county, or state. The raw datasets were reviewed as they often contained additional details which removed as part of the aggregation to a combined MGIS data schema. The desktop review documented the following at each feature:

- Likely location of the outlet/outfall
- Type of outlet
- Source of GIS data that was used to identify the outlet location
- If there is sufficient GIS data to represent the outlet structure in StormWise (e.g. elevation and diameter)
- If as-builts were noted in the GIS datasets
- Recommendation of survey or additional data request

The desktop screening of 256 features resulted in:

- Additional information required: 148 features

- o Request as-builts: 12
 - o Collecting field survey: 136
- Feature has sufficient data: 36
- Outlet was a channel or overland flow path not requiring additional information: 59

For those features requiring more information (155 total):

- Culverts or pipes: 113
- Outlet structures: 20
- Lift Stations: 4
- Unknown if pipe or structure present: 18 - Field investigation required to verify

Feature Data Requirements

Three main feature types were identified to control outflows from surface water bodies. Each feature type has specific data requirements for representation within stormwater modeling environments. Additional data collection (field survey or as-built review) will attempt to capture each of the below described feature characteristics:

- Culvert
 - o Entrance/exit configuration
 - o Upstream and downstream invert elevations
 - o Material
 - o Geometry: shape and dimensions
- Lift Stations
 - o Wet well geometry: dimensions and elevation
 - o Pump curve(s)
 - o Pumping set points for operation
 - o Outlet pipe geometry: material, size, shape, inverts
- Outlet control structures: Details for an example structure included in attachment
 - o Inlet pipe: inverts, diameter, material
 - o Outlet pipe: inverts, diameter, material
 - o Drop structure: invert, diameter
 - o Grate: elevation, diameter, description
 - o Notch, orifice, weir, or gate characteristics if present

Next Steps

This waterbody screening and prioritization is the first step at reviewing waterbodies and their respective outlet control structures or outfalls for additional data needs. It included a review of 256 frequently inundated areas and features described as lakes or ponds. Future efforts could expand the analysis to review more of the lake and pond features and/or include wetland features.

For those features with identified data needs (155) the following summarizes the approach to gather data:

- Culverts/pipes (113): MCWD is currently completing culvert survey on other culvert features in the watershed and intends to include these 113 into their data collection.
- Outlet structures (20): HDR survey team will collect data at identified outlet control structures.
- Lift Stations (4): Request for lift station operations will be made to the feature owner
- Unknown (18): Provided to MCWD for staff desktop review and potential field verification

Electronic Data Delivery

Waterbodies that were considered for review are provided as a geodatabase electronically along with this memorandum.

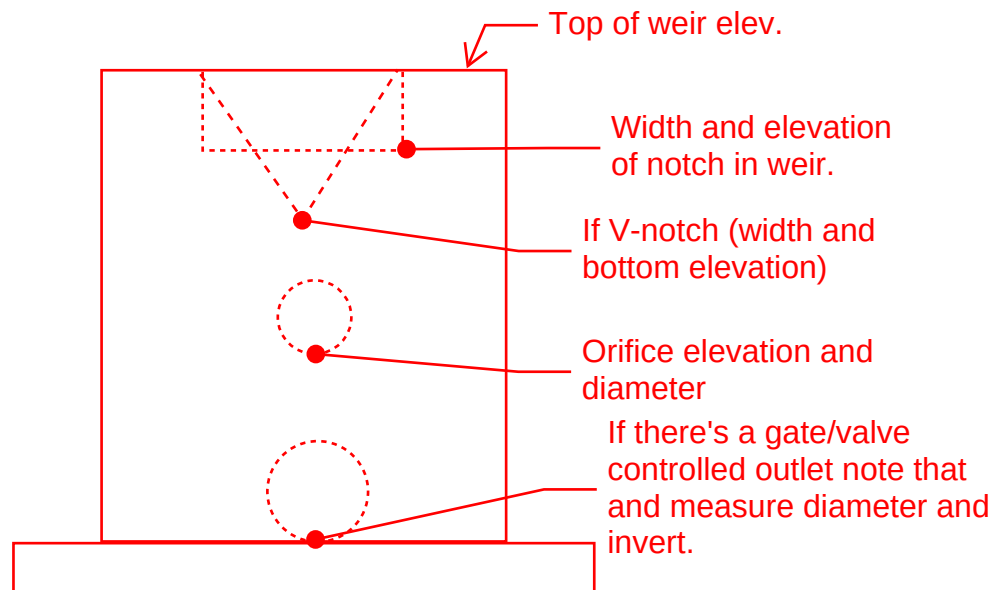
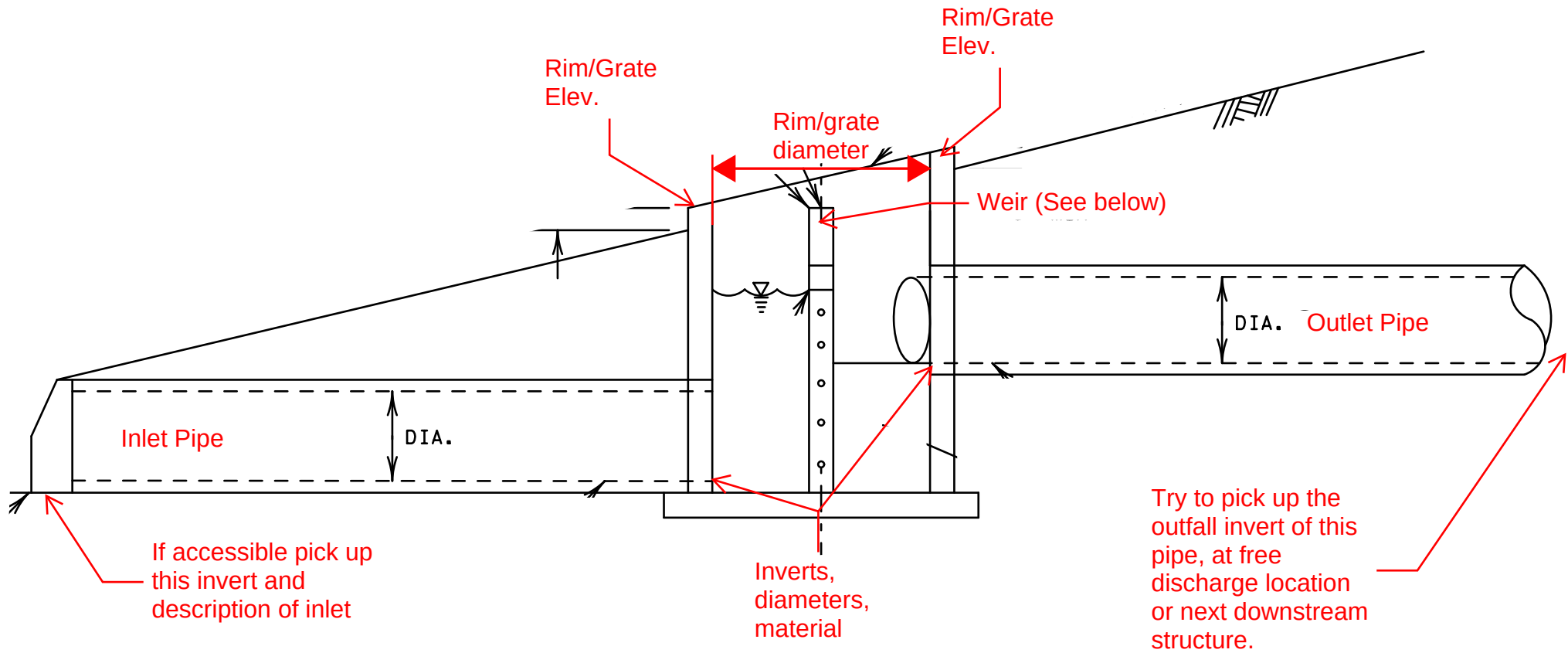
Geodatabase of all waterbodies considered for review and comments on each of the reviewed features: Survey_Prioritization.gdb

Attributes associated with the feature class include:

- Should Be Review – Identifies features in the largest 200 LiDAR surface areas or within the largest 200 total aggregated surface area for desktop review
- Outlet – Location of the outlet and the datasets that were used to identify the outlet
- Comments – Comments from desktop review containing additional pertinent information about the features
- Sizes and Elevations – Yes or “null”, Yes indicates there is enough information contained in the GIS dataset
- Survey Needed – 1 or “null”, 1 means survey or as-built information is likely needed
- Outlet Type – Observed outlet type
- LiDAR area – Calculated area from LiDAR breaklines representing open water
- Lake area – Calculated area for the Task 3 generated waterbodies

Attachment 1: Example Outlet Control Structure

Example Outlet Structure Configuration



Inlet Pipe:

U/S Invert, dia., material, end section description

D/S Invert, dia. material

Outlet pipe:

U/S Invert, dia., material

D/S Invert, dia., material, end section description

Structure Info:

Structure invert

Structure diameter

Grate:

Grate elevation (top and bottom if sloped)

Grate diameter

Grate Description (flat, sloped, beehive, other)

Weir:

Width/thickness

(If weir is made of stop logs make a note of that)

Notch:

Shape - Rectangular/V/Other

Width, invert elevation

Orifice:

Invert elevation, diameter

Gate or valve control?

Invert, diameter, type of valve