Bassett Creek Hydrologic and Hydraulic Analyses

Phase 2 XPSWMM Model Report

Prepared for
Bassett Creek Watershed Management Commission

May 10, 2017

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Contents

List of Tables

List of Figures

Certifications

I hereby certify that this engineering document was prepared by me or under my direct personal supervision and that I am a duly licensed Professional Engineer under the laws of the State of Minnesota.

Jennifer Koehler, PE	5/10/2017
MN PE #: 47500	Date

Acronyms

Acronym	Description
BCWMC	Bassett Creek Watershed Management Commission
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center River Analysis System
JPA	joint powers agreement
LiDAR	Light Detection and Ranging
MnDOT	Minnesota Department of Transportation
MnDNR	Minnesota Department of Natural Resources
MSL 1912	Mean Sea Level Datum of 1912
NAVD88	North American Vertical Datum of 1988
NCDC	National Climatic Data Center
NEXRAD	Next-Generation Radar
NGIA	National Geospatial Intelligence Agency
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWL	Normal Water Level
NWS	National Weather Service
PCSWMM	Storm Water Management Module (interface by PC Solutions)
SSURGO	Soil Survey Geographic Dataset maintained by the NRCS
TAC	Technical Advisory Committee
TMDL	Total Maximum Daily Load
TP40	Technical Paper 40
USACE	United States Army Corps of Engineers
WOMP	Watershed Outlet Monitoring Program
WMO	Watershed Management Organization
WRMP	Water Resources Management Plan
XPSWMM	Storm Water Management Module (interface by XP Solutions)

Executive Summary

The Bassett Creek Watershed Management Commission (BCWMC) Phase 2 XPSWMM model update incorporated more detailed subwatershed, storage, and storm sewer information for the watershed, including the major ponds and wetlands. The Phase 2 XPSWMM modeling effort included the following items:

- Increasing the number of the subwatersheds for the entire BCWMC watershed from approximately 55 to approximately 1,160 (see Figure 2-1)
- Developing revised watershed hydrology inputs based on more current soils data and impervious coverage information for the Twin Cities area.
- Modeling of storm sewer and outlet structures based on data provided by the member cities and agencies.
- Integrating detailed storage (e.g. ponds and wetlands) within each of the subwatersheds based on recent topographic data.
- Ensuring consistent vertical datum in the model with the entire Phase 2 XPSWMM model updated to be in the NAVD88 vertical datum.
- Developing the model to fully capture and route the Atlas 14 100-year design storm event.
- Performing flow/elevation monitoring at Douglas Drive on the North Branch of Bassett Creek (in 2015).
- Calibrating at several locations including Plymouth Creek, Wisconsin Avenue, the North Branch of Bassett Creek (at Douglas Drive), and at the Watershed Outlet Monitoring Program (WOMP) gage.
- Using the calibrated model to estimate the Atlas 14 100-year flood elevations along the Bassett Creek system and within the contributing watershed.

The Phase 2 XPSWMM model is a tool that can be utilized by the BCWMC, member cities, and other entities to evaluate projects and make informed watershed management decisions. One of the primary applications is evaluating and updating flood management elevations to reflect current and future infrastructure and land use conditions. However, there are a variety of other uses of the BCWMC Phase 2 XPSWMM model, such as assessing the capacity of the existing and proposed storm sewer systems, identifying localized flooding issues in the watershed, verifying and designing outlet and storm sewer modifications, and estimating various flow regimes for stream stabilization and restoration analysis and design projects. Section 1.2.1 further discusses other potential uses of the Phase 2 XPSWMM model, and Section 1.2.2 outlines the model structure and organization. Additionally, the BCWMC may update the XPSWMM model annually to include projects built within the nine member cities.

The BCWMC Phase 2 XPSWMM model was calibrated at flow/elevation monitoring gages at various points within the watershed, including two locations upstream of Medicine Lake (Parkers Lake storm sewer inflow and on Plymouth Creek), two locations on the Main Stem of Bassett Creek (Wisconsin Avenue control structure and the WOMP station), and one location on the North Branch of Bassett Creek (Douglas Drive). Calibration was performed for both a small precipitation event and a large precipitation event. Once calibrated, the model was run for a third validation event that was a precipitation depth between the small and large event. To evaluate the calibration and validation results, we used several parameters to compare the Phase 2 XPSWMM model performance with the monitoring data. These parameters include the percent error in peak flow and/or peak elevation/flow depth, percent error in volume (if flow monitoring data was available), and the Nash-Sutcliffe efficiency index. The calculated Nash-Sutcliffe efficiency indices and the percent error statistics indicate a good fit for both the small and large calibration events as well as the validation events for the various monitoring stations in the watershed. Also, review of the calibration plots indicate that the XPSWMM model results are closely matching the monitoring data magnitudes and hydrograph shapes for the various storm events. Additional discussion related to the modeling methodology and calibration results can be found in Sections 2.0 and 3.0, respectively, in the report.

The historic 100-year flood elevations reported in the current BCWMC *Watershed Management Plan* were based on the *Technical Paper 40* (TP40) precipitation data which was equivalent to a storm event with 6.0 inches of precipitation falling within a 24-hour period. In 2013, the precipitation depths outlined in the *Atlas 14 Precipitation Frequency Atlas of the United* States (Atlas 14), Volume 8 replaced the TP40 design storm events; the new 100-year (1% chance) storm event is 7.42 inches of precipitation falling within a 24-hour period (~25% increase in the design storm precipitation depth). The final, calibrated XPSWMM model was used to evaluate the Atlas 14 100-year (1% chance) design storm event.

Table 3-7 summarizes the flood elevations and peaks discharges as summarized in the BCWMC Watershed Management Plan, the corresponding flood elevations and peak discharges as estimated by the Phase 2 XPSWMM model, and the difference between the data sources. Figure 3-16 through Figure 3-19 show the expected extents of inundation based on the peak flood elevations from BCWMC Phase 2 XPSWMM model for the Atlas 14 100-year as applied to the 2011 MnDNR LiDAR elevation data. The inundation mapping was developed using a level pool mapping methodology, based on the modeled peak flood elevation for each subwatershed and the MnDNR LiDAR elevation data. This method is more accurate for lakes, wetlands, and ponds, whereas the inundation extents shown along Plymouth Creek, North Branch Bassett Creek, and Bassett Creek Main Stem are approximate. To more accurately determine the flood inundation along the creeks, the elevations summarized in Table 3-7 should be used.

In general, it would be expected that evaluating the Atlas 14 design storm event across the Bassett Creek watershed would result in increases of the peak flood elevations and discharge rates throughout the watershed due to the larger magnitude of the design storm precipitation depth. However, the Phase 2 XPSWMM model also incorporated significantly more detail, including the refined subwatersheds, the storage available in all of the ponds and wetlands throughout the watershed, and the incorporation of storm sewer systems connecting the ponds and wetlands, compared to the previous modeling efforts for the watershed. As a result, the estimated peak flood elevations and discharge rates for the Atlas 14 design storm event are higher than the values included in the BCWMC Watershed Management Plan in some locations, while in other locations in the watershed, a slight decrease in the peak flood elevations are observed.

The following are some general observations regarding the changes in the 100-year flood elevations and flows from the BCWMC Watershed Management Plan to the Phase 2 XPSWMM modeling (organized by location in the watershed):

Bassett Creek Main Stem

- Flood elevations upstream of the New Tunnel inlet increased significantly (approximately 3.6 feet), as well as along the channel to the Cedar Lake Road Bridge (0.4-2.6 feet increase).
- Flood elevations generally increased upstream of the Fruen Mill Dam to Noble Lane, with flood elevations between Golden Valley Road and Noble Lane increasing significantly (2.2 to 4.1 feet)
- Flood elevations near Highway 100 and the confluence with the North Branch of Bassett Creek rose significantly (1.4 to 2.6 feet).
- Flood elevations between Duluth Street and the Golden Valley Country Club increased moderately (between 0.4 and 1.5 feet).
- Flood elevations between the Golden Valley Country Club control structure and Wisconsin Avenue increased significantly (1.1 to 2.2 feet). Flood elevations near Hampshire Avenue increased between 0.7 and 0.8 feet.
- Flood elevations upstream of Wisconsin Avenue, including the Brookview Golf Course, to Medicine Lake are similar to, but slightly lower than, the Bassett Plan water surface elevations (-0.3 to -1.2 feet).

North Branch of Bassett Creek

- Flood elevations between Highway 100 through Bassett Creek Park Pond Park increased significantly (1.4 to 2.0 feet).
- Flood elevations between Brunswick Avenue and 32nd Avenue decreased (-1.5-2.2 feet).
- Flood elevations upstream of the Edgewood Embankment and especially upstream of Winnetka Pond East increased significantly (2.0 to 3.3 feet)
- The flood elevation of Northwood Lake increased by 1.6 feet.

Sweeney Branch

- Flood elevations between the upstream side of Highway 100 to the Ravine Storage Area increased substantially (0.4 to 5.6 feet).
- The flood elevation of Sweeney and Twin Lakes increased by 0.2 feet.

Plymouth Creek/Medicine Lake

- Flood elevations in the Dunkirk flood storage area increased substantially (0.0 to 5.3 feet).
- Flood elevations upstream of County Road 9 (Rockford Road) decreased substantially (-4.2 feet).
- The flood elevation of Medicine Lake decreased slightly (-0.2 feet).
- The Crane Lake flood elevation decreased by 0.5 feet.

Based on a review of the inundation mapping, the LiDAR data, and aerial photos, the new flood elevations and inundation mapping indicate several structures are potentially at-risk of flooding during the Atlas 14

100-year design storm event. Some of the potentially at-risk structures are located along the Bassett Creek Main Stem; however, other potentially at-risk properties are located in upstream portions of the watershed within the Cities' jurtistiction. Topographic surveys of these structures would be needed to confirm if these structures are at-risk of flooding.

1.0 Background and Purpose

1.1 Past Water Management Planning

The Bassett Creek Watershed Management Commission (BCWMC) has a long history of water management planning. The BCWMC was originally created in 1968 as the Bassett Creek Flood Control Commission to address flooding concerns. In 1984, the Bassett Creek Flood Control Commission revised its joint powers agreement (JPA) and created the Bassett Creek Watershed Management Commission.

The United States Army Corps of Engineers (USACOE) developed hydrologic and hydraulic (HEC-1 and HEC-2) models of the Bassett Creek watershed and Bassett Creek in partnership with the BCWMC for the evaluation of the BCWMC Flood Control Project. The most recent model updates occurred in 1998. The Minnesota Department of Natural Resources (MnDNR) was also involved in the review of these models.

In 2012, the BCWMC updated the HEC-1 and HEC-2 models to the XPSWMM modeling software to account for changes in the watershed (the Phase 1 XPSWMM model). XPSWMM is a software package that incorporates both hydrology and hydraulics and determines flood elevations, calculates channel flow rates and velocities, and effectively models backwater conditions and complex outlet structures. The intent of updating the models to XPSWMM was to create a tool for the BCWMC and the member cities to use when evaluating how changes to the watershed will effect flow rates and flood elevations in Bassett Creek. However, because of the coarse level of detail in the number of subwatersheds and associated storage in this model, calibration was not feasible without incorporating unrealistic inputs into the model. The differences between the modeled and observed hydrographs was likely due to the coarse level of detail in the modeled subwatersheds and not accounting for upstream storage in the smaller ponds and wetlands throughout the watershed (1). Ultimately, the Phase 1 XPSWMM model was used to evaluate the TP-40 design storm events including the 100-year, 24 hour storm.

In 2015, the BCWMC authorized updating the Phase 1 XPSWMM model to incorporate more detailed subwatershed and storage information for the watershed, including the major ponds and wetlands as well as the storm sewer data for the systems connecting the upstream ponds and wetlands to the major water resources within the watershed (the Phase 2 XPSWMM model). The major changes from the Phase 1 XP-SWMM model to the Phase 2 model included the following items:

- Increasing the resolution of the subwatersheds for the entire BCWMC watershed from approximately 55 to approximately 1,160 based on the ponds and wetlands within the watershed, more current topographic data, and storm sewer data provided by the member cities
- Developing revised watershed hydrology inputs based on more current soils data and impervious coverage information for the Twin Cities area.
- Modeling of storm sewer and outlet structures based on storm sewer GIS data and construction/as-built drawings provided by the member cities.
- Integrating detailed storage within each of the subwatersheds based on recent topographic data to account for the storage available in the upper watershed.

- Ensuring consistent vertical datum in the model. The entire Phase 2 XPSWMM model was updated to be in the NAVD88 vertical datum. Historically, the flood elevations along the creek have been summarized in NGVD 1929.
- Developing the Phase 2 XPSWMM model to fully capture and route the Atlas 14 precipitation data and design storm events, including the 100-year event using the MN MSE3 storm distribution. Once calibrated, the model will be used to estimate the Atlas 14 100-year flood elevations along the Bassett Creek system and within the watershed.
- Performing flow/elevation monitoring and calibration at several locations including Plymouth Creek, Wisconsin Avenue, the North Branch of Bassett Creek (at Douglas Drive), and at the Watershed Outlet Monitoring Program (WOMP) gage at Irving Avenue.

The following report summarizes the BCWMC Phase 2 XPSWMM modeling methodology, calibration, and results.

1.2 Stormwater Model Uses, Structure, & Updates

1.2.1 Model Applications

There are many useful applications of the BCWMC's updated Phase 2 XPSWMM model, which can be used by the BCWMC, member cities, and other entities to evaluate projects and make informed watershed management decisions. One of the primary applications is evaluating and updating flood management elevations to reflect current and future infrastructure and land use conditions. Other uses include assessing the capacity of the existing and proposed storm sewer system and optimizing future system modifications, thereby reducing long-term infrastructure costs. Potential uses of the model span several BCWMC and municipal functions, including planning, public safety, flood protection, and water quality protection. The following list identifies numerous specific model applications:

- Re-evaluating flood management elevations for waterbodies throughout the BCWMC with Atlas 14 rainfall.
- Identifying localized flooding issues.
- Verifying and designing outlet and storm sewer modifications
- Identifying impacts of infrastructure changes on upstream and downstream flood elevations
- Characterizing stormwater discharges (flows and velocities) throughout the BCWMC, including discharges to the stream systems.
- Assisting in Total Maximum Daily Load (TMDL) studies for the creeks and lakes within the BCWMC with respect to estimating incoming water flows.
- Using in conjunction with water quality models to evaluate and design potential best management practices (BMP) for stormwater treatment and water quality improvements.
- Evaluating and estimating various flow regimes for stream stabilization and restoration analysis and design projects.

1.2.2 Model Structure & Management

Because XPSWMM is a proprietary software, a license key (either a stand-alone physical key that plugs into your computer or a network key) is required to open and utilize the software. XPSWMM license keys come in a variety of sizes depending on the needs of the user and can range from 200 nodes to 10,000 or even unlimited nodes (with the cost of the license increasing with size). A common size for XPSWMM license keys is 1,000 or 2,000 nodes.

The final calibrated BCWMC Phase 2 XPSWMM model has a total of 4,715 links and 4,145 nodes. As combined, the model would require a 5,000 node XPSWMM license key. Recognizing that BCWMC will be sharing the final calibrated Phase 2 XPSWMM model with the member cities (and their consultants) for a variety of uses, we have subdivided the Phase 2 XPSWMM model for the BCWMC in two locations to create three separate XP-SWMM models (see Figure 1-1) to encompass the entire Bassett Creek watershed. To open and utilize these separate models will require a 2,000 node XPSWMM license key.

The breaks points in the XP-SWMM model are located at:

- The outlet from Medicine Lake in the City of Plymouth
- The Fruen Mill dam downstream of Glenwood Avenue in the City of Minneapolis

These break points were selected as locations where downstream tailwater conditions will have minimal impact on the estimated upstream flood elevations.

To accommodate the break points in the model, outflow hydrographs must be exported from the upstream models and imported as a boundary condition for the downstream models. Table 1-1 summarizes the three XP-SWMM models that cover the BCWMC watershed.

Table 1-1 BCWMC Phase 2 XPSWMM Model Structure

XPSWMM Model	Model Description	Inflow Hydrograph	Hydrograph Source
Model A: BCWMC_XPSWMM_Ph2_ModelA.xp	Watershed to Outlet from Medicine Lake, including Plymouth Creek, Turtle Lake, Parkers Lake, Crane Lake, and Medicine Lake	A) Inflow hydrograph at node MLNE-024A (overflows from Pilgrim Lane Elementary School) B) Inflow hydrograph at node MLS-024 (overflow from Shelard Park area)	A) Link LNWD057.O2 from the BCWMC_XPSWMM_Ph2_ModelB.xp B) Link L-BUW-115O from the BCWMC_XPSWMM_Ph2_ModelB.xp
Model B: BCWMC_XPSWMM_Ph2_ModelB.xp	Watershed from Medicine Lake to the Fruen Mill Dam, including the Main Stem and North Branch of Bassett Creek, Lost Lake, Northwood Lake, Westwood Lake,	A) Inflow hydrograph at node • N-BUW-135 (discharge from Medicine Lake)	A) Link L-MLD-197 from the BCWMC_XPSWMM_Ph2_ModelA.xp

XPSWMM Model	Model Description	Inflow Hydrograph	Hydrograph Source
	North & South Rice Pond, Grimes Pond, Sweeney Lake, Twin Lake, and Wirth Lake		
Model C: BCWMC_XPSWMM_Ph2_ModelC.xp	Watershed from Fruen Mill Dam to the Mississippi River, including the watersheds to both the New and Old Tunnels	A) Inflow hydrograph at node N-BCD-055 (discharge immediately downstream of Fruen Mill Dam) B) Inflow hydrograph at node LOTI_100yr (overflows from Lake of the Isles)	A) Link L-BCD-056 from the BCWMC_XPSWMM_Ph2_ModelB.xp B) Hydrograph provided by the City of Minneapolis from the Lake of the Isles XPSWMM model on 12/2/2016

BCWMC is the owner of the Phase 2 XPSWMM model. Requests for the XPSWMM model should come to the BCWMC through the member cities. Currently the BCWMC does not have a Conditional Use License regarding the sharing of the XPSWMM model files. In the past, the BCWMC has used the Barr Engineering Standard Conditional Use License prior to sharing the XPSWMM model files.

When the BCWMC Phase 2 XPSWMM model is requested, the following information will be shared upon receiving a signed Conditional Use License:

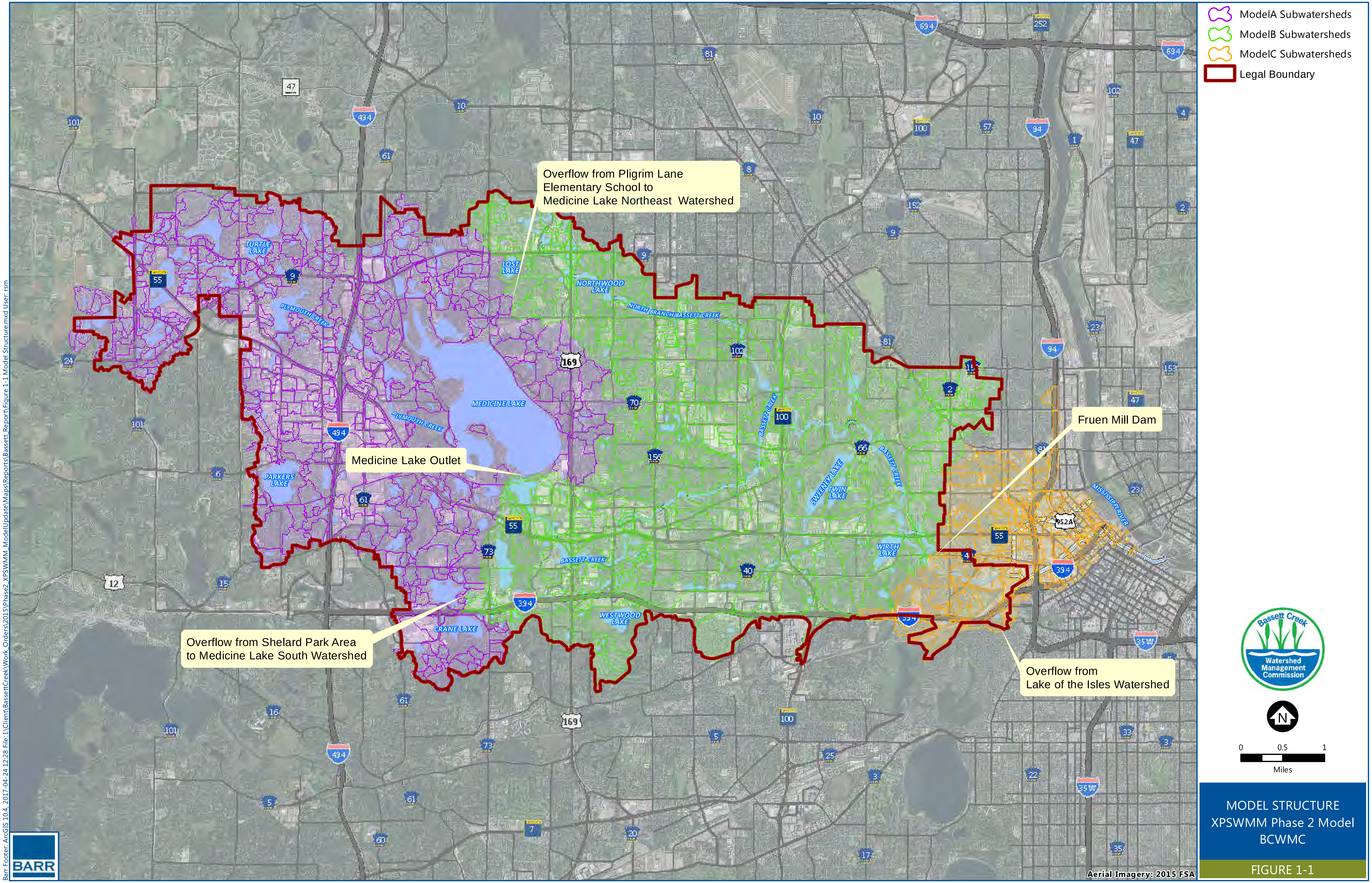
- Three XPSWMM model files (Models A, B, & C) – final calibrated model
- The BCWMC Phase 2 XPSWMM subwatershed divides (in GIS format)
- This *Bassett Creek Hydrologic and Hydraulic Analyses* report

1.2.3 XP-Viewer Files

Based on feedback from the BCWMC Technical Advisory Committee (TAC) during the model review process, an XP-Viewer file for the entire BCWMC model was developed, once the XP-SWMM model was finalized. The final XP-SWMM model was run for the Atlas 14 2-year, 10-year, and 100-year, 24-hour design storm events. Although the results for the 2- and 10-year events will not be summarized in this report, the results will be encrypted as an XP-Viewer file. XP-Viewer is a free software develop by XP-SWMM that allows users to open the encrypted XP-Viewer file and see model inputs and results without needing an XP-SWMM license. However, the model cannot be modified or re-run in XP-Viewer.

1.2.4 Model Updates

The final calibrated BCWMC Phase 2 XPSWMM model may be updated annually by the BCWMC to incorporate information on projects constructed within the watershed, as provided by member cities. The updates to the XP-SWMM model will be coordinated with the P8 water quality model updates.


ModelA Subwatersheds
ModelB Subwatersheds
ModelC Subwatersheds
Legal Boundary
Overflow from Pligrim Lane Elementary School to Medicine Lake Northeast Watershed
Medicine Lake Outlet
Fruen Mill Dam
Overflow from Shelard Park Area to Medicine Lake South Watershed
Overflow from Lake of the Isles Watershed
TURTLE LAKE
LOST LAKE
NORTHWOOD LAKE
NORTH BRANCH BASSETT CREEK
PLYMOUTH CREEK
MEDICINE LAKE
PARKERS LAKE
SWEENEY LAKE
TWIN LAKE
BASSETT CREEK
WIRTH LAKE
WESTWOOD LAKE
CRANE LAKE
MISSISSIPPI RIVER
Bassett Creek Watershed Management Commission
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MODEL STRUCTURE
XPSWMM Phase 2 Model
BCWMC
FIGURE 1-1

2.0 Methodology for Hydrologic and Hydraulic Modeling

2.1 Model Overview

The following sections include a general discussion about the BCWMC Phase 2 modeling.

2.1.1 XPSWMM Computer Modeling Software

The U.S. EPA's Storm Water Management Model (SWMM), with a computerized graphical interface provided by XP Software (XPSWMM), was chosen as the computer modeling package for the BCWMC Phase 2 model update. XPSWMM uses rainfall and watershed characteristics to generate local runoff, which is routed simultaneously through complicated pipe and overland flow networks. The model can account for detention in ponding areas, backflow in pipes, surcharging of manholes, as well as tailwater conditions that may exist and affect upstream storage or pipe flows. Version XPSWMM 2014, Service Pack 1, was the most current version of the model available at the beginning of the study and used to model the storm sewer, ponding and overland flow systems within the study area.

2.1.2 Project Extents

The Bassett Creek watershed is located entirely within Hennepin County, in the northwestern portion of the Twin Cities. The watershed of Bassett Creek covers all or part of the following nine cities:

- Crystal
- Golden Valley
- Medicine Lake
- Minneapolis
- Minnetonka
- New Hope
- Plymouth
- Robbinsdale
- St. Louis Park

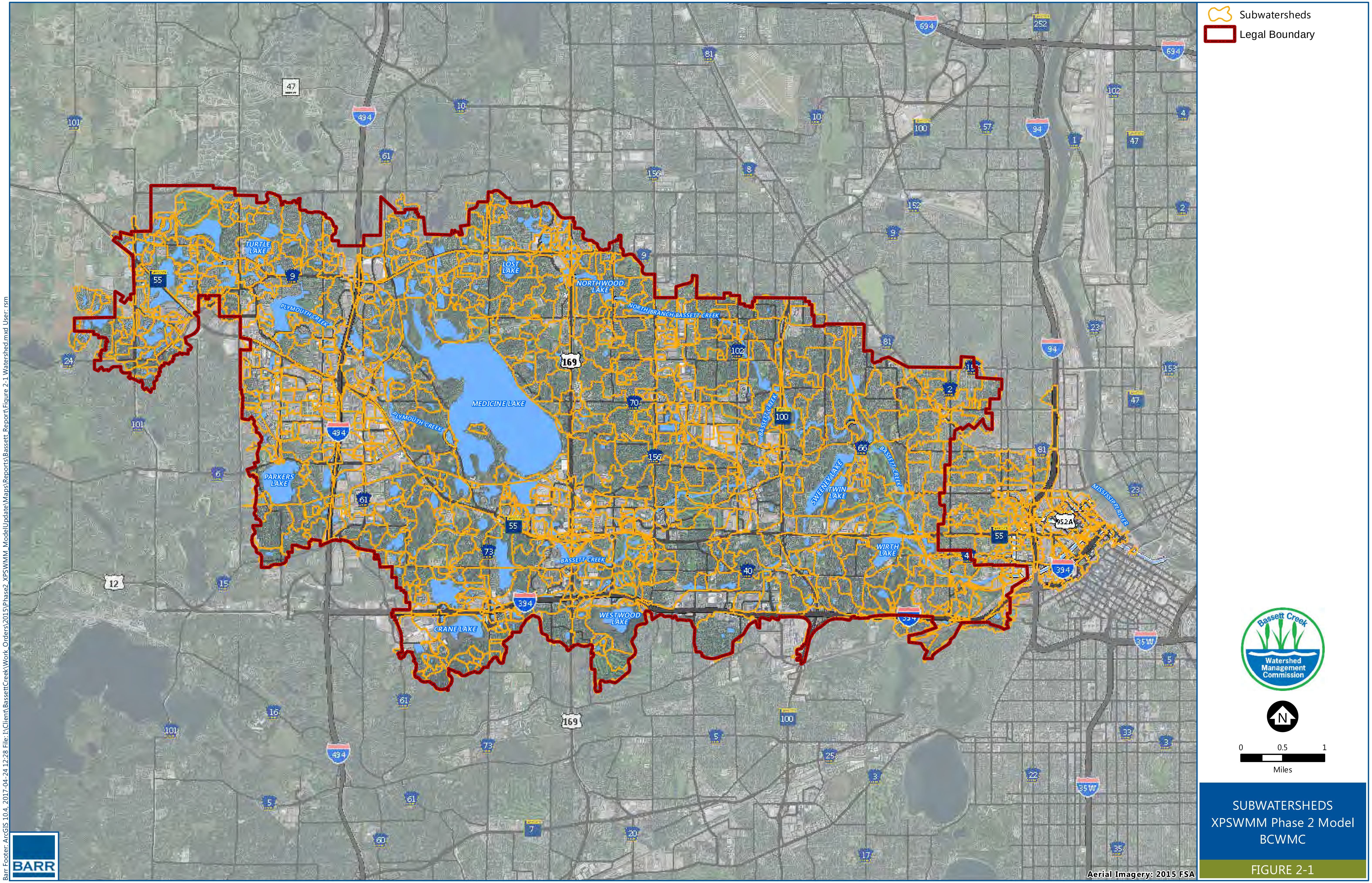
The downstream end of the Bassett Creek watershed is a tunnel (the "New" Tunnel) which conveys Bassett Creek under downtown Minneapolis and discharges into the Mississippi River below St. Anthony Falls. The legal boundary of the BCWMC, as shown in Figure 2-1, ends at the entrance to the "New" Tunnel. The total drainage area of the Bassett Creek watershed upstream of the New Tunnel is 39.4 square miles. In 2000, the BCWMC and the Mississippi Watershed Management Organization (MWMO) entered into a joint and cooperative agreement for a boundary change. This boundary change transferred approximately 1,002 acres from the BCWMC to the MWMO to reflect the changed drainage conditions upon completion of the Bassett Creek Flood Control Project. The drainage area within the MWMO drains to what is often referred to as the "Old Tunnel". With the project in place, the watershed areas tributary to the Old Tunnel and directly tributary to the "New Tunnel" are under jurisdiction of the City of Minneapolis and MWMO (2). However, because high flows from the Bassett Creek main stem are occasionally diverted to the Old

Tunnel (just upstream from the inlet to the New Tunnel), the Phase 2 XPSWMM model also includes the Old Tunnel watershed as well as the portions of Minneapolis that discharge to the New Tunnel (even through the jurisdiction of these areas falls within the MWMO).

2.1.3 Subwatersheds

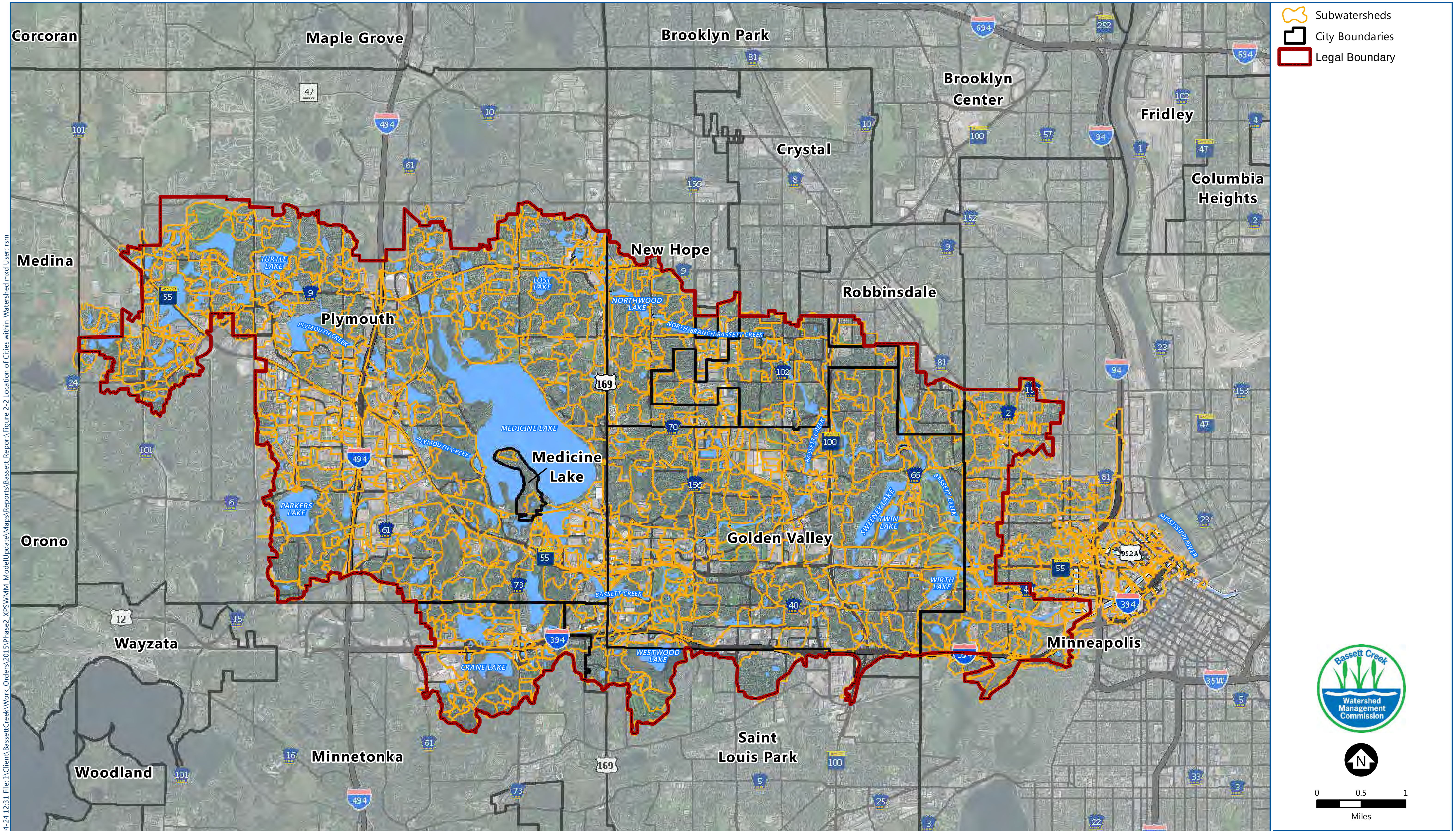
The subwatersheds from the 2012 P8 water quality study (3) were used as the starting point for the development of the Phase 2 XPSWMM model. The subwatersheds were evaluated and revised based on the available digital mapping for both public and private storm sewer systems and updated topographic data (the MnDNR 2011 LiDAR elevation dataset). Subwatersheds were delineated at a scale that represents the direct drainage area to each of the waterbodies (ponds, wetlands, or lakes), low points in the streets and parking lots, and at key connections to the storm sewer system. In areas where the direction of flow was not clear based on the digital topographic data, watershed delineations were field verified. A total of 1,160 separate subwatersheds were delineated within this study area. The delineated subwatersheds are shown in Figure 2-1. Figure 2-2 shows the subwatersheds in relation to the municipal boundaries for each of the cities.

Historically the Bassett Creek watershed has been subdivided into smaller subwatersheds groupings. Those historic subwatershed groupings are shown in Figure 2-3, and match the map included in the current BCWMC *Watershed Management Plan*.



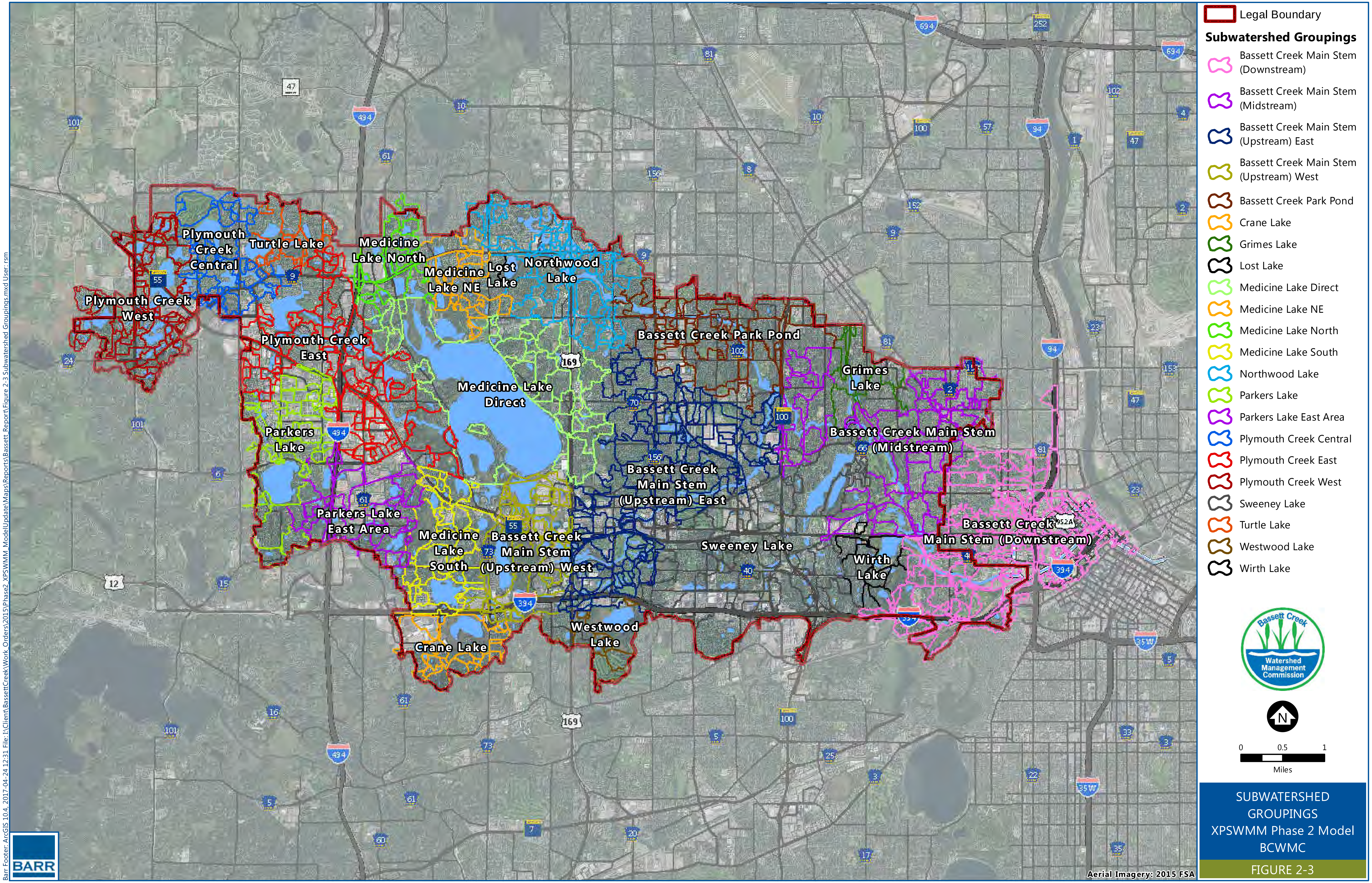
SUBWATERSHEDS
XPSWMM Phase 2 Model
BCWMC

FIGURE 2-1



LOCATION OF CITIES WITHIN WATERSHED
XPSWMM Phase 2 Model
BCWMC

FIGURE 2-2



SUBWATERSHED GROUPINGS
XPSWMM Phase 2 Model
BCWMC

FIGURE 2-3

BARR

Barr Footer: ArcGIS 10.4, 2017-04-24 12:31 File: I:\Client\BassettCreek\Work_Orders\2015\Phase2_XPSWMM_ModelUpdate\Maps\Reports\Bassett_Report\Figure 2-3 Subwatershed Groupings.mxd User: rsm

2.1.4 Naming Convention

Subwatersheds used were named using an abbreviation and numbering system. Abbreviations for each subwatershed were assigned based on the historical subwatershed groupings (Figure 2-3).

Nodes used to model channel features, catch basins, and manholes use the same naming convention, but are preceded by "N-". Links throughout this historical groupings use the same convention as nodes, but are preceded by "L-".

Table 2-1 Naming Convention

Historical Subwatershed Group	XPSWMM Node Prefix
Bassett Creek Main Stem Downstream[1]	BCD
Bassett Creek Main Stem Midstream	BCM
Bassett Creek Park Pond	BPP
Bassett Creek Main Stem Upstream East	BUE
Bassett Creek Main Stem Upstream West	BUW
Crane Lake	CL
Grimes Pond	GRL
Lost Lake	LLK
Medicine Lake North	MLN
Medicine Lake North East	MLNE
Medicine Lake South	MLS
Medicine Lake Direct	MLD
Medicine Lake North	MLN
Northwood Lake	NWD
Parkers Lake	PL
Parkers Lake East Area	PLE
Plymouth Creek West	PCW
Plymouth Creek Central	PCC
Plymouth Creek East	PCE
Sweeney Lake	SW
Turtle Lake	TL
Westwood Lake	WWL
Wirth Lake	WL

1 – Bassett Creek Main Stem Downstream (BCD) includes the watershed areas contributing to the Old Tunnel and the portion of the City of Minneapolis contributing to the New Tunnel downstream of the tunnel inlet.

2.1.5 Boundary Conditions

The following sections discuss boundary conditions used in the Phase 2 XPSWMM model.

2.1.5.1 Downstream Boundary Conditions

The downstream boundary conditions of the model are the Mississippi River at the outlet of Bassett Creek New Tunnel and Old Tunnel. The New Tunnel discharges to the Mississippi River between the Upper and Lower Falls, while the Old Tunnel discharges to the Mississippi River upstream of the Upper Falls approximately 700 feet downstream of the Plymouth Avenue North Bridge, as shown in Figure 2-4.

Calibration and Validation Events

Stage hydrographs from the USACE St. Paul District Water Control Center were used at each of these locations for the calibration and validation events. The vertical datum specified in the records from the USACE St. Paul District Water Control Center were converted from MSL 1912 to NAVD88.

Frequency Events

The methodology follows guidance from the Minnesota Department of Transportation (MnDOT) Drainage Manual (4). The MnDOT drainage manual recommends evaluating the coincidental probability of two events occurring at the same time. The relative independence of the events can be qualitatively evaluated by the ratio of the drainage areas. A short duration storm, which causes a peak discharge in the study area, will likely not similarly affect the Mississippi River drainage basin upstream of the study area. Recommendations from the MnDOT Drainage Manual are shown in Table 2-2.

The stage elevation of the river is based on a ratio of the study area, approximately 26,900 acres (see Section 2.1.2), to the drainage area of the Mississippi River upstream of the study area (approximately 12,600,000 acres). This results in a ratio of approximately 1:500. For the purposes of this study an interpolated value between the 10-year and the 50-year Mississippi River stage was used as the tailwater condition for the 100-year storm event.

Table 2-2 Joint probability tailwater recommendations – adapted from MnDOT Drainage Manual

Drainage Area Ratio	Frequencies for Coincidental Occurrence	
	Bassett Creek Region Study Area Outlet	Mississippi River
1:1,000	100-year return interval	10-year stage
1:200	100-year return interval	25-year stage

The effective Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) study for Hennepin County provides established peak elevation frequency relationships for the 10-, 50-, 100-, and 500-year recurrence intervals for the Mississippi River (5). These profiles were used to select the Mississippi River elevations for the downstream boundary conditions for the Atlas 14 100-year design storm runs. The tailwater elevation used for the Upper Pool of the Mississippi River was 806.0 ft MSL

NAVD88. The tailwater elevation used for the Lower Pool of the Mississippi River was 756.0 ft MSL NAVD88.

2.1.5.2 Water Surface Elevations of Small Waterbodies

Water levels of waterbodies and the creek network were assumed to be at the normal water level (NWL)-the outlet invert elevation for pipes and other hydraulic structures. Initial water levels of land-locked basins were placed at apparent water levels from the 2011 MnDNR LiDAR data. Designed infiltration basins were assumed to be empty prior to rainfall.

2.1.5.3 Water Surface Elevations of Select Large Waterbodies

The BCWMC has conducted long term water level monitoring of lake levels throughout the watershed. Monitoring data from the BCWMC was used for the calibration events for select lake levels prior to the beginning of the analysis. The lakes with specified elevations include: Bassett Creek Park Pond, Crane Lake, Medicine Lake, Northwood Lake, Parkers Lake, Sweeney Lake, Westwood Lake, and Wirth Lake. For the 100-year event, the initial water level of these lakes was placed at the normal water levels.

2.1.6 Elevation Data

Existing topography was defined using LiDAR data, which is available from the Minnesota Geospatial Information Office. The LiDAR data was collected for the Twin Cities by the MnDNR in the spring and fall of 2011 (6). The one meter cell size was selected.

Water bodies with known bathymetric data were updated according to historical surveys.

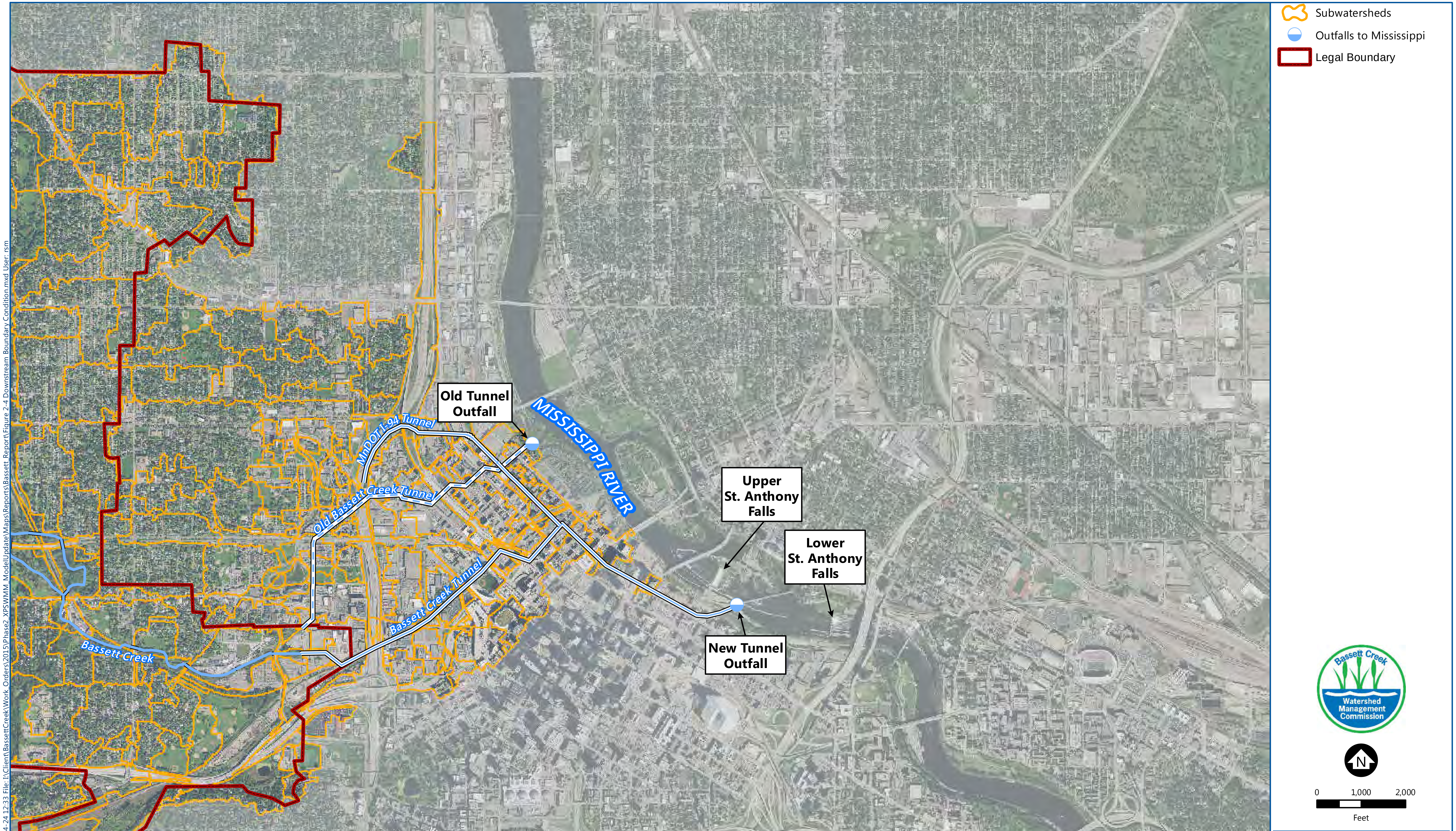
2.1.7 Datum

The horizontal datum and units of the model are Hennepin County Coordinates in feet. All elevations and depths in this document are reported in feet with the North American Vertical Datum of 1988 (NAVD88). To convert elevation data reported in NGVD29 or in Mean Sea Level Datum of 1912 (MSL 1912), the following equations were used:

$$NAVD88 = NGVD29 + 0.18\ feet$$ **Equation 2-1**

$$NAVD88 = MSL1912 + 0.72\ feet$$ **Equation 2-2**

The reported datum on plan sheets (such as as-built plans or developments plans) were adjusted as needed to NAVD88. Many of the cities and agencies provided files (e.g. GIS, CAD files, or undated plans) to Barr without a specified vertical datum. Plan dates and the location of the infrastructure were used to determine the most likely vertical datum of the information. All elevations referenced in this report are in NAVD88 unless otherwise noted.



DOWNSTREAM BOUNDARY CONDITIONS
XPSWMM Phase 2 Model
BCWMC

FIGURE 2-4

2.2 Hydrologic Model Parameters

Generation of stormwater runoff was simulated using the SWMM Runoff Non-linear Reservoir Method in the XPSWMM software. This method simulates hydrologic processes to determine the amount of rainfall that will infiltrate, evaporate, or remain on the ground surface and the amount of rainfall that will leave the watershed as runoff throughout the duration of a precipitation event. To predict the rate and volume of stormwater runoff from a watershed, it is necessary to develop input parameters to describe the physical characteristics of the watershed that impact the hydrologic processes. These input parameters, determined specifically for each watershed, are used to generate inflow hydrographs at various points in the stormwater system. Three major types of information are incorporated into XPSWMM for hydrologic modeling: (1) watershed characteristics, (2) hydrologic parameters, and (3) precipitation data. The methodologies used to develop the watershed characteristics and hydrologic parameters are described in the following sections.

2.2.1.1 Impervious

The imperviousness of a watershed is a highly influential hydrologic parameter for the total runoff generated within that watershed. The imperviousness or total impervious fraction of a watershed represents the portion of the watershed that is covered by impervious surface. The amount of runoff generated from different land uses varies based on the imperviousness of the land. Land use characterized by high imperviousness (for example, commercial areas) will generate higher runoff rates and volumes than land uses with lower imperviousness (for example, residential areas).

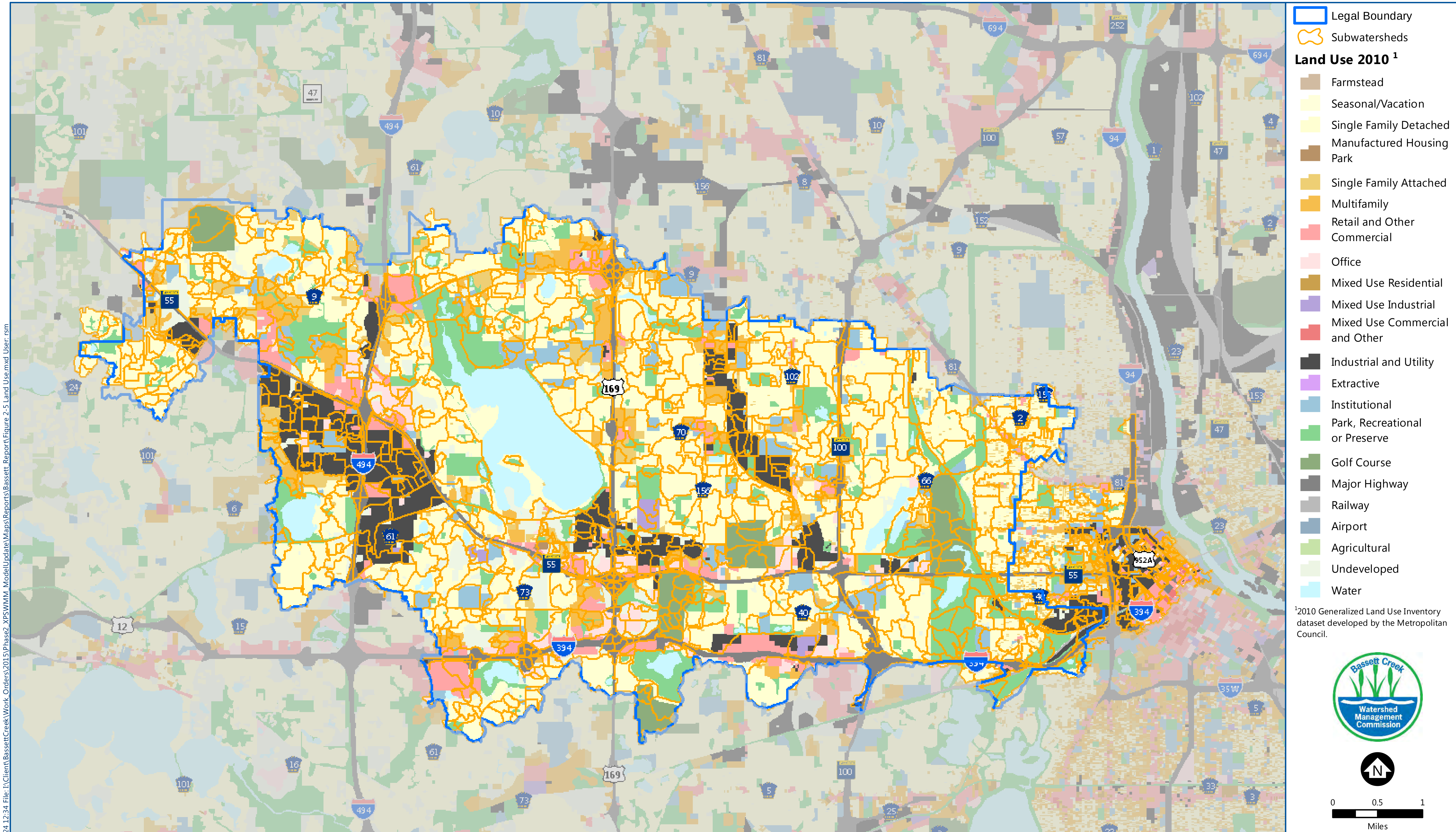
The “directly-connected” impervious fraction represents the impervious surfaces that are hydraulically connected to a stormwater conveyance system. For example, if a rooftop drains onto an adjacent pervious area such as a turfed yard, it is not a “directly-connected” impervious area. However, if a rooftop drains onto a driveway, which drains to the street and thence to a stormwater catch basin, the rooftop would be a “directly-connected” impervious area. XPSWMM only considers the directly-connected impervious fraction.

The *2011 University of Minnesota Twin Cities Metropolitan Area Landsat Remote Sensing* impervious raster dataset was used to classify areas of total impervious (7). The 2011 Landsat data from the University of Minnesota also provided limited land use classifications. This study used the 2010 Metropolitan Council land use classifications (see Figure 2-5). The 2011 University of Minnesota impervious raster and 2010 Metropolitan Council land use classifications were correlated so that the directly-connected impervious fraction could be identified. Land classifications in traditionally heavily impervious areas were classified such that 100% of the total impervious area identified was assumed to be directly-connected impervious. This methodology was applied to the following land uses: Industrial and Utility; Institutional; Major Highways; Manufactured Housing Parks; Mixed Use Commercial; Mixed Use Industrial; Mixed Use Residential; Multifamily; Office; Open Water, Railways; and Retail and Other Commercial. For land uses of lower imperviousness, the impervious areas were refined using the building polygons from the MnDNR 2011 LiDAR. The areas of these buildings (often houses and out buildings) were removed from the total impervious area leaving only the streets and driveways as the directly-connected impervious area. This methodology was applied to the following land uses: Agricultural; Farmstead; Golf courses, Parks; Recreational, or Preserve; Single Family Attached, Single Family Detached, and Undeveloped areas.

Table 2-3 summarizes the initial directly-connected impervious percentages and assumptions that were used in the original XPSWMM model runs prior to calibration. The impervious areas were refined during model calibration as discussed in Section 2.4.

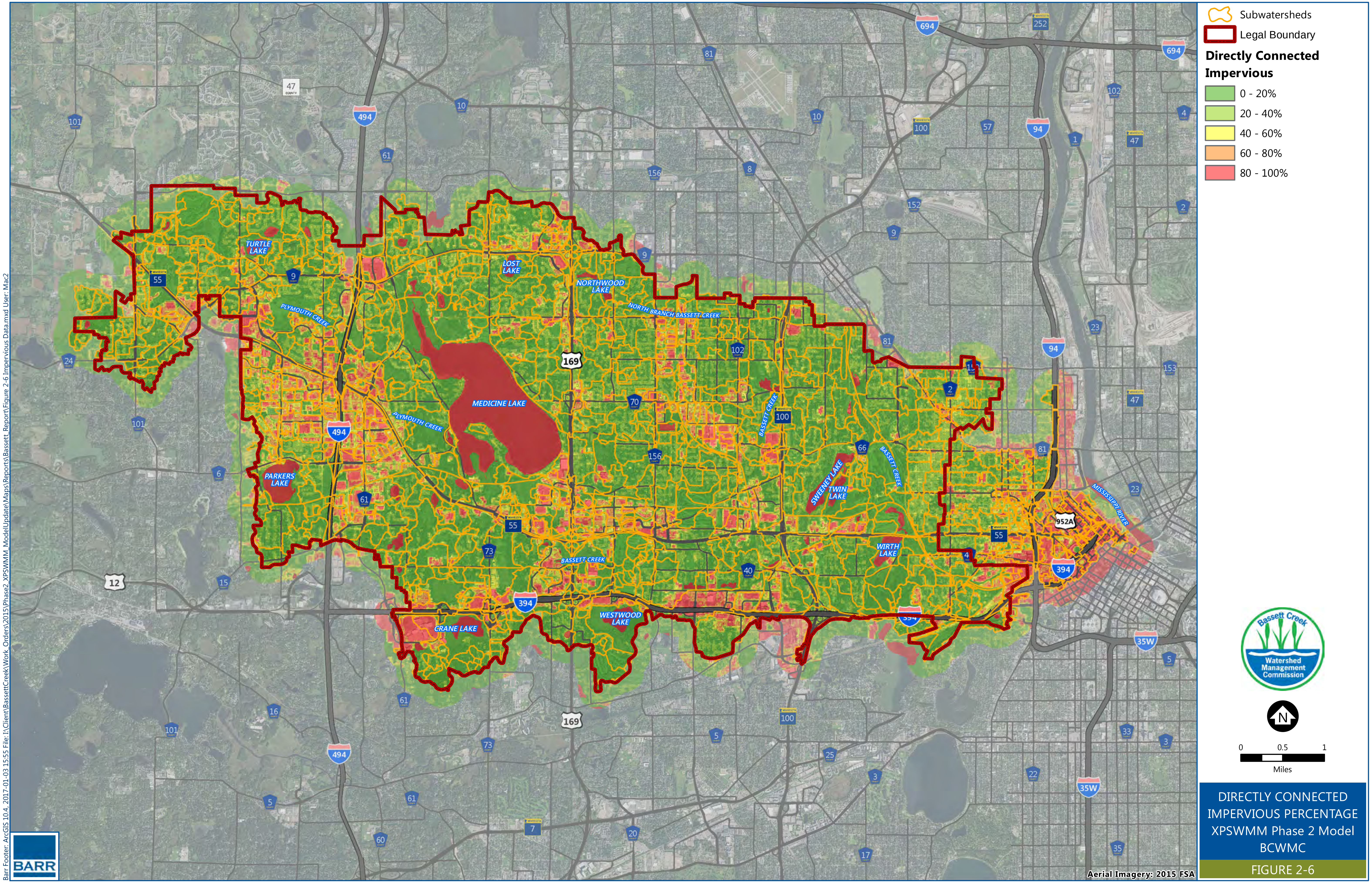
Table 2-3 Land Use Categories and Initial Impervious Percentage Assumptions

2010 Metropolitan Council Land Use Classification	Area within Watershed (acres)	Directly Connected Impervious Percentage of Total Impervious Watershed	Average Directly Connected Percent Impervious (%)
Agricultural	1.9	Varies based on methodology described above	17.5
Farmstead	0.4	Varies based on methodology described above	58.8
Golf Course	852.6	Varies based on methodology described above	4.2
Industrial and Utility	2,313.7	100%	70.4
Institutional	1,376.9	100%	44.0
Major Highway	1,437.7	100%	58.5
Manufactured Housing Parks	7.8	100%	52.7
Mixed Use Commercial	19.1	100%	97.5
Mixed Use Industrial	119.9	100%	54.6
Mixed Use Residential	23.1	100%	75.5
Multifamily	1,076.8	100%	50.3
Office	600.4	100%	62.9
Open Water	1,475.2	100%	100
Park, Recreational, or Preserve	2,917.3	Varies based on methodology described above	10.5
Railway	42.3	100%	54.0
Retail and Other Commercial	1,239.5	100%	73.6
Single Family Attached	1,098.5	Varies based on methodology described above	26.7
Single Family Detached	10,753.8	Varies based on methodology described above	20.3
Undeveloped	1,547.1	Varies based on methodology described above	12.1



LAND USE
XPSWMM Phase 2 Model
BCWMC

FIGURE 2-5



DIRECTLY CONNECTED IMPERVIOUS PERCENTAGE
XPSWMM Phase 2 Model
BCWMC
FIGURE 2-6

2.2.1.2 Watershed Width

In XPSWMM, surface runoff from subwatersheds is routed to the stormwater system via the nonlinear reservoir methodology. During each time-step XPSWMM calculates the surface runoff from the watershed.

The flow rate from a subwatershed is directly related to the watershed slope, overland flow surface roughness, depression storage, and width parameter. As the subwatershed width increases, the flow rate from the subwatershed also increases. With a higher runoff rate, less runoff is stored within the subwatershed and less infiltration occurs. This increases the runoff volume for a given rainfall event. However, as the subwatershed width decreases the opposite occurs; the flow rate from the subwatershed decreases, infiltration increases, and less runoff volume is generated.

The XPSWMM User's Manual suggests estimating the subwatershed width by dividing the subwatershed area by the longest flow path (8). Initial subwatershed widths were estimated using this methodology. The longest flow path of each subwatershed was digitized based on the MnDNR 2011 one meter LiDAR data and the available storm sewer information.

Watershed widths were revised during the calibration, as discussed in Section 2.4.

2.2.1.3 Watershed Slope

The area-weighted average watershed slope (feet/feet) for each subwatershed was calculated using GIS and a digital elevation model (DEM) created from MnDNR LiDAR data (2011) three meter grid for Hennepin County. For comparison purposes, the subwatershed slope was also calculated using the 2011 LiDAR one meter grid data that is publically available from the MnDNR as well as the National Geospatial-Intelligence Agency (NGIA) 2008 LiDAR dataset which used 20 foot grid cells. On average the three datasets produced similar values for subwatershed slope; however, the three meter grid results were used as it reduces statistical variation of the one meter grid and is a more updated elevation dataset than the 2008 LiDAR dataset.

2.2.1.4 Infiltration Parameters (Soils and Open Water Areas)

Infiltration is the movement of water into the soil surface. For a given storm event, the infiltration rate will vary with time. The infiltration rate at the beginning of the storm is the maximum rate because the soil surface is typically drier and full of voids. As the storm event continues, the infiltration rate will gradually decrease as the voids fill with water. For long storms, the infiltration rate will reach a constant value—the minimum infiltration rate or the soil's hydraulic conductivity. The Horton infiltration equation was used to simulate the relationship between infiltration rate and time. The Natural Resource Conservation Service (NRCS) soil survey geographic database (SSURGO) released in 2014 was used to determine the hydrologic soil group classifications of the soils within the study area. Between 2013 and 2014, the NRCS revised many of the soils from B soils classification to C soils classification (reduced infiltration capacity).

Figure 2-7 shows the SSURGO hydrologic soil group data for the Bassett Creek watershed. The areas shown in gray are areas with unclassified soil types which includes the very urban areas that may have been developed prior to the NRCS soil survey efforts. These unclassified soils cover much of the downstream/urban portions of the watershed. These unclassified areas were assumed to be the dominant soil type in the watershed, which are hydrologic soil group C, for the initial model runs.

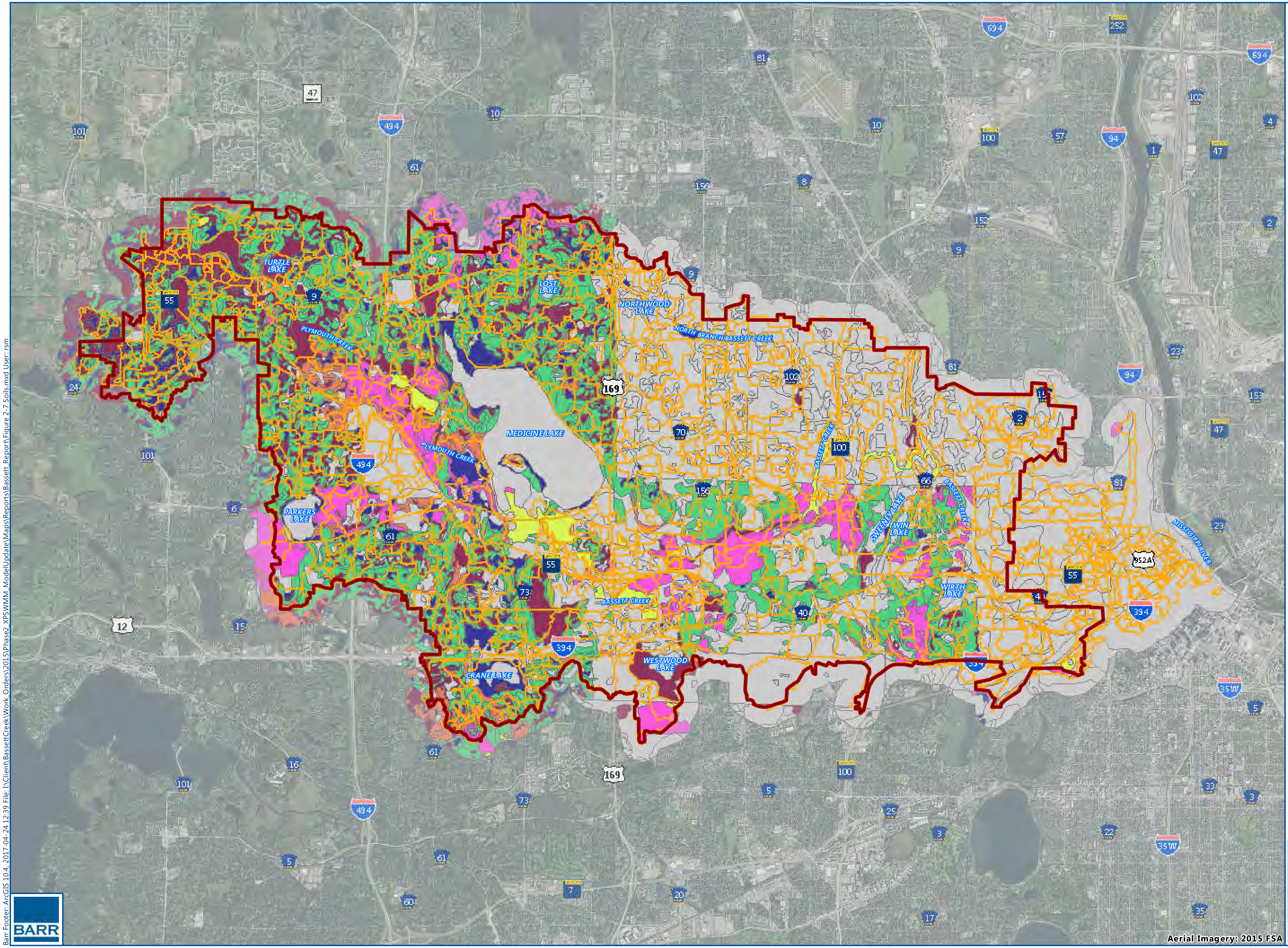
Horton infiltration input parameters for each hydrologic soil group were selected based on the recommended values in the XPSWMM User's Manual. The XPSWMM User's Manual refers to research by G.W. Musgrave of the United States Department of Agriculture (9) for minimum infiltration (hydraulic conductivity) and Akan for maximum infiltration rate (10) . Composite infiltration parameter values were estimated by computing an area-weighted average for each parameter based on the percentage of each soil type within the watershed, using the values shown in Table 2-4.

Table 2-4 Horton Infiltration Parameters

Hydrologic Soil Groups (HSG)	Typical Types of Soils	Range of Minimum Infiltration Rates (in/hr)	Selected Minimum Infiltration Rate (in/hr)	Range of Maximum Infiltration Rate (in/hr)	Selected Maximum Infiltration Rate (in/hr)
A	Sand, loamy sand, sandy loam	0.30-0.45	0.38	1.5-10.0	5.0
B	Silt loam, loam	0.15-0.30	0.23	0.9-6	3.0
C	Sandy clay loam	0.05-0.15	0.1	0.6-4	2.0
A/D	Undrained sand, loamy sand, sandy loam	0.009-0.06	0.03	1.5-10.0	5.0
B/D	Undrained silt loam, loam	0.009-0.06	0.03	0.9-6	3.0
C/D	Undrained sandy clay loam	0.009-0.06	0.03	0.6-4	2.0
D	Clay loam, silty clay loam, sandy clay, silty clay, clay	0.00-0.05	0.03	0.3-2	1.0

Open water areas were defined based on the MnDNR 100k Hydrology dataset. This dataset was assembled by MnDNR Division of Waters in 2003 and 2004 (11).

Watershed infiltration parameters were revised, especially for portions of the watershed with unclassified soils, during the calibration as discussed in Section 2.4.



Subwatersheds
Legal Boundary

2014 SSURGO Hydrologic Soils Group

- A
- A/D
- B
- B/D
- C
- C/D
- Unclassified

0 0.5 1
Miles

HYDROLOGIC SOIL GROUPS
XPSWMM Phase 2 Model
BCWMC

FIGURE 2-7

2.2.1.5 Depression Storage and Overland Flow Roughness

Depression storage, which includes the areas that must be filled with water prior to generating runoff from both pervious and impervious areas, was set for each land use classification based on the values shown in Table 2-5 . The methodology defined in this study was also used to assign overland flow roughness values for each land use classification. The selected depression storage values for the initial XPSWMM model runs are shown in Table 2-5.

Table 2-5 Depression Storage Coefficients

Land Cover Type	Range of Depression Storage Values	Selected Depression Storage Value
Pervious Areas	0.1-0.40 (10) (12)	0.17
Impervious Area	0.05-0.125 (13) (14)	0.07

Research into impervious depression storage determined a depth of 0.05 inches for two and a half percent slopes (13) and between 0.0625 and 0.125 inches for one percent slopes (14).

Overland flow is the surface runoff that occurs as sheet flow over land surfaces prior to the flow concentrating into defined channels. The shallow flows typically associated with overland flow result in substantial increases in surface friction. As a result of the difference in flow depth compared to open channel flow the roughness coefficients typically used in open channel flow calculations are not applicable to overland flow estimates. The overland roughness can change significantly with the depth of flow over the surface. The selected overland roughness values for the initial XPSWMM model runs are shown in Table 2-6.

Table 2-6 Overland Roughness Values

Land Cover Type	Range of Overland Roughness Values	Selected Overland Roughness Value
Pervious Areas	0.15-0.4 (15)	0.2
Impervious Area	0.011-0.5 (16) (17)	0.015

Watershed depression storage and overland roughness parameters were revised during the calibration as discussed in Section 2.4.

2.3 Hydraulic Model Parameters

The stormwater runoff hydrographs generated by XPSWMM are routed through the storm sewer, ponding, and stream network in the hydraulic mode of the model. XPSWMM has advanced hydraulic capabilities and can handle complex hydraulic situations such as large drainage networks, detailed hydraulic structures, natural channel stream flow, detention in ponding areas, backflow in pipes, surcharging of manholes, and impacts of tailwater conditions on upstream storage or flows. The data required and assumptions made for the hydraulic modeling are summarized below.

2.3.1 Storm Sewer Data

Data detailing the existing storm sewer network within the BCWMC was provided by the member cities and other agencies. Data provided included electronic GIS datasets, construction and/or as-built plans, and surveys. Other data was used from historical Barr projects, previous Barr field surveys, BCWMC development reviews, historic models, and reference material. Where this data was incomplete, additional information was estimated based on professional judgment. However, in general, the BCWMC Phase 2 model reflects infrastructure conditions as of 2015.

The pipe material information from this storm sewer data was used to assign the roughness coefficient (Manning's "n") for each storm sewer pipe as listed in Table 2-7. The values in Table 2-7 are consistent with guidance from the Federal Highway Administration (18).

Table 2-7 Pipe Type with Modeled Manning's Roughness

Pipe Material	Modeled Manning's Roughness
Reinforced Concrete Pipe (RCP)	0.013
Corrugated Metal Pipe (CMP)	0.024
Ductile Iron Pipe (DIP)	0.011
Corrugated High-Density Polyethylene Pipe (HDPE)	0.024
Smooth wall High-Density Polyethylene Pipe (HDPE)	0.010
Polyvinyl Chloride Pipe (PVC)	0.010

2.3.2 Stormwater Storage Areas

The flood pool storage volume (live storage above the normal water level) for each pond, lake, and waterbody was calculated in ArcMap using the MnDNR 2011 LiDAR data. The live storage represents the storage volume between the normal water elevation and the flood elevation. For landlocked areas, the normal water level was assumed to be the same as the water surface as captured in the MnDNR 2011 LiDAR data.

Select stormwater storage volumes were adjusted based on available survey data or discrepancies in the LiDAR elevation.

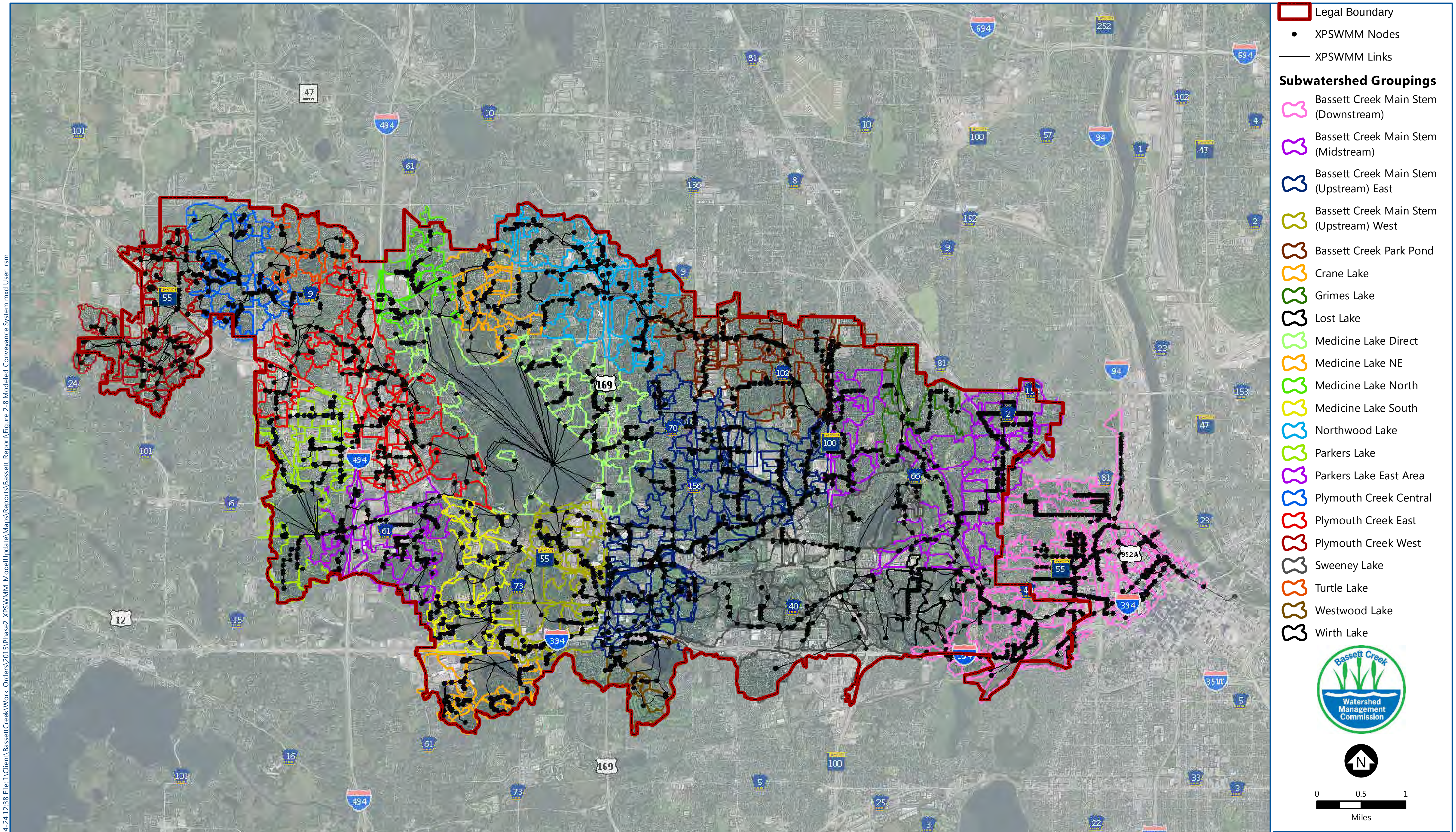
2.3.3 Stream Cross Sections

The majority of the stream cross sections used in the Phase 2 XPSWMM model utilized cross sections in the same locations as the USACE HEC-2 model. Cross sections from the USACE HEC-2 models were georeferenced in GIS and the cross sections were recut from the MnDNR 2011 LiDAR data in the floodplain areas while the channel bathymetry (e.g. between the banks) was replaced with the USACE HEC-2 model information which is based on surveys of the creek.

Manning's roughness values were assigned based on apparent vegetation and land use. Guidance on the selection of Manning's roughness was taken from the USACE HEC-RAS Reference Manual (19). Channel roughness values vary between 0.030 and 0.050 for Plymouth Creek, 0.035 and 0.05 for North Branch Bassett Creek, and 0.025 and 0.035 for Bassett Creek Main Stem. Floodplain roughness values vary between 0.06 and 0.12 for Plymouth Creek, are 0.08 for North Branch Bassett Creek, and vary between 0.05 and 0.08 for Bassett Creek Main Stem.

2.3.4 Overland Flow Network

An overland flow channel network was included in the XPSWMM model to account for runoff that surcharges from the storm sewer system or overflows from waterbodies and other storage areas and flows along streets or natural drainage channels. The characteristics of the overland flow channels were approximated utilizing the MnDNR 2011 LiDAR data and aerial photos of the area.



MODELED CONVEYANCE SYSTEM
XPSWMM Phase 2 Model
BCWMC

FIGURE 2-8

BARR

2.4 Model Calibration and Validation

A discussion of the BCWMC Phase 2 XPSWMM model and calibration and validation is presented in the following sections.

2.4.1 Calibration and Validation Event Precipitation

The Phase 2 XPSWMM model was calibrated to two independent storm events and validated to one additional event. The calibration events included a smaller storm event that is dominated by runoff from impervious surfaces and a larger storm event that has runoff from both impervious and pervious surfaces. The validation event selected has a precipitation depth that falls between the two calibration events.

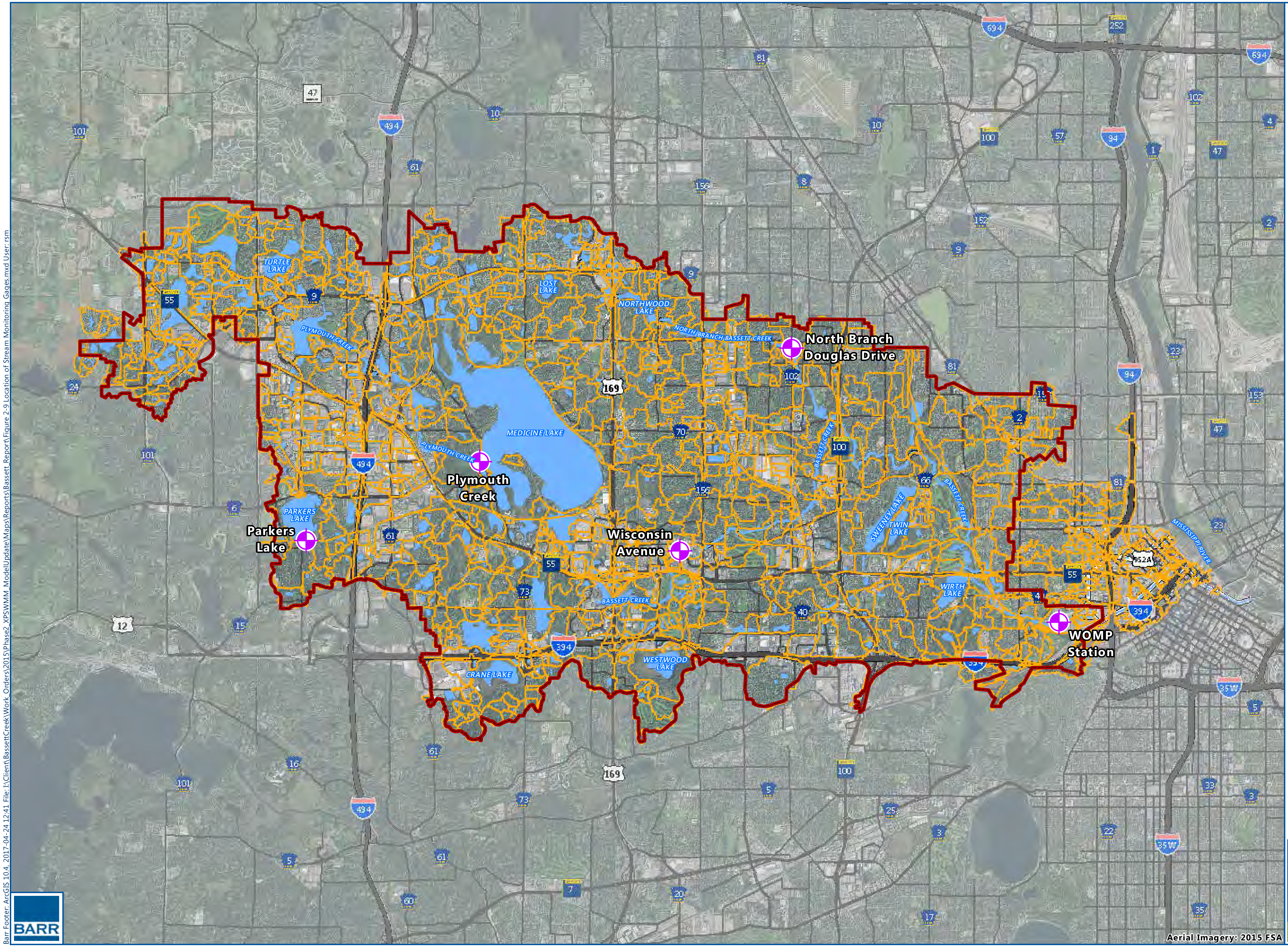
Due to the availability of rainfall and stream gage data and the breakdown of the project scope and schedule, the calibration of the BCWMC model was split at Medicine Lake. The XPSWMM model upstream of Medicine Lake was calibrated and validated in 2015, based on storm events and monitoring data from 2013. The portion of the model downstream of Medicine Lake was calibrated and validated in 2016, based on storm events and monitoring data from 2015.

The data sources and date ranges of provided gage data is shown in Table 2-8. The location of the gages described in Table 2-8 is shown in Figure 2-9.

Table 2-8 Dates of Provided Stream and Water Body Monitoring Data

Gage Name	Reach	Data Available	Data Source	First Date of Provided Data	Final Date of Provided Data
PL1 (Parkers Lake)	Parkers Lake	Flow	Three Rivers Park District	4/17/2013	10/28/2014
PC2 (Plymouth Creek)	Plymouth Creek	Flow	Three Rivers Park District	4/7/2010	10/23/2014
Water Body Elevation Data	Full List of Waterbodies is described in Section 2.1.5.3	Elevation	BCWMC	11/18/1972	9/30/2015
Wisconsin Avenue	Main Stem Bassett Creek	Elevation	City of Golden Valley	9/1/2014	5/11/2016
Douglas Drive	North Branch Bassett Creek	Water Level	BCWMC	6/28/2015	11/5/2015
WOMP	Main Stem Bassett Creek	Elevation & Flow	BCWMC/ Metropolitan Council	1/1/2013	12/31/2015 [1]

[1] All 2015 data provided at the WOMP Gage are considered preliminary



LOCATION OF STREAM MONITORING GAGES
XPSWMM Phase 2 Model
BCWMC

FIGURE 2-9

BARR

Precipitation data for the XPSWMM model calibration and validation was collected from several sources including Next Generation Radar (NEXRAD) and local rainfall gages to develop accurate precipitation hyetographs. Combining precipitation data from several sources allowed development of hyetographs that closely approximated both the distribution and magnitude of precipitation that occurred over the study area.

The NEXRAD data reflects the approximate rainfall intensity. The NEXRAD data was processed using PCSWMM modeling software. The rainfall depth predicted by the NEXRAD data using the PCSWMM model was compared to the recorded rainfall gage depths. In some cases, the NEXRAD rainfall intensity estimates can slightly over- or underestimate the total rainfall at the site when compared to these recorded rainfall gage depths. A scale factor was used for the storm or gages to adjust the intensity of the rainfall recorded in the NEXRAD data so it matched recorded rainfall gage data. In other cases, certain rainfall gages were removed from the analysis because these gages reported significantly different precipitation depths than nearby gages. The selected rainfall gages are shown in Table 2-11 and the location of the gages is shown in Figure 2-10. The selected rainfall events are shown in Table 2-9 and Table 2-10.

XPSWMM is limited to 1,000 unique rainfall records. Since the XPSWMM model exceeded 1,000 subwatersheds, the watersheds were aggregated and the same rainfall hyetograph was applied to those groupings of subwatersheds to limit the overall number of rainfall records. The groupings of subwatersheds for the rainfall processing are shown in Figure 2-11.

Table 2-9 Calibration and Validation Events Used Upstream of Medicine Lake

Event Name	Beginning of Modeled Event	End of Modeled Event	Average Rainfall Depth over Watershed (inch)
Calibration Event 1 (Large Event)	6/21/2013 00:00	6/23/2013 00:00	3.6
Calibration Event 2 (Small Event)	7/9/2013 00:00	7/10/2013 00:00	0.3
Validation Event 1	6/15/2013 11:45	6/16/2013 23:45	1.3

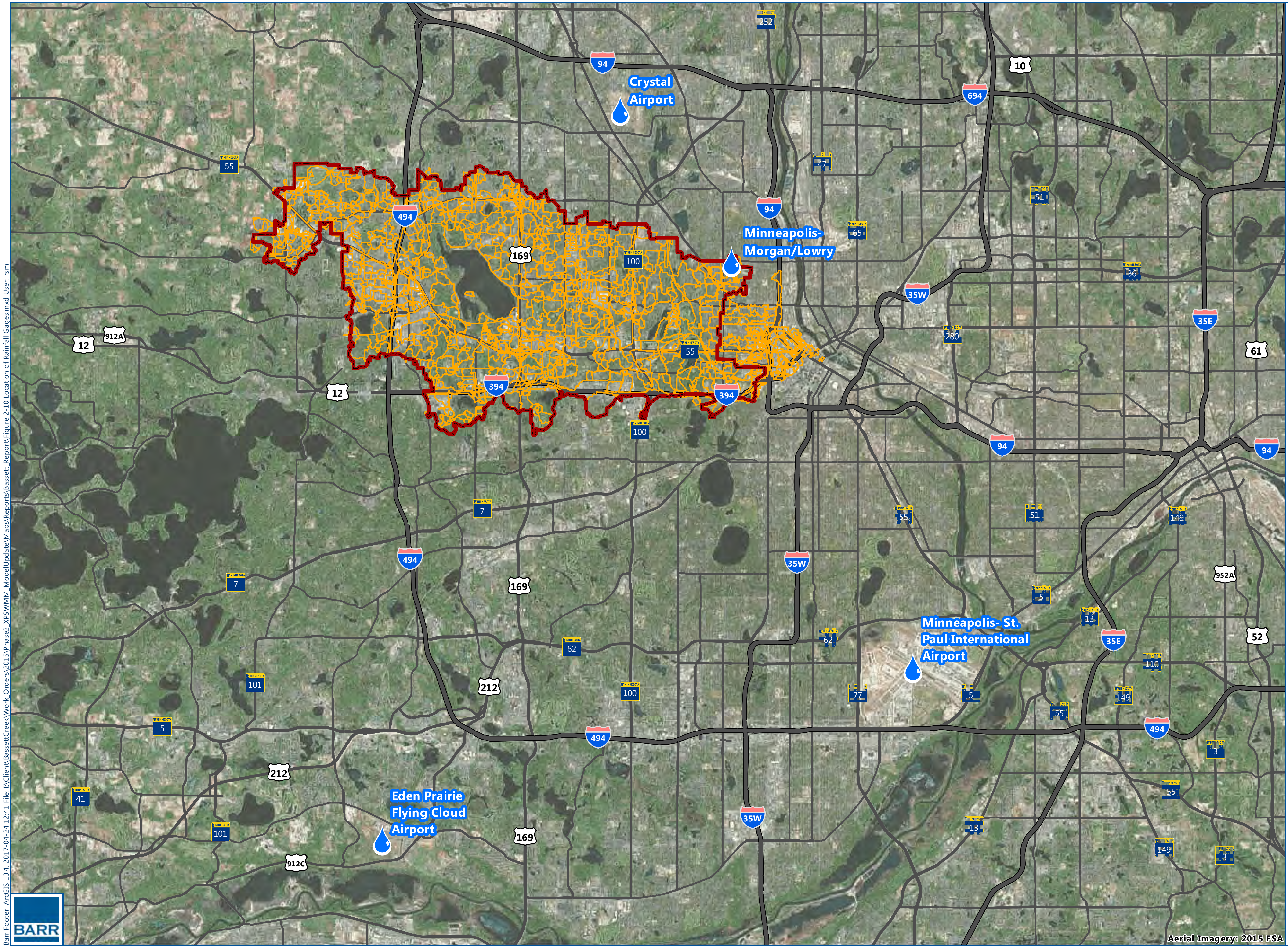
Table 2-10 Calibration and Validation Events Used Downstream of Medicine Lake (Bassett Creek Main stem and North Branch Bassett Creek)

Event Name	Beginning of Modeled Event	End of Modeled Event	Average Rainfall Depth over Watershed
Calibration Event 3 (Large Event)	7/6/2015 00:00	7/8/2015 00:00	2.5
Calibration Event 4 (Small Event)	8/22/2015 00:00	8/25/2015 00:00	0.4
Validation Event 2	7/28/2015 00:00	7/30/2015 00:00	1.2

2.4.2 Location of Rainfall Gages

Table 2-11 Precipitation Gages used for XPSWMM Model Calibration

Precipitation Gage	Precipitation Data Timestep
Crystal Airport	1 hour
Eden Prairie/Flying Cloud Airport	1 hour
City of Minneapolis-Morgan/Lowry	5 Minutes
Minneapolis- St. Paul International Airport	1 hour
Minnesota State Climatology Working Group	Historic Daily Data Retrieval using the Mapable MNGage precipitation data set



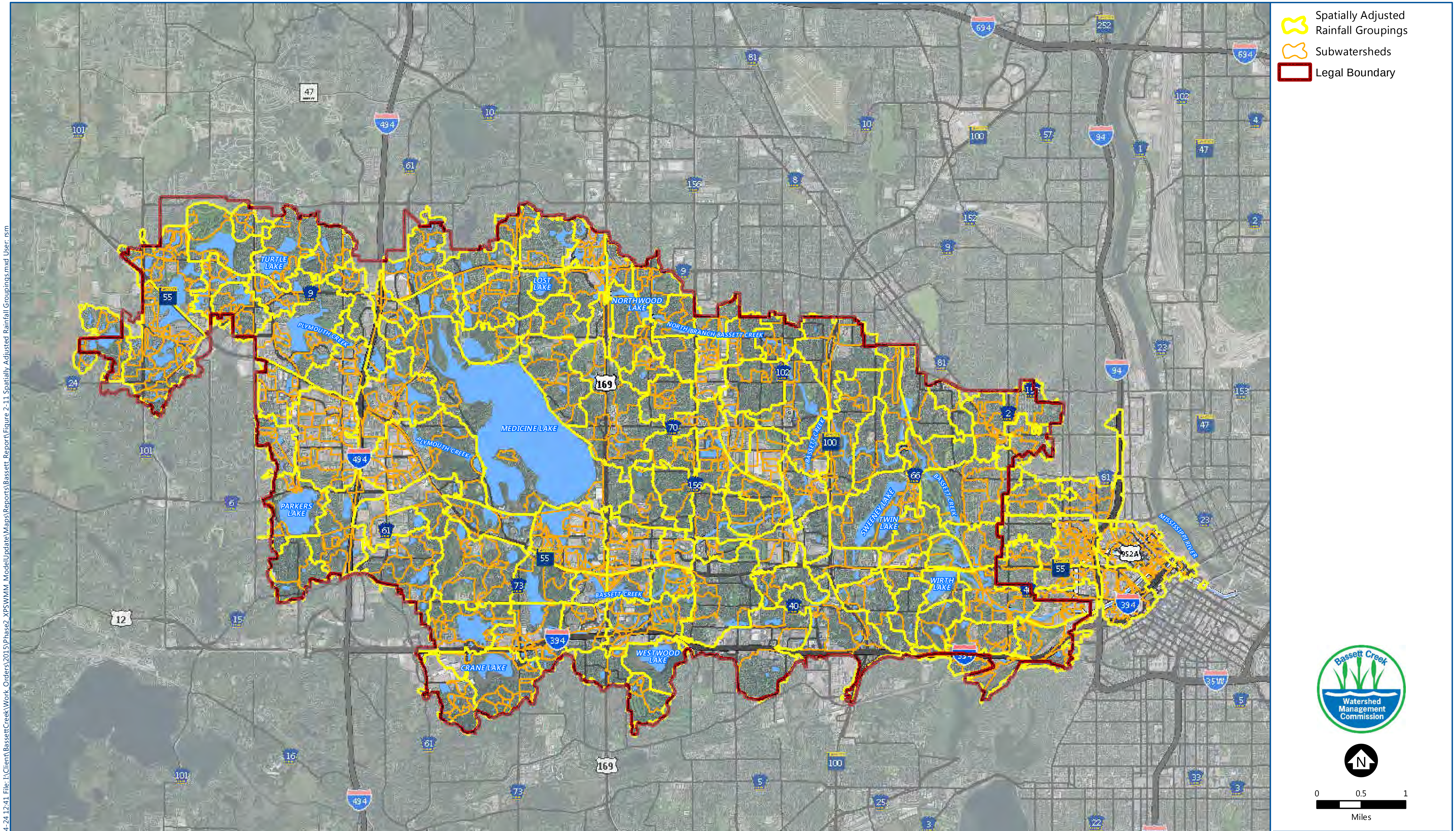
Subwatersheds
Legal Boundary
Rainfall Gages[1]

[1]Gages utilized to process NEXRAD data for calibration & validated events.

0 1 2
Miles

LOCATION OF RAINFALL GAGES
XPSWMM Phase 2 Model
BCWMC

FIGURE 2-10



SPATIALLY ADJUSTED RAINFALL GROUPINGS
XPSWMM Phase 2 Model
BCWMC

FIGURE 2-11

2.4.3 Observed Runoff Coefficient at Monitoring Sites

Gage data was reviewed and scrutinized prior to model calibration. For each event, a runoff coefficient based on the monitoring data was calculated if flow data was available. The observed runoff coefficient is the volume of runoff divided by the total rainfall volume across the watershed upstream. The volume recorded by each stream gage was calculated as the volume of runoff. The observed runoff coefficient was compared to the runoff coefficient calculated using the equation developed by Schueler. The Simple Method by Schueler (20) was used to help check the monitored data as shown in Equation 2-3.

$$R_v = 0.05 + 0.9I_a$$ **Equation 2-3**

In the equation above, R_v is the runoff coefficient and I_a is the impervious fraction. For typical metro impervious fractions of 20 to 50%, a runoff coefficient of 0.23 to 0.5 is expected. Generally speaking, the larger the rainfall event, the higher the runoff coefficient. Gages where reported flows and volumes were inconsistent with runoff expectations were not used for model calibration.

Table 2-12 Observed Runoff Coefficients for Model Calibration and Validation Upstream of Medicine Lake

Event	Average Rainfall Depth over Watershed	Observed Runoff Coefficient PL1 Gage	Observed Runoff Coefficient at PC2 Gage[1]
Calibration Event 1 (Large Event)	3.6	0.18	0.15
Calibration Event 2 (Small Event)	0.3	0.13	0.05
Validation Event 1	1.3	0.10	0.19

[1]Runoff coefficient calculation includes a total watershed area that includes the Parkers Lake watershed, which has a pumped outlet and therefore the estimated runoff coefficients appear low.

Table 2-13 Observed Runoff Coefficients for Model Calibration and Validation Downstream of Medicine Lake[1]

Event	Average Rainfall Depth over Watershed	Observed Runoff Coefficient at WOMP Station
Calibration Event 3 (Large Event)	2.5	0.2
Calibration Event 4 (Small Event)	0.4	0.2
Validation Event 2	1.2	0.25

[1]Runoff coefficients could not be calculated at the Wisconsin Avenue control structure or at the Douglas Drive monitoring station as the data collected at these stations were water elevation/levels (not flow rate)

2.4.4 Calibration Methodology

The XPSWMM model calibration methodology included the general process outlined below:

1) Calibrating to the smaller storm event, focusing on modifying parameters related to runoff generation from impervious surfaces and system hydraulics,
2) Calibrating to the larger storm event, focusing on modifying parameters related to runoff generation from pervious surfaces and system hydraulics,
3) Running the validation event to confirm the model calibration is appropriate.

Through the calibration process, the following model input parameters were modified from the original assumptions to improve the model predictions to better match the monitoring data:

- Subwatershed width
- Percentage of directly- connected impervious surfaces
- Impervious depression storage
- Impervious roughness
- Horton infiltration assumptions related to soil types (especially areas with undefined soils)
- Pervious depression storage
- Pervious roughness
- Channel roughness

Table 2-14 summarizes the final calibrated model parameters for the subwatersheds based on the calibration points within the watershed.

Table 2-14 Final Calibration Parameters for the BCWMC XPSWMM Model as Applied to Calibration Watersheds

Model Parameter	Original Value	Medicine Lake[1]	North Branch Bassett Creek[2]	Main Stem Bassett Creek – Upstream[3]	Main Stem Bassett Creek – Downstream[4]	Tunnel Reach of Bassett Creek[5]
Width	Area divided by longest flow path	Half of area divided by longest flow path	Half of area divided by longest flow path	Area divided by longest flow path	Half of area divided by longest flow path	Half of area divided by longest flow path
Percent directly-connected impervious	See Table 2-3	Industrial and Utility land use revised to 80% directly-connected	Industrial and Utility land use revised to 100% directly-connected	See Table 2-3	Land use with 100% directly-connected impervious in Table 2-3 revised to 80% directly-connected	See Table 2-3
Impervious Depression Storage	0.07	0.07	0.1 for upstream of Winnetka Pond and North of 36th Ave, 0.07 for the rest	0.1	0.1	0.1
Impervious Roughness	0.015	0.015	0.015	0.018	0.015	0.015
Horton Infiltration Parameters	Undefined assumed to be HSG C	Undefined assumed to be HSG C	Undefined soils assumed to be HSG B upstream of Winnetka Pond and North of 36th Ave, HSG C for the rest of watershed	Undefined assumed to be HSG B	Undefined assumed to be HSG B	Undefined assumed to be HSG B
Pervious Depression Storage	0.17	0.3	0.4	0.25	0.25	0.25
Pervious Roughness[6]	0.2	0.2	0.2	0.25	0.25	0.25
Decay Rate of Infiltration	0.00115	0.00115	0.00115	0.0008	0.00115	0.00115
Channel Roughness[6]	0.03-0.045 See Section 2.3.3	0.04-0.05	Upstream of Winnetka Pond: 0.07 Downstream of Winnetka Pond: Depth Varying: Under 2.5ft: 0.05-0.07 Above 2.5 ft: interpolated between 0.05 to 0.02	0.035	0.028-0.04	Tunnel (pipe material roughness shown in Table 2-7)

[1]Calibration to flows at the PL1 and PC2 monitoring stations, applied to all watersheds contributing to Medicine Lake (PCE, PCC, PCW, PLE, PL,TL, MLN, MLD, MLS, MLNE, MLN, and CL)

[2]Calibration to water elevations at the Douglas Drive monitoring station, applied to all watersheds contributing to the North Branch Bassett Creek (NWD, BPP, and LL)

[3]Calibration to water elevations at the Wisconsin Avenue monitoring station, applied to all watersheds contributing to the Main stem Bassett Creek (BUW, BUE, and WWL) from the outlet of Medicine Lake to Highway 100 along the Main stem Bassett Creek

[4]Calibration to water elevations at the WOMP monitoring station, applied to all watersheds contributing to the Main stem Bassett Creek between the Highway 100 and the WOMP (BCM, portions of BCD, GRL, WL, and SL) downstream of the Highway 100.

[5]Portions of the watershed that contribute to either the new or old tunnel of Bassett Creek (downtown Minneapolis and surrounding area)

[6]The Pervious Roughness values in XPSWMM are adjusted to include consideration of indirectly-connected impervious

[6]Original Value channel roughness are those used in the HEC-2 models (Section 1.1)

3.0 Calibration and Validation Results

3.1.1 Calibration Events Results

To evaluate the calibration and validation results, we used several parameters to compare the Phase 2 XPSWMM model performance with the monitoring data. These parameters include the percent error in peak flow and/or peak elevation/flow depth, percent error in volume (if flow monitoring data was available), and the Nash-Sutcliffe efficiency index.

The percent error equation is shown below:

$$\%_{err=} \left| \frac{Y_i - \hat{Y}_i}{Y_i} \right| (100)$$

Equation 3-1

Where,
$\hat{Y}_i$ = peak model predicted value
Y_i = peak measured value

Generally, a percent error within 10 to 20 percent is considered a good fit; however, the model results should always be evaluated on an individual basis based on an understanding of the modeling and monitoring data.

The Nash-Sutcliffe efficiency index is a commonly used statistic for assessing the degree of fit of models to observed data. The values of the Nash-Sutcliffe efficiency index range between negative infinity (-∞) and 1 with 1 indicating a perfect fit to the observed data. The Nash-Sutcliffe efficiency index compares the model results and the observed results for exactly the same time step. Generally, a Nash-Sutcliffe efficiency index exceeding 0.6 is considered a good fit; however, the model results should always be evaluated on an individual basis. The Nash-Sutcliffe efficiency index (E_f) was calculated for each storm event at the five calibration stations to evaluate the degree of fit of the modeled hydrographs with observed conditions.

The Nash-Sutcliffe efficiency index equation is shown below:

$$E_{f=}1 - \frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y}_i)^2}$$

Equation 3-2

Where,
$\hat{Y}_i$ = model predicted value
Y_i = measured value
$\bar{Y}_i$ = mean of measured value
n = sample size.

However, because the Nash-Sutcliffe efficiency equation is based on a comparison of values at corresponding time steps, in some cases, subtle differences in the time step resolution of the precipitation data, the monitoring data, and the modeling results, may indicate the model is poorly calibrated when the model is actually performing well. The aggregation of the NEXRAD precipitation to the larger rainfall watersheds (typically 5-10 subwatersheds) can also result in slight differences in the XPSWMM model timing when compared to the monitoring data. A modified Nash-Sutcliffe efficiency index can be estimated using the equation above by altering the modeled time step by a small amount of time (typically less than the data collection time (e.g. 15-minutes)) to better align the modeled data with the time step of the observed data.

Also, antecedent soil conditions, starting elevations of waterbodies, debris in the channel, and groundwater inflow are all parameters that cannot be captured by the XPSWMM model unless monitoring data or observations are available. There is no additional data beyond the monitoring stations, the major lake level monitoring data, and the annual flood control project inspection photos to better define these parameters for the smaller ponds and wetlands located throughout the watershed. However, the assumptions related to these parameters can significantly impact the model results and the estimated calibration parameters.

3.1.1.1 Calibration of the Watershed Upstream of Medicine Lake

The original BCWMC Phase 2 XPSWMM model update scope called for calibration to the Plymouth Creek gage. We utilized the PC2 monitoring station for calibration along Plymouth Creek upstream of Medicine Lake. This monitoring station is located immediately downstream of a rock weir and W. Medicine Lake Drive in West Medicine Lake Park. The flows at this station are also impacted by the downstream water levels in Medicine Lake.

In addition to calibration to the monitoring station on Plymouth Creek, we also calibrated to monitoring data available in the Parkers Lake watershed (PL1) to help refine hydrologic parameters for the larger Parkers Lake, Plymouth Creek, and Medicine Lake watersheds. The monitoring site PL1 is located in a 48-inch diameter storm sewer that discharges to Parkers Lake and collects runoff from a small residential watershed with limited ponding or storage upstream.

For the Phase 2 XPSWMM model upstream of Medicine Lake, the two monitoring gages collect flow data at 15-minute intervals. The precipitation data used in the XPSWMM model from processed NEXRAD data is aggregated at approximately 5-minute intervals, a much finer resolution than the monitoring data. As a result, it is possible that the XPSWMM model will result in a higher peak that may not be captured in the monitoring data due to the longer time step.

The monitoring data at the Parkers Lake site (PL1) is particularly ‘peaky’- meaning the flow hydrograph rapidly rises and falls back to no flow in a short period of time, in some cases almost within the 15-minute data collection interval. However, the timestep of the XPSWMM model is much finer and resulted in a higher peak than captured by the monitoring data. Because of this, the modified Nash-Sutcliffe efficiency indices were calculated for this site as well as the site at Plymouth Creek.

The Plymouth Creek site (PC2) is impacted by water levels in Medicine Lake, located immediately downstream of the station. During calibration, the elevations of the major lakes within the Plymouth Creek watershed, including Parkers Lake, Crane Lake, and Medicine Lake were estimated based on interpolation between the historic BCWMC lake level data at the start of the event. This data is collected approximately every two weeks and although it provides a good estimate of the lake levels at the start of the event, it does not reflect potential fluctuations in water levels between the lake level monitoring dates. Additionally, this monitoring station was very sensitive to the available storage in the upstream wetland and to the roughness associated with the rock weir immediately upstream of the monitoring station.

The results for the calibration statistics for the two stations within the Medicine Lake watershed are summarized in Table 3-1 and Table 3-2. Figure 3-1 through Figure 3-4 show plots of the observed and modeled data for each of the calibration events at the two monitoring gages upstream of Medicine Lake.

The modified Nash-Sutcliffe efficiency indices and the percent error statistics indicate a good fit for both the small and large calibration events, especially along Plymouth Creek. Additionally, review of the calibration plots indicate that the XPSWMM model results are closely matching the monitoring data magnitudes and hydrograph shapes for both calibration events.

Table 3-1 Model Calibration Summary Statistics for Calibration Event 1(Large Event)

Gage	Modeled Peak Flow / Monitored Peak Flow (cfs)	Error in Modeled Peak Flow vs Monitored Peak Flow (%)	Error in Modeled Volume vs Monitored Volume (%)	Nash-Sutcliffe Efficiency Index	Modified Nash-Sutcliffe Efficiency Index
PL1 (Parkers Lake)	75 / 31	141	12	-1.54	0.52
PC2 (Plymouth Creek)	176 / 147	20	19	0.50	0.62

Table 3-2 Model Calibration Summary Statistics for Calibration Event 2 (Small Event)

Gage	Modeled Peak Flow / Monitored Peak Flow (cfs)	Error in Modeled Peak Flow vs Monitored Peak Flow (%)	Error in Modeled Volume vs Monitored Volume (%)	Nash-Sutcliffe Efficiency Index	Modified Nash-Sutcliffe Efficiency Index
PL1 (Parkers Lake)	14 / 12	14	17	0.19	0.87
PC2 (Plymouth Creek)	7 / 8	14	6	0.85	0.87

Figure 3-1 Calibration Event 1 at PL1 (Parkers Lake)

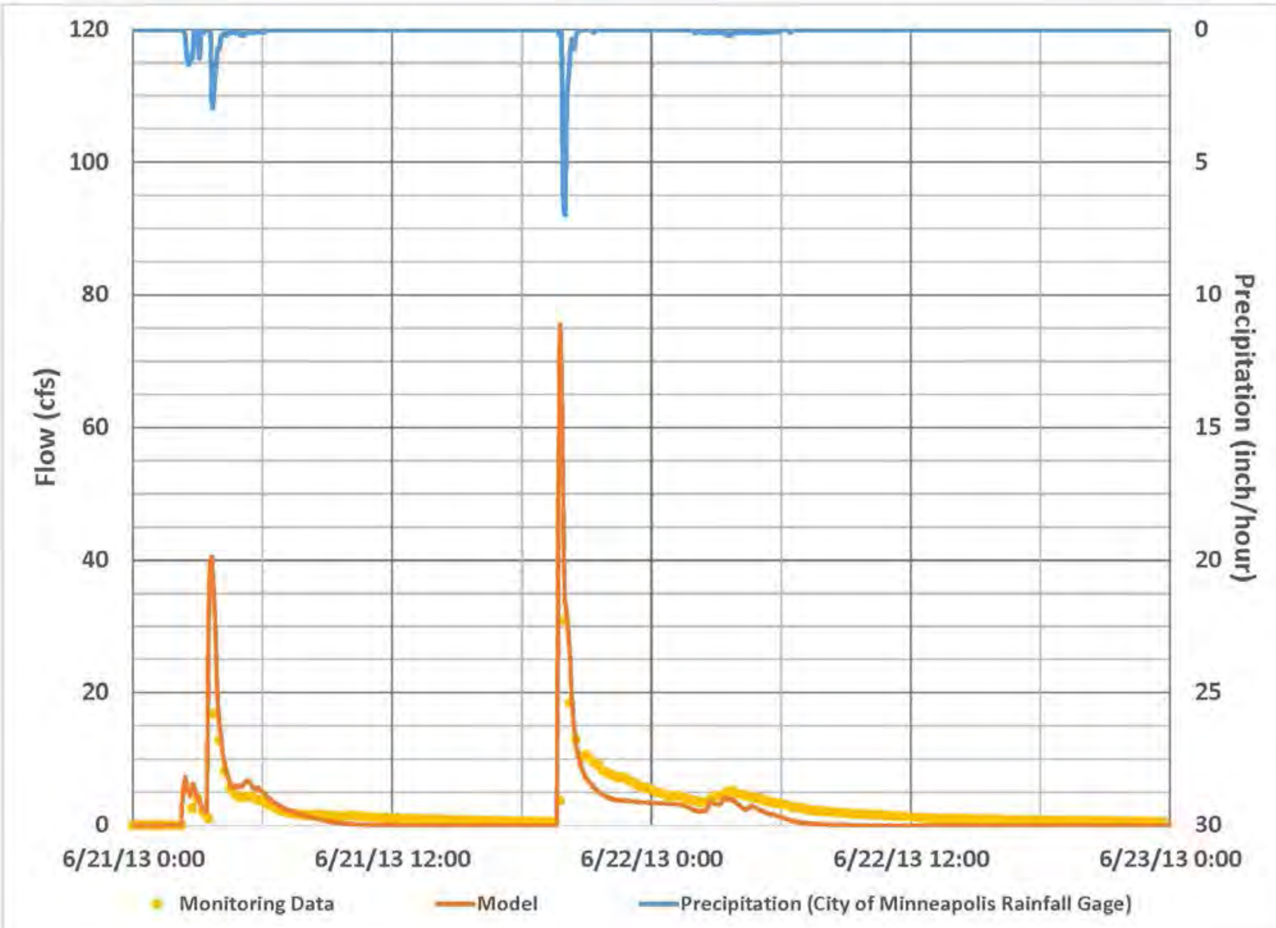


Figure 3-2 Calibration Event 1 at PC2 (Plymouth Creek)

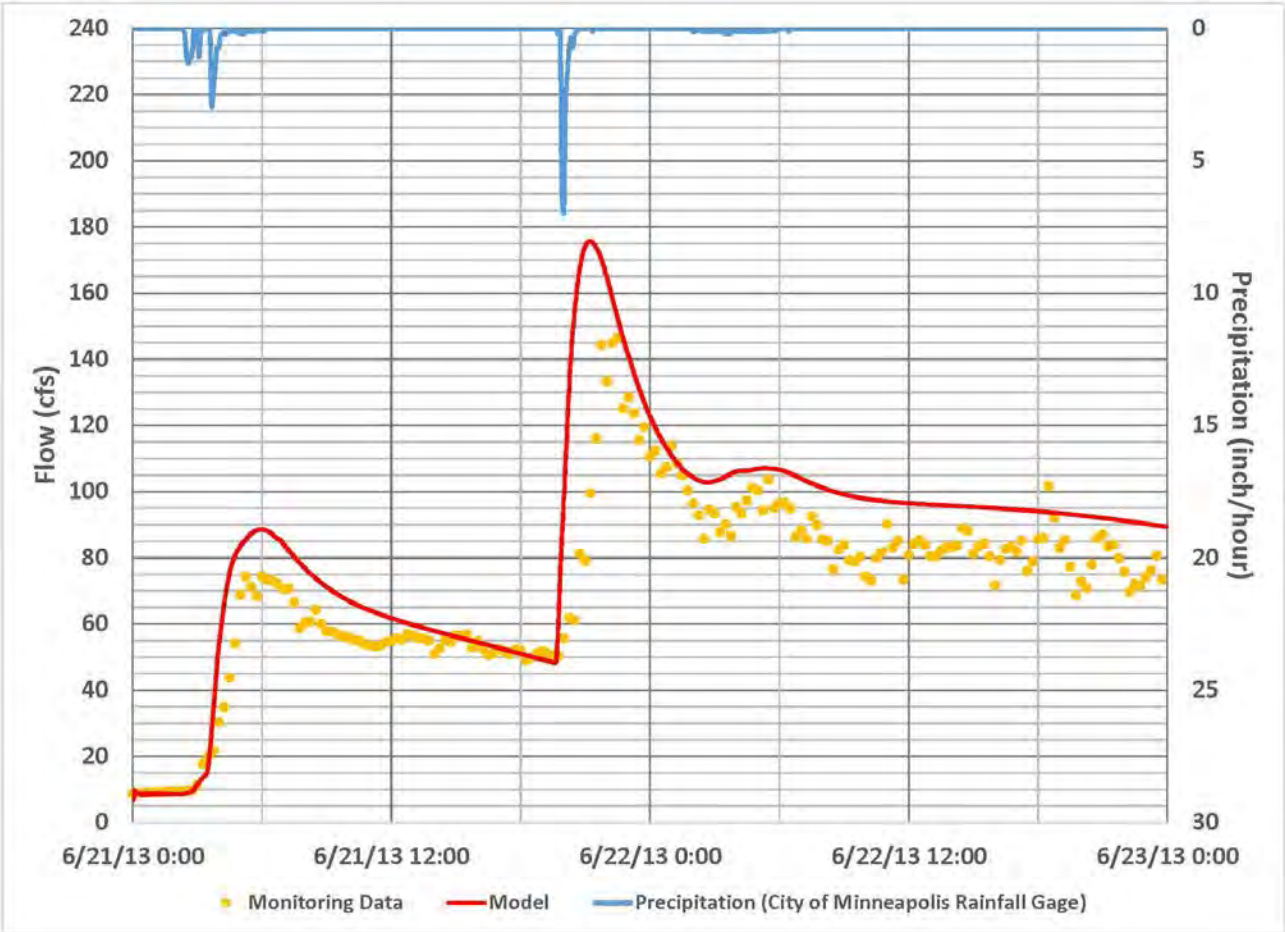


Figure 3-3 Calibration Event 2 at PL1 (Parker's Lake)

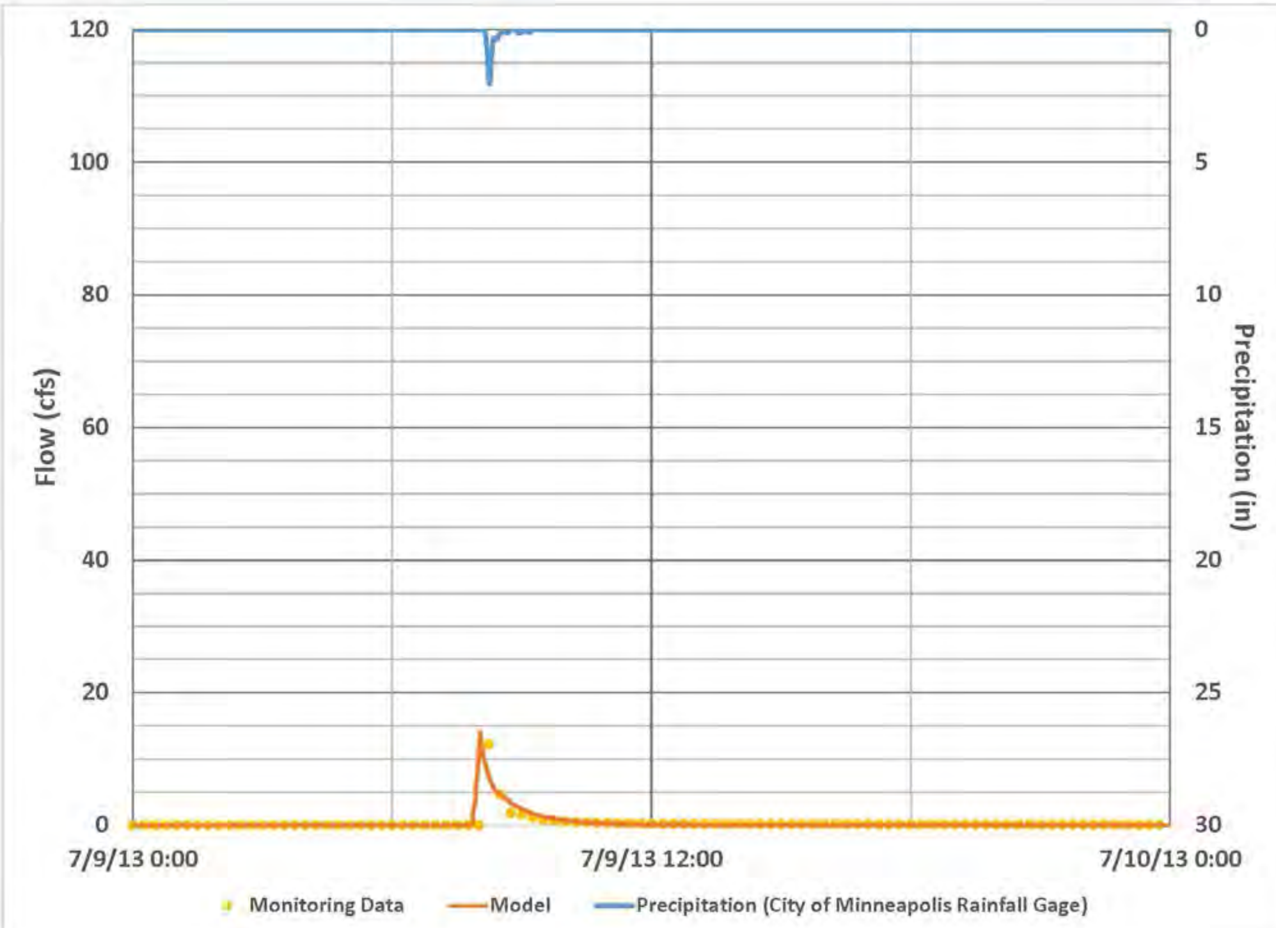
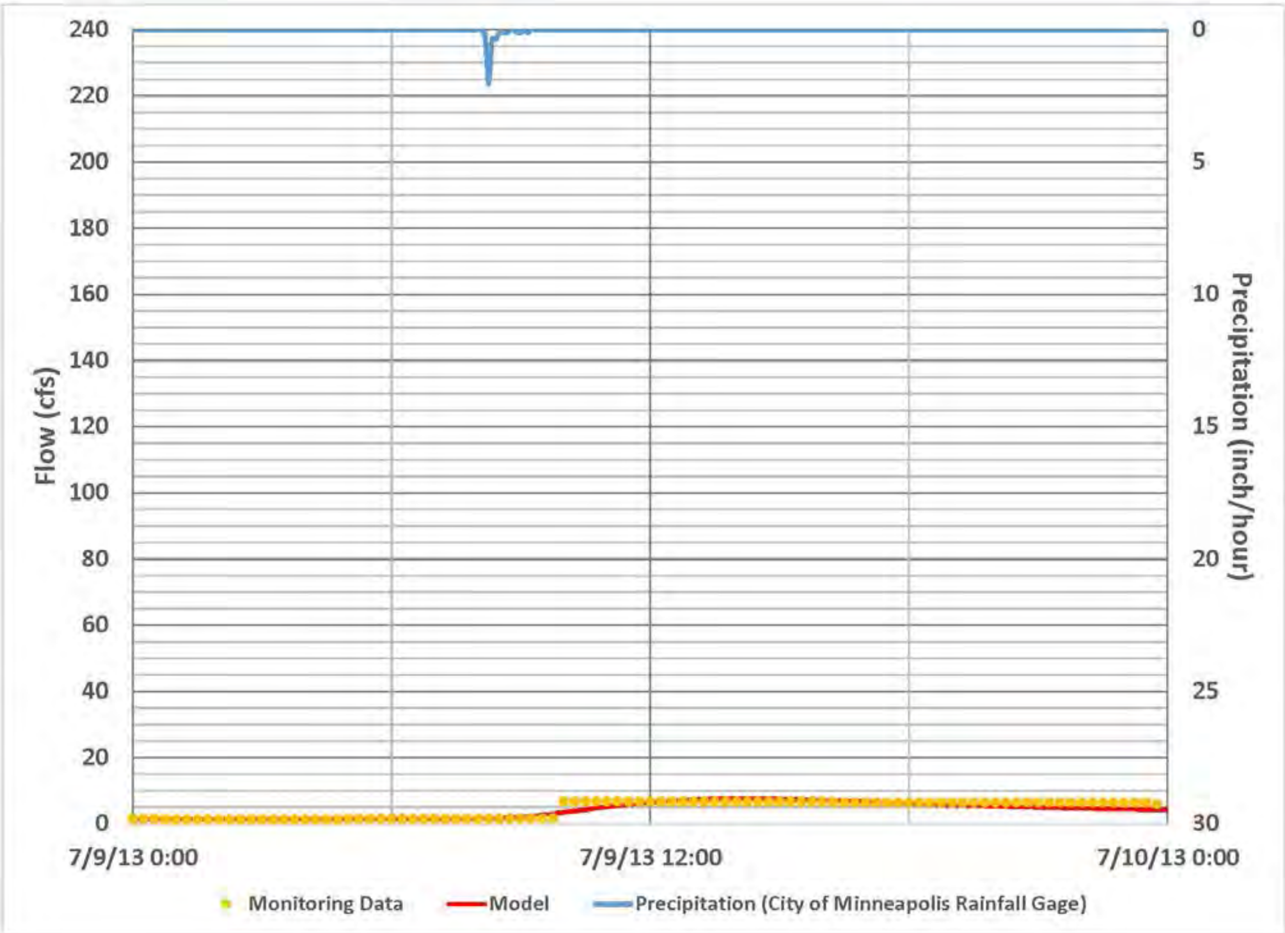


Figure 3-4 Calibration Event 2 at PC2 (Plymouth Creek)



3.1.1.2 Calibration of the Watershed Downstream of Medicine Lake (Bassett Creek Main Stem and North Branch Bassett Creek)

We utilized three monitoring stations for calibration in the portion of the BCWMC watershed downstream of Medicine Lake.

The Wisconsin Avenue control structure is located along the main stem of the creek and is part of the larger Bassett Creek Flood Control Project. The Wisconsin Avenue Control Structure is an adjustable gate structure on the upstream side of Wisconsin Avenue. The purpose of the structure, as stated in the Wisconsin Avenue Operations and Maintenance Manual, is to minimize the length of time that flooding (inundation) occurs on the Brookview Golf Course without increasing downstream flood elevations. The adjustable gate is automated except in the event of power outages or other malfunctions. The gate is operated by leaving the gate at its minimum setting (there is a 2-foot tall by 8-foot wide orifice at the channel bottom) during the initial part of a storm event, while the water level of the creek is rising. When the level of the creek has crested and begins to fall, it must first be verified that the water surface elevation at Hampshire Avenue is at or below 869.5 feet. The gate may then be opened if the water level is falling or stable for more than four hours. At all times, the flow level at Hampshire Avenue will be monitored by the system to minimize potential flooding of local residences (21).

The complex communication between monitoring equipment at Hampshire Avenue and the automated adjustments to the Wisconsin Avenue Control Structure cannot be easily simulated in XPSWMM. The calibration reviewed several modeling options for the condition at the Wisconsin Avenue control structure including a time-varying orifice and a time-weighted rectangular orifice based on the gate opening information provided by the City of Golden Valley. However, we selected a 2-foot tall by 8-foot wide box culvert of incremental length as the final assumptions for the Wisconsin Avenue control structure. Since the 2-foot by 8-foot opening is used through the peak of a given storm event, this assumption is appropriate for the evaluation of the Atlas 14 100-year event, as well as the calibration and validation events.

The monitoring station along the North Branch of Bassett Creek was installed in the upstream end of a 4-foot tall by 12-foot wide box culvert at Douglas Drive. This box culvert is immediately downstream of the Edgewood Embankment (constructed as part of the BCWMC Flood Control Project) and a section of channel that was stabilized with riprap on the channel banks. During calibration, the elevations of the major lakes within the North Branch watershed, including Northwood Lake were estimated based on interpolation between the historic BCWMC lake level data at the start of the event. This data is collected approximately every two weeks and although it provides a good estimate of the lake levels at the start of the event, it does not reflect potential fluctuations in water levels between the lake level monitoring dates.

The WOMP station is located in the main stem of the creek near Irving Avenue in the City of Minneapolis. The station is located in between the Freun Mill Dam and the inlet to the New Tunnel. During calibration, the elevations of the major lakes within the main stem watershed, including Sweeney and Twin Lakes, Westwood Lake, and Wirth Lake, were estimated based on interpolation between the historic BCWMC lake level data at the start of the event. This data is collected approximately every two weeks and although it provides a good estimate of the lake levels at the start of the event, it does not reflect potential fluctuations in water levels between the lake level monitoring dates. During the calibration process, we learned that the elevations and flows observed at the WOMP station were very sensitive to the estimated starting water levels in Sweeney Lake.

For the model downstream of Medicine Lake to the Mississippi River, the monitoring gages collect data at varying intervals. At Wisconsin Avenue, the SCADA system measures water elevation multiple times per minute. At the station on the North Branch of Bassett Creek at Douglas Drive, water level data was collected at either 10- or 15-minute intervals, depending on the event. At the WOMP station, water level data was collected at 15-minute intervals. Similar to the calibration effort upstream of Medicine Lake, the NEXRAD precipitation data used in the XPSWMM model is aggregated at approximately 5-minute intervals.

Additionally, through the calibration process, field surveys of two targeted areas within the watershed were conducted to help rectify the results of the modeling with the monitoring data, as briefly discussed below.

First, historic lake level data at Westwood Lake indicated that the observed lake levels are typically 1-2 feet higher than the expected normal water level based on the invert elevation of the outlet pipe (886.18 ft MSL NAVD88). Inspection and survey of the outlet channel from Westwood Lake to this pipe confirmed that accumulated sediment in the channel has historically controlled the Westwood Lake levels to 887.6 ft MSL NAVD88. For the calibration, validation, and Atlas 14 100-year design storm event, we assumed that the normal water level of Westwood Lake is at 887.6 ft MSL NAVD88.

Second, monitored water elevations at the start of all of the calibration and validation events at the Wisconsin Avenue control structure indicated that there is consistently 2 feet of water on the upstream side of the control structure. To maintain this depth of water at the start of the calibration and validation storm events, a significant amount of baseflow needed to be entered into the XPSWMM model. However, the amount of baseflow needed at the Wisconsin Avenue structure in the model conflicted with the flow rates observed at the downstream WOMP station, with the required baseflow at Wisconsin Avenue being higher than observed at the downstream WOMP station. Additionally, review of the annual Bassett Creek inspection photos from the past several years helped support that there is consistently approximately 2 feet of water on the upstream side of the Wisconsin Avenue control structure. A survey of the Bassett Creek Main Stem thalweg (lowest point in the channel) was completed in the channel downstream of Wisconsin Avenue, as well as downstream of Winnetka Avenue to determine the elevation of the Bassett Creek channel bottom. The invert elevation of the Wisconsin Avenue control structure is 879.0 ft MSL NAVD88; however the field survey confirmed that the thalweg of the channel downstream of Wisconsin Avenue is approximately 1.8 feet higher than the control structure invert (880.8 ft MSL NAVD88) and acts as the ultimate control of the water levels at the Wisconsin Avenue control structure. Field survey downstream of Winnetka Avenue indicated that the channel invert downstream of Winnetka Avenue is 879.2 ft MSL NAVD88.

The results for the calibration statistics for the three monitoring stations from Medicine Lake to the Mississippi River are summarized in Table 3-3 through Table 3-4. Figure 3-5 through Figure 3-10 show plots of the observed and modeled data for each of the calibration events at the monitoring stations in the portion of the watershed between Medicine Lake and the Mississippi River, including the two stations along the Bassett Creek Main Stem and the one station along the North Branch of Bassett Creek.

The smaller storm events for these stations downstream of Medicine Lake tend to have lower Nash-Sutcliffe efficiency indices than the validation and larger events. In these cases, the smaller events are typically more sensitive to the initial assumptions (e.g. starting water elevations for the ponds and wetlands in the model, baseflows, etc.) at the start of the XPSWMM model run than for the larger calibration and validation events.

For example, for the small storm calibration event (calibration event 4), there was little to no rain in the 4-5 of days prior to the start of the event, which is reflective of dry antecedent moisture conditions. It was possible that there was additional storage available in the ponds and wetlands throughout the contributing watershed (e.g. water levels slightly below their normal water levels). An analysis of flows from the contributing watershed at the Wisconsin Avenue station suggested that portions of the watershed may not have contributed significant flow during this event; however, there is no monitoring data available to justify changing the assumption that all of the ponds and wetlands were at their normal water level at the start of the event.

Both the Nash-Sutcliffe efficiency indices and the modified Nash-Sutcliffe efficiency indices (accounting for small shifts in timing) were calculated for the three monitoring stations. Although the Nash-Sutcliffe efficiency indices and the modified Nash-Sutcliffe efficiency indices do not indicate a good fit for the small calibration event at two of the three monitoring locations downstream of Medicine Lake, the percent error statistics are acceptable and review of the calibration plots indicate that the XPSWMM model results are closely matching the magnitudes and hydrograph shapes for the small event.

For the large calibration event the Nash-Sutcliffe efficiency indices and the percent error statistics indicate a good fit between the XPSWMM model data and the monitored data at all three monitoring locations downstream of Medicine Lake. The calibration plots also indicate that the XPSWMM model results are closely matching the magnitudes and hydrograph shapes for this event.

Table 3-3 Model Calibration Summary Statistics for Calibration Event 3 (Large Event)

Gage	Modeled Peak Flow (or Elevation) / Monitored Peak Flow (or Elevation) (cfs or ft MSL NAVD88)	Error in Modeled Peak Flow (or Depth[1]) vs Monitored Peak Flow (or Depth) (%)	Error in Modeled Volume vs Monitored Volume (%)	Nash-Sutcliffe Efficiency Index	Modified Nash-Sutcliffe Efficiency Index
Wisconsin Avenue (Main Stem) (Elevation)	884.2 / 884.2	0.5	N/A	0.96	0.97
Douglas Drive (North Branch) (Elevation)	866.7 / 866.3	1	N/A	0.96	0.97
WOMP (Main Stem) (Flow)	315 / 234	35	28	0.24	0.64
WOMP (Main Stem) (Elevation)	805.2 / 804.9	11	N/A	0.90	0.90

[1]Error in depth estimated based on difference between the peak elevation and the channel/bottom invert

Table 3-4 Model Calibration Summary Statistics for Calibration Event 4 (Small Event)

Gage	Modeled Peak Flow (or Elevation) / Monitored Peak Flow (or Elevation) (cfs or ft MSL NAVD88)	Error in Modeled Peak Flow (or Depth[1]) vs Monitored Peak Flow (or Depth) (%)	Error in Modeled Volume vs Monitored Volume (%)	Nash-Sutcliffe Efficiency Index	Modified Nash-Sutcliffe Efficiency Index
Wisconsin Avenue (Main Stem) (Elevation)	882.4 / 882.1	1	N/A	-5.27	-4.73
Douglas Drive (North Branch) (Elevation)	864.5 / 864.6	6	N/A	-1.17	-0.84
WOMP (Main Stem) (Flow)	65 / 57	14	6	0.65	0.65
WOMP (Main Stem) (Elevation)	803.8 / 803.7	7	N/A	0.04	0.04

[1]Error in depth estimated based on difference between the peak elevation and the channel/bottom invert

Figure 3-5 Calibration Event 3 at Wisconsin Avenue (Main Stem)

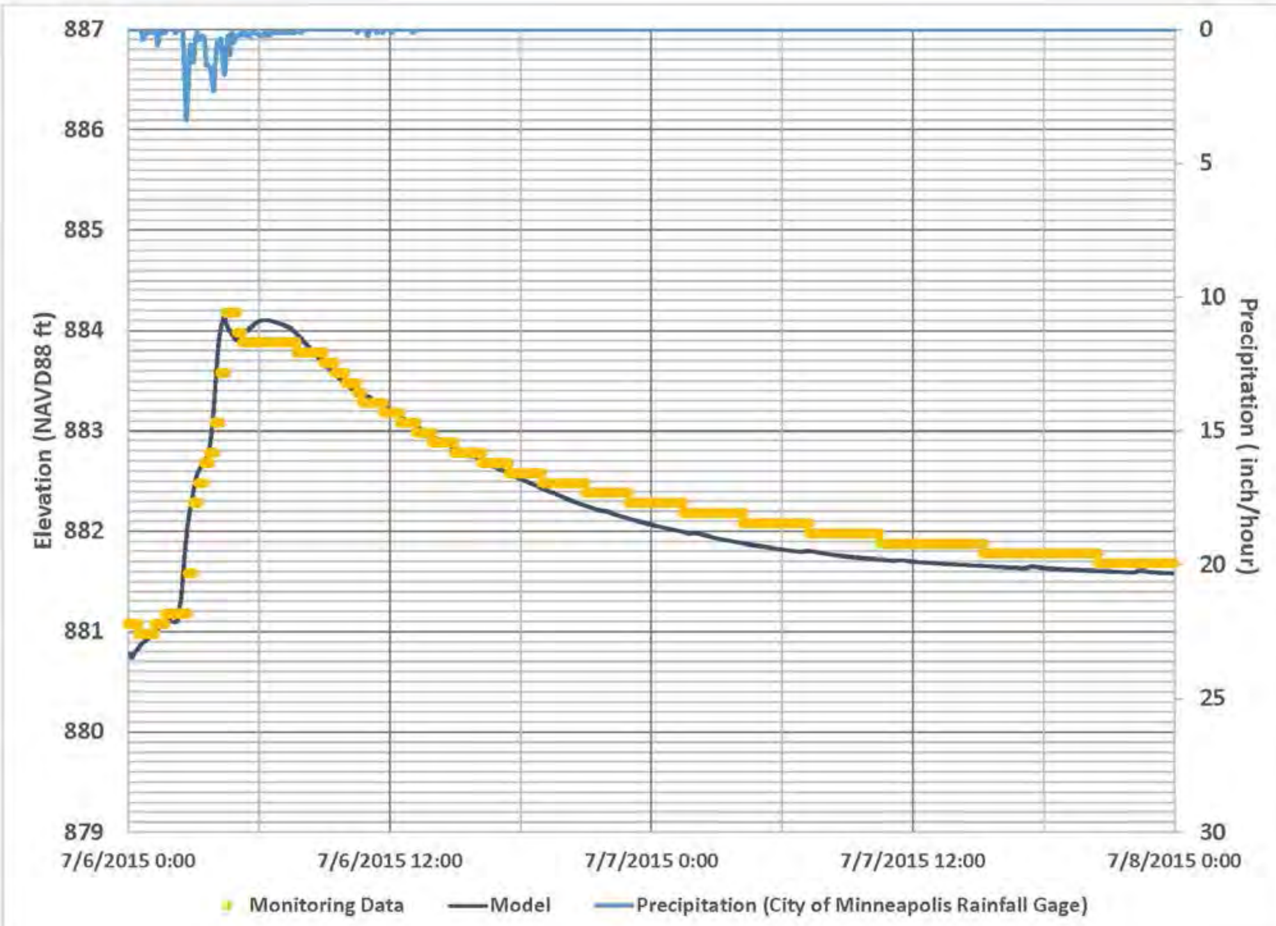


Figure 3-6 Calibration Event 3 at Douglas Drive (North Branch)

Figure 3-7 Calibration Event 3 at WOMP Station (Main Stem)

Figure 3-8 Calibration Event 4 at Wisconsin Avenue (Main Stem)

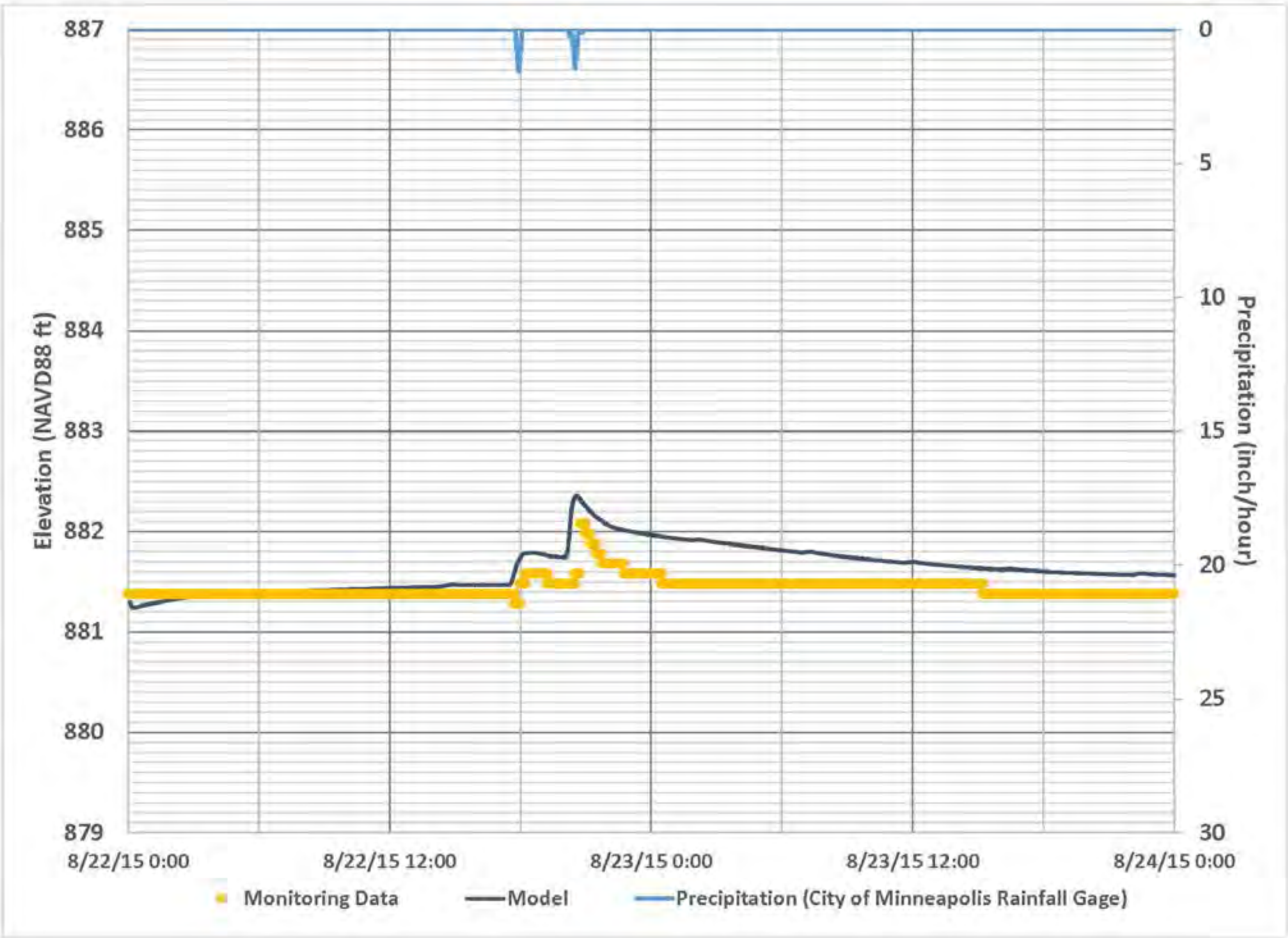


Figure 3-9 Calibration Event 4 at Douglas Drive (North Branch)

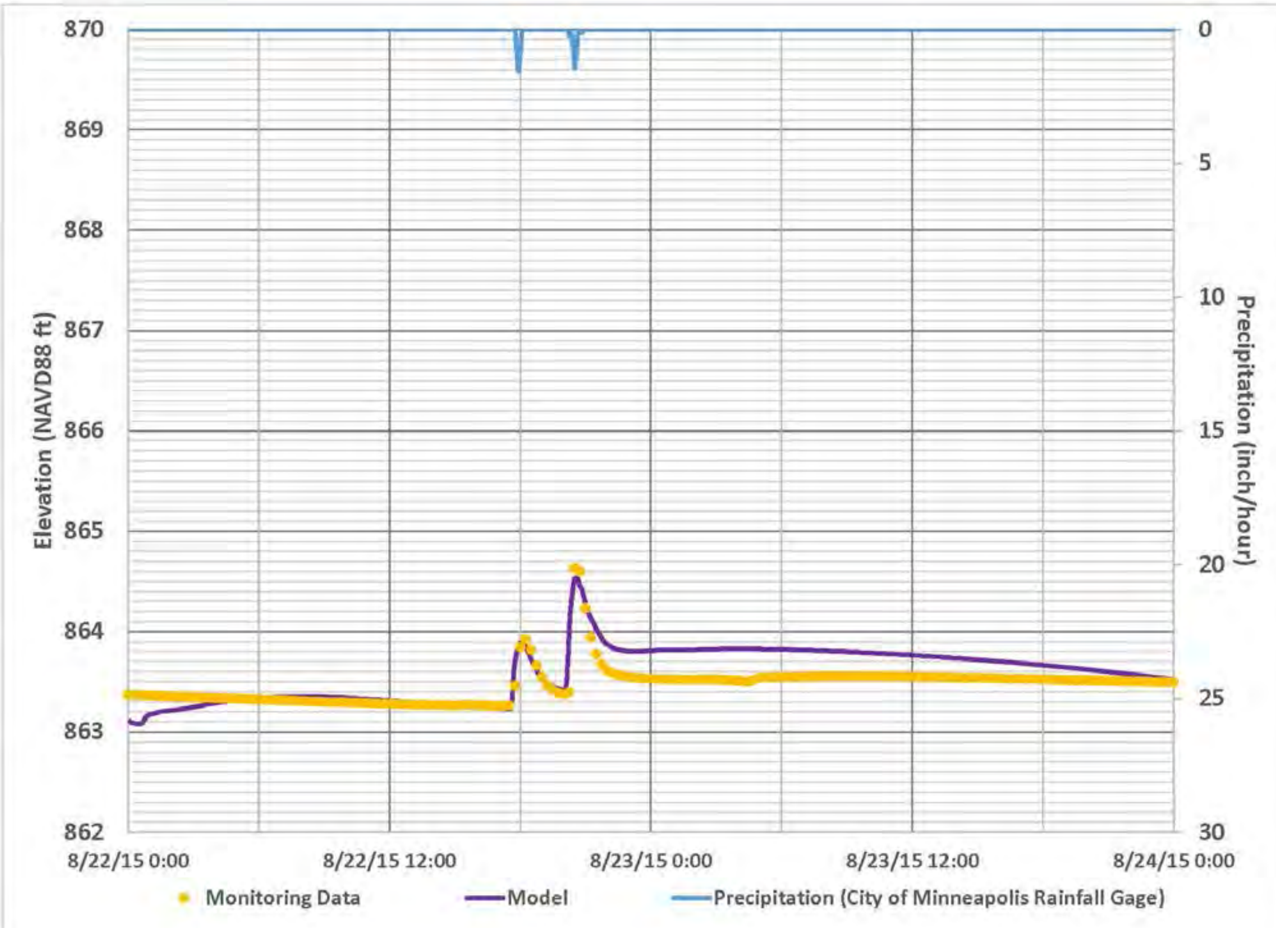
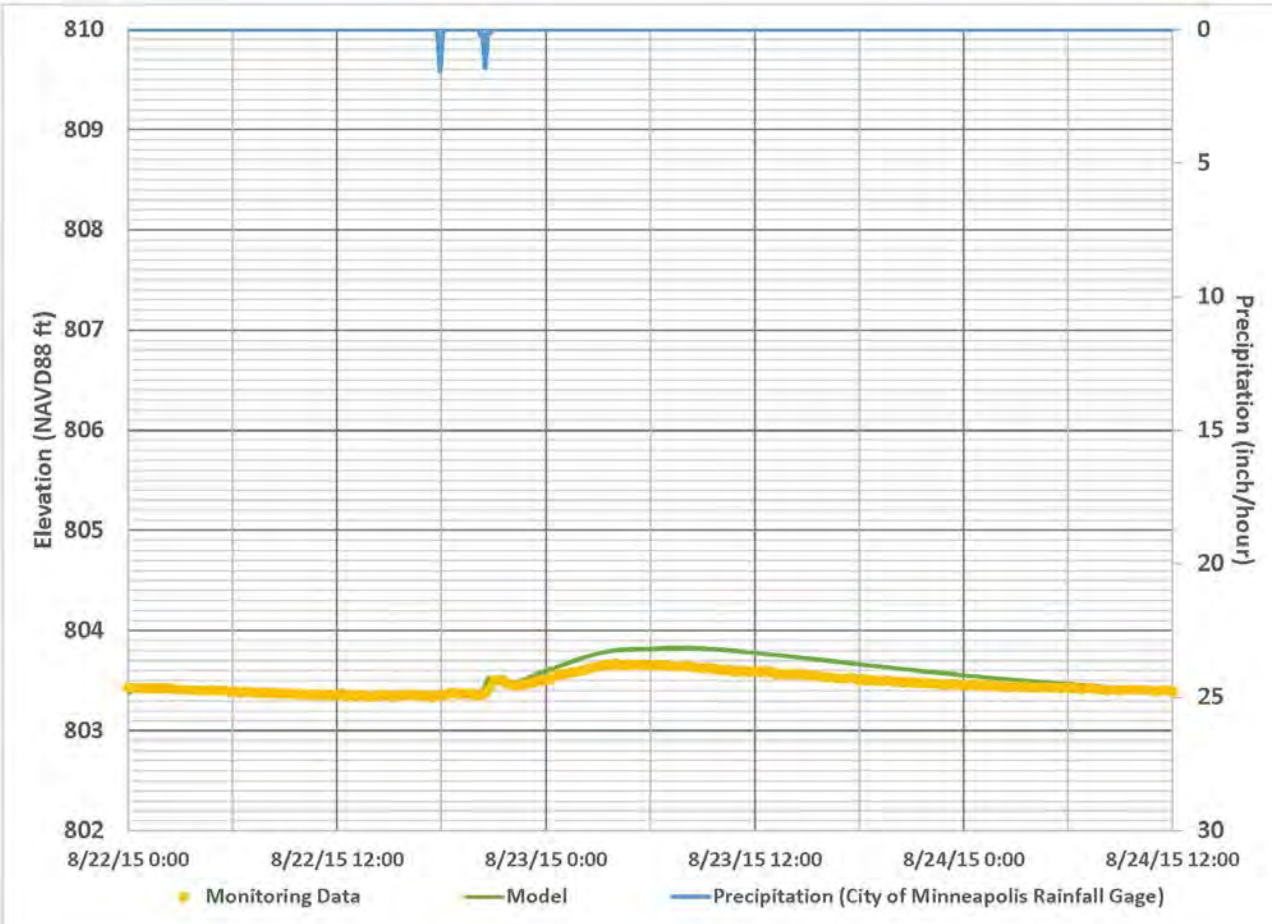


Figure 3-10 Calibration Event 4 at WOMP Station (Main Stem)



3.1.2 Validation Event Results

Following BCWMC Phase 2 XPSWMM model calibration, the model was validated using an intermediate storm event. The XPSWMM model validation verifies that the calibrated model can replicate a flood event of a different magnitude and timing than the original calibration events.

3.1.2.1 Validation of the Watershed Upstream of Medicine Lake

Table 3-5 summarizes the statistics for the validation events for the monitoring stations upstream of Medicine Lake. Figure 3-11 and Figure 3-12 show plots of the observed and modeled data for each validation event at the monitoring stations in the portion of the watershed upstream of Medicine Lake including the the Parkers Lake station and the station on Plymouth Creek. For the validation event, the Nash-Sutcliffe efficiency indices and the percent error statistics indicate a good fit between the XPSWMM model data and the monitored data on Plymouth Creek. The validation plots also indicate that the XPSWMM model results are closely matching the magnitudes and hydrograph shapes for this event.

Table 3-5 Model Validation Summary Statistics for Validation Event 1

Gage	Modeled Peak Flow / Monitored Peak Flow (cfs)	Error in Modeled Peak Flow vs Monitored Peak Flow (%)	Error in Modeled Volume vs Monitored Volume (%)	Nash-Sutcliffe Efficiency Index	Modified Nash-Sutcliffe Efficiency Index
PL1 (Parkers Lake)	49 / 13	278	58	-4.88	0.2
PC2 (Plymouth Creek)	70 / 71	1	0	0.8	0.88

Figure 3-11 Validation Event 1 at Parkers Lake 1 (PL1)

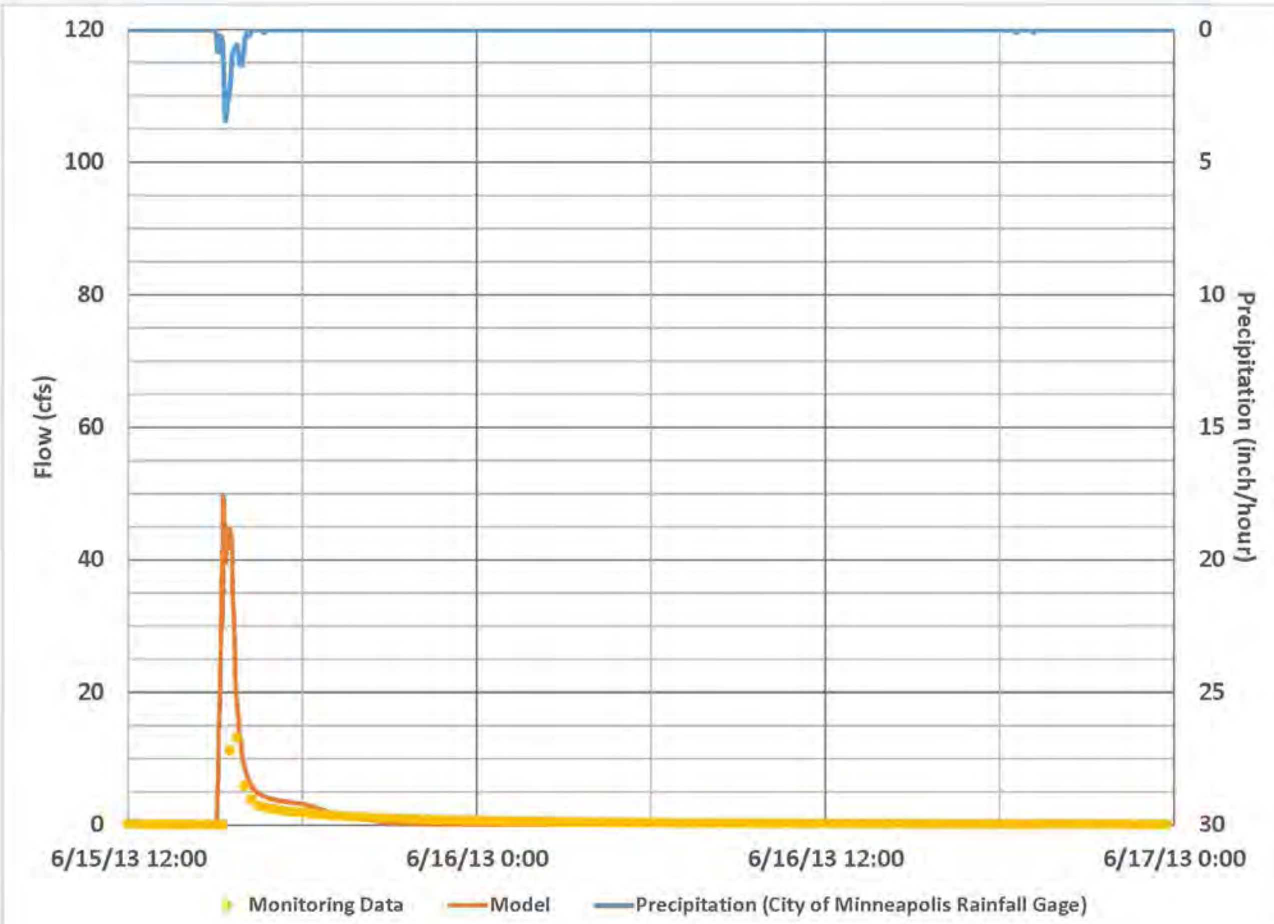
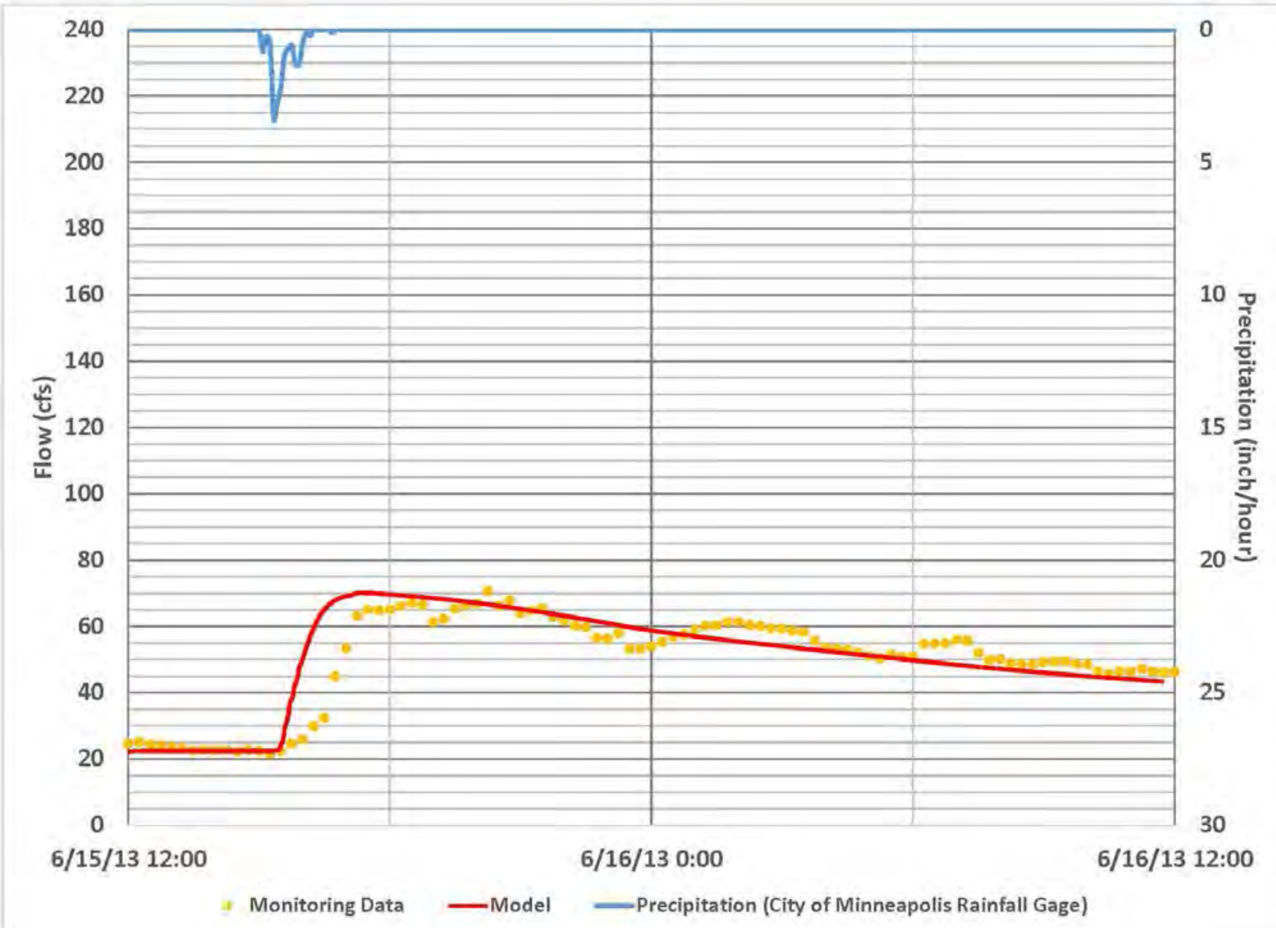


Figure 3-12 Validation Event 1 at Plymouth Creek 2 (PC2)



3.1.2.2 Validation of the Watershed Downstream of Medicine Lake (Bassett Creek Main stem and North Branch Bassett Creek)

Table 3-6 summarizes the statistics for the validation events for the monitoring stations downstream of Medicine Lake to the Mississippi River. Figure 3-13 through Figure 3-15 show plots of the observed and modeled data for each validation event at the monitoring stations in the portion of the watershed downstream of Medicine Lake to the Mississippi River, including the Wisconsin Avenue control structure, the Douglas Drive monitoring station, and the WOMP station. For the validation event, the Nash-Sutcliffe efficiency indices and the percent error statistics indicate a good fit between the XPSWMM model data and the monitored data. The validation plots also indicate that the XPSWMM model results are closely matching the magnitudes and hydrograph shapes for this event at all locations.

Table 3-6 Model Validation Summary Statistics for Validation Event 2

Gage	Modeled Peak Flow (or Elevation) / Monitored Peak Flow (or Elevation) (cfs or ft MSL NAVD88)	Error in Modeled Peak Flow (or Depth[1]) vs Monitored Peak Flow (or Depth) (%)	Error in Modeled Volume vs Monitored Volume (%)	Nash-Sutcliffe Efficiency Index	Modified Nash-Sutcliffe Efficiency Index
Wisconsin Avenue (Main Stem) (Elevation)	883.9 / 884.2	5	N/A	0.76	0.81
Douglas Drive (North Branch) (Elevation)	867.7 /866.9	4	N/A	0.87	0.92
WOMP (Main Stem) (Flow)	209 / 157	33	31	0.18	0.2
WOMP (Main Stem) (Elevation)	804.6 / 804.4	7	N/A	0.80	0.80

[1]Error in depth estimated based on difference between the peak elevation and the channel/bottom invert

Figure 3-13 Validation Event 2 at Wisconsin Avenue (Main Stem)

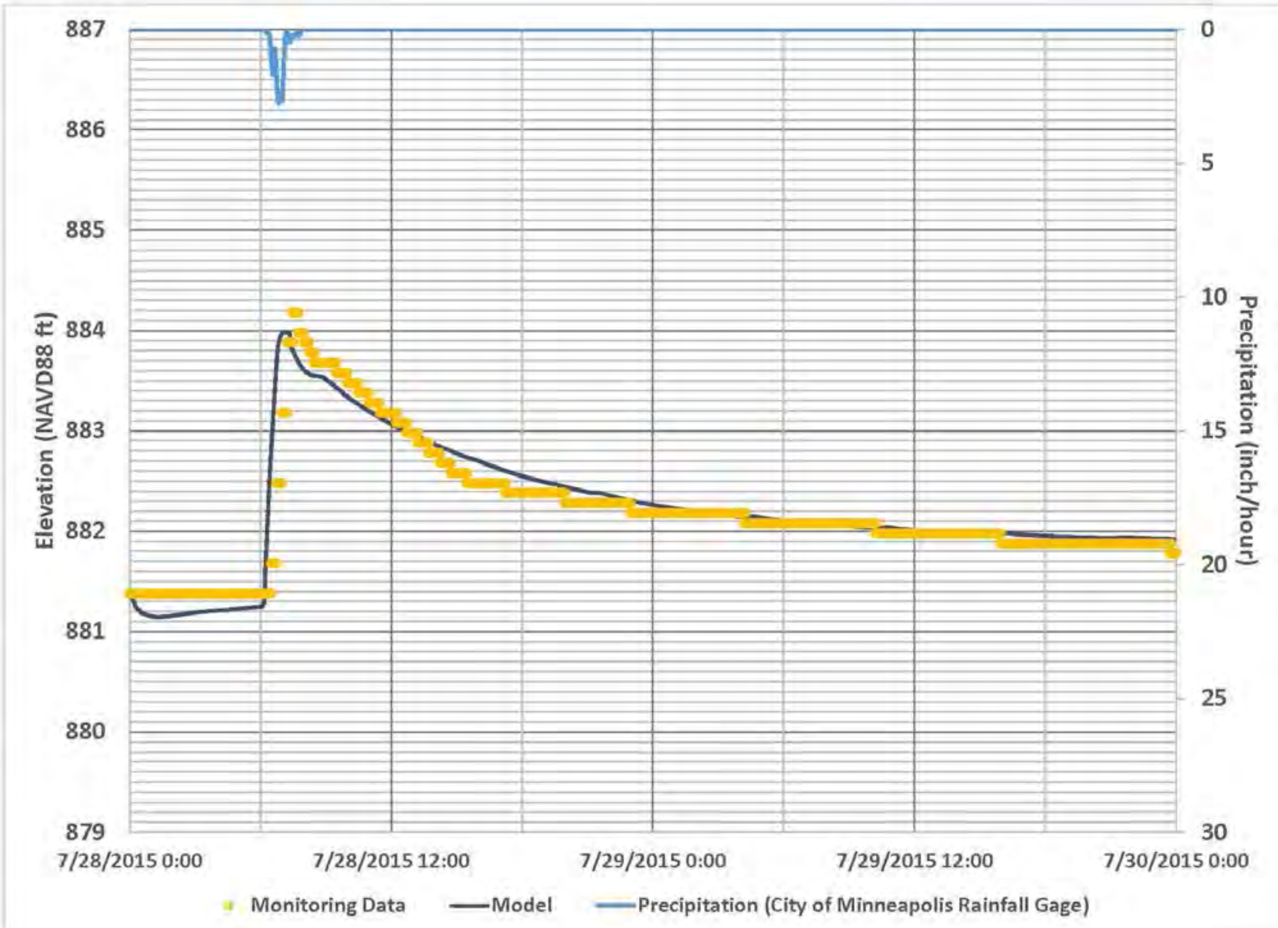


Figure 3-14 Validation Event 2 at Douglas Drive (North Branch)

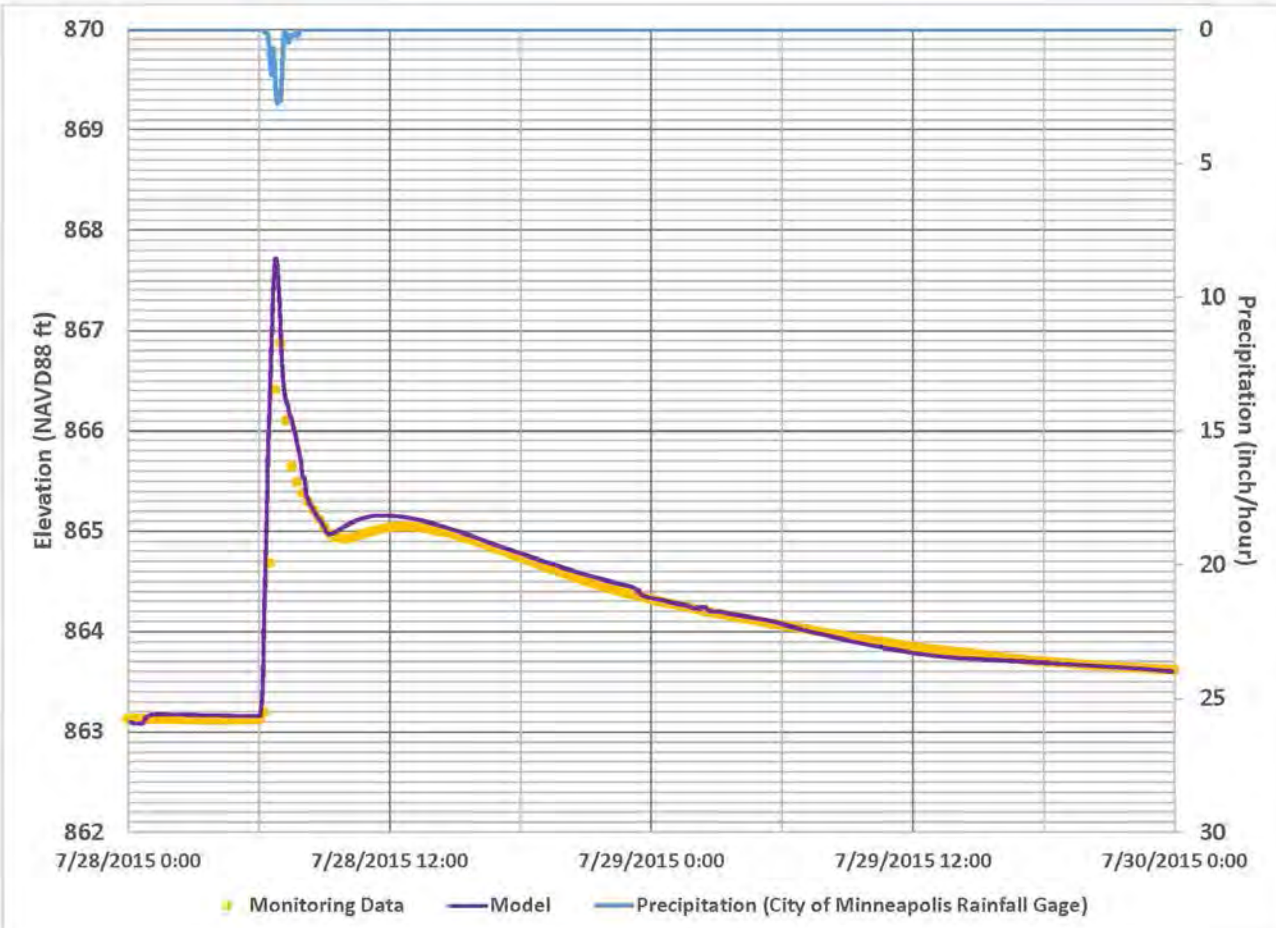
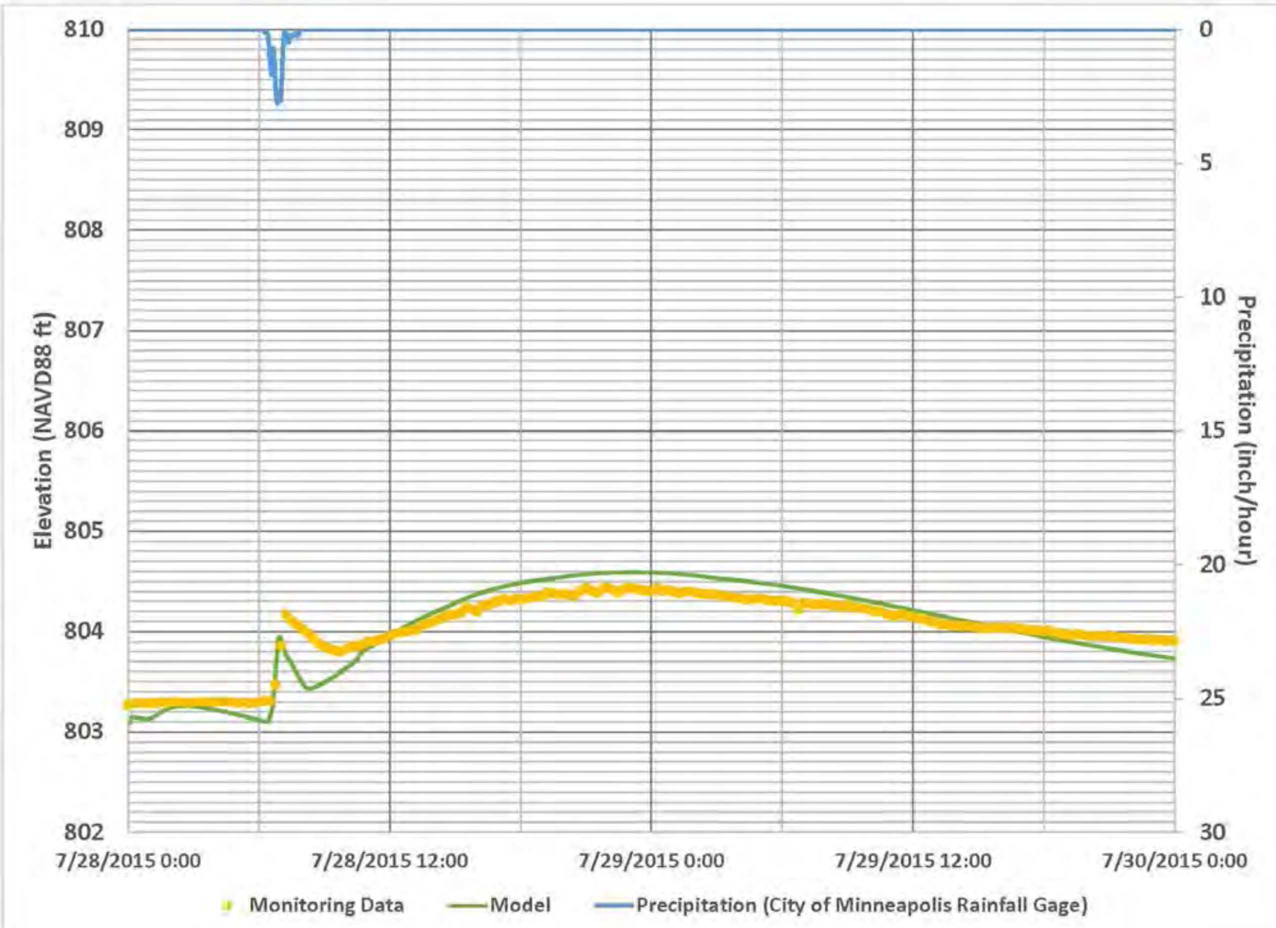


Figure 3-15 Validation Event 2 at WOMP Station (Main Stem)



3.2 Evaluation of the Atlas 14 100-Year (1% Chance) Event

The rainfall frequency estimates by the National Oceanic and Atmospheric Administration (NOAA) 2013 publication titled *Atlas 14 Precipitation Frequency Atlas of the United* States, Volume 8 (Atlas 14), includes precipitation frequency estimates for 11 Midwestern states, including Minnesota. Atlas 14 replaces the U.S. Weather Bureau's *Technical Paper No. 40* (TP40), published in 1961. The Atlas 14 100-year 24-hour depth is 7.42 inches for the Bassett Creek watershed, which represents a 25% increase over the TP-40 100-year 24-hour depth of 6.0 inches.

The Atlas 14 100-year recurrence interval storm event was modeled to determine the one percent (1%) chance flood elevation for each subwatershed. The one percent chance flood is a rainfall or runoff event that has a one percent probability of being equaled or exceeded in any given year. This flood is the result of the critical duration one percent chance storm falling on the watershed. This is also commonly called the "100-year" event or flood. The calibrated XPSWMM model was used to evaluate the 100-year, 24-hour duration rainfall event using the MSE3 storm distribution. The Natural Resources Conservation Service (NRCS) developed temporal storm distributions for Atlas 14 rainfall data across the United States. The MSE 3 temporal storm distribution developed by the NRCS covers the majority of the state of Minnesota, and many state agencies have adopted the MSE 3 distribution as the standard for all of Minnesota. The MSE 3 rainfall distribution associated with Atlas 14 rainfall replaces the SCS Type II rainfall distribution for TP40 rainfall data.

The final calibrated BCWMC Phase 2 XP-SWMM model was used to evaluate the Atlas 14 100-year (1% chance) design storm event. When evaluating the 1% chance storm event, the starting elevations of all water bodies and elevations along the creek were placed at their control elevations/normal water levels.

3.2.1 Atlas 14 100-Year (1% Chance) Event Results and Discussion

3.2.1.1 BCWMC TAC Review of the XP-SWMM Phase 2 Modeling

The preliminary results of the BCWMC XP-SWMM Phase 2 modeling were presented to the BCWMC Commissioners in January 2017 followed by a presentation to the BCWMC TAC in February 2017. Follow-up information was provided to each of the member cities to more closely review the flood elevations, areas with more significant change in flood elevations, and areas with potentially impacted structures. Individual meetings were held in March 2017 with member city (as requested) to review the model results and discuss specific questions related to the modeling/model results. Meetings were conducted with the Cities of Plymouth, Minnetonka, Medicine Lake, Golden Valley, Crystal, and New Hope. Meetings were not requested by the Cities of Robbinsdale, St. Louis Park, or Minneapolis.

The meetings with the member cities resulted in a handful of minor changes to the BCWMC Phase 2 XP-SWMM model. The revised Phase 2 XP-SWMM model was rerun for the Atlas 14 100-year (1% chance), 24-hour design storm event. The plots of the original 100-year hydrographs (from the calibrated January 2017 model) were compared with the updated 100-year hydrographs (from the revised April 2017 model) at each of the four calibration locations. The hydrographs for the design storm event were very similar between the January and April 2017 models suggesting that the modifications to the model would not impact the model calibration results.

The following list is a summary of the minor changes to the BCWMC Phase 2 XP-SWMM model based on feedback from member cities:

- Verify stop logs are modeled in-place at Central Park Pond (Link L-PCE-134) (Plymouth)
- Revise overflow for subwatershed MSL-032 (Minnetonka)
- Update inlet capacity at Jersey and 36th to reflect 16 catch basins (Crystal)
- Incorporate small development at Georgia Avenue north of 32nd (Crystal)
- Revise subwatershed (BPP-019) south of Jersey and 36th (Crystal)
- 10th Avenue Culvert Crossing: Updated to reflect recent survey data and existing field conditions (versus conditions shown in construction plans) (Golden Valley)
- Revise Highway 55 structure elevations based on survey data provided by the Blue Line Project Office (Golden Valley)
- Revise arch pipe dimensions for those modeled in Golden Valley to reflect revised data provided by the City (Golden Valley)
- Revise Northwood Lake outlet weir/structure based on recent survey data collected by City of New Hope (New Hope)

3.2.1.2 Final 100-Year (1% Chance) Event Results

Figure 3-16 through Figure 3-19 shows the expected extents of inundation based on the peak flood elevations from the final BCWMC Phase 2 XPSWMM model for the Atlas 14 100-year event, as applied to the 2011 MnDNR LiDAR elevation data. The inundation mapping was developed using a level pool mapping methodology, based on the modeled peak flood elevation for each subwatershed and the MnDNR LiDAR elevation data. This method is more accurate for lakes, wetlands, and ponds, whereas the inundation extents shown along Plymouth Creek, North Branch Bassett Creek, and Bassett Creek Main Stem are approximate. To more accurately determine the flood inundation along the creeks, the elevations summarized in Table 3-7 should be used. Table 3-7 summarizes the 100-year flood elevations and peak discharge rates as summarized in the current BCWMC *Watershed Management Plan* and the corresponding Atlas 14 100-year flood elevations and peak discharge rates estimated by the BCWMC Phase 2 XPSWMM model. Additionally, the inundation mapping is color-coded, in blue to reflect the inundation areas located along the BCWMC trunk system (see Figure 2-15 in the 2015-2025 BCWMC Watershed Management Plan) versus inundation areas identified in yellow in the upstream contributing watershed (within the member Cities' jurisdiction).

In general, it would be expected that evaluating the Atlas 14 design storm event across the Bassett Creek watershed would result in increases of the peak flood elevations and discharge rates throughout the watershed due to the larger magnitude of the design storm precipitation depth. However, the Phase 2 XPSWMM model also incorporated significantly more detail, including the refined subwatersheds, the storage available in all of the ponds and wetlands throughout the watershed, and the incorporation of storm sewer systems connecting the ponds and wetlands, compared to the previous modeling efforts for the watershed. As a result, the estimated peak flood elevations and discharge rates for the Atlas 14 design storm event are higher than the values included in the BCWMC Watershed Management Plan in some locations, while in other locations in the watershed, a slight decrease in the peak flood elevations are observed.

The following are some general observations regarding the changes in the 100-year flood elevations and flows from the BCWMC Watershed Management Plan to the Phase 2 XPSWMM modeling (organized by location in the watershed):

Bassett Creek Main Stem

- Flood elevations upstream of the New Tunnel inlet increased significantly (approximately 3.6 feet), as well as along the channel to the Cedar Lake Road Bridge (0.4-2.6 feet increase).
- Flood elevations generally increased upstream of the Fruen Mill Dam to Noble Lane, with flood elevations between Golden Valley Road and Noble Lane increasing significantly (2.2 to 4.1 feet)
- Flood elevations near Highway 100 and the confluence with the North Branch of Bassett Creek rose significantly (1.4 to 2.6 feet).
- Flood elevations between Duluth Street and the Golden Valley Country Club increased moderately (between 0.4 and 1.5 feet).
- Flood elevations between the Golden Valley Country Club control structure and Wisconsin Avenue increased significantly (1.1 to 2.2 feet). Flood elevations near Hampshire Avenue increased between 0.7 and 0.8 feet.
- Flood elevations upstream of Wisconsin Avenue, including the Brookview Golf Course, to Medicine Lake are similar to, but slightly lower than, the Bassett Plan water surface elevations (-0.3 to -1.2 feet).

North Branch of Bassett Creek

- Flood elevations between Highway 100 through Bassett Creek Park Pond Park increased significantly (1.4 to 2.0 feet).
- Flood elevations between Brunswick Avenue and 32nd Avenue decreased (-1.5-2.2 feet).
- Flood elevations upstream of the Edgewood Embankment and especially upstream of Winnetka Pond East increased significantly (2.0 to 3.3 feet)
- The flood elevation of Northwood Lake increased by 1.6 feet.

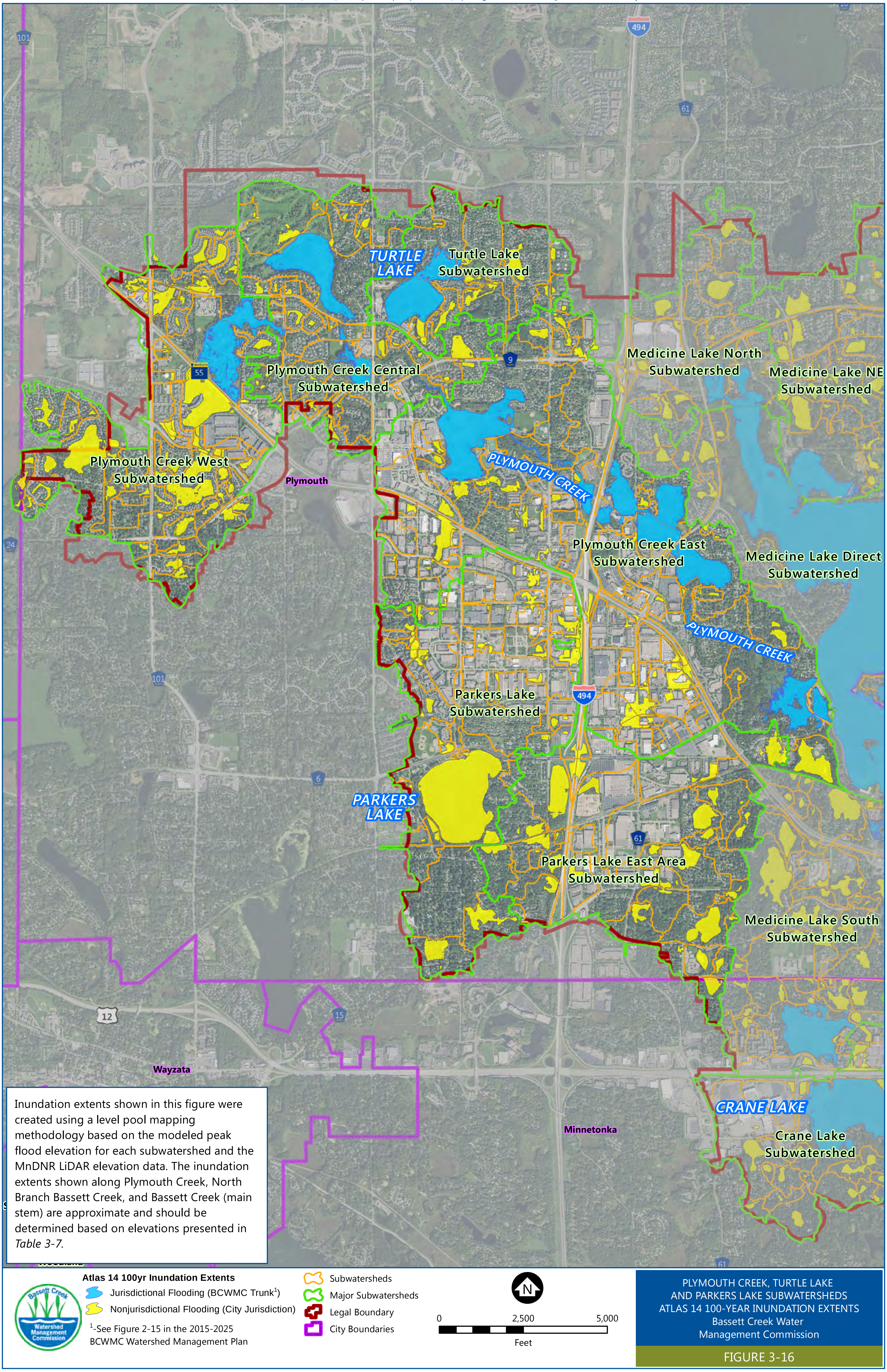
Sweeney Branch

- Flood elevations between the upstream side of Highway 100 to the Ravine Storage Area increased substantially (0.4 to 5.6 feet).
- The flood elevation of Sweeney and Twin Lakes increased by 0.2 feet.

Plymouth Creek/Medicine Lake

- Flood elevations in the Dunkirk flood storage area increased substantially (0.0 to 5.3 feet).
- Flood elevations upstream of County Road 9 (Rockford Road) decreased substantially (-4.2 feet).
- The flood elevation of Medicine Lake decreased slightly (-0.2 feet).
- The Crane Lake flood elevation decreased by 0.5 feet.

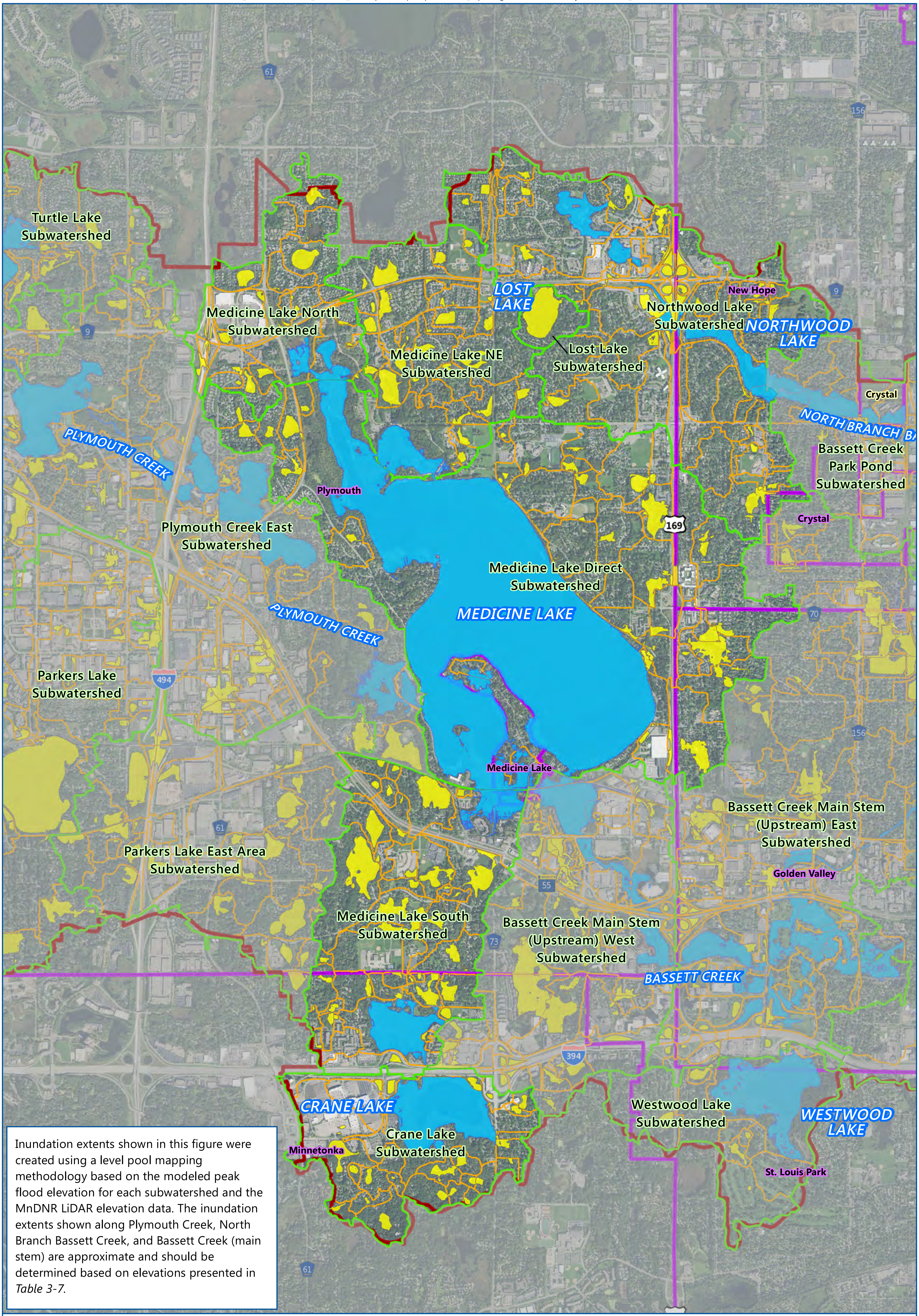
Based on a review of the inundation mapping, the LiDAR data, and aerial photos, the new flood elevations and inundation mapping indicate several structures are potentially at-risk of flooding during the Atlas 14 100-year design storm event. Some of the potentially at-risk structures are located along the Bassett Creek Main Stem; however, other potentially at-risk properties are located in upstream portions of the watershed (within the Cities' jurisdiction). Topographic surveys of these structures would be needed to confirm if these structures are at-risk of flooding.



Inundation extents shown in this figure were created using a level pool mapping methodology based on the modeled peak flood elevation for each subwatershed and the MnDNR LiDAR elevation data. The inundation extents shown along Plymouth Creek, North Branch Bassett Creek, and Bassett Creek (main stem) are approximate and should be determined based on elevations presented in *Table 3-7*.

PLYMOUTH CREEK, TURTLE LAKE AND PARKERS LAKE SUBWATERSHEDS
ATLAS 14 100-YEAR INUNDATION EXTENTS
Bassett Creek Water Management Commission

FIGURE 3-16



Inundation extents shown in this figure were created using a level pool mapping methodology based on the modeled peak flood elevation for each subwatershed and the MnDNR LiDAR elevation data. The inundation extents shown along Plymouth Creek, North Branch Bassett Creek, and Bassett Creek (main stem) are approximate and should be determined based on elevations presented in *Table 3-7*.

Atlas 14 100yr Inundation Extents

- Jurisdictional Flooding (BCWMC Trunk[1])
- Nonjurisdictional Flooding (City Jurisdiction)

[1]-See Figure 2-15 in the 2015-2025 BCWMC Watershed Management Plan

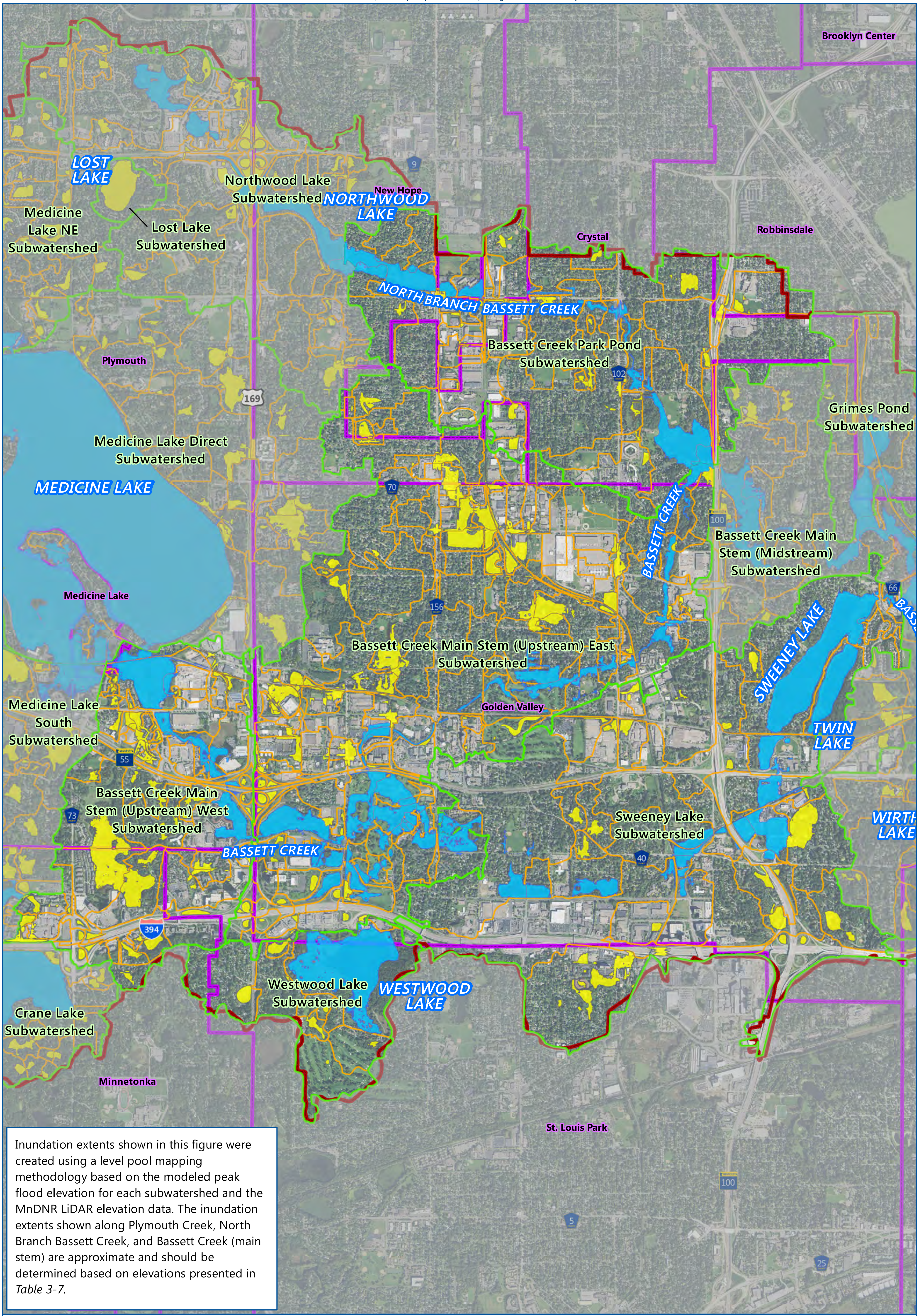
- Subwatersheds
- Major Subwatersheds
- Legal Boundary
- City Boundaries

N

0 2,500
Feet

LOST LAKE, NORTHWOOD LAKE, CRANE LAKE, AND MEDICINE LAKE SUBWATERSHEDS
ATLAS 14 100-YEAR INUNDATION EXTENTS
Bassett Creek Water Management Commission

FIGURE 3-17



Inundation extents shown in this figure were created using a level pool mapping methodology based on the modeled peak flood elevation for each subwatershed and the MnDNR LiDAR elevation data. The inundation extents shown along Plymouth Creek, North Branch Bassett Creek, and Bassett Creek (main stem) are approximate and should be determined based on elevations presented in *Table 3-7*.

Atlas 14 100yr Inundation Extents

- Jurisdictional Flooding (BCWMC Trunk[1])
- Nonjurisdictional Flooding (City Jurisdiction)

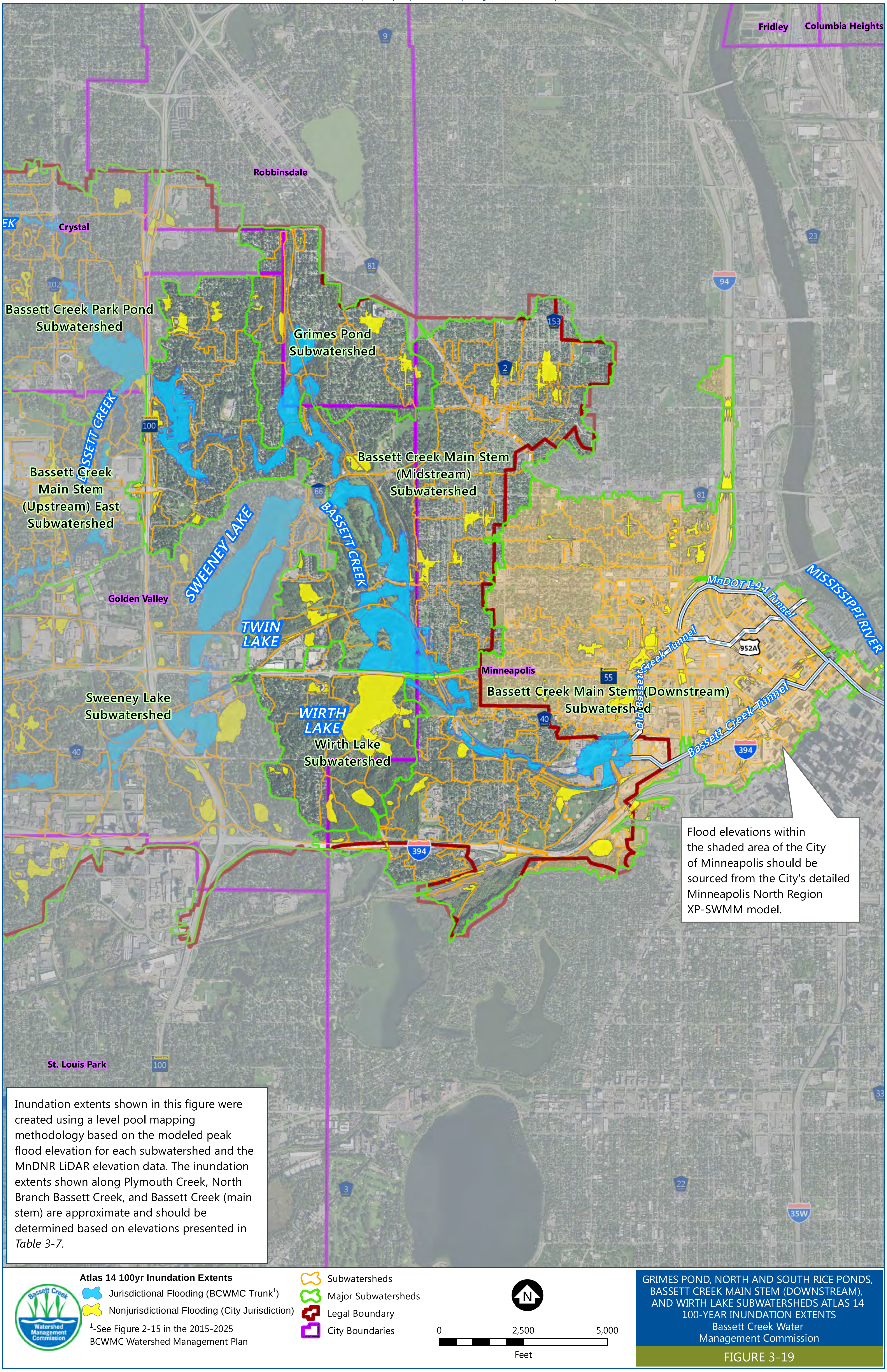
[1]-See Figure 2-15 in the 2015-2025 BCWMC Watershed Management Plan

- Subwatersheds
- Major Subwatersheds
- Legal Boundary
- City Boundaries

0 2,500 5,000
Feet

BASSETT CREEK MAIN STEM (UPSTREAM), WESTWOOD LAKE, BASSETT CREEK PARK POND, AND SWEENEY LAKE ATLAS 14 100-YEAR INUNDATION EXTENTS
Bassett Creek Water Management Commission

FIGURE 3-18



GRIMES POND, NORTH AND SOUTH RICE PONDS, BASSETT CREEK MAIN STEM (DOWNSTREAM), AND WIRTH LAKE SUBWATERSHEDS ATLAS 14 100-YEAR INUNDATION EXTENTS
Bassett Creek Water Management Commission

FIGURE 3-19

Table 3-7 Comparison of BCWMC Watershed Management Plan to the Phase 2 XPSWMM Model - Flood Elevations and Peak Discharges

Location	Creek Distance above the Mississippi River (feet)	Normal Water Level (NAVD88)	BCWMC Watershed Management Plan[1] 100-yr Flood Elevation (NAVD88 feet)	BCWMC Watershed Management Plan[1] 100-yr Flow Rate (cfs)	BCWMC Phase 2 XP-SWMM Model - Atlas 14 (4/19/2017) 100-yr Atlas 14 MSE3 Flood Elevation (NAVD88 feet)	BCWMC Phase 2 XP-SWMM Model - Atlas 14 (4/19/2017) 100-yr Atlas 14 MSE3 Flow Rate (cfs)	Change in Flood Elevations and Flow Rates XPSWMM - Plan Flood Elevation (feet)	Change in Flood Elevations and Flow Rates XPSWMM - Plan Flow Rate (cfs)
BASSETT CREEK MAIN STEM								
Tunnel Inlet	8,000		807.3	1,220	810.9	1,380	3.6	160
Irving Avenue Bridge (DS)	9,800		808.6	1,135	811.2	1,380	2.6	245
Irving Avenue Bridge (US)	---		809.3	1,135	811.3	1,380	2.0	245
Cedar Lake Rd (Bridge)	10,900		812.9	945	813.3	1,380	0.4	435
MN&S RR Bridge	11,600		814.8	945	813.7	1,370	-1.1	425
Old Penn Ave Bridge (DS)	12,410		814.9	705	814.5	1,370	-0.4	665
Old Penn Ave Bridge (US)	---		815.2	705	814.5	1,370	-0.7	665
BN RR Bridge	12,670		815.3	705	814.4	1,370	-0.9	665
MN&S RR Bridge (DS)	13,930		816.2	465	815.6	1,370	-0.6	905
MN&S RR Bridge (US)	---		816.4	465	815.8	1,370	-0.6	905
Fruen Mill Dam (DS)	14,150		816.5	510	817.2	1,370	0.7	860
Fruen Mill Dam (US)	---		818.2	510	819.8	1,370	1.6	860
Glenwood Ave	14,855		820.3	680	822.2	1,290	1.9	610
Hwy 55 (DS)	16,500		821.7	680	823.4	1,190	1.7	510
Hwy 55 (US)	---		826.2	680	826.5	1,500	0.3	820
Golf Cart Bridge	---		826.2	680	826.6	1,520	0.4	840
MN&S RR Bridge	18,700		826.2	945	826.6	1,520	0.4	575
Plymouth Ave Bridge	19,500		826.2	680	826.7	1,550	0.5	870
Wirth Parkway (DS)	20,480		826.2	1,570	826.7	1,450	0.5	-120
Wirth Parkway (US) Bridge	---		826.5	1,570	826.8	1,460	0.3	-110
Confluence w/ Sweeney Lake Branch	22,000		827.2	----	827.2	1,460	0.0	---
Golden Valley Road (DS)	23,800		827.4	790	828.2	1,350	0.8	560
Golden Valley Road (US)	23,800		830.2	680	833.8	1,340	3.6	660
Dresden Lane (DS)	25,900		830.5	680	834.1	1,340	3.6	660
Dresden Lane (US)	---		831.6	680	834.1	1,350	2.5	670
Bassett Creek Drive (DS)	---		832.2	665	834.4	1,290	2.2	625
Bassett Creek Drive (US)	---		832.9	665	837.0	1,300	4.1	635
Noble Lane (DS)	29,200		839.7	660	838.7	1,320	-1.0	660
Noble Lane (US)	---		839.7	660	839.7	1,300	0.0	640
Regent Avenue (DS)	30,800		---	660	---	1,300	---	640
Regent Avenue (US)	---		842.1	660	843.7	1,280	1.6	620
Minnaqua Avenue	31,650		842.7	---	844.0	1,260	1.3	---
Highway 100 (DS)	34,020		843.4	770	844.8	1,300	1.4	530
Highway 100 (US)	34,020		849.2	610	851.2	1,040 [2]	2.0	430
DS Confluence N. Branch	34,400		849.2	495	851.2	1,040 [2]	2.0	545
Westbrook Road (DS)	37,000		857.3	940	859.0	870	1.7	-70

version May 2017

Table 3-7 Comparison of BCWMC Watershed Management Plan to the Phase 2 XPSWMM Model - Flood Elevations and Peak Discharges

Location	Creek Distance above the Mississippi River (feet)	Normal Water Level (NAVD88)	BCWMC Watershed Management Plan[1] 100-yr Flood Elevation (NAVD88 feet)	BCWMC Watershed Management Plan[1] 100-yr Flow Rate (cfs)	BCWMC Phase 2 XP-SWMM Model - Atlas 14 (4/19/2017) 100-yr Atlas 14 MSE3 Flood Elevation (NAVD88 feet)	BCWMC Phase 2 XP-SWMM Model - Atlas 14 (4/19/2017) 100-yr Atlas 14 MSE3 Flow Rate (cfs)	Change in Flood Elevations and Flow Rates XPSWMM - Plan Flood Elevation (feet)	Change in Flood Elevations and Flow Rates XPSWMM - Plan Flow Rate (cfs)
Westbrook Road (US)	---		858.3	940	860.0	870	1.7	-70
Duluth Street (DS)	38,400		861.5	850	861.9	850	0.4	0
Duluth Street (US)	---		862.0	850	862.6	830	0.6	-20
St. Croix Avenue (DS)	39,800		863.2	850	864.5	830	1.3	-20
St. Croix Avenue (US)	---		864.3	850	864.7	800	0.4	-50
MN&S RR (DS)	41,660		869.7	760	870.3	700	0.6	-60
MN&S RR (US)	---		869.7	760	870.5	690	0.8	-70
Douglas Drive (DS)	42,130		870.4	670	871.0	700	0.6	30
Douglas Drive (US)	---		871.2	670	871.8	690	0.6	20
Florida Avenue (DS)	42,820		871.8	670	872.6	690	0.8	20
Florida Avenue (US)	---		872.5	670	873.0	690	0.5	20
Hampshire Ave (DS)	43,410		872.7	630	873.4	690	0.7	60
Hampshire Ave (US)	---		873.2	630	874.0	670	0.8	40
GV Country Club (DS)	44,320		874.6	365	876.1	660	1.5	295
GV Country Club (US)	---		878.6	405	880.6	650	2.0	245
Pennsylvania Avenue (DS)	46,500		879.5	380	881.6	650	2.1	270
Pennsylvania Avenue(US)	---		880.7	375	882.9	550	2.2	175
C&NW RR (DS)	47,200		881.9	375	884.1	560	2.2	185
C&NW RR (US)	---		883.1	375	885.0	460	1.9	85
Winnetka Ave (DS)	48,000		883.5	360	885.1	440	1.6	80
Winnetka Ave (US)	---		883.7	360	885.3	430	1.6	70
Wisconsin Ave (DS)	49,750		884.9	360	886.0	430	1.1	70
Wisconsin Ave (US)	50,100		888.2	340	887.6	360	-0.6	20
Golden Valley Road (DS)	---		888.2	290	887.7	340	-0.5	50
Golden Valley Road (US)	---		888.2	290	887.7	340	-0.5	50
Westbound Hwy 55 (DS)	51,250		888.2	290	887.7	340	-0.5	50
Eastbound Hwy 55 (US)	---		888.3	290	887.8	410	-0.5	120
Boone Ave (DS)	---		888.4	280	887.9	320	-0.5	40
Boone Ave (US)	---		888.5	280	887.9	220	-0.6	-60
Hwy 169 (DS)	56,500		888.6	255	888.3	300	-0.3	45
Hwy 169 (US)	---		888.7	250	888.4	240	-0.3	-10
Hwy 55 Ramp (DS)	58,300		888.7	235	888.4	210	-0.3	-25
Hwy 55 Ramp (US)	---		888.7	235	888.4	210	-0.3	-25
Hwy 55 Eastbound (DS)	58,500		888.7	235	888.4	210	-0.3	-25
Hwy 55 Eastbound (US)	---		888.7	235	888.4	210	-0.3	-25
Hwy 55 Westbound (DS)	---		888.7	235	888.4	210	-0.3	-25
Hwy 55 Westbound (US)	---		889.0	235	888.4	210	-0.6	-25
Hwy 169 ramp to W 55 (DS)	58,750		889.0	235	888.4	210	-0.6	-25

Table 3-7 Comparison of BCWMC Watershed Management Plan to the Phase 2 XPSWMM Model - Flood Elevations and Peak Discharges

Location	Creek Distance above the Mississippi River (feet)	Normal Water Level (NAVD88)	BCWMC Watershed Management Plan[1]		BCWMC Phase 2 XP-SWMM Model - Atlas 14 (4/19/2017)		Change in Flood Elevations and Flow Rates	
			100-yr		100-yr Atlas 14 MSE3		XPSWMM - Plan	
			Flood Elevation (NAVD88 feet)	Flow Rate (cfs)	Flood Elevation (NAVD88 feet)	Flow Rate (cfs)	Flood Elevation (feet)	Flow Rate (cfs)
Hwy 169 ramp to W 55 (US)	---		889.0	235	888.5	210	-0.5	-25
Hwy 55 N Frontage Rd (DS)	58,850		889.2	235	888.5	210	-0.7	-25
Hwy 55 N Frontage Rd (US)	---		889.2	235	888.5	210	-0.7	-25
10th Ave (DS)	---		889.2	---	888.9	210	-0.3	---
10th Ave (US)	---		889.2	---	889.1	210 [2]	-0.1	---
C&NW RR Bridge (DS)	63,450		889.2	200	889.1	210 [2]	-0.1	10
C&NW RR Bridge (US)	---		889.6	200	889.1	210	-0.5	10
South Shore Drive (DS)	63,800		889.6	190	889.3	210	-0.3	20
South Shore Drive (US)	---		890.5	190	889.3	210 [2]	-1.2	20
Medicine Lake Weir (DS)	63,960		890.5	190	889.3	210	-1.2	20
Inundation Areas								
Theodore Wirth Park (Area upstream of Highway 55 Control Structure)	---	815.7	826.2	---	826.5	---	0.3	---
South Rice Pond	---		831.7	---	834.3	---	2.6	---
North Rice Pond	---	832.5	838.2	---	836.4	---	-1.8	---
Grimes Avenue Pond	---	832.5	838.2	---	836.4	---	-1.8	---
Golden Valley Country Club	---		878.6	---	880.6	---	2.0	---
Brookview Golf Course	---		888.3	---	887.8	---	-0.5	---
Westwood Lake	---	887.6 [3]	889.2	---	890.0	---	0.8	---
Medicine Lake	---	887.9	890.5	---	890.3	---	-0.2	---
NORTH BRANCH								
Hwy 100 Control (US)	---		849.2	610	851.2	1,040	2.0	430
Confluence w/Main Stem	---		849.2	---	851.2	1,740 [2]	2.0	---
29th Avenue (DS)	200		849.2	1,515	851.2	1,740 [2]	2.0	225
29th Avenue (US)	---		849.7	1,515	851.2	1,290 [2]	1.5	-225
32nd Avenue (DS)	2,600		849.8	1,175	851.2	1,290 [2]	1.4	115
32nd Avenue (US)	---		854.2	1,175	852.7	560 [2]	-1.5	-615
Brunswick Avenue (DS)	3,000		854.9	1,175	852.7	560 [2]	-2.2	-615
Brunswick Avenue (US)	---		856.1	1,175	856.7	510	0.6	-665
34th Culvert (DS)	4,200		863.0	700	861.5	520	-1.5	-180
34th Culvert (US)	---		866.3	430	867.2	500	0.9	70
Douglas Drive (DS)	5,250		870.2	670	869.6	580 [2]	-0.6	-90
Douglas Drive (US)	---		870.3	670	870.5	380 [2]	0.2	-290

version May 2017

Table 3-7 Comparison of BCWMC Watershed Management Plan to the Phase 2 XPSWMM Model - Flood Elevations and Peak Discharges

Location	Creek Distance above the Mississippi River (feet)	Normal Water Level (NAVD88)	BCWMC Watershed Management Plan[1]		BCWMC Phase 2 XP-SWMM Model - Atlas 14 (4/19/2017)		Change in Flood Elevations and Flow Rates	
			100-yr		100-yr Atlas 14 MSE3		XPSWMM - Plan	
			Flood Elevation (NAVD88 feet)	Flow Rate (cfs)	Flood Elevation (NAVD88 feet)	Flow Rate (cfs)	Flood Elevation (feet)	Flow Rate (cfs)
Edgewood Emb (DS)	5,600		870.9	430	871.0	380 [2]	0.1	-50
Edgewood Emb (US)	---		878.4	340	880.4	340	2.0	0
Georgia Avenue (DS)	6,250		878.4	305	880.4	460	2.0	155
Georgia Avenue (US)	---		878.6	305	880.8	520 [2]	2.2	215
36th & Hampshire (DS)	6,800		878.6	260	880.8	480 [2]	2.2	220
36th & Hampshire (US)	6,980		879.2	260	881.3	280 [2]	2.1	20
Louisiana Ave. (DS) (Street Elevation Approx. 882.4)	8,000		881.2	---	883.3	490 [2]	2.1	---
Maryland Ave. (Street Elevation Approx. 885.7)	8,500		---	---	886.0	260 [2]	---	---
Oregon Ave. (Street Elevation Approx. 885.4)	9,000		---	---	888.8	90 [2]	---	---
MN & S RR (Street Elevation Approx. 889.1)	9,300		---	---	889.6	90 [2]	---	---
Inlet of 42" CMP (East Winnetka Pond)	9,500		888.2	---	890.9	100 [2]	2.7	---
Service Road (West Winnetka Pond)	10,000		888.2	---	891.1	190 [2]	2.9	---
Winnetka Ave. (DS)	10,600		888.2	---	891.1	220 [2]	2.9	---
Winnetka Ave. (US)	---		889.2	---	891.3	270	2.1	---
Boone Ave. (DS)	13,500		889.5	---	891.4	730 [2]	1.9	---
Boone Ave. (US)	---		889.7	---	891.4	270 [2]	1.7	---
Northwood Lake	---		889.7	---	891.4	270 [2]	1.7	---
TH 169 (DS)	16,850		889.7	---	893.0	270 [2]	3.3	---
TH 169(US)	---		890.7	---	893.1	750 [2]	2.4	---
Rockford Road (DS)	18,350		890.7	---	893.1	750 [2]	2.4	---
Rockford Road (US)	---		898.7	---	897.2	--- [2]	-1.5	---
Inundation Areas								
Bassett Creek Park	---	840.6	849.7	---	851.2	---	1.5	---
Edgewood Avenue Pond	---		878.4	---	880.4	---	2.0	---
Winnetka Pond (DS of Winnetka Avenue)	---	879.8	888.2	---	890.8	---	2.6	---
Northwood Park	---		889.5	---	891.3	---	1.8	---
Northwood Lake	---	884.6	889.7	---	891.3	---	1.6	---
SWEENEY LAKE BRANCH								
Confluence w/Main Stem	---		827.2	---	827.2	1,460	0.0	---
France Ave extension (DS)	700		827.2	---	827.7	170 [2]	0.5	---
France Ave (US)	---		829.2	---	828.0	170 [2]	-1.2	---

Table 3-7 Comparison of BCWMC Watershed Management Plan to the Phase 2 XPSWMM Model - Flood Elevations and Peak Discharges

Location	Creek Distance above the Mississippi River (feet)	Normal Water Level (NAVD88)	BCWMC Watershed Management Plan[1]		BCWMC Phase 2 XP-SWMM Model - Atlas 14 (4/19/2017)		Change in Flood Elevations and Flow Rates	
			100-yr		100-yr Atlas 14 MSE3		XPSWMM - Plan	
			Flood Elevation	Flow Rate	Flood Elevation	Flow Rate	Flood Elevation	Flow Rate
			(NAVD88 feet)	(cfs)	(NAVD88 feet)	(cfs)	(feet)	(cfs)
Courage Center & Hidden Lakes Parkway (DS)	900		829.2	---	830.6	170	1.4	---
Courage Center & Hidden Lakes Parkway (US)	---		831.2	---	831.9	170	0.7	---
Precast Concrete Dam (DS)	1,700		831.7	---	831.9	170	0.2	---
Sweeney Lake	---		831.7	---	831.9	170	0.2	---
Union Pacific RR (DS)	6,800		831.7	---	831.9	400	0.2	---
Union Pacific RR (US)	---		835.8	311	836.3	480 [2]	0.5	169
Hwy 55 (DS)	8,150		835.8	680	836.8	860 [2]	1.0	180
Hwy 55 (US)	---		836.9	680	838.4	310 [2]	1.5	-370
MN & S RR (DS)	9,000		836.9	233	838.4	260	1.5	27
MN & S RR (US)	---		839.5	233	841.7	260	2.2	27
Breck Pond & Control Structure (US)	9,580		839.9	296	842.5	270 [2]	2.6	-26
TH 100 (DS) (Breck Pond)	10,400		839.9	298	842.5	440 [2]	2.6	142
TH 100 (US)	---		845.4	298	851.0	500 [2]	5.6	202
Turners Crossroad (US)	10,950		854.9	241	857.2	430 [2]	2.3	189
Glenwood Pond A	---		854.9	---	857.2	---	2.3	---
MN & S RR (DS)	11,550		854.9	233	857.2	440 [2]	2.3	207
MN & S RR (US)	---		855.0	233	857.2	440 [2]	2.2	207
Glenwood Pond B	---		855.0	---	857.2	---	2.2	---
Glenwood Ave (DS)	---		855.0	84	857.2	100 [2]	2.2	16
Glenwood Ave (US)	---		855.0	84	857.2	100	2.2	16
Duck Pond	---		855.0	---	857.2	---	2.2	---
MN & S RR (DS)	---		855.0	233	857.2	560 [2]	2.2	327
MN & S RR (US)	---		858.9	233	859.4	300 [2]	0.5	67
Ravine Storage Area	---		858.9	---	859.4	90 [2]	0.5	---
Courtlawn Pond	---		873.1	---	873.6	120 [2]	0.5	---
East Ring Pond	---		879.0	---	879.4	180 [2]	0.4	---
78” RCP Equalizer	18,800		---	---	---	480 [2]	---	---
West Ring Pond	---		879.0	---	879.4	---	0.4	---
Ravine Storage Area Overflow								
Glenwood Pond B	---		855.0	---	857.2	---	2.2	---
MN & S RR (DS)	---		855.0	---	857.2	---	2.2	---
MN & S RR (US)	---		857.3	---	859.4	---	2.1	---
Glenwood Ave (DS)	---		855.0	---	857.2	---	2.2	---
Glenwood Ave (US)	---		855.0	---	857.2	---	2.2	---

version May 2017

Table 3-7 Comparison of BCWMC Watershed Management Plan to the Phase 2 XPSWMM Model - Flood Elevations and Peak Discharges

Location	Creek Distance above the Mississippi River (feet)	Normal Water Level (NAVD88)	BCWMC Watershed Management Plan[1]		BCWMC Phase 2 XP-SWMM Model - Atlas 14 (4/19/2017)		Change in Flood Elevations and Flow Rates	
			100-yr		100-yr Atlas 14 MSE3		XPSWMM - Plan	
			Flood Elevation (NAVD88 feet)	Flow Rate (cfs)	Flood Elevation (NAVD88 feet)	Flow Rate (cfs)	Flood Elevation (feet)	Flow Rate (cfs)
Inundation Areas								
Sweeney Lake	---	827.2 [4]	831.7	---	831.9	---	0.2	---
Twin Lake	---	827.2 [4]	831.7	---	831.9	---	0.2	---
Breck Pond	---	831.6	839.9	---	842.5	---	2.6	---
Courtlawn Pond	---	870.1	873.1	---	873.6	---	0.5	---
East Ring Pond	---	874.1	879.0	---	879.4	---	0.4	---
West Ring Pond	---	874.1	879.0	---	879.4	---	0.4	---
MEDICINE LAKE BRANCH (PLYMOUTH CREEK)								
West Medicine Lake Drive (DS)	10,450		890.5	---	890.6	290	0.1	---
West Medicine Lake Drive (US)	---		891.7	---	893.6	690 [2]	1.9	---
26th Avenue N. (DS)	16,500		925.2	---	924.4	230	-0.8	---
26th Avenue N. (US)	---		925.7	---	925.0	230	-0.7	---
28th Avenue N. Dike (DS)	---		928.2	---	929.9	230	1.7	---
28th Avenue N. Dike (US)	---		931.0	---	932.3	260 [2]	1.3	---
County Road 61 (DS)	---		931.0	---	932.3	260	1.3	---
County Road 61 (US)	---		931.4	---	933.9	230	2.5	---
Xenium Lane (DS)	20,850		931.4	---	933.9	440	2.5	---
Xenium Lane (US)	---		931.7	---	934.2	460 [2]	2.5	---
I-494 (DS)	22,500		935.2	---	938.1	440	2.9	---
I-494 (US)	---		938.7	---	938.9	410	0.2	---
Fernbrook Lane (DS)	25,000		947.2	---	946.5	260	-0.7	---
Fernbrook Lane (US)	---		948.2	---	946.6	260	-1.6	---
Central Park Pond Outlet Structure (DS)	---		949.2	---	949.6	260	0.4	---
Central Park Pond Outlet Structure (US)	---		953.2	---	954.7	690 [2]	1.5	---
37th Avenue	28,900		956.2	---	954.8	690 [2]	-1.4	---
County Road 9	30,450		959.2	---	955.0	390	-4.2	---
Vicksburg Lane (DS)	31,300		961.2	---	963.0	380	1.8	---
Vicksburg Lane (US)	---		962.2	---	963.7	280	1.5	---
Dunkirk Lane (DS)	---		979.2	---	977.6	80	-1.6	---
Dunkirk Lane (US)	34,450		982.2	---	982.2	90	0.0	---
T.H. 55 (DS)	38,300		982.2	---	987.5	40	5.3	---
T.H. 55 (US)	---		982.7	---	987.5	---	4.8	---
Inundation Areas								

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Table 3-7 Comparison of BCWMC Watershed Management Plan to the Phase 2 XPSWMM Model - Flood Elevations and Peak Discharges

Location	Creek Distance above the Mississippi River (feet)	Normal Water Level (NAVD88)	BCWMC Watershed Management Plan[1] 100-yr Flood Elevation (NAVD88 feet)	BCWMC Watershed Management Plan[1] 100-yr Flow Rate (cfs)	BCWMC Phase 2 XP-SWMM Model - Atlas 14 (4/19/2017) 100-yr Atlas 14 MSE3 Flood Elevation (NAVD88 feet)	BCWMC Phase 2 XP-SWMM Model - Atlas 14 (4/19/2017) 100-yr Atlas 14 MSE3 Flow Rate (cfs)	Change in Flood Elevations and Flow Rates XPSWMM - Plan Flood Elevation (feet)	Change in Flood Elevations and Flow Rates XPSWMM - Plan Flow Rate (cfs)
Xenium Lane	---		931.7	---	934.2	---	2.5	---
Central Park Pond	---	948.2	952.2	---	954.7	---	2.5	---
Turtle Lake	---	962.9 [5]	964.2	---	967.0	---	2.8	---
Rockford Road	---		968.2	---	968.5	---	0.3	---
Dunkirk Lane	---		982.2	---	982.2	---	0.0	---
Oak Knoll Pond	---	914.4	917.3	---	918.6	---	1.3	---
Crane Lake	---	917.3	920.7	---	920.2	---	-0.5	---

Notes

[1]Values reported in the Bassett Plan were presented in NGVD29 and have been updated to NAVD88 (NAVD88=NGVD29+0.18ft)

[2]Multiple inflows to node. The reported peak inflow reflects the sum all inflow peaks.

[3]Barr study surveyed outlet of Westwood Lake and found the outlet ditch has filled with sediment to evelevation 887.6ft.
The outlet pipe invert elevation (historical normal water level) is at 886.18ft

[4]As-built survey November 27,2012

[5]Turtle Lake Feasibility Study, November 10, 2011

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