BCWD Hydrologic & Hydraulic Model Update Technical Report

Image: Brown’s Creek at Confluence with the St. Croix River (MnDOT Bridge No. 8424)

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1 PROJECT OVERVIEW

The Brown's Creek Watershed District hydrologic and hydraulic (H&H) model was initially constructed in 1998 using XP Solutions, Inc. XP-SWMM software. In 2004, the XP-SWMM model was updated to include more detailed geographical information such as high-resolution aerial photography, two-foot topography, and modifications to the hydraulic system associated with District and city projects. Since 2004, the H&H model has been maintained as a "living model," meaning it is updated when new information, such as hydraulic structure surveys and land-altering development data, becomes available. The last significant update to the model occurred in 2015 and included:

- Transition of the model from XP-SWMM to PCSWMM software.
- Revision of subcatchment boundaries based on 2011 Minnesota State Lidar-derived elevation models, BCWD structure survey data, and the cities of Stillwater and Oak Park Heights storm sewer lines.
- Change of the hydrology method from the SCS Curve Number method to the Green-Ampt method.
- Calibration and validation of the model to growing seasons, simulation of design rainfall events, and determining 100-year high water levels for DNR waterbodies.

Further information regarding past modeling studies can be found in the 2017 BCWD Watershed Management Plan Land and Water Resource Inventory, as well as in individual H&H study reports for each major update.

Since the last major update, several changes within the watershed necessitated updating the model to provide an accurate assessment of rainfall runoff characteristics and impacts in the watershed. These updates ensure the model includes the latest available information to evaluate existing conditions (i.e., land use).

2025 H/H Model Update Highlights:

- Includes hydraulic data for major and minor road crossings as well as conveyance structures and best management practices from thirty development permit as-built surveys.
- Includes 1-meter resolution land cover data for parameterizing hydrologic model parameters, e.g., impervious area, land surface roughness and depressional storage.
- Based on the 2024 LiDAR elevation data, reflecting the latest land form changes, and higher accuracy than the 2011 predecessor (eight points per square meter instead of 1.5). The average subcatchment size is approximately 31 acres, ranging from tenths of an acre, representing individual street catch basin catchments, to 500 acres in less developed areas.
- Generated 100-year, 24-hour high water levels (HWLs) for the District’s waterbodies under existing and a future (projected) climate condition. This information was incorporated into the BCWD’s 2027-2036 Watershed Management Plan.

The result of this modeling effort is a comprehensive, flexible software package containing continuous and event-based runoff model scenarios with input and results in the form of Geographic Information System (GIS) input layers. The layers can be used and reviewed in common GIS platforms such as ESRI ArcMap, QGIS and Google Earth, making it easier for the BCWD to share with stakeholders and permittees.

The model update was completed in three phases due to delayed dataset availability. The phases consisted of the following:

<u>Phase 1)</u>

1) Updated climatology and precipitation data
   - Updated climatology and rainfall data library includes the growing season data collected at the BCWD's weather station, as well as recent complete year data at nearby bias-corrected gauges using historical radar data to ready the model for continuous simulations.
2) Updated model hydraulics:
   - Review of as-builts of thirty developments with significant changes and addition of these developments to the BCWD H&H model.

<u>Phase 2)</u>

1) Processed 2022 LiDAR data (published 2024) and used BCWD structure survey data and the cities of Stillwater and Oak Park Heights' storm sewer database to update subcatchment boundaries
2) Updated waterbody storage, depressions, and overland channels based on new LiDAR data.
3) Processed the observed creek flow and MnDNR water level data as calibration inputs for the model.

<u>Phase 3)</u>

1) Updated land cover using the 2012 TCMA dataset (published 2016), as the newest TCMA dataset had not become available yet (originally anticipated in late 2024). This dataset was updated using BCWD permit land cover changes since 2012. The land cover data was used to calculate hydrologic parameters that determine the volume, and rate that water runs off of the landscape such as the imperviousness, surface roughness, runoff coefficient, and depression storage for each subcatchment.
2) Model calibration - Model calibration is a process where model results are compared to observed data within the watershed and model parameters are adjusted to ensure the model predicts flows similar to observed conditions. Calibration is required with any major model update to correct for uncertainties inherent in the input data and in the model itself. The previous model calibration was performed for the 2014 growing season. Several changes have occurred in the contributing drainage area to the creek, lakes and wetlands, justifying a new calibration to more recent data. The upgraded model was calibrated to water levels in 17 DNR inventoried lakes and wetlands, stream flow at the Manning Avenue monitoring station, Stonebridge station as well as the Brown's Creek Watershed Outlet Monitoring Program (WOMP) station for the 2020 growing season.
3) Model validation - Model validation is a process where the calibrated model is used to compared to observed data, but for a different time period than used for the calibration, ensuring the model can accurately predict flows for a variety of conditions (for example, years with drought or wet conditions). The calibrated model was validated using data from the 2022 growing season. This period marked the start of

monitoring at Manning Avenue following the completion of the culvert crossing replacement. Our validation involved comparing water level measurements from 17 DNR-inventoried lakes and wetlands, along with streamflow data from the Manning Avenue, Stonebridge Trail, and WOMP monitoring stations.

4) Model Simulation - Following validation, a 100-year, 24-hour rainfall event was simulated on the calibrated model, consistent with the current BCWD stormwater management requirements. This simulation utilized the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 rainfall depths and a Natural Resources Conservation Service (NRCS) Midwest and Southeast (MSE3) MN rainfall distribution. Furthermore, to address community sustainability and resilience, a forecasted extreme rainfall scenario (using the upper 90% confidence interval value from NOAA Atlas 14) was also ran to account for climate change impacts.

5) Mapping of the 100-year floodplains was conducted for both current conditions and for the extreme rainfall scenarios, thereby allowing comparison of projected water level increase, and amount of inundated land that may be expected under future conditions. Flood maps for the entire district are included in Appendix B, (larger maps or digital versions are available by request to the BCWD Administrator). The waterbodies with the greatest change in flood area of inundation are included in Appendix C.

2 MODEL DEVELOPMENT

2.1 BCWD Model History

Models have previously been created for the BCWD for several purposes. The relevant existing models are listed in Table 1.

Table 1. Hydrology and Hydraulics Model History

Year	Model Description
1998	Initial BCWD Hydrology & Hydraulics Study using XP-SWMM
2003	Oak Park Heights Surface Water Analysis
2004	Major update and recalibration Hydrology & Hydraulics Study
2005-2012	Periodic minor model updates to include permitted development projects
2006	Market Place Surface Water Management Study
2015	Major update and recalibration of model using PCSWMM (EPA SWMM5)
2025	Major update and recalibration of model using PCSWMM (EPA SWMM5)

2.2 Climate Change Scenarios

The Hydrometeorological Design Studies Center of the National Weather Service unveiled NOAA Atlas 14, Volume 8 in 2013. This comprehensive atlas offers precipitation frequency estimates specifically tailored for several Midwestern states, including Minnesota. The analysis of this historical precipitation data also provides 90% confidence interval (CI) tables. A 90% CI for any storm recurrency (e.g., 1-yr., 100-yr., 500-yr.) is the range of precipitation depth that has a 90% probability to fall in that recurrency. For example, a precipitation event between 6" and 10" in 24-hours (Figure 1) has a 90% probability of being a 100-year event (an event that has a 1-in-100 chance of occurring in any given year). is just an example for illustration purposes. The values used in the model runs are shown in Table 1.

Table 1. Rainfall Depth for existing MSE 3 and future climate change 90 percent interval

Return Period	24-hour Rainfall Depth (in)	
	Current	Upper 90% (Future)
1 year	2.43	2.98
2 year	2.79	3.44
10 year	4.16	5.15
100 year	7.2	9.5

The use of the 90th percentile values aligns with work previously conducted by EOR for the CLFLWD, BCWD, CMSCWD, and the City of Rochester's Comprehensive Surface Water Management Plan. The depth corresponding to the upper 90% CI range was used to represent the future depth and intensity of precipitation for equivalent return periods. This upper 90% CI value is a commonly used way to assess vulnerabilities given the uncertainty in future conditions until NOAA Atlas 15 is released. NOAA Atlas 15 will account for climate change by taking non-stationarity and climate change projections into consideration. NOAA Atlas 15 is not due for release until 2025 (for review and comment) and is not expected to be finalized until sometime in 2026.

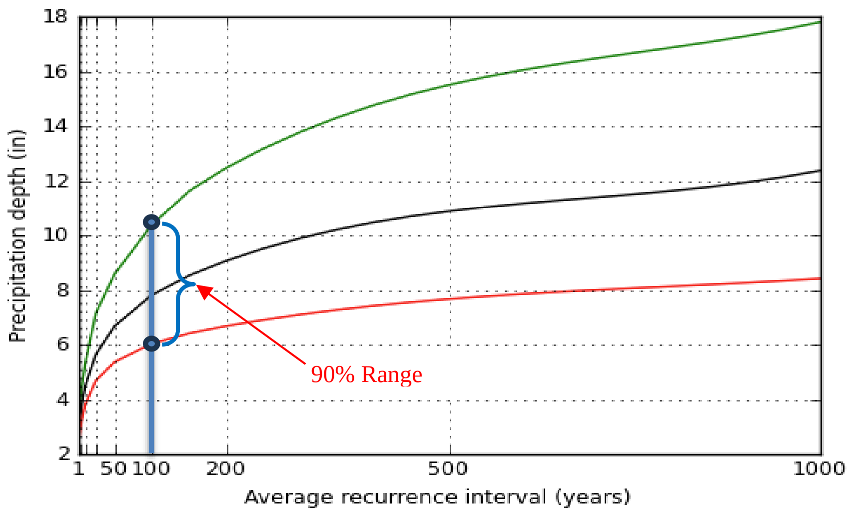


Figure 1. 90% Confidence Interval for 100-yr. 24-hours Storm

2.3 Delineation of Subcatchments (Subwatersheds)

The catchment area for each lake was delineated using a combination of tools and source data as described below. The resulting boundaries, color-coded to the major outlet points (calibration locations), are shown in . Note, subwatershed and subcatchment is used synonymously in this report.

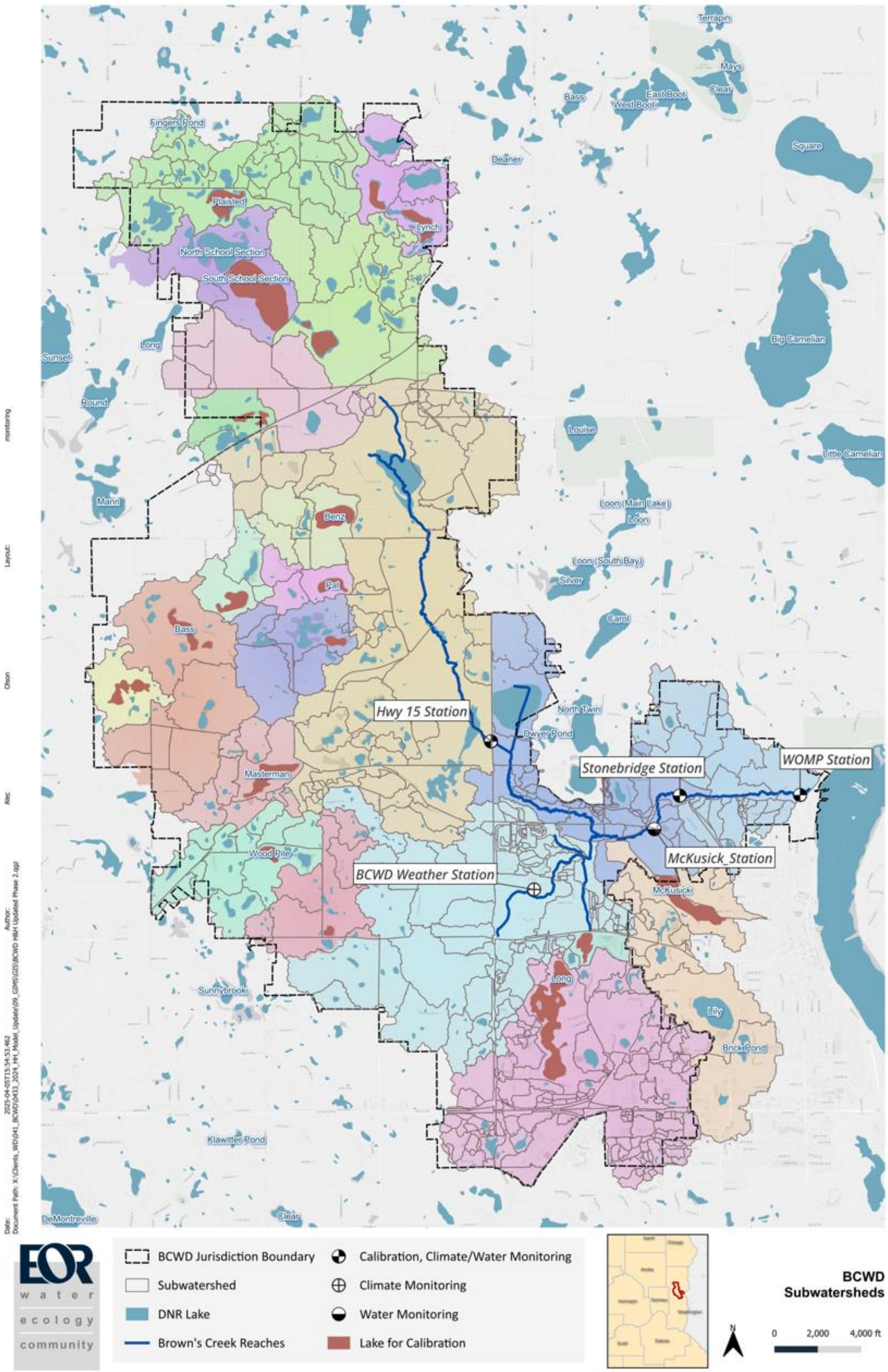


Figure 2. Watershed Color-coded to DNR Waterbodies, with Model Calibration Locations

2.3.1 Elevation Data Source

Elevation data is used in the model to define flow paths and subcatchment boundaries. In early 2024, higher-resolution Minnesota LiDAR data became available for Washington County that could be used to refine drainage divides and storage throughout the model. The new dataset, collected between 2022 and 2023, provides eight data points per square meter within the BCWD boundary, a significant improvement over the 2011 Minnesota LiDAR used in the 2015 model update, which had only 1.5 data points per square meter. Typically, the Minnesota Geospatial Advisory Council 3D Geomatics (3DGeo) Data Acquisition Committee processes the raw LiDAR data into a digital elevation model (DEM) and releases it to the public on the MN Lidar Hub website. However, the committee indicated that the DEM for Washington County would not be available until later in 2024 or early 2025. As such, EOR processed the raw 2024 published LiDAR data into a DEM in-house so that the higher resolution data could be used to update the model to current conditions. The bare earth LiDAR points were generalized into a DEM at a 1-meter by 1-meter resolution.

The elevation differences between the new and old LiDAR datasets range from approximately -30 feet to 25 feet, with extreme values observed where development occurred, such as at the Trunk Highway 36 & Manning Interchange. Generally, the elevation differences across most land areas are minor, with larger variations noted on roadway overflows. However, the cumulative difference for defining waterbody storage across the floodplain is impactful to defining flood footprints.

2.3.2 Hydrologic Reconditioning

Hydrologic reconditioning, or correction is to modify the DEMs to accurately represent the surface water flow, which removes artificial barriers, “digital dams”, that happen when roads, bridges, or other features disrupt the natural flow of water, but is managed through culverts or storm sewer systems.

The areas within the Brown’s Creek Watershed District were hydrologically reconditioned using the new DEM processed from the new LiDAR data. Reconditioning is an iterative process that corrects the elevation data based on user input and interpretation of runoff characteristics within the watershed. Sub-surface drainage structures, such as storm sewers and culverts, are not accounted for in the LiDAR. Therefore, features such as roadbeds create false digital dams in the elevation data. The process of reconditioning consists of interpreting hydraulic structures and accounting for them by lowering the elevations at their location on the DEM, a process called “burning in”. Thus, allowing flow through the digital dam during terrain processing.

Several sources of data were analyzed to assist in interpreting the watershed hydrology and flow directions, including:

- MNDOT bridge and culvert database
- City of Stillwater pipe inventory
- City of Oak Park Heights pipe inventory

- Carnelian Marine St. Croix Watershed District structure inventory
- Survey data throughout the District collected by the District Engineer
- Aerial photography and satellite imagery

Following reconditioning of the DEM, an in-house GIS-based delineation model was used to generate flow lines and create a contiguous network of streams that indicate flow direction and connectivity throughout the watershed. The average delineated subcatchment area was set to 15 acres to evaluate smaller-scale subcatchments relative to those in the current model, allowing us to identify subcatchments that require further refinement. Existing model outlet locations were incorporated as outlet points to ensure consistency between the new delineation and the current model's subcatchment outlets. Quality control was carried out by reviewing subcatchment connectivity using professional engineering judgment and the institutional knowledge of the District engineer.

2.4 Hydrology

The hydrologic portion of the model is represented by the subcatchment elements. Simply put, these elements use precipitation data (a model input) to predict runoff rates and volumes from the landscape to various hydraulic features (e.g., lakes, streams). Defining the hydrology of the watershed (i.e. "hydrologic parameterization") was primarily conducted using four data types:

1. Soils
2. Land Cover
3. Impervious Cover
4. Topography (LiDAR)

The associated datasets—discussed in detail below—were used to initialize model subcatchment parameters through area weighting.

2.4.1 Hydrology Simulation Method

The modified Green-Ampt infiltration method was used in conjunction with the EPA-SWMM runoff method to generate runoff for both continuous (i.e., historical) and event-based (i.e., synthetic) simulations.

The modified Green-Ampt, compared to Green-Ampt, incorporates dynamic soil moisture conditions and variable infiltration rates, resulting in a more accurate representation of real-world dynamic infiltration processes. It calculates infiltration using the soil's hydraulic conductivity and the soil's water saturation level (i.e., the moisture content at the onset of precipitation), with the excess rainfall (the portion not infiltrated) considered runoff.

This method performs well for both design storms (short-duration, high-intensity events) and continuous simulations (extended, less intense precipitation events), making it ideal for model calibration against year-round monitoring data. The EPA-SWMM runoff method explicitly distinguishes between pervious and impervious areas, further differentiating impervious surfaces with surface storage (e.g., roads, parking lots, rooftops) from those with zero surface storage (e.g., open water). Additionally, it requires defining a subcatchment flow length, Manning's roughness coefficient, and average slope to generate accurate runoff hydrograph responses.

2.4.2 Soil Properties

This model update used the same methodology to simulate soil properties as previous updates by utilizing the NRCS Soil Survey Geographic Database (SSURGO) to obtain key hydrologic parameters and applying the modified Green-Ampt method for infiltration calculations. Primarily, two SSURGO attributes are utilized: First, the representative saturated hydraulic conductivity (KSAT_R) defines the conductivity term in the modified Green-Ampt parameters. This value is integrated with empirical relationships from Rawls, et al., shown in Table 2, (e.g. *Green-Ampt Infiltration Parameters from Soils Data*, Journal of Hydraulic Engineering, 1983) to establish functional and dynamic relationships with both the initial moisture deficit and the suction head parameters (as depicted in Figure 3 and Figure 4, respectively). When the saturated hydraulic conductivity is altered during calibration, adjustments are made using PCWMM auto-expressions set up in the SWMM layer attributes. Second, the soil texture class (TEXCL) is used to identify unclassed, lowland areas—referred to as 'muck' in SSURGO—which are treated differently from the rest of the landscape. Since no KSAT_R value is provided for these 'muck' features, they are considered impervious and are assigned higher storage and roughness coefficients than other impervious surfaces such as asphalt and open water.

Figure 3: Relationship between conductivity and initial moisture deficit.

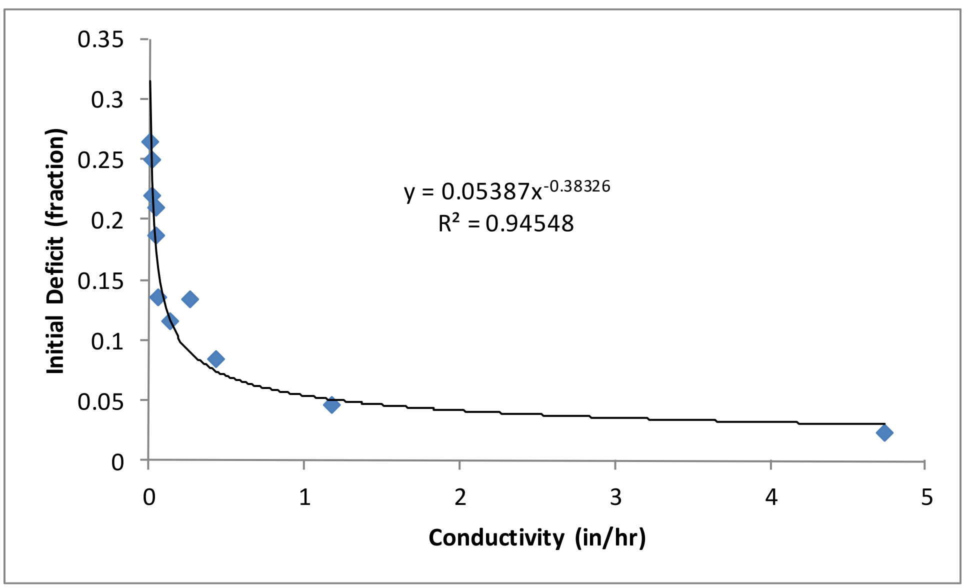


Figure 4: Relationship between conductivity and suction head.

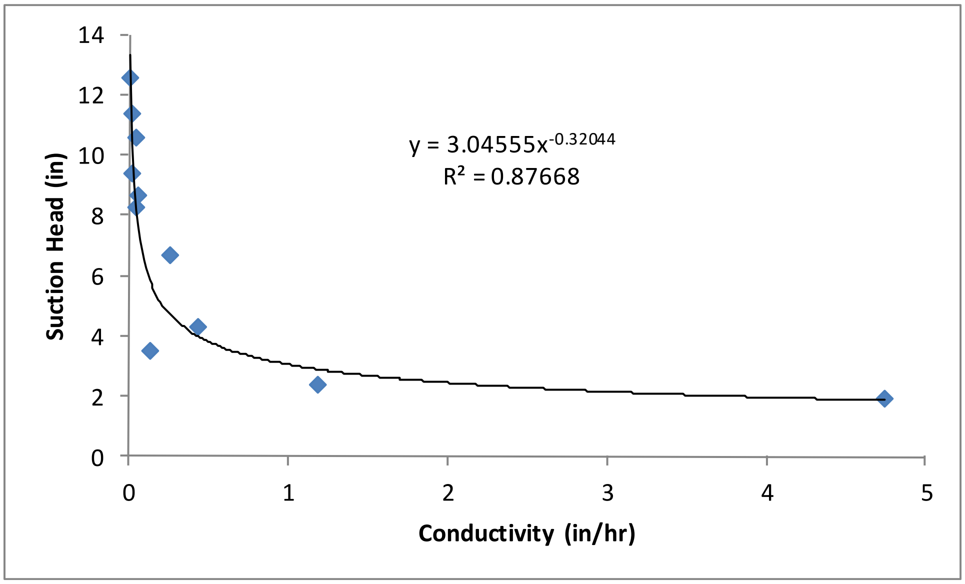


Table 2. Soil Parameter Lookup (Rawls et al.)

Soil Type	Conductivity (in/hr)	Suction Head (in)	Initial Deficit (fraction)
Sand	4.74	1.93	0.413
Loamy Sand	1.18	2.4	0.390
Sandy Loam	0.43	4.33	0.368
Loam	0.13	3.5	0.347
Silt Loam	0.26	6.69	0.366
Sandy Clay Loam	0.06	8.66	0.262
Clay Loam	0.04	8.27	0.277
Silty Clay Loam	0.04	10.63	0.261
Sandy Clay	0.02	9.45	0.209
Silty Clay	0.02	11.42	0.228
Clay	0.01	12.6	0.210

2.4.3 Subcatchment Depressional Storage and Manning’s Roughness

This model update employed the same methodology established in the 2015 update for determining subcatchment depressional storage and Manning’s roughness. Manning’s roughness for overland flow, which is used to determine runoff rates, and depressional storage depths were initialized for pervious areas using the Minnesota Land Cover Classification System (MLCCS) spatial dataset. Each land class within the BCWD was assigned typical parameter values based on a literature review, as summarized in Subcatchment Land Cover Roughness and Depressional Storage (EOR, 2014). Since both Manning’s roughness and depressional storage serve as calibration parameters, the primary objective was to differentiate between land covers with significant differences in magnitudes of roughness and storage (e.g., coniferous forest versus turf grass), rather than to accurately estimate their absolute values.

Given the presence of numerous small landscape depressions within the BCWD, an additional depressional storage depth was incorporated beyond that derived from the MLCCS categorization. A terrain analysis was conducted using a hydrologically corrected DEM to quantify the storage capacity in these depressions on a subcatchment basis. Explicitly defined landscape storage areas, such as hydraulically modeled ponds and wetlands, were excluded from this analysis to avoid double counting storage in the model.

Table 3. Subcatchment Land Cover Roughness and Depressional Storage

Land Cover Type	Manning's Roughness	Depressional Storage [inch]
Grasses & Trees with Impervious	0.205	0.116
Short Grasses	0.215	0.119
Cropland	0.245	0.153
Long Grasses, Shrubs & Trees	0.35	0.187
Upland Forest	0.35	0.186
Lowland Forest & Swamp	0.55	0.25
Shoreland, Floating Vegetation	0.215	0.119

2.4.4 Impervious Area

One of the most important inputs to hydrologic and hydraulic models is the impervious surface area in the watershed. The UMN Twin Cities Metropolitan Area (TCMA) 1-meter land cover dataset was used to define the percentage of impervious surface within each subcatchment (Figure 6).

The National Land Cover Database (NLCD) imperviousness raster (30-meter cells with a value from 0 to 100% impervious) was joined with the UMN TCMA raster (discrete values, each cell is either 0 or 100% impervious) to estimate the average impervious areas for each subcatchment. However, the UMN TCMA has discrete land cover categories for roads, buildings, and water surface that could be directly reclassified to impervious surface. Therefore, the UMN TCMA was preferable to the NLCD dataset.

Zero Impervious is defined as the percent of impervious areas with no depressional storage, which typically includes open water and excludes paved surfaces, which have a small amount of storage in surface undulations. Zero impervious was calculated by reclassifying impervious surfaces and area-weighting over the total impervious surface within each subcatchment.

Percent impervious weighted averages per subcatchment were then extracted using a zonal statistics routine. Impervious areas for new developments since 2015 were manually entered as a model input for the subcatchments that were divided according to the individual project plans, using plans and models from the permits, as well as aerial imagery.

2.4.5 Physical Parameters

Several catchment input parameters (area, width, and slope) are based on geometry and were calculated directly from GIS. It is important to note that the SWMM parameter "width" refers to the width of the overland flow path while "flow length" refers to the length of overland sheet flow, not total length of flow through a subcatchment. The DEM used to estimate slope was resampled from 1-meter resolution to 5-meter resolution to prevent overestimation of slope due to small undulations within the landscape. For the subcatchments that were divided according to individual project plans for the new developments, the maximum length flow path through each catchment was estimated by hand from the DEM. These lengths were used to estimate the width of catchments according to the following rules. Flow length was then estimated by dividing the area by the width.

1. Flow path through center of catchment – width represents 2 times the length of the flow path
2. Flow path along the perimeter of catchment – width represents the length of the flow path
3. Direct drainage to a lake – width represents the perimeter of the lake

Figure 5 shows how these general catchments were transformed into their corresponding rectangular catchments in SWMM, where ω is the width and ***l*** is the flow length. In the physical catchments $\bar{s}$ is the average sheet flow length, L is the concentrated flow path, and P is the water body perimeter.

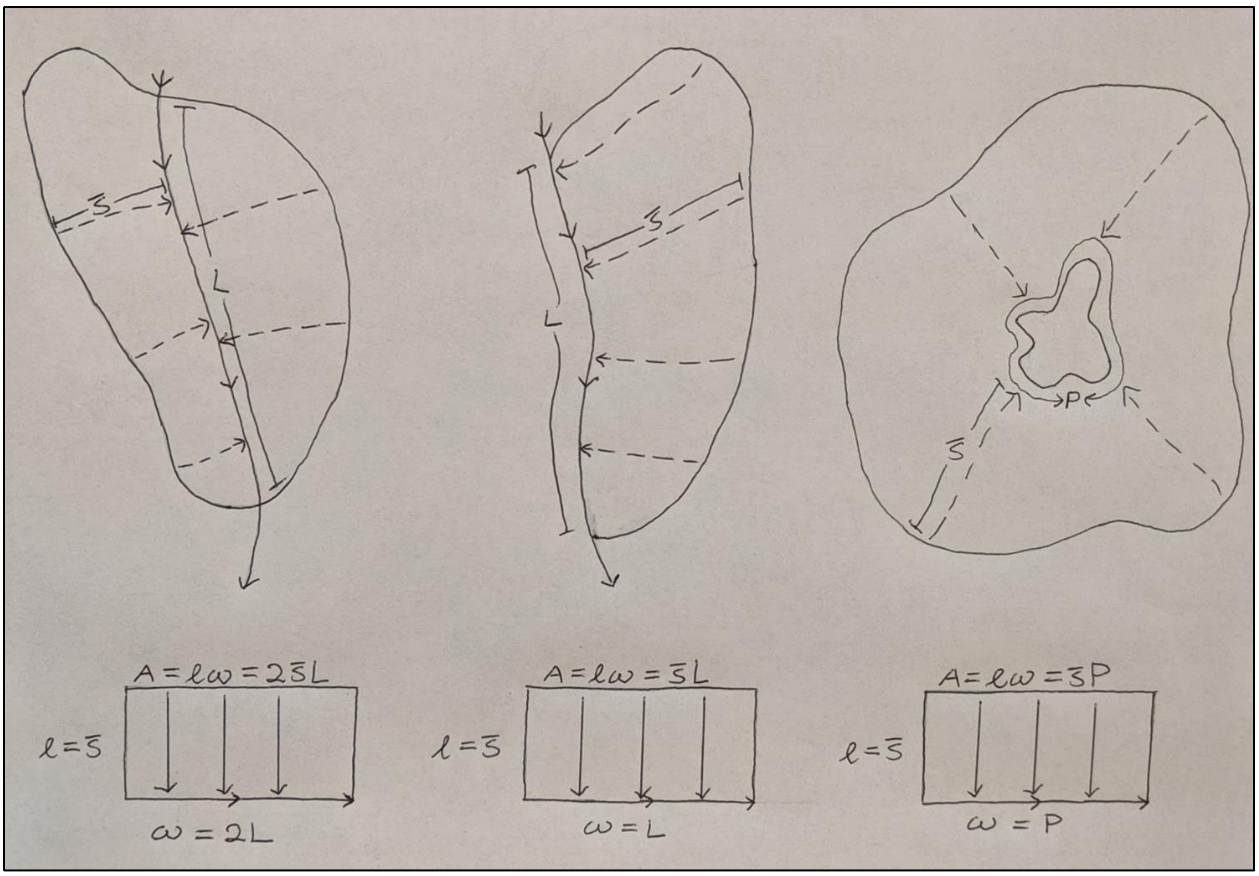


Figure 5. Subcatchment Width Calculations

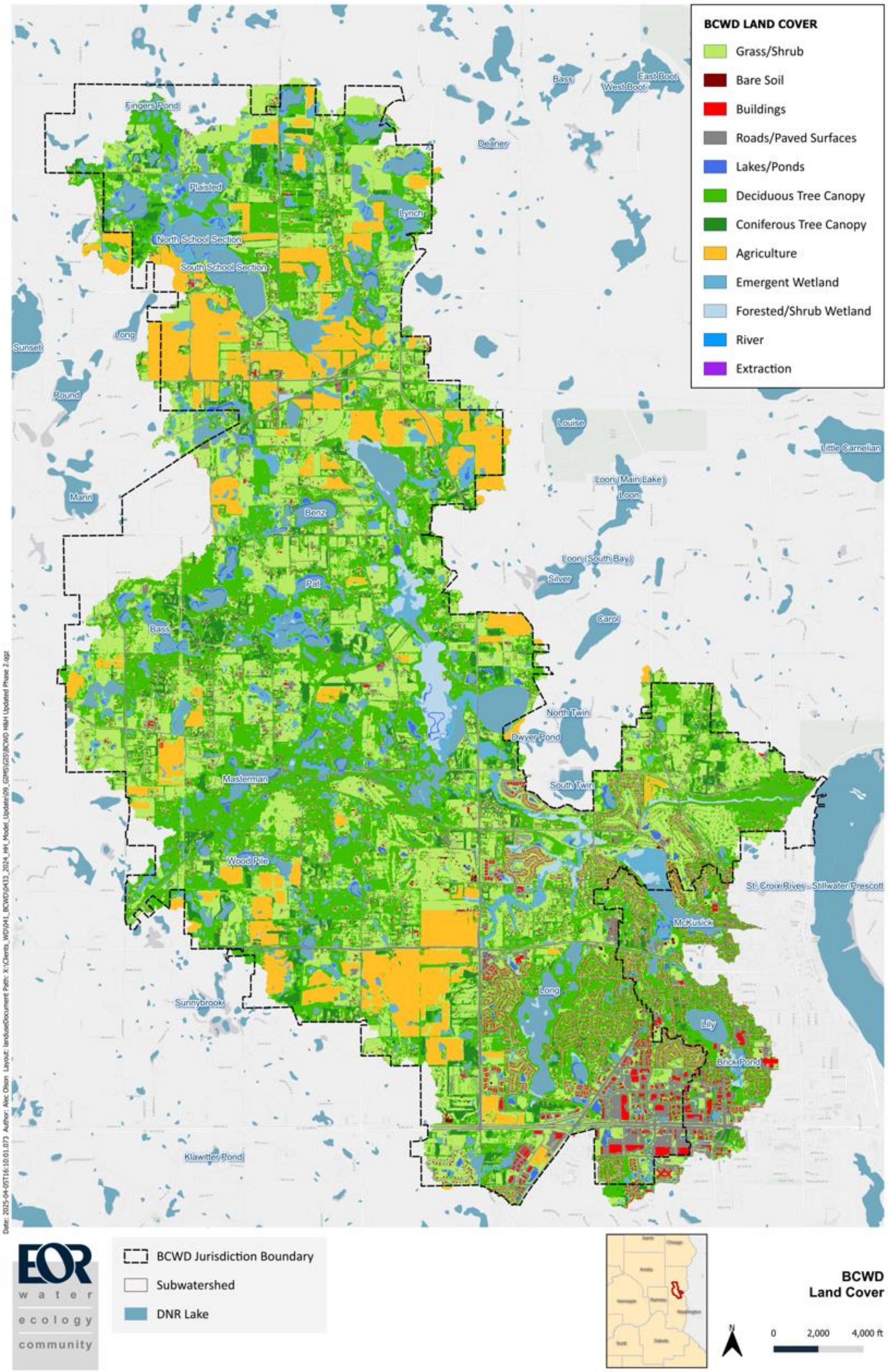


Figure 6.TMCA Land Cover

2.2.6. Land Cover Parameters

A second set of parameters can be determined based on land cover. These parameters are area weighted to obtain an average value within each subcatchment. The following lookup table contains suggested values for each UMN TCMA classification from a compilation of sources and should be used to assign the necessary land cover parameters to each subcatchment. Parameters are defined as follows.

- N Imperv – Manning's roughness for impervious surfaces. **Typically set to 0.01" regardless of surface type.**
- N Perv – Manning's roughness for pervious surface.
- Dstore Imperv – Depressional storage (in) for impervious surface. **Typically set to 0.1" regardless of surface type.**
- Dstore Perv – Depressional storage (in) for pervious surface.

Subcatchments are divided into subareas of pervious and impervious surface, with three routing options between subareas. Pervious areas can be routed to impervious. Impervious areas can be routed to pervious (e.g. roof runoff), or both areas can be routed directly to the subcatchment outlet.

Table 5 provides recommendations for routing based on percent impervious. However, routing must be based on their best judgement and familiarity with the nature of the flow, especially for larger subcatchments or subcatchments with varied land cover. Deviations from

Table 5 are documented in the attribute coding of the model subcatchment layer.

Table 4. Land Cover Parameter Lookup

Land Cover Classification	N Perv	Dstore Perv (in)
Bare Soil	0.0113	0.15
Deciduous Tree Canopy	0.56	0.45
Coniferous Tree Canopy	0.52	0.45
Agriculture	0.2538	0.225
Emergent Wetland	0.1825	0.25
Forested/Shrub Wetland	0.086	0.3

Table 5. Subarea Routing

Percent Impervious	Subarea Routing	Percent Routed
> 70%	IMPERVIOUS	100%
50-70%	OUTLET	100%
30-50%	PERVIOUS	25%
15-30%	PERVIOUS	50%
< 15%	PERVIOUS	100%

2.2.7. Groundwater

Groundwater can be included in SWMM models by defining an aquifer associated with each subcatchment. While this can be useful in systems that are heavily groundwater-dependent, it requires knowledge on the underlying aquifer properties, including elevations, aquifer porosity, and conductivity. In the absence of this information, groundwater parameters can be adjusted and manipulated during the calibration process, but it may be more efficient to define baseflow (using the Inflows editor at a node) within a stream as a stand-in for groundwater inflows, such is the case for the BCWD model.

2.5 Hydraulics

2.5.1 Stream Geometry

With additional subcatchments and refined storage nodes integrated into the model, new flow connections were established to more accurately capture actual flow patterns. Based on the Washington County GIS layer and survey information from EOR, 46 overland flow paths and 26 culverts were added to connect these new storage nodes. Moreover, new LiDAR data was used, and the PCSWMM transect creator tool was employed to generate cross-sectional profiles of stream geometry. These enhancements significantly improve the model's representation of the hydrological flow network.

2.5.2 Storage Areas

Storage curves were defined using a combination of the new LiDAR data (2024), the old LiDAR data (2012), and the existing storage curves from the previous PCSWMM model. Storage above the water surface elevation for each water body was defined using the 2024 LiDAR data. For DNR Waterbodies, the elevation differences between the old DEM and the new DEM varied from 2 to 5 feet, with most new LiDAR data showing higher elevations due to the season of collection. As such, the old DEM was used to define storage for the lower elevations not captured by the new DEM. Where available, the storage curves from the previous model were then used to define storage below the lowest elevation of the combined storage curve created from the old and new DEMs. Prioritizing the new DEM when defining storage provides a higher degree of accuracy in the available flood storage above the normal water levels in these waterbodies.

2.5.3 Channel Roughness

SWMM uses a Manning's roughness coefficient to determine channel energy losses (n-value). The roughness characteristics vary slightly from upstream to downstream along Brown's Creek, as well as across a given cross section of the channel. The channel in the upper portion of the watershed is generally slow moving due to the flat gradient of the wetland complexes that the creek meanders through in the headwater area. Lower in the watershed the channel characteristics change as the creek careens through the gorge area of the watershed. While creek stage (water level) is sensitive to the channel n-values, creek volume, peak flows, and timing were the calibration benchmarks and relatively insensitive to changing n-values. The channel n-values range from 0.03 to 0.05 and the overbanks range from 0.05 to 0.1 based on the literature values for open channel hydraulics (Chow, V.T., 1959).

2.6 Boundary Conditions

2.6.1 Initial Conditions

To better represent the initial soil moisture condition and align with the updated infiltration method (from Green-Ampt to modified Green-Ampt), the hotstart file method was employed to simulate more dynamic and accurate initial conditions. The hotstart file initializes the model using previously recorded soil moisture and water level data, providing a realistic starting point for the simulation. For the calibration year 2020 and the validation year 2022, the model was run with a maturation period beginning in March and continuing until approximately the first date in May when DNR Lake Finder started monitoring lake levels. At that point, the hotstart file was saved to capture the soil conditions and water levels across all storage areas. The lake levels for the 17 calibration lakes were then adjusted to match the recorded values in the hotstart file, ensuring accurate initial lake levels. This initial water level was also used as the starting point for design event model runs, selected as a conservative, wet condition for flood modeling

The 100-year Runoff Event (7.2 inches of precipitation over seven days with frozen ground conditions) was simulated as it is often the critical event for landlocked systems where runoff volume drives water levels higher, rather than runoff rate. The initial water elevation for the runoff event was established based on the average recorded early spring water elevation from the DNR Lakefinder period of record. The initial lake elevations used are in Table 6.

Table 6. Initial Water Surface Elevations

Waterbody	Node Name	Calibration & Design Event Initial Elevation	
		May 5th, 2020 Rainfall	100-yr Runoff
Masterman	CBC-2a	954.52	954.54
South School Section	GSL-12a	970.96	969
Lynch Lake	GSL-14a	1008	1006.44
Goggins	GSL-20a	970.99	968.87
Plaisted	GSL-7a	970.67	968.53
Unnamed Bass	KPL-1	984.23	981.8
Bass	KPL-2	954.33	953.24
Unnamed Bass	KPL-5	961.39	958.2
Kismet E	KPL-6a	943.61	942.72
Pat	KPL-7	944.27	942.43
Long	LL-20	890.04	890.61
Jackson	LL-22	889.9	890.61
McKusick	McK-18	854.26	855.18
Unnamed Benz	UBC-1	977.86	974.02
Benz	UBC-5f	954.78	954.82
Wood Pile	WKL-3	968.88	967.74
Kimbro	WKL-4	934.04	930.92

2.6.2 Downstream Boundary Condition

The downstream boundary of the model is the St. Croix River. For the 100-year and 10-year modeled return periods, the 100-year and 10-year St. Croix River elevations were used. These were obtained from the Washington County Flood Insurance Study (FIS) Report. As shown in Table 7, the DNR Ordinary High Water Level was used for the 2-year return period. A stage time series outfall condition was created based on the St. Croix River stage observed data for the 2020 calibration period and 2022 validation period (USACE – St. Paul District).

Table 7. Downstream Boundary Conditions

Modeled Return Period	Boundary Condition [ft NAVD 88]
2-year	680.46 (St. Croix DNR OHW)
10-year	688.00 (St. Croix River 10-year elevation)
100-year	693.00 (St. Croix River 100-year elevation)

2.7 Model Documentation

The flexibility for documentation allowed in the model enables transparency of the methods used to parameterize and calibrate the model. Two examples of this are linked plan sheets and photos to model elements that display the base data for which the model was constructed, as well as the ability to keep references to the initialized soil parameters in the model while using calibration coefficients to adjust them. Because of this, the purpose of this report is to explain the approach used to update the H&H model and present results, rather than include detail on parameters for which details are already well documented in SWMM5 literature and also included in the parameter lookup tables within the model.

In order to communicate pertinent information and instructions to the model user, the model Title Panel includes notes specific to the following topics:

- Naming standard for all model elements to be adhered to for future model changes;
- Base model scenarios included and to be updated for future model changes;
- Instructions on how to alter and run additional model simulations;
- Summary of permitted development included in the 2024 model update; and

3 MODEL CALIBRATION

Input parameters were adjusted to calibrate the model to the 2020 growing season. This period was selected based on the following factors:

- Exhibited long durations of both high and low flows in the creek;
- Included several back-to-back rainfall events;
- High-quality DNR Lakefinder data captured several distinct peaks during rainfall events, reinforcing the calibration process and confirming the model's ability to reflect dynamic hydrological responses.

An automated calibration process was implemented using custom scripts developed with the built in PCSWMM Python graphical user interface and its pcpy package. The calibration approach employed a genetic algorithm, an optimization method based on natural selection principles that evolves a set of potential solutions over multiple iterations to determine optimal parameter values. Calibration was performed in two stages. The first stage focused on calibrating runoff volume by adjusting subcatchment hydrologic parameters such as impervious area, pervious depressional storage, surface roughness, and infiltration conductivity. The seepage conductivity of storage nodes representing 17 lakes was also calibrated to ensure the simulated runoff volume matched observed lake level data during the growing season of a wet year. A population size three times the number of calibrated parameters was used with each run consisting of 10 generations. In the second stage, hydraulic parameters, including catchment slope and flow length, were refined to accurately capture flow routing and timing during significant rainfall events. The custom calibration script automated parameter adjustments and analysis, ensuring that the process was documented, repeatable, and flexible enough to allow simultaneous adjustments of multiple parameters. This iterative calibration refined the model's ability to simulate both runoff volume and flow timing, accurately representing the watershed's hydrologic behavior.

3.1 Observed Data

The primary observed data used in model construction and calibration include:

- Climate data (e.g. rainfall, temperature, wind speed)
- Lake level measurements
- Stream flow monitoring

3.1.1 Climate data

Meteorological data required for the project was acquired from the BCWD weather station at Stillwater Public Works, and an Automated Surface Observing Systems (ASOS) station located near the city of Stillwater, MN. Data from these stations were used to generate the climate file and included measurements of air temperature, relative humidity, solar radiation, and wind speed. This high quality, continuous data set provided reliable and localized meteorological conditions for our modeling efforts, ensuring that the simulation accurately reflects the region's climate.

3.1.2 Seasonal Variation

The version of the SWMM engine used (OpenSWMM 5.1.912) allows for varying certain hydrologic parameters seasonally by applying monthly multipliers ("Time Patterns"). In this effort, two parameters were chosen for seasonal variation: pervious area depressional storage (DSPerv) and Green-Ampt conductivity (Conduct). The DSPerv multiplier is intended primarily to reflect the change in storage due to leaf growth and senescence, while the Conduct multiplier is intended to reflect the change in soil infiltration capacity due to freezing and thawing. Values were calibrated for spring and fall months. Since simulations were run for April-October, no calibration for the winter months was performed.

Table 8: Seasonal Variation Multipliers

	Multiplier	
Month	DSPerv	Conduct
Jan	N/A	N/A
Feb	N/A	N/A
Mar	N/A	N/A
Apr	0.5	0.5
May	0.75	0.9
Jun	1	1
Jul	1	1
Aug	1	1
Sep	1	1
Oct	0.75	1
Nov	N/A	N/A
Dec	N/A	N/A

3.2 Lake Level Calibration

Data was downloaded from the DNR's Lake Finder website for all lakes within the District that were found to have observed lake level data. A total of 17 lakes had sufficient observed data during the calibration and validation periods, and these locations are listed along with calibration statistics in Table 9 below. The lake level measurements are generally taken in weekly to monthly intervals, and so they are suitable for calibrating to the general trend of lake level over a season but are poorly suited for calibrating to sub-weekly spikes in lake level, as from a large storm event. These spikes tend to be more dramatic in lakes with constructed outlet structures and are often missed entirely in the observed dataset. Conversely, this lack of detail is of much less concern in landlocked or semi-landlocked basins, where lake level drawdown time following a storm is often less dramatic. In addition to adjustments to the hydrologic parameters, the storage nodes' seepage conductivity was calibrated to match the observed lake level drawdown rates. From 2019 to 2024, lake levels have consistently decreased, and so seepage conductivity was optimized to reflect this trend. This parameter was critical to the calibration process and was precisely adjusted to ensure that the model accurately captured the observed drawdown behavior.

The Nash-Sutcliffe Efficiency (NSE) quantitatively describes the accuracy of hydrologic models. It is calculated by interpolating between computed results to the time steps of observed data values and then uses the computed results and observed data to calculate error functions. While values between 0 and 1 are generally viewed as acceptable, the closer this value is to 1, the more confident one can be in the predictive power of the model. As Table 9 displays, the simulated lake level prediction accuracy varies, with some achieving greater than 0.75, which is considered very good to excellent. Those with relatively low NSE values can be due to:

- Systematic Bias in Prediction – Such as for Plaisted (GSL-7a), Bass (KPL-2), and Jackson WMA (LL-22), where the model consistently, or for a duration of the simulation, overestimates or underestimates lake levels, NSE penalizes systematic errors heavily, leading to a lower score.
- Temporal Lag in Predictions – Such as for Kismet (KPL-6a), Long (LL-20), and Benz (UBC-5f), where the model predicts lake levels with a slight advance or delay (e.g., reacting to rainfall events too early or late), the NSE is lower because the timing of predictions is off.

The R-squared (R^2), also known as the coefficient of determination, widely used in statistics and regression analysis, measures the proportion of variance and overall correlation of the models ability to predict trends in the data. R^2 values range from 0 to 1, where 1 means the model explains all variability in the data, and 0 means it explains none. R^2 values are within acceptable ranges with values greater than 0.6 for all but Jackson WMA (LL-22).

Lacking accurate rainfall data for the northern portion of the District may be an explanation for how the model evaluation deviates from observed. In addition to systemic bias and temporal lag, lower statistical fit of the data for the developed portions of the watershed may be explained by the complexity of hydraulic system interactions with other waterbodies, such as the connection of Long Lake to Jackson WMA, with multi-stage outlet structures and wetland in between. Figures depicting each lake calibration are included in Appendix A.

Table 9: Lake Level Calibration Statistics

Lake Name	Node Name	DNR ID	NSE	R^2	Outlet Elev. (ft)
Masterman	CBC-2a	82012600	0.74	0.77	954.6
South School Section	GSL-12a	82015100	0.85	0.97	967.8
Lynch Lake	GSL-14a	82004200	0.75	0.82	1007.5
Goggins	GSL-20a	82007700	0.88	0.97	970.5
Plaisted	GSL-7a	82014800	0.26	0.92	966.4
Unnamed	KPL-1	82012800	na[1]	na[1]	988.5
Bass	KPL-2	82012300	-0.15	0.8	973.0
Unnamed (Bass)	KPL-5	82012400	0.52	0.95	974.0
Kismet	KPL-6a	82033400	0.2	0.92	943.5
Pat	KPL-7	82012500	0.57	0.95	950.5
Long	LL-20	82002100	0.47	0.92	889.8
Jackson WMA	LL-22	82030500	0.01	0.31	888.8
McKusick	McK-18	82002000	0.04	0.84	854.0
Unnamed (July Ave)	UBC-1	82031800	0.70	0.99	984.5
Benz	UBC-5f	82012000	0.40	0.91	954.5
Wood Pile	WKL-3	82013200	0.75	0.81	972.0
Kimbro	WKL-4	82034900	0.62	0.93	935.5

1: KPL-1 2020 water level data only included one observation.

3.3 Stream Flow Calibration

Stream flow calibration was performed at three locations with monitored flow data for 2014:

1. Brown's Creek at Manning Avenue;
2. Brown's Creek at Stonebridge Trail; and
3. Brown's Creek at Highway 96 (WOMP).

Flow calibration followed lake level calibration, since predicted lake discharges influence flow volume in the Brown’s Creek. As discussed in 2.2.7, aquifer parameters are not included in the model, therefore baseflow was added as several points along the Creek as a constant inflow with a temporally-variant multiplier based on the observed, non-storm observed flow (i.e. a monthly time pattern).

The new culvert crossing at Manning Avenue was constructed in 2021, between the calibration period in 2020 and the validation period in 2022. As a result, flow calibration and validation were performed using different culvert structures and parameters, which poses a challenge since calibration parameters derived before the modification may not fully apply during validation. An additional challenge was observed during two rainfall events on May 27 and June 29. Although the peak flows were similar, the recession periods recorded at the final two monitoring stations in the model were slower than those observed in the field, a discrepancy attributed to lateral flow contributions from Lake McKusick outflow channel. Moreover, observed lake levels for Lake McKusick were higher than the model predictions from August to October, remaining slightly above the outlet elevation. Considering the low rainfall during this period along with infiltration and evaporation losses, the likely causes of these discrepancies are the lack of groundwater simulation in the model and potential variations in rainfall distribution, as the available rain gauge data may not fully represent the entire watershed. As shown in Table 10, stream flow calibration statistics show the predictive power of the model to be relatively good, making it sufficient for individual event predictions.

Validation of streamflow was performed for May through October 2022. Overall, the validation results suggest that the model is over-predicting runoff, likely due to over-calibration for 2020 conditions and the construction of a culvert crossing at Manning’s Ave. However, peak flows in the calibration or the validation runs are very close to observed data, which is ideal for design storm simulations.

Table 10: Stream Flow Calibration Statistics

Location Name	Link Name	NSE	R^2
Manning Avenue	CBC-11_188-187	0.81	0.84
Stonebridge Trail	LBC-5a1_065-064	0.15[1]	0.73
WOMP	LBC-6_023-022	0.44	0.76

1:See discussion on Temoral Lag in Predictions Lake Level Calibration Section 3.2

4 DESIGN STORM SIMULATION

4.1 Precipitation

In 2013, The National Weather Service Hydrometeorological Design Studies Center released NOAA Atlas 14, Volume 8. This document supersedes precipitation frequency estimates contained in Technical Paper 40 and 49 for Minnesota. In 2015, NOAA developed the MSE3 MN type rainfall distribution for a dimensionless unit hydrograph to replace the NRCS Type II used in previous flood studies. The current 100-year 24-hour depth of 7.2 inches and also the 90% CI, which results in a 100-year 24-hour depth of 9.5 inches, are shown in Figure 7.

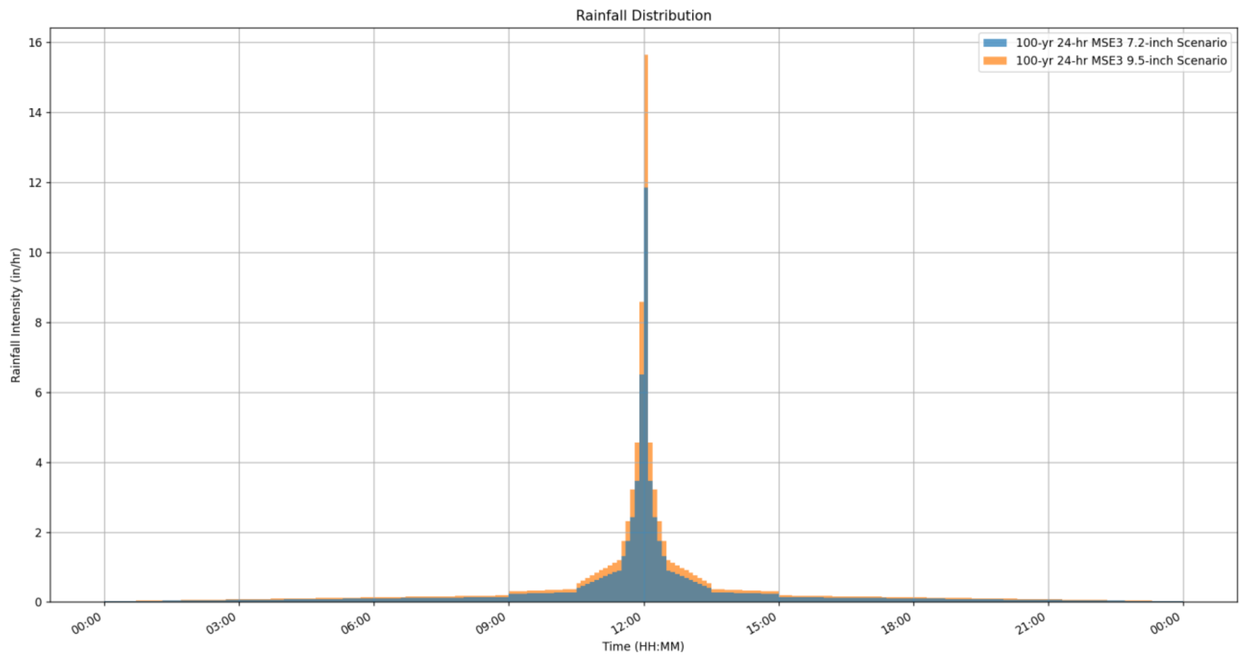


Figure 7: 100-Year 24-Hour Rainfall – Current versus 90% CI

4.2 Simulation Results Comparison

The model was run for both current and future (90% CI) 100-year, 24-hour storm scenarios. Under future conditions, the increased storm depth combined with higher rainfall intensity is expected to result in a higher peak surface water elevation. Figures in Appendix B presents the floodplain map for the entire watershed, and Appendix C provides a detailed examination of the top ten areas with the greatest increase in surface flooding under future conditions.

5 RECOMMENDATIONS & FUTURE ENHANCEMENTS

With the most recent LiDAR dataset released in 2024, the model has been refined to incorporate enhanced terrain details. Automation scripts were employed for both calibration and validation, and the hotstart file method was implemented to more accurately initialize soil conditions. These enhancements strengthen flood risk assessments and empower community partners with reliable hydrologic and hydraulic insights for collaborative projects. The BCWD H&H model is in high demand for development efforts across the District and can now be confidently shared as the most up-to-date resource. As listed below, the process of updating the model brought to light several opportunities for future enhancements of the model itself as well as for a future flood vulnerability assessment.

1. Revise subcatchment hydrologic parameters once the new land cover dataset becomes available (Anticipated in 2025-2026).

2. Conduct re-calibration for the newly constructed culvert crossing at Manning Avenue during a wet year to capture its impact on flow dynamics.

3. Incorporate comprehensive storm sewer data to better delineate flooding footprints in key urban areas.

4. Consider transitioning to 2D modeling for urban areas (e.g., Marketplace) to improve understanding of flood dynamics, evaluate sewer system performance and pipe capacity, and assess roadway overtopping depths.

5. Use the updated model to perform critical event analysis and evaluate social, environmental, and infrastructural impacts.

6. Share results with member communities and collaborate with local partners to review flood reduction opportunities and develop actionable strategies.

7. Coordinate with community partners to collect climactic data in or near the norther portion of the District (nearest stations are Forest Lake and Osceola).

8. More accurately account for groundwater contributions/losses from the system, potentially by statistical means (Vetting of SWMM Groundwater module found it does not suite the seasonal dynamic of creek and tributary reaches gaining and losing groundwater input depending on rainfall fluctuations).

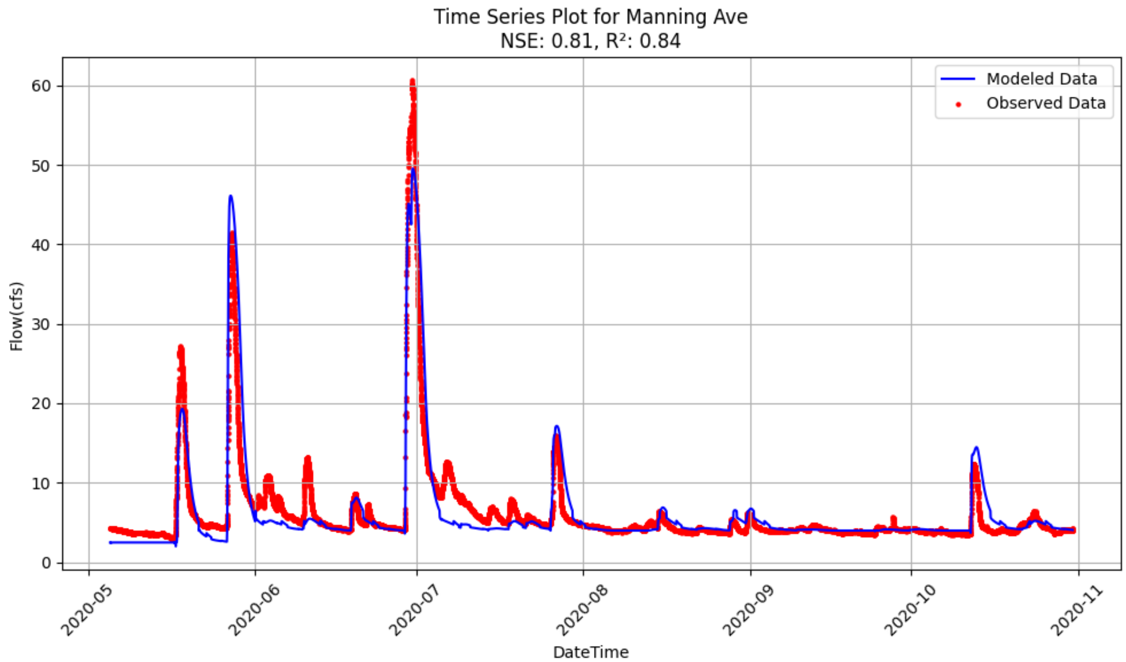
6 LITERATURE CITED

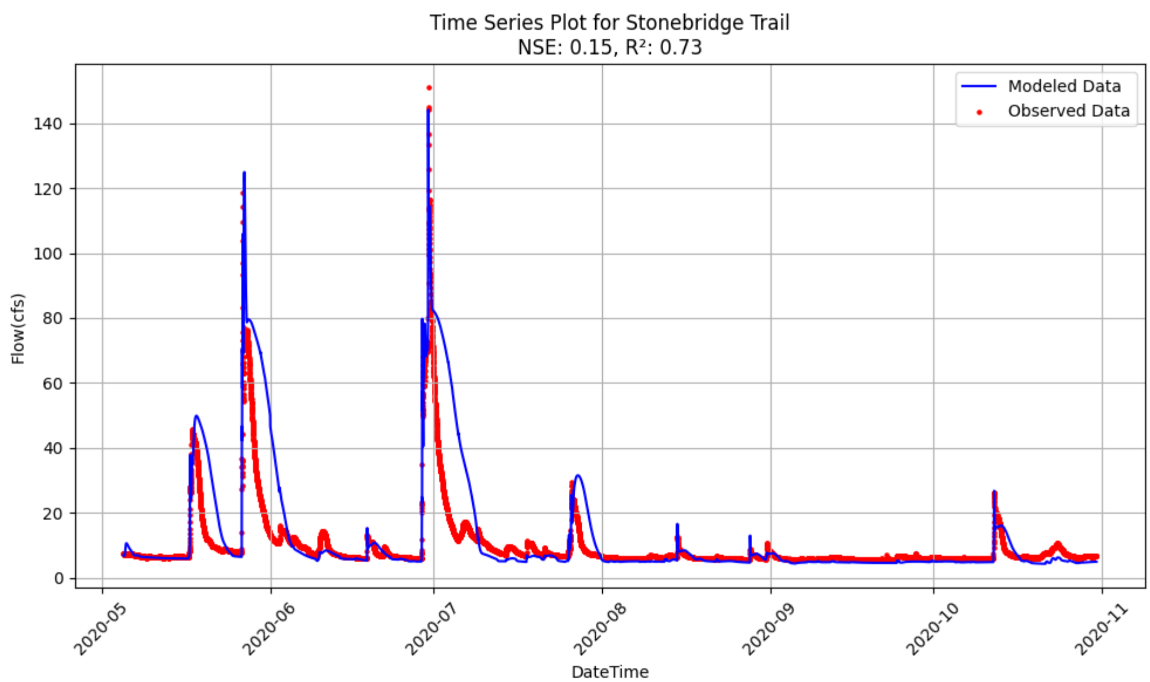
1. Emmons & Olivier Resources, Inc., and Computational Hydraulics International. 2014. Development of a Rural Stormwater Management Model to Manage Water Quality in Lake Huron Watersheds. Final Report. http://www.ruralstormwater.com/docs/Rural-Stormwater-Management-Model-Report-FINAL-low-res.pdf.
2. Chow, V.T., 1959, Open-channel hydraulics: New York, McGraw-Hill.
3. Rawls, W. J., Brakensiek, D. L. (1989). Estimation of Soil Water Retention and Hydraulic Properties. In: H. J. Morel-Seytoux (Ed.), Unsaturated Flow in Hydrologic Modeling.

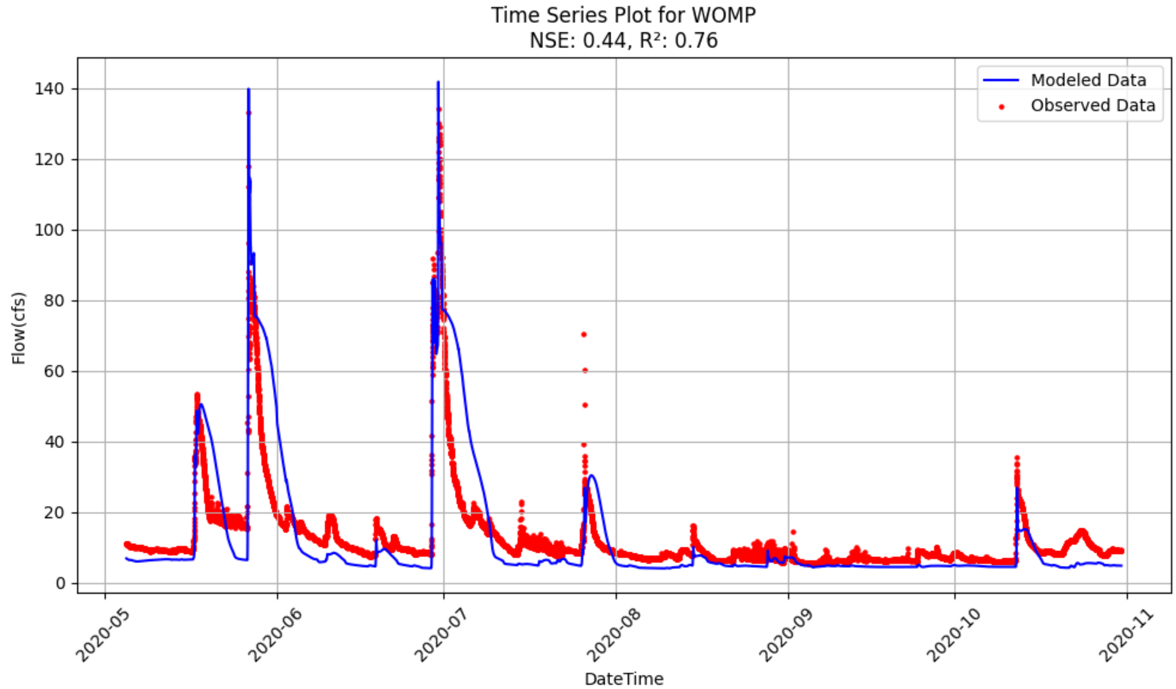
7 APPENDIX A: Model Calibration and Validation Graphical Plots

Appendix A includes calibration and validation graphical result plots at three flow monitoring sites and 17 lake level calibrations.

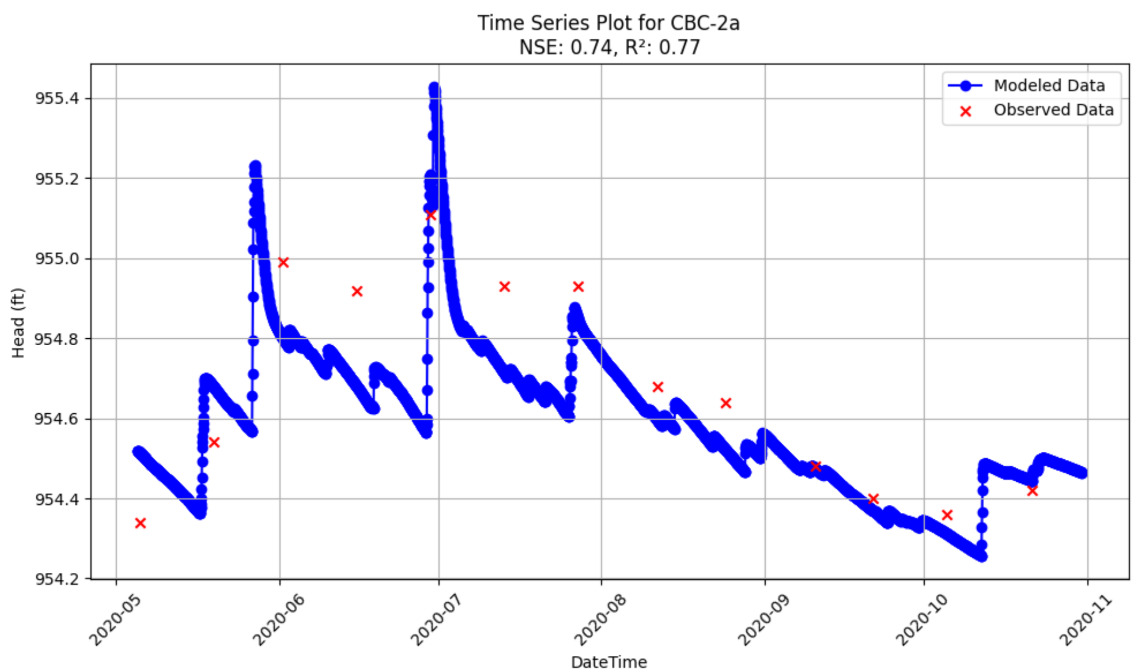
Flow Calibration – 2020

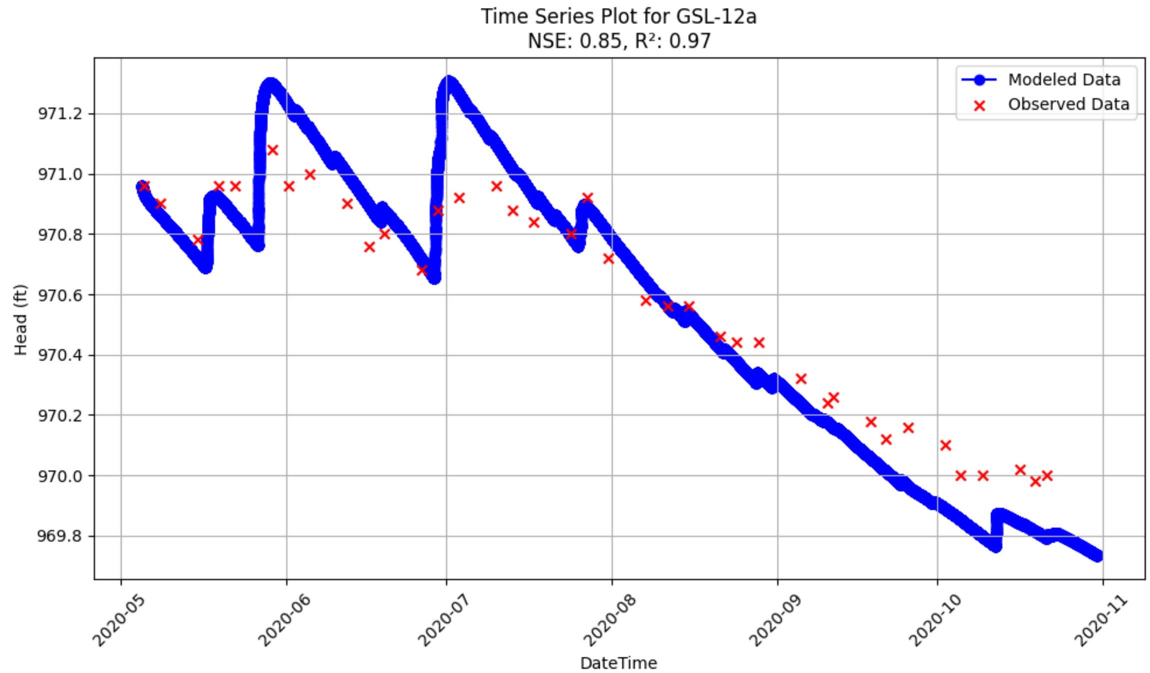






Lake Calibration – 2020




Time Series Plot for GSL-12a
NSE: 0.85, R²: 0.97
Modeled Data
Observed Data
Head (ft)
971.2
971.0
970.8
970.6
970.4
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970.0
969.8
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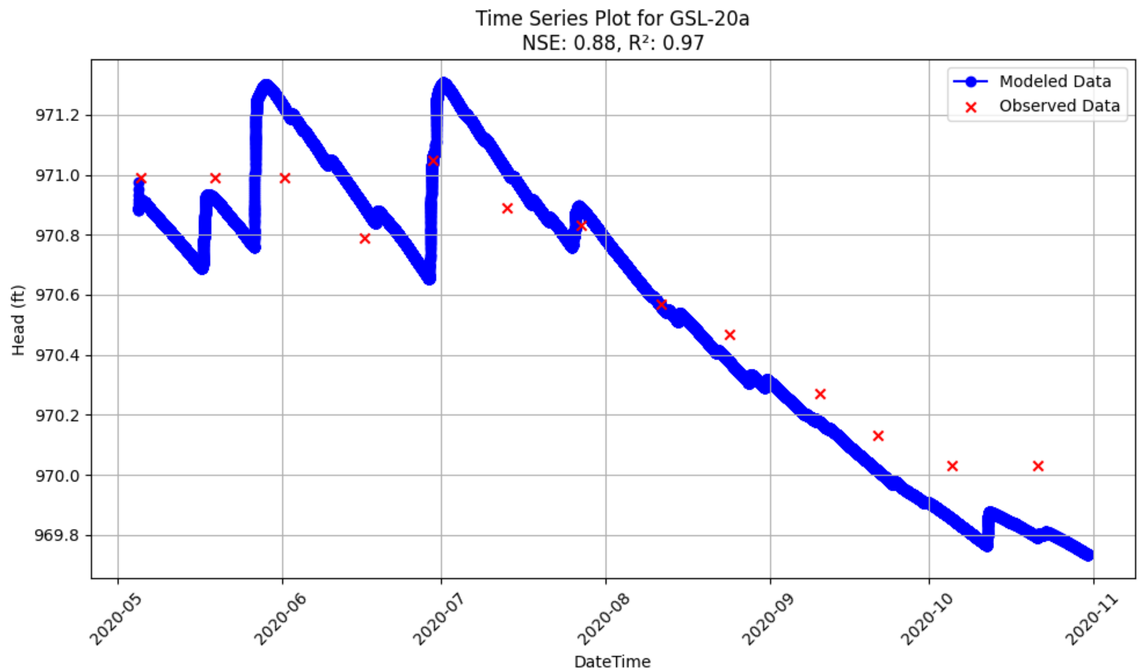
2020-10
2020-11
DateTime


Time Series Plot for GSL-20a
NSE: 0.88, R²: 0.97
Modeled Data
Observed Data
Head (ft)
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971.0
970.8
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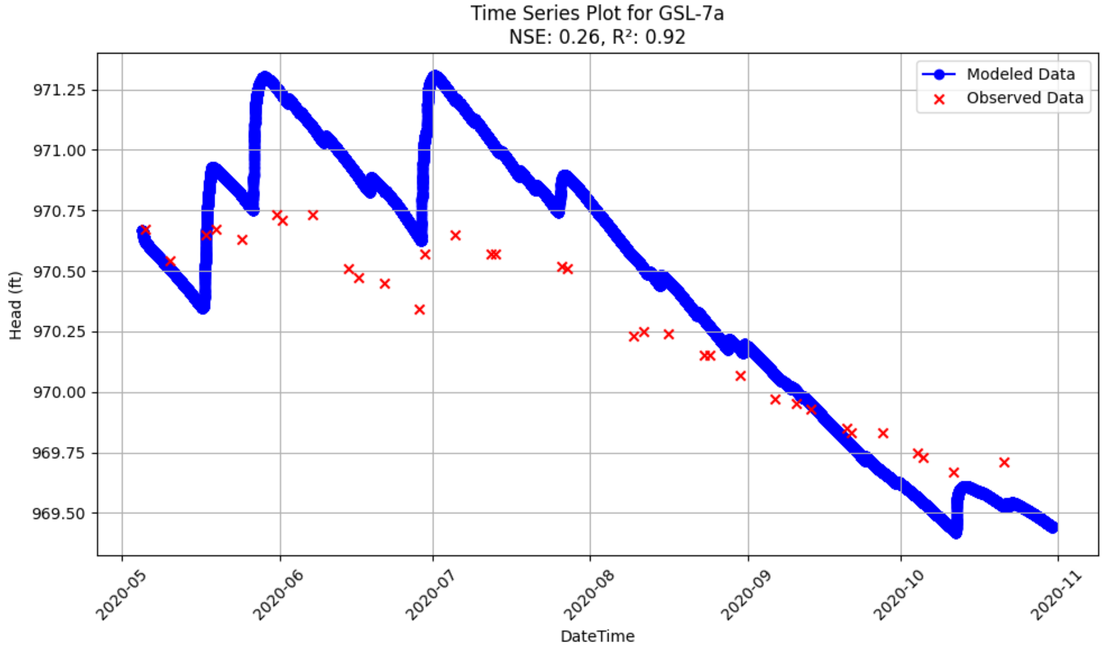
2020-10
2020-11
DateTime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Observed Data
Head (ft)
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971.00
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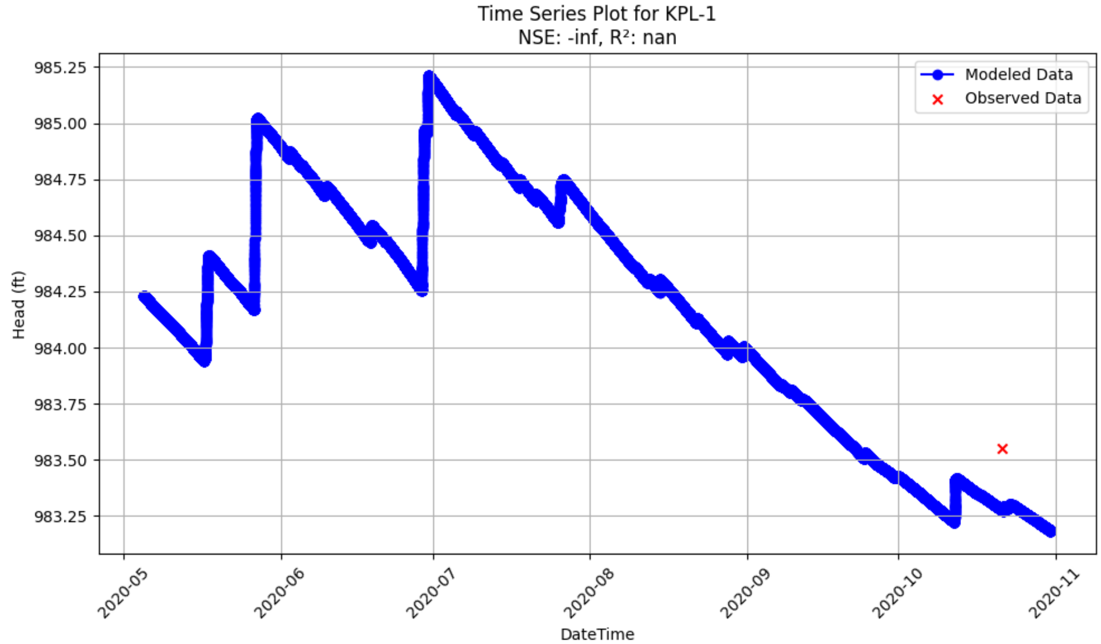
2020-09
2020-10
2020-11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Observed Data
Head (ft)
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985.00
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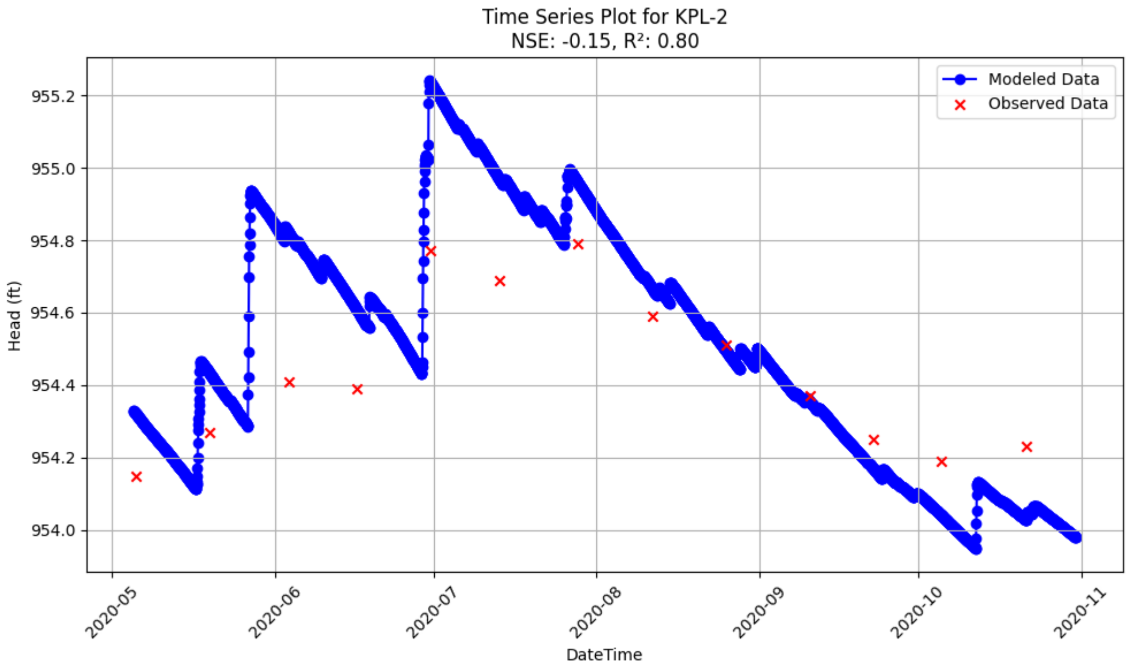
2020-10
2020-11


Time Series Plot for KPL-2
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Observed Data
Head (ft)
DateTime
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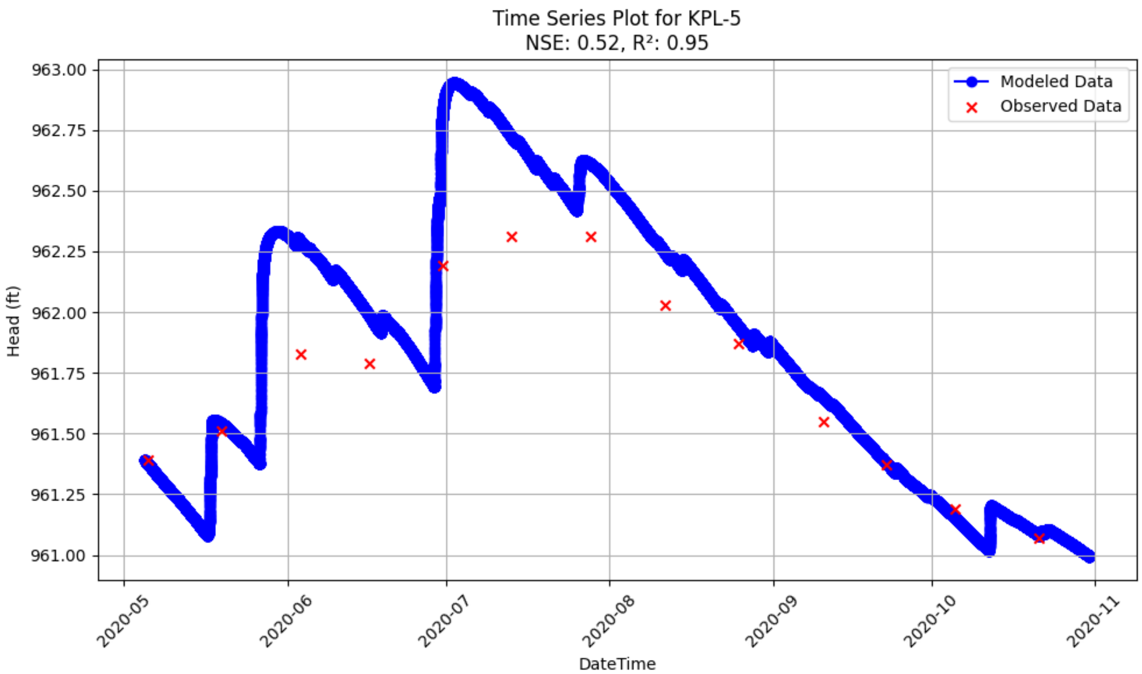
2020-09
2020-10
2020-11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Head (ft)
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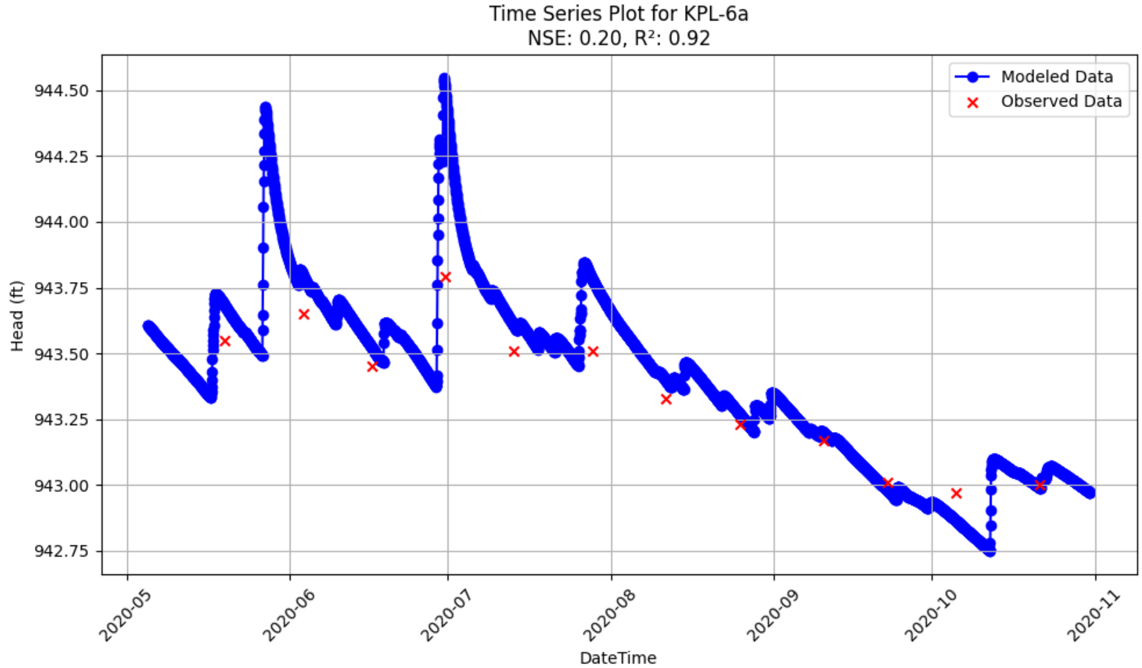
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Observed Data
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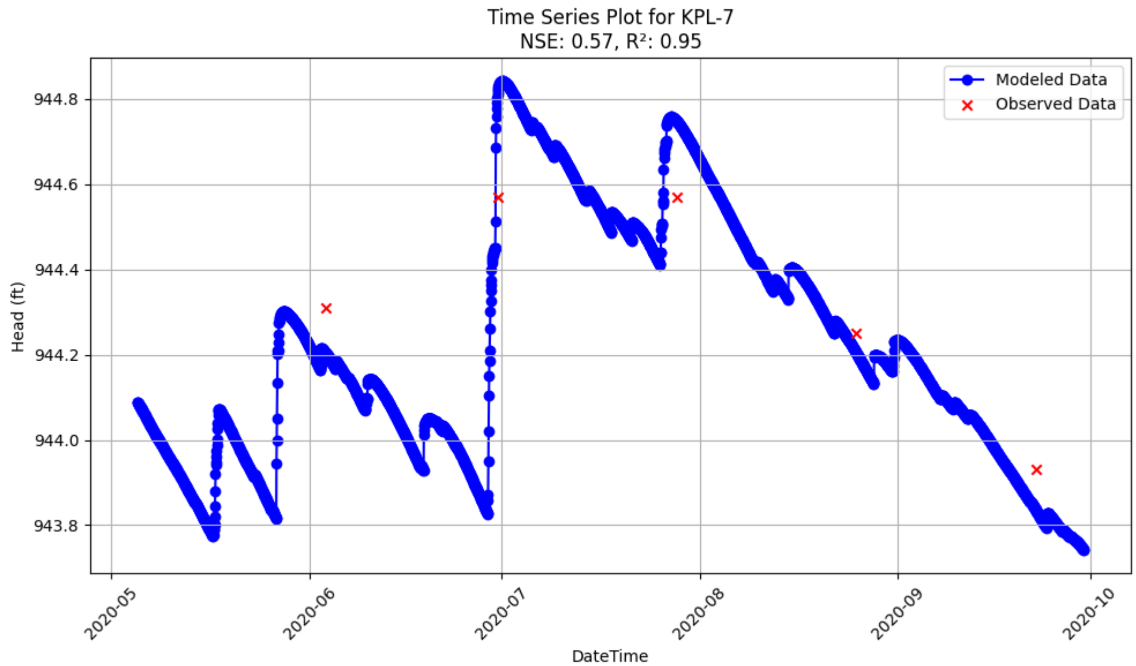
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Modeled Data
Observed Data
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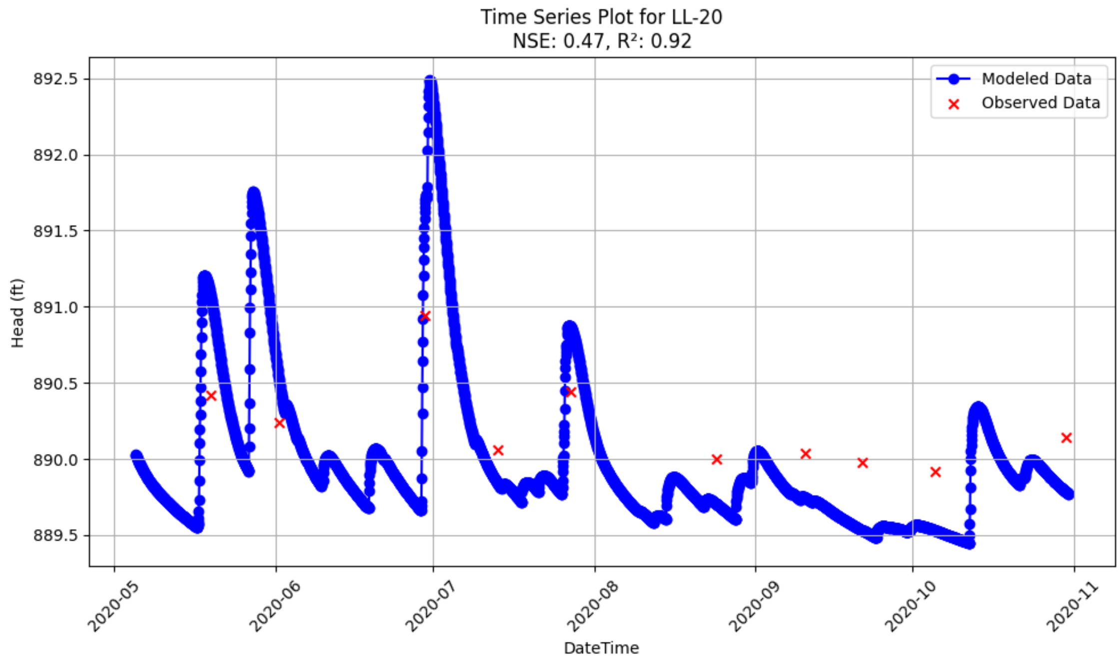
Time Series Plot for LL-20
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Modeled Data
Observed Data
Head (ft)
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892.0
891.5
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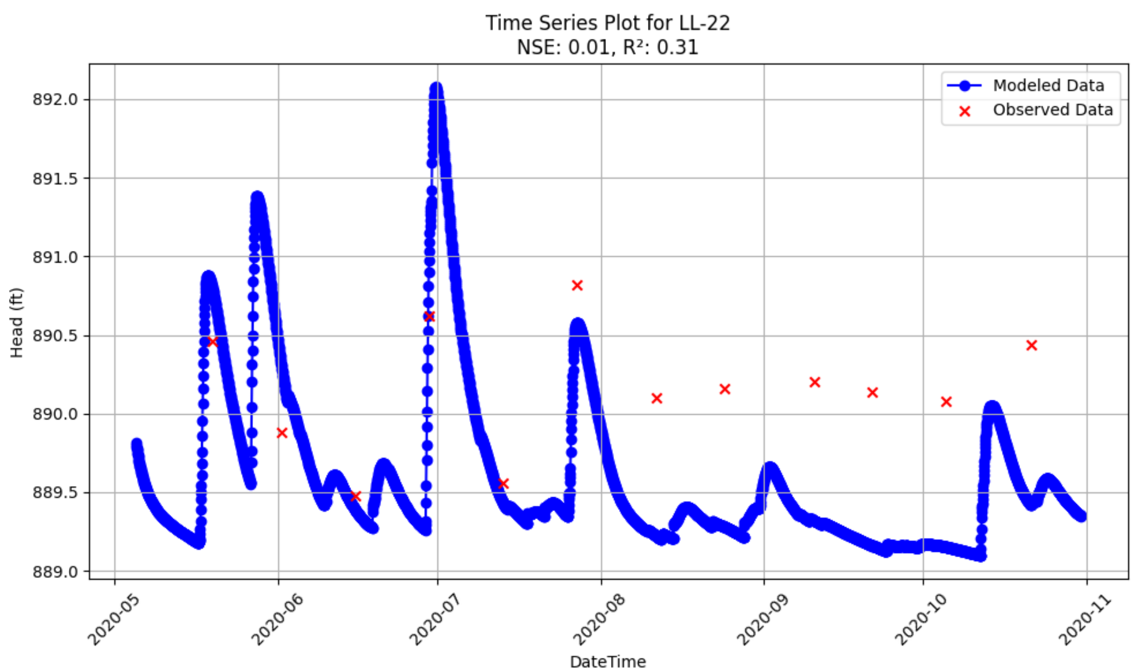
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Observed Data
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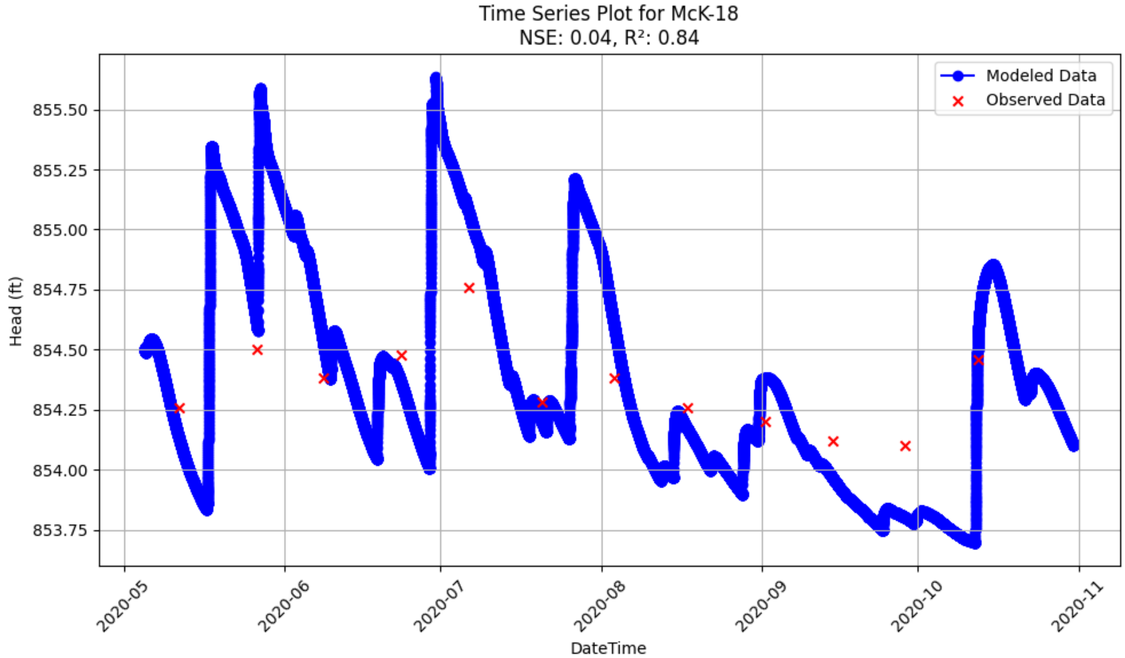
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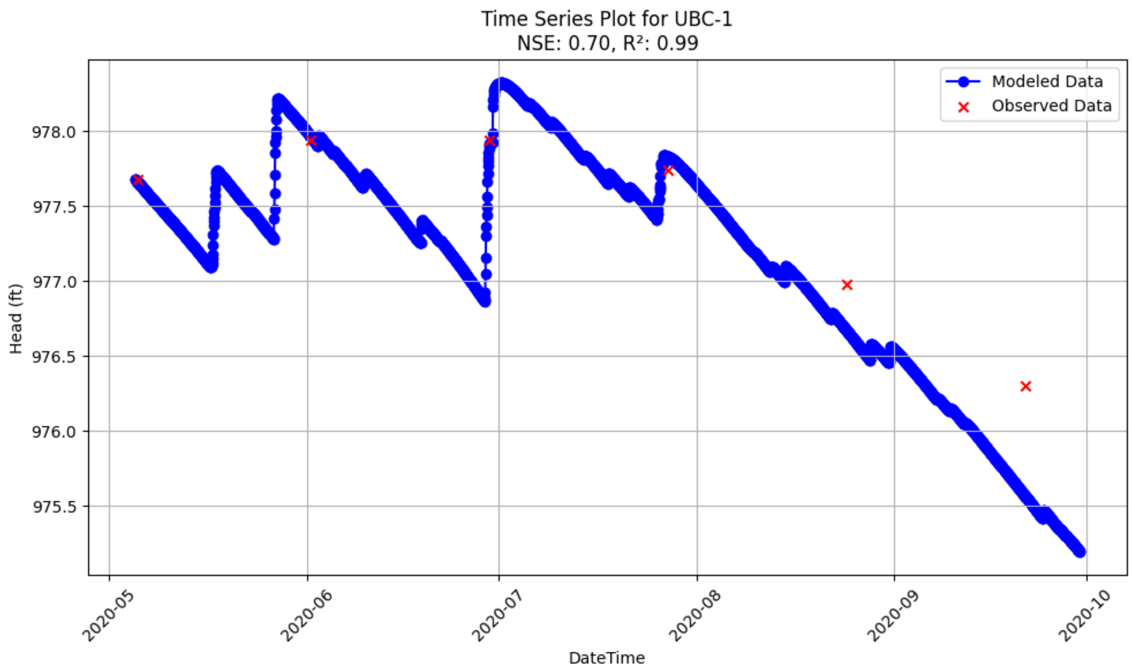
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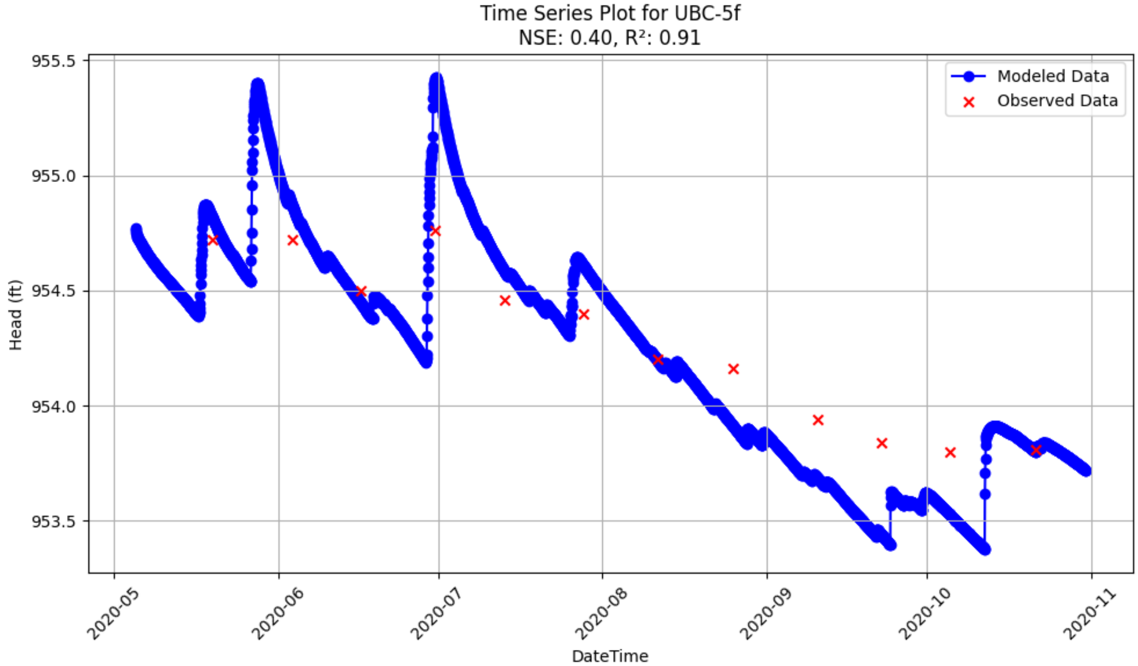
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Observed Data
Head (ft)
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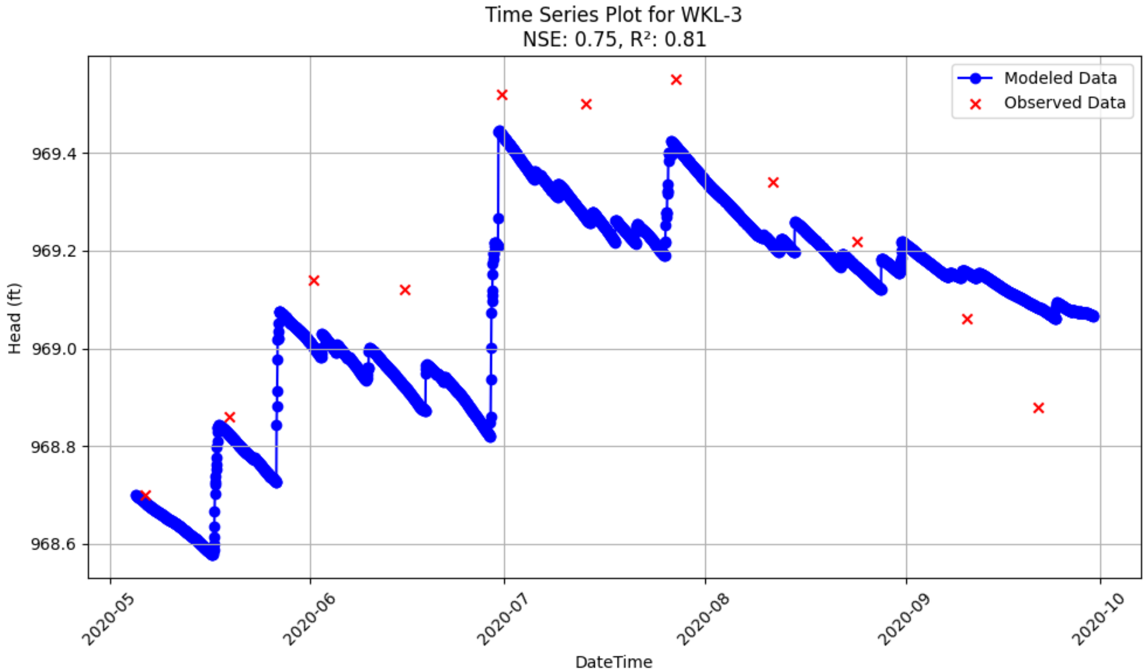
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Observed Data
Head (ft)
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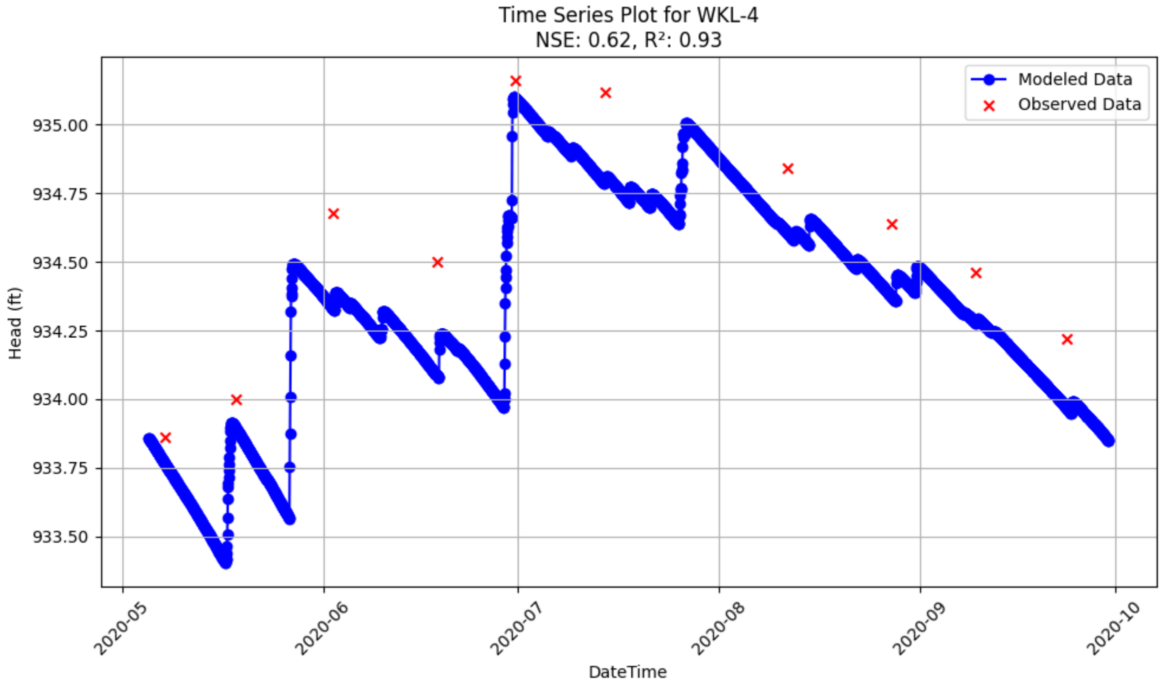
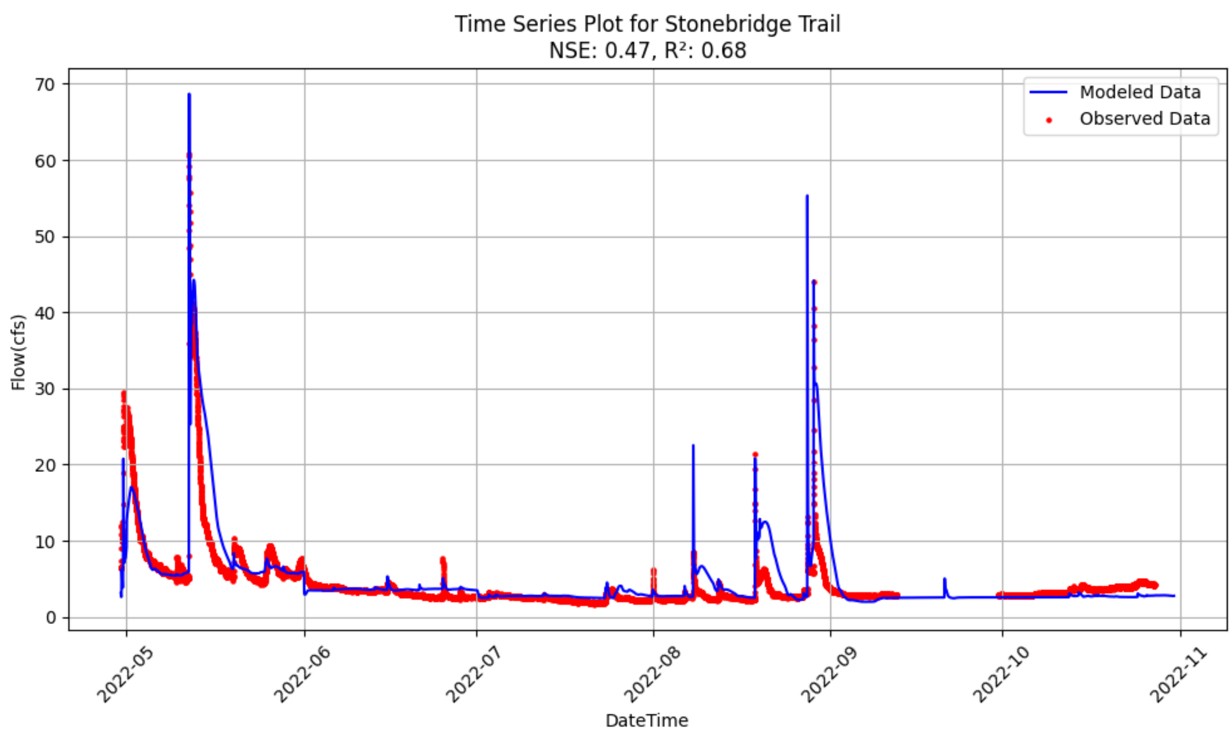
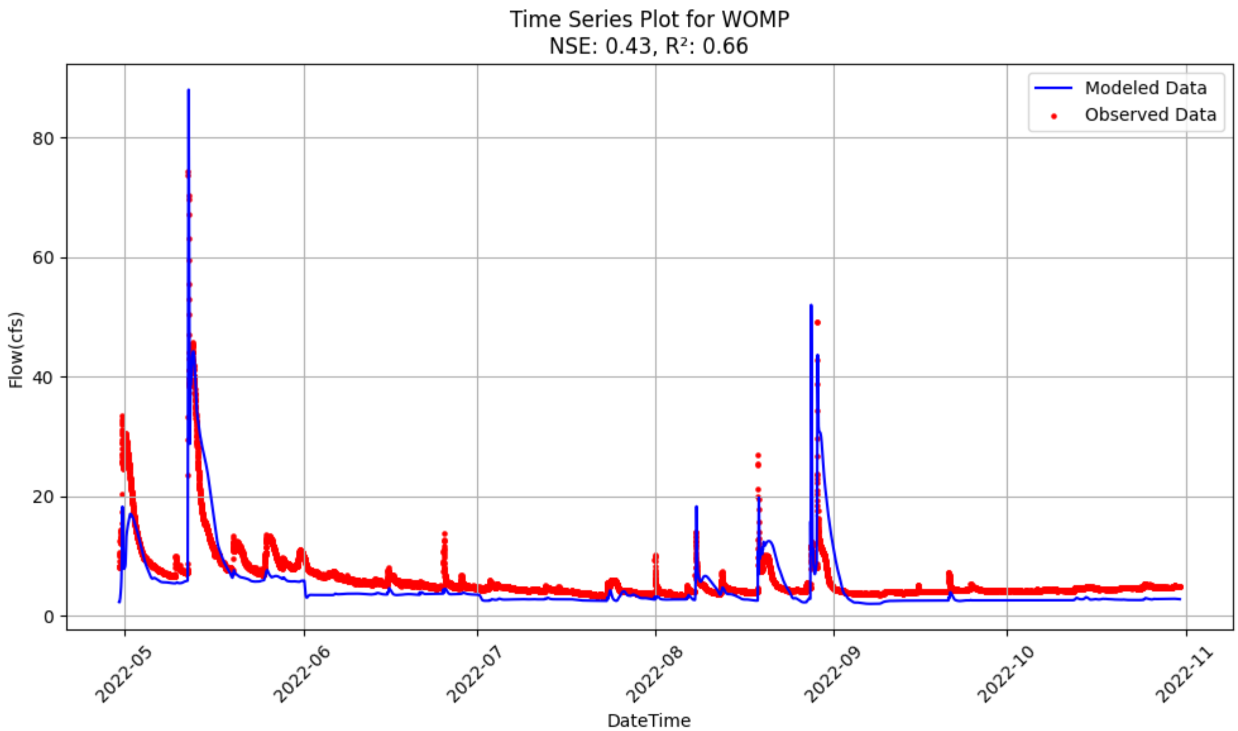
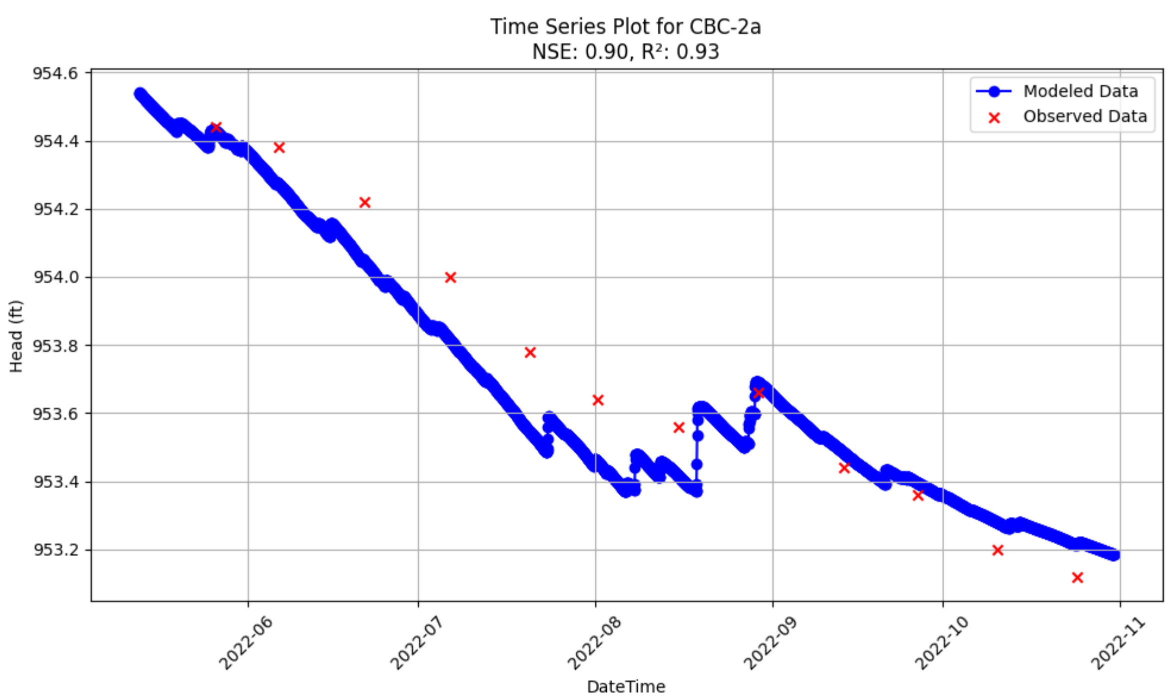


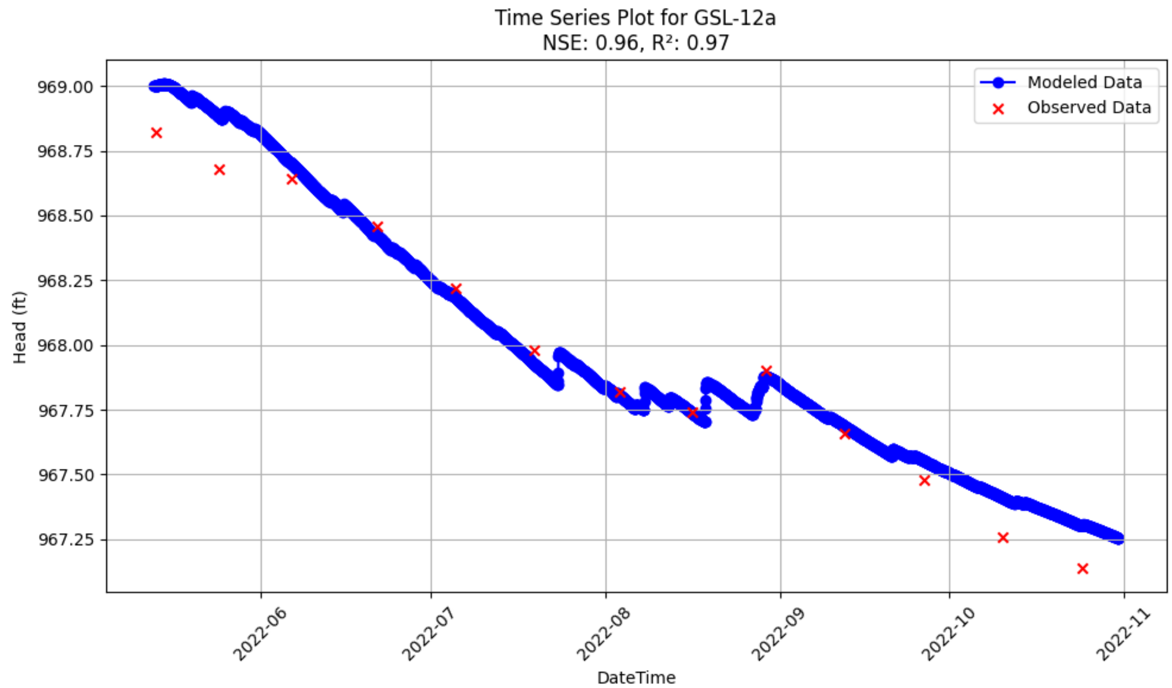
Flow Validation – 2022





Lake Validation – 2022

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Observed Data
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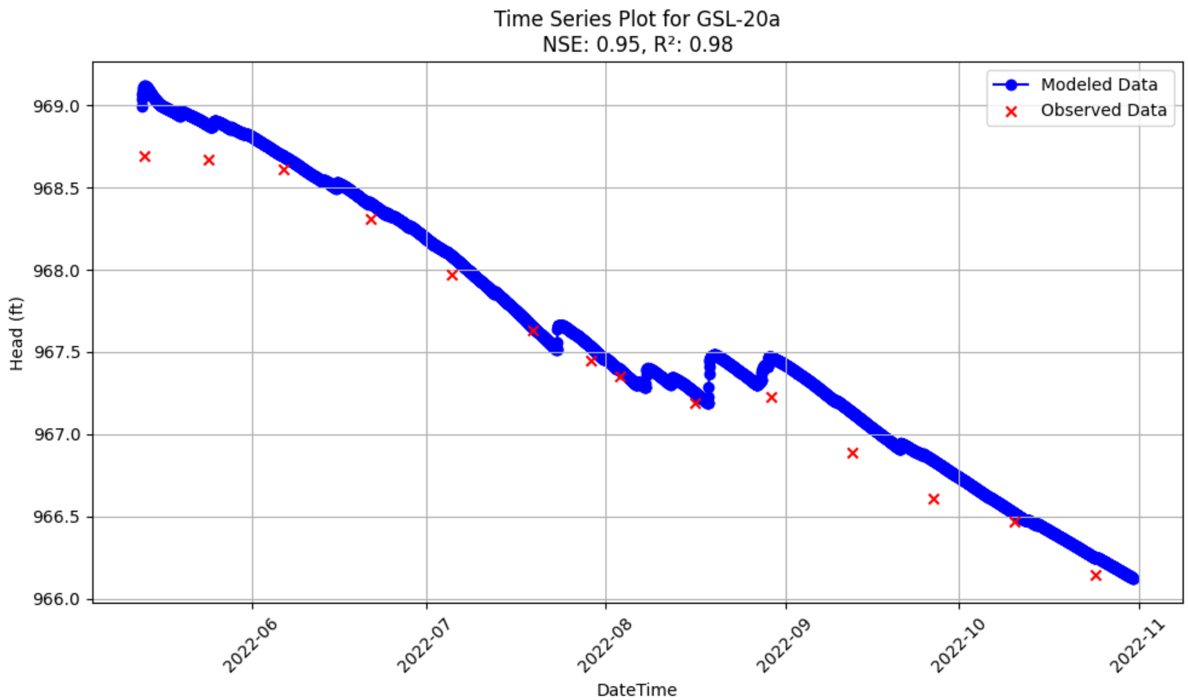
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Observed Data
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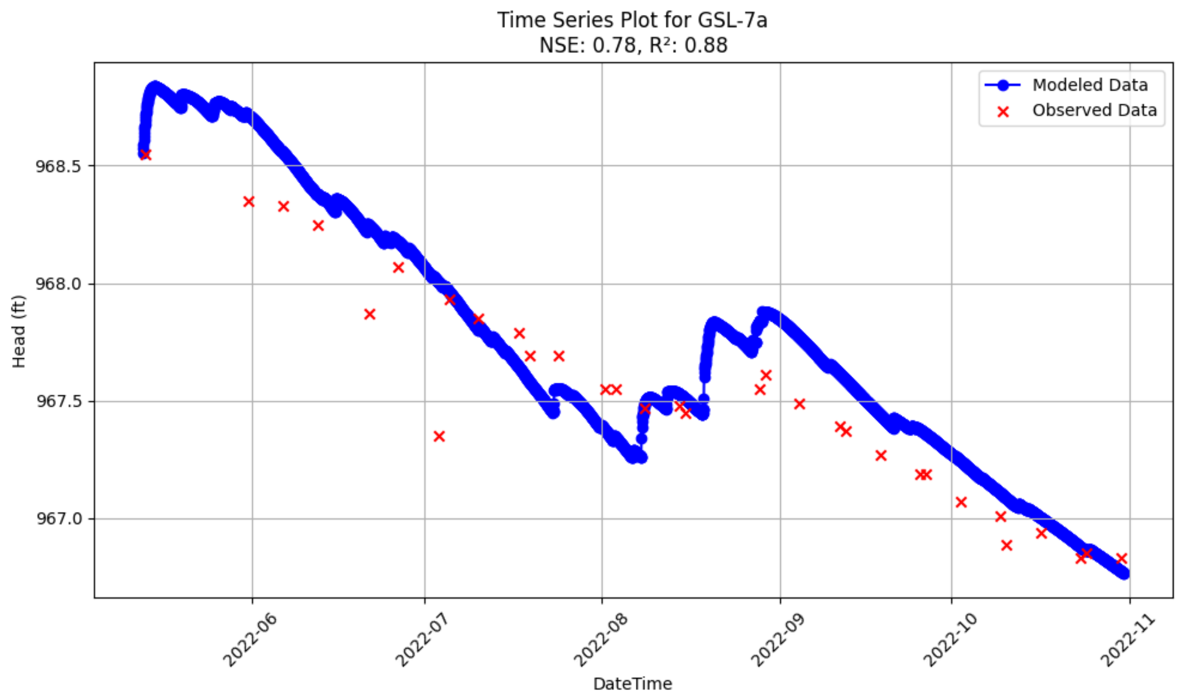
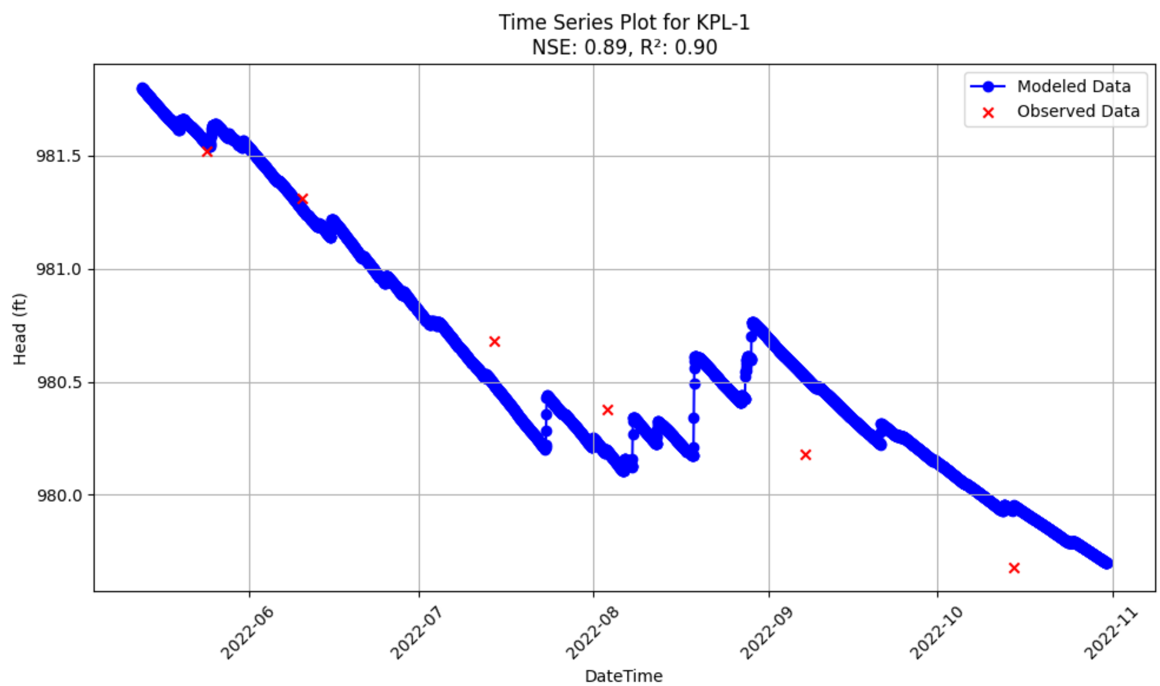
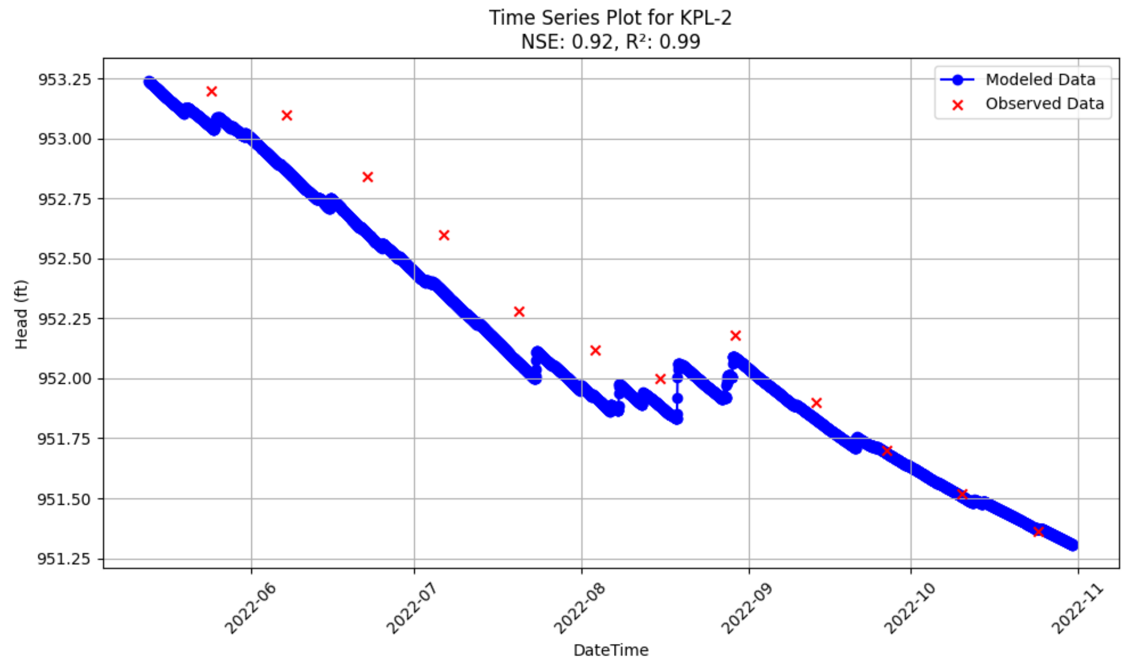
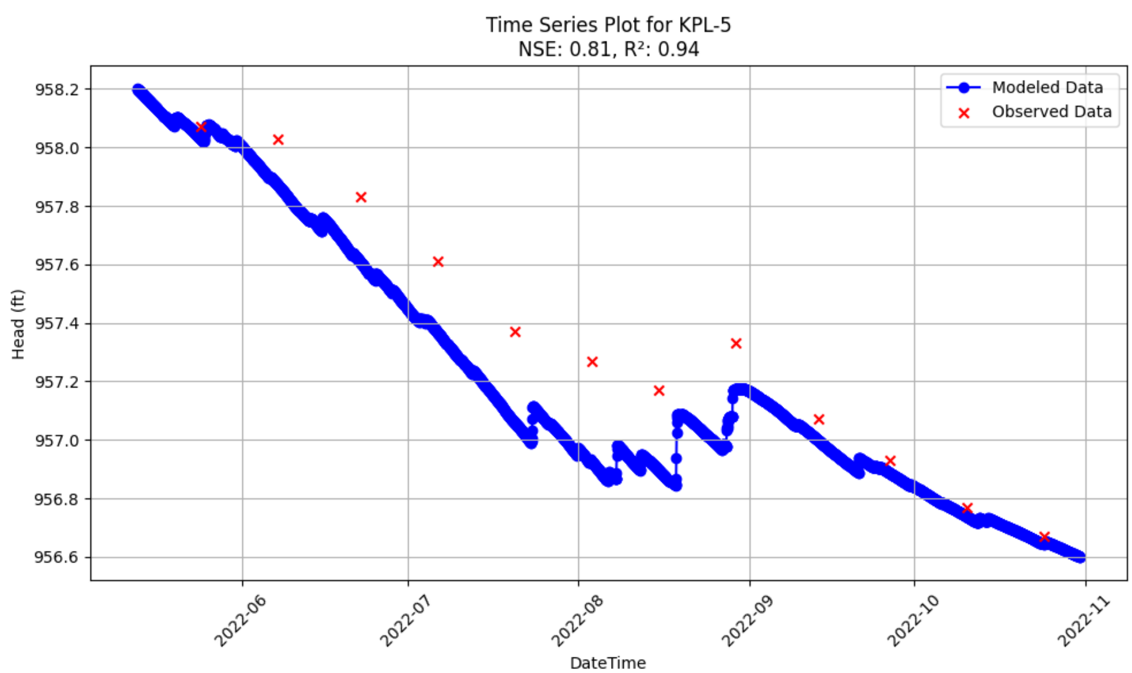
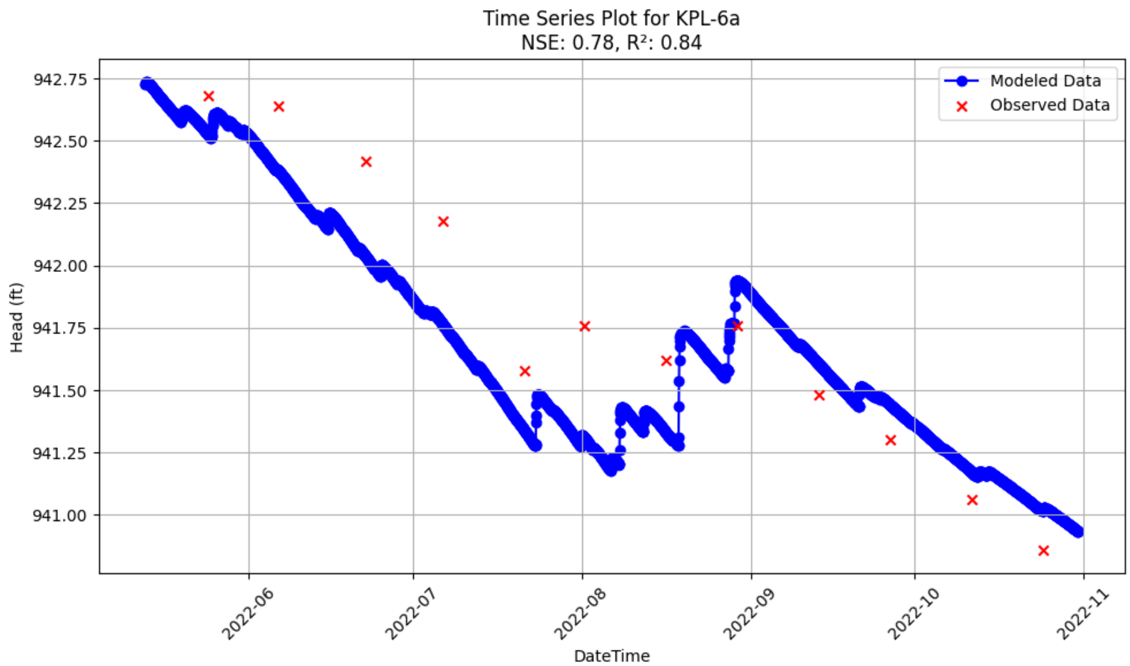
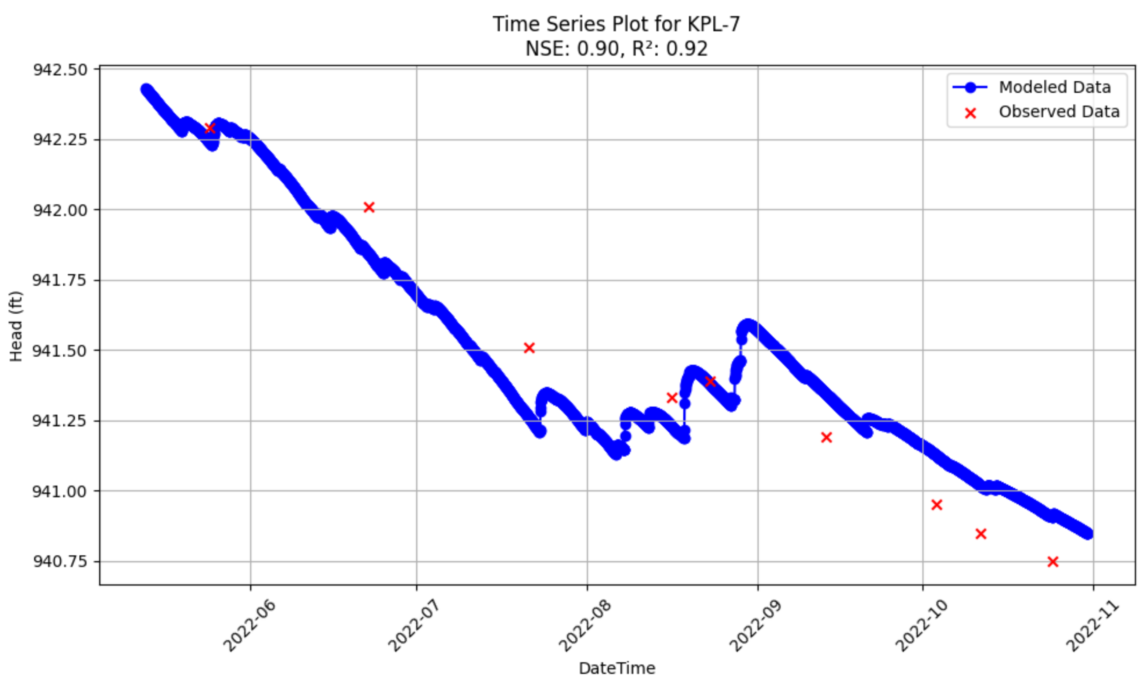

Time Series Plot for GSL-7a
NSE: 0.78, R²: 0.88
Modeled Data
Observed Data
Head (ft)
968.5
968.0
967.5
967.0
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime

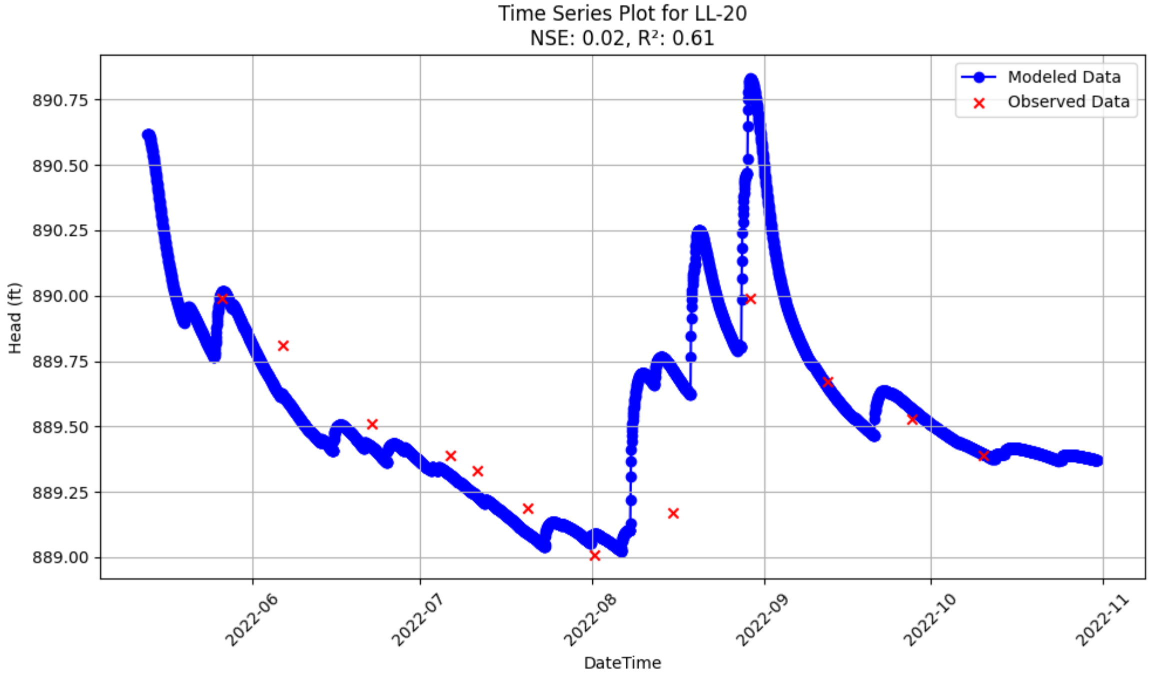

Time Series Plot for KPL-1
NSE: 0.89, R²: 0.90
Modeled Data
Observed Data
Head (ft)
981.5
981.0
980.5
980.0
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime

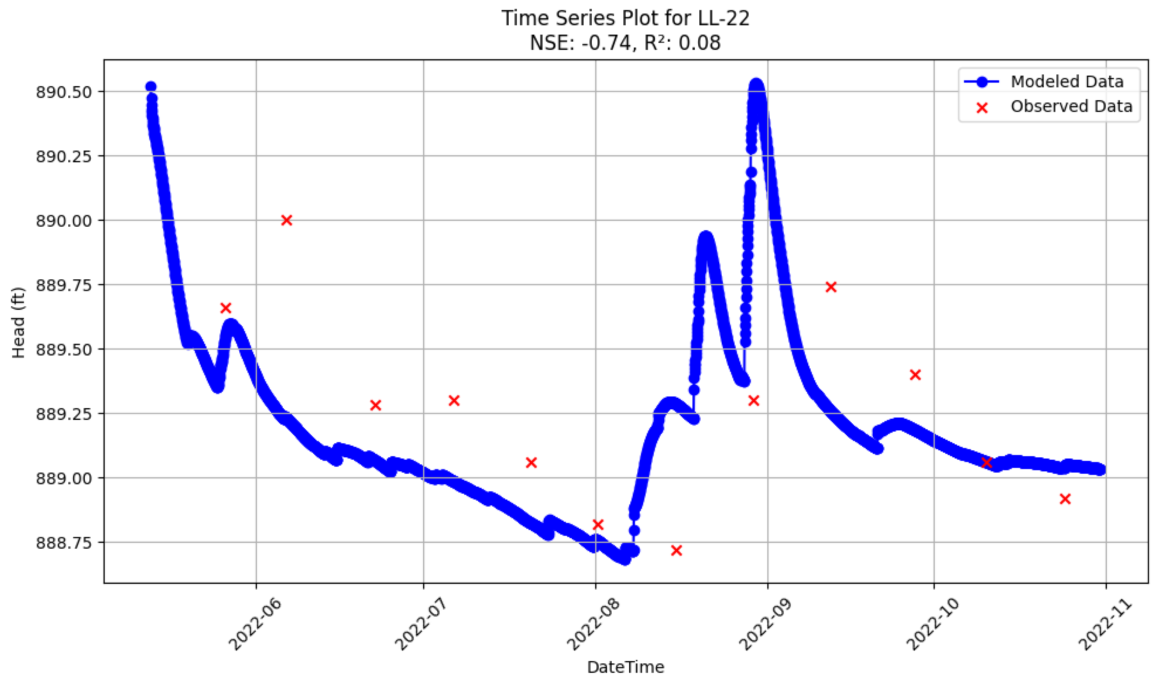

Time Series Plot for KPL-2
NSE: 0.92, R²: 0.99
Head (ft)
DateTime
Modeled Data
Observed Data
953.25
953.00
952.75
952.50
952.25
952.00
951.75
951.50
951.25
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11

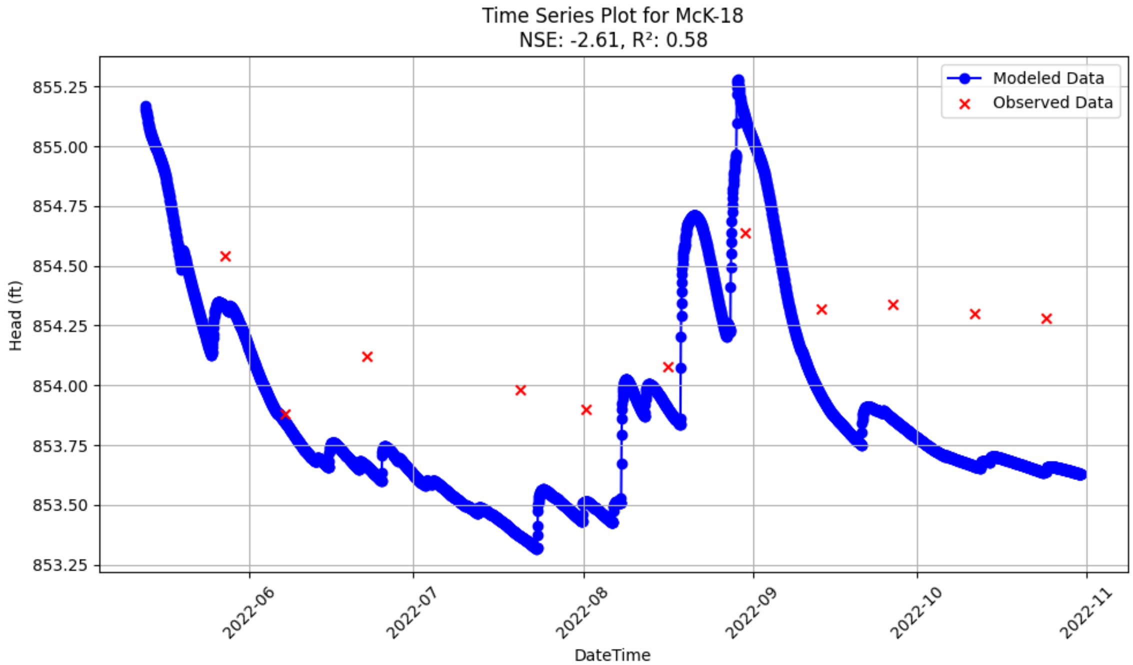

Time Series Plot for KPL-5
NSE: 0.81, R²: 0.94
Head (ft)
DateTime
Modeled Data
Observed Data
958.2
958.0
957.8
957.6
957.4
957.2
957.0
956.8
956.6
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11

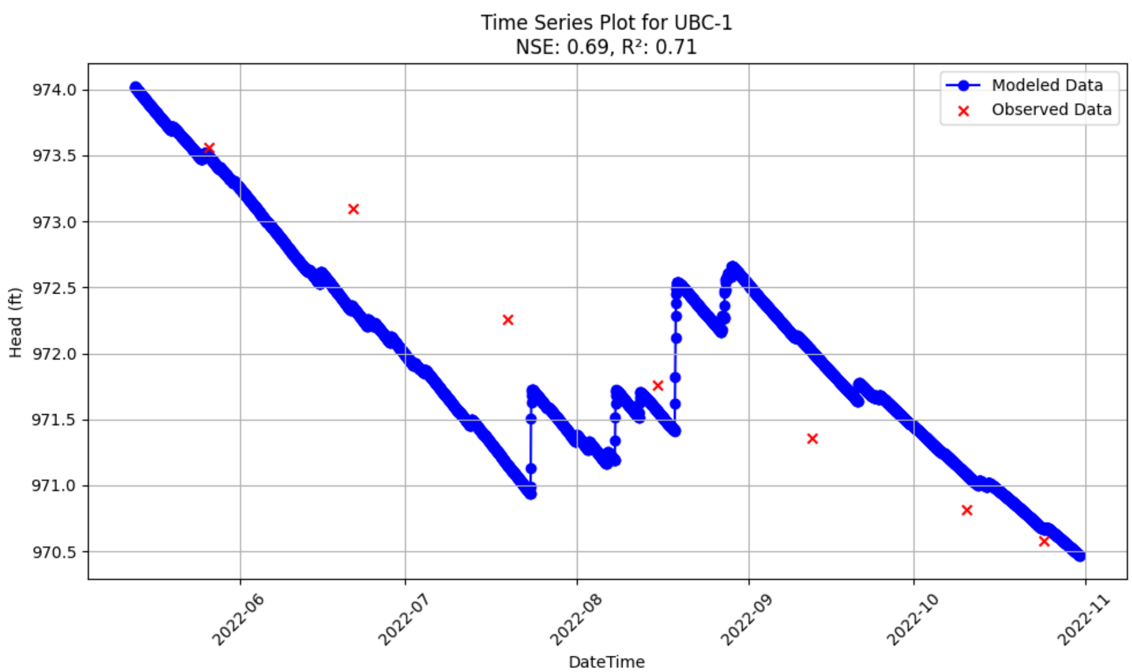

Time Series Plot for KPL-6a
NSE: 0.78, R²: 0.84
Modeled Data
Observed Data
Head (ft)
942.75
942.50
942.25
942.00
941.75
941.50
941.25
941.00
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime

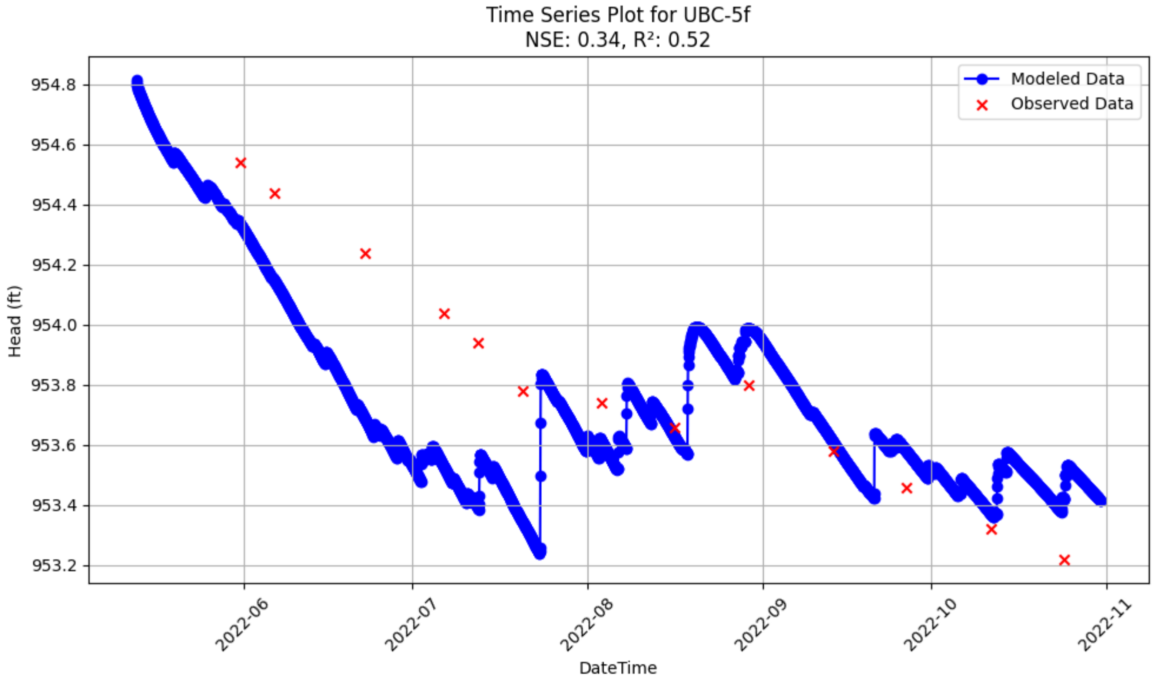

Time Series Plot for KPL-7
NSE: 0.90, R²: 0.92
Modeled Data
Observed Data
Head (ft)
942.50
942.25
942.00
941.75
941.50
941.25
941.00
940.75
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime

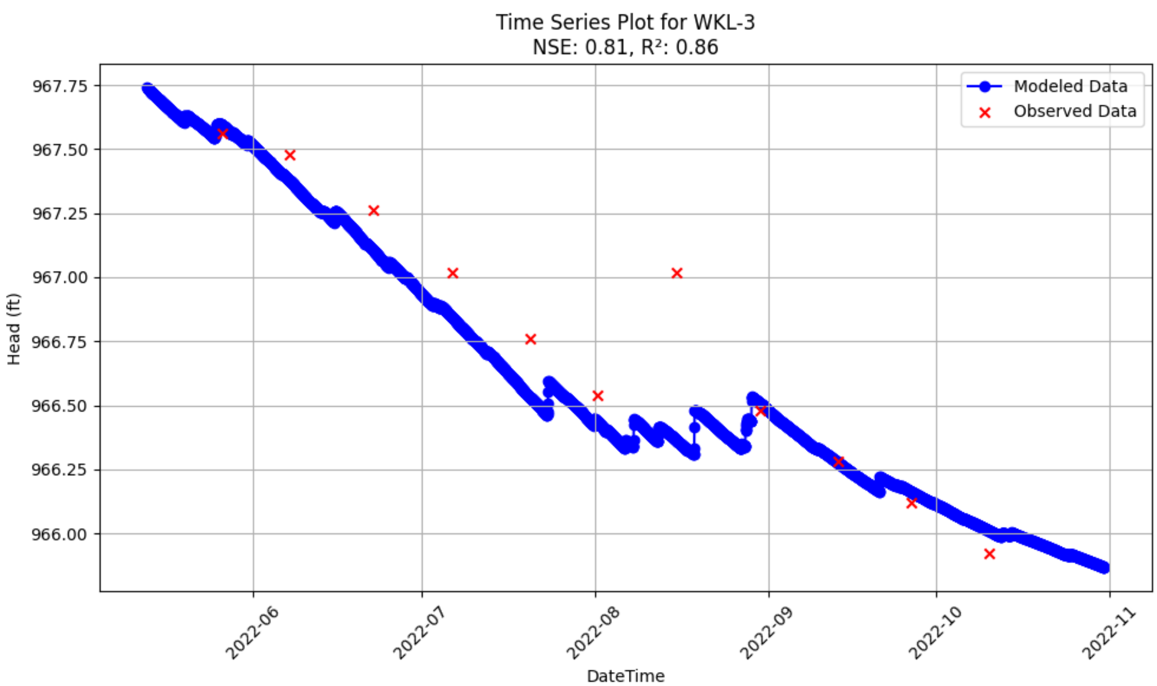

Time Series Plot for LL-20
NSE: 0.02, R²: 0.61
Modeled Data
Observed Data
Head (ft)
890.75
890.50
890.25
890.00
889.75
889.50
889.25
889.00
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime

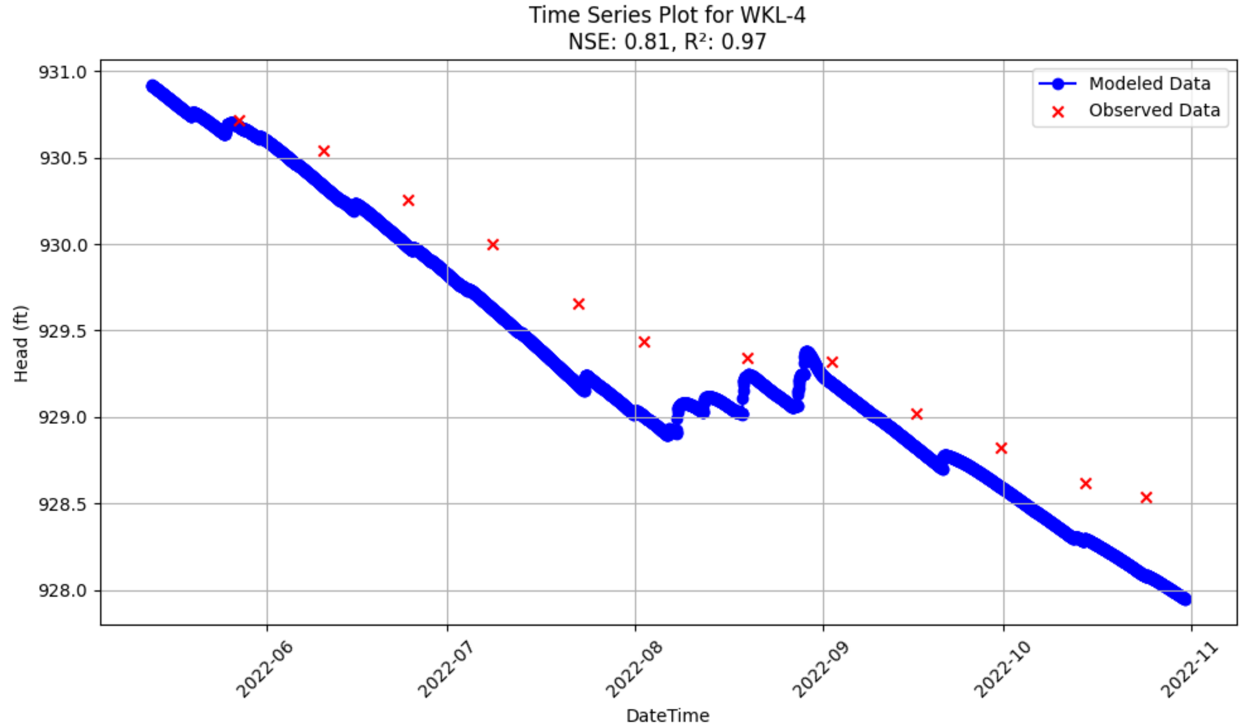

Time Series Plot for LL-22
NSE: -0.74, R²: 0.08
Modeled Data
Observed Data
Head (ft)
890.50
890.25
890.00
889.75
889.50
889.25
889.00
888.75
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime


Time Series Plot for McK-18
NSE: -2.61, R²: 0.58
Modeled Data
Observed Data
Head (ft)
855.25
855.00
854.75
854.50
854.25
854.00
853.75
853.50
853.25
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime


Time Series Plot for UBC-1
NSE: 0.69, R²: 0.71
Modeled Data
Observed Data
Head (ft)
974.0
973.5
973.0
972.5
972.0
971.5
971.0
970.5
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime

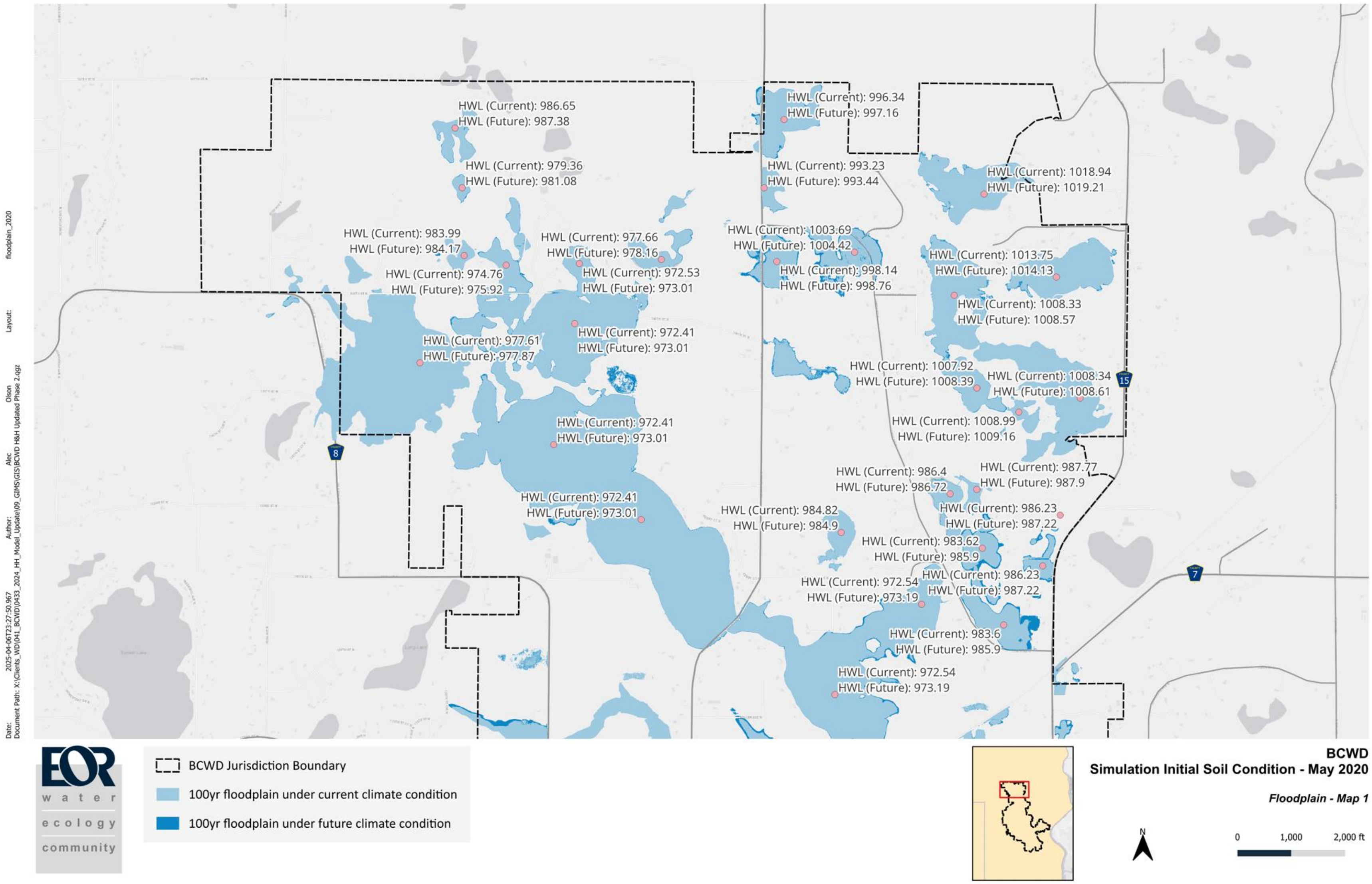

Time Series Plot for UBC-5f
NSE: 0.34, R²: 0.52
Modeled Data
Observed Data
Head (ft)
954.8
954.6
954.4
954.2
954.0
953.8
953.6
953.4
953.2
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime

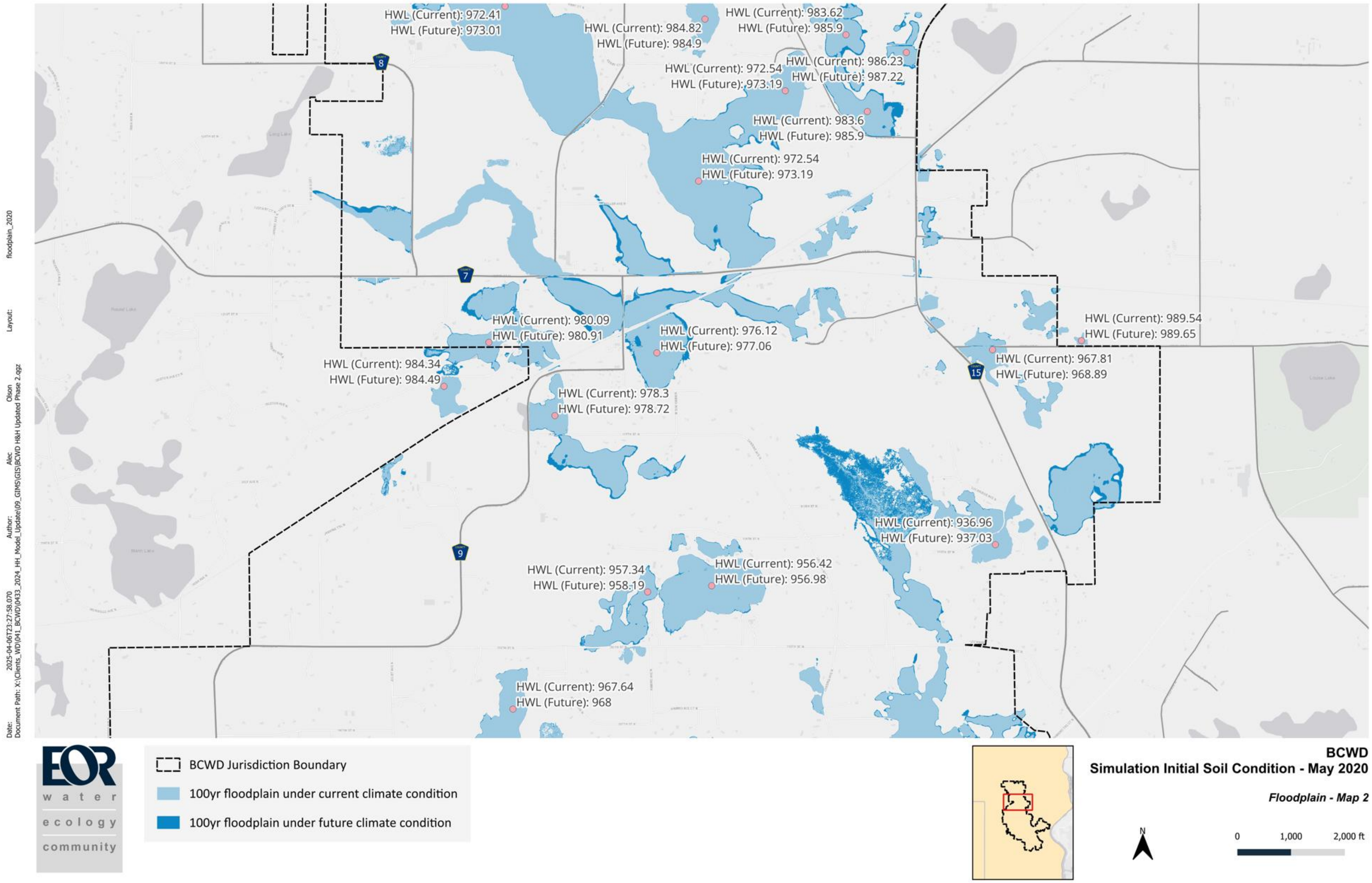

Time Series Plot for WKL-3
NSE: 0.81, R²: 0.86
Modeled Data
Observed Data
Head (ft)
967.75
967.50
967.25
967.00
966.75
966.50
966.25
966.00
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime

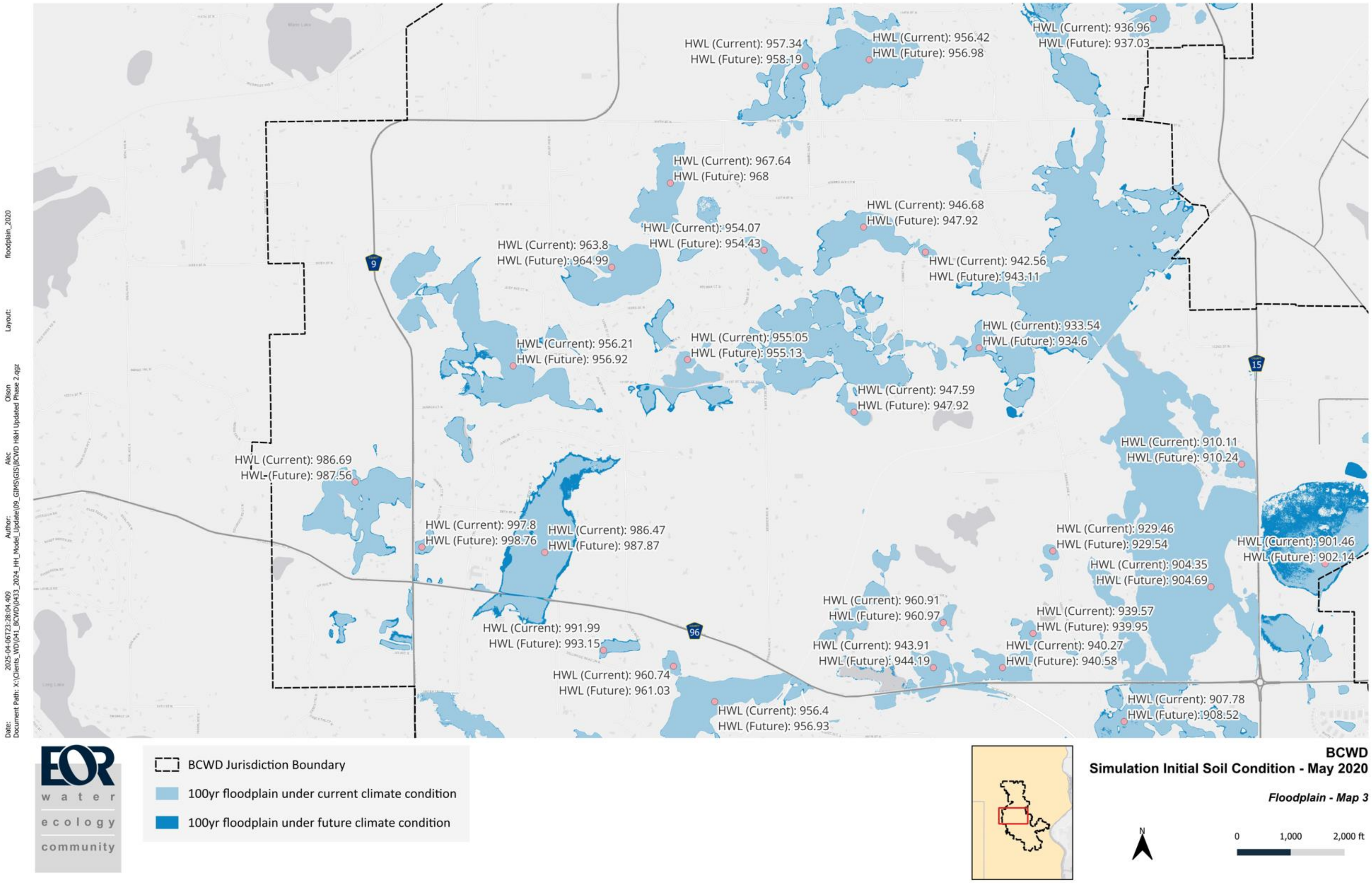

Time Series Plot for WKL-4
NSE: 0.81, R²: 0.97
Modeled Data
Observed Data
Head (ft)
931.0
930.5
930.0
929.5
929.0
928.5
928.0
2022-06
2022-07
2022-08
2022-09
2022-10
2022-11
DateTime

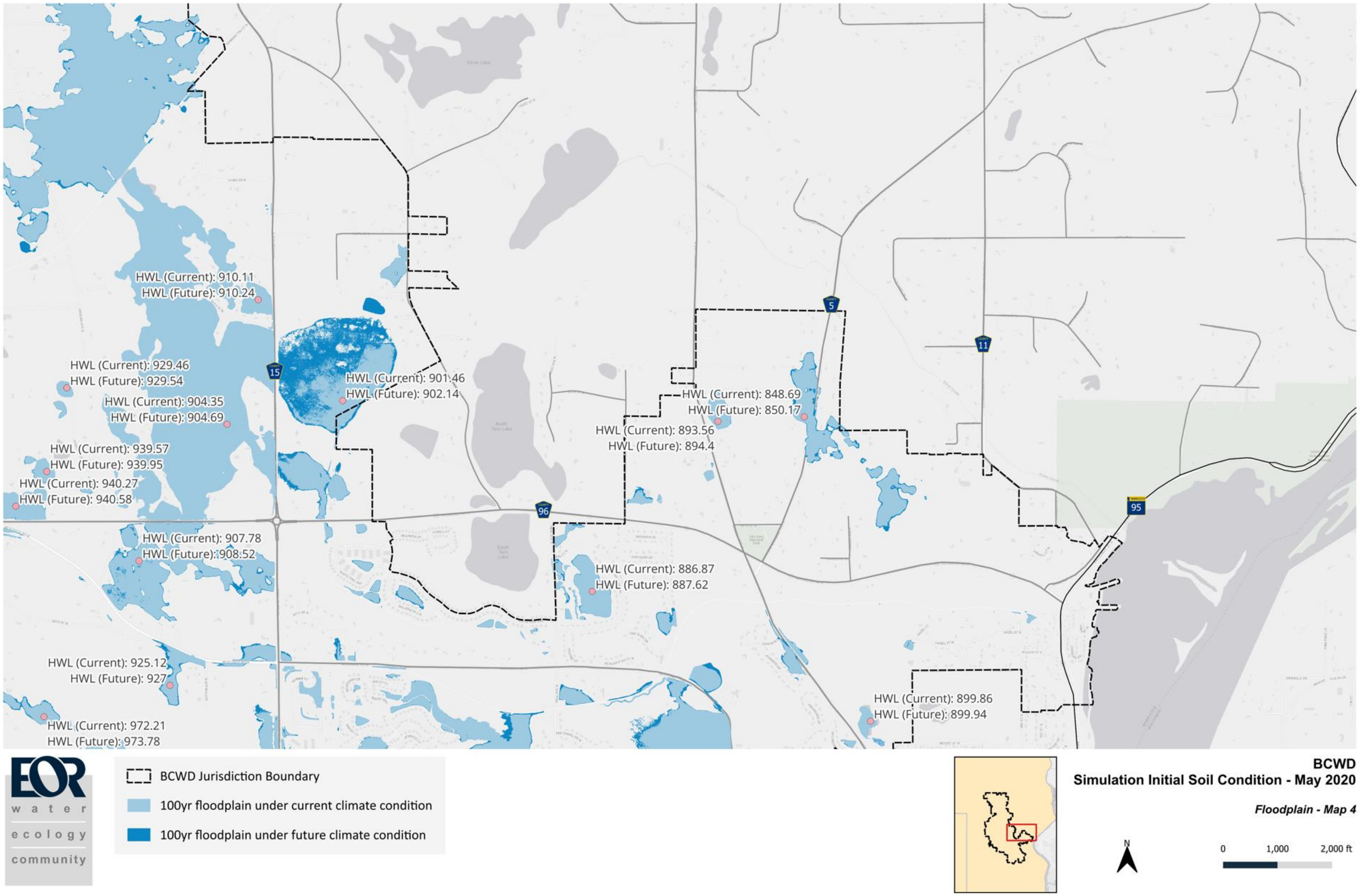
8 Appendix B: BCWD 100-year Event Flood Plain Map (2020 Soil Condition)

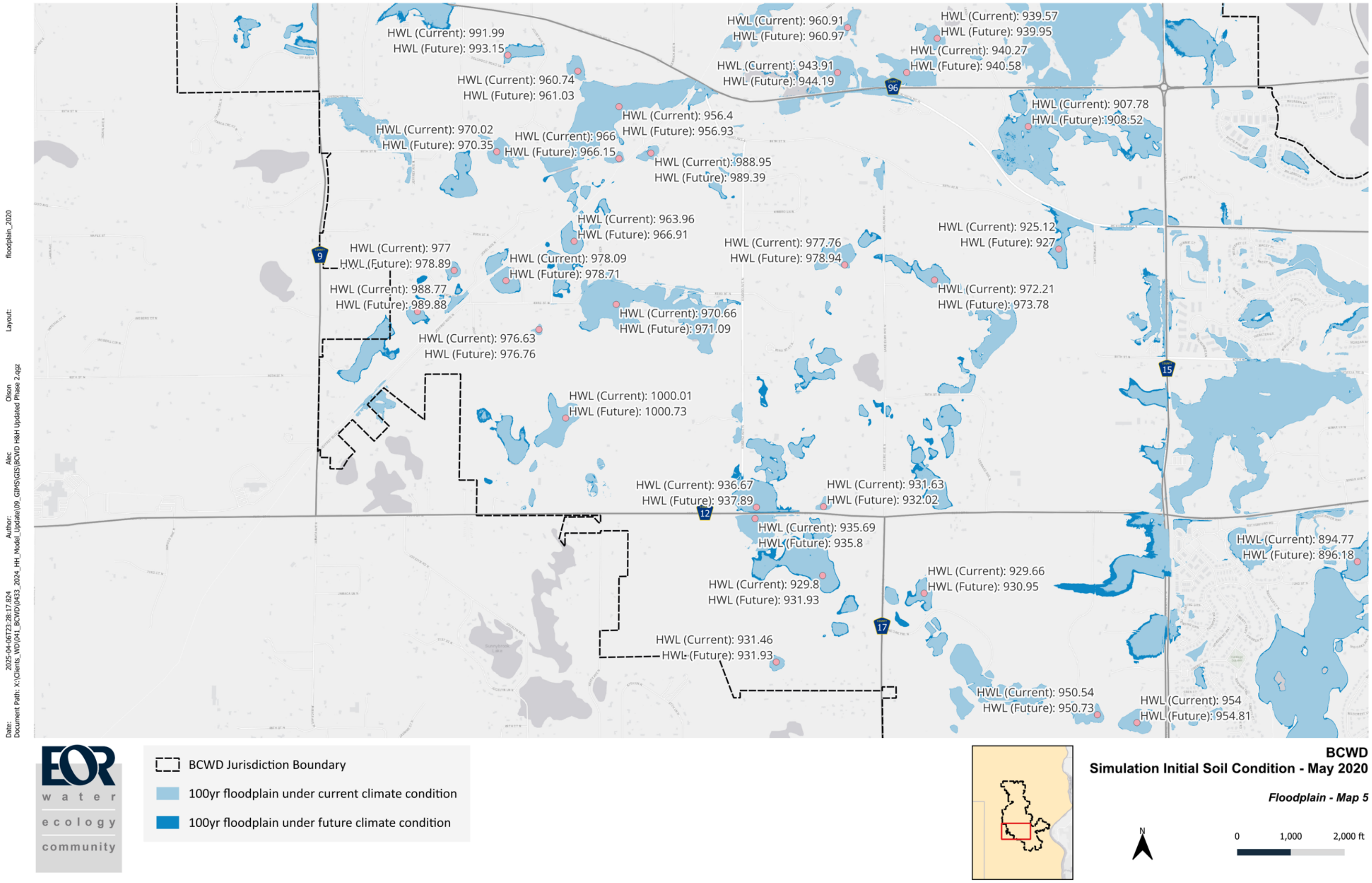
Appendix B shows the flood footprint for both 7.2" and 9.5" upper bound 100-year events

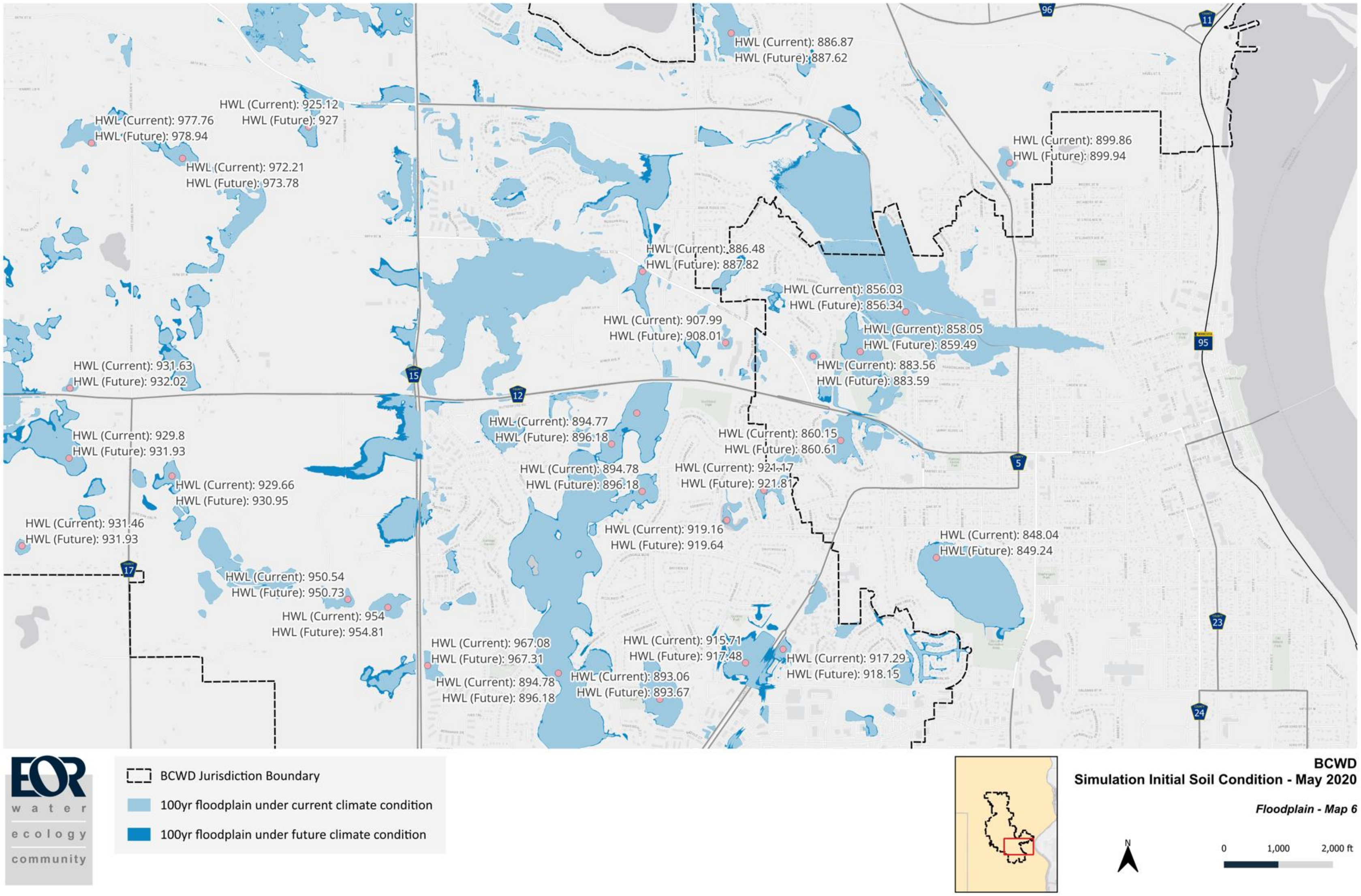


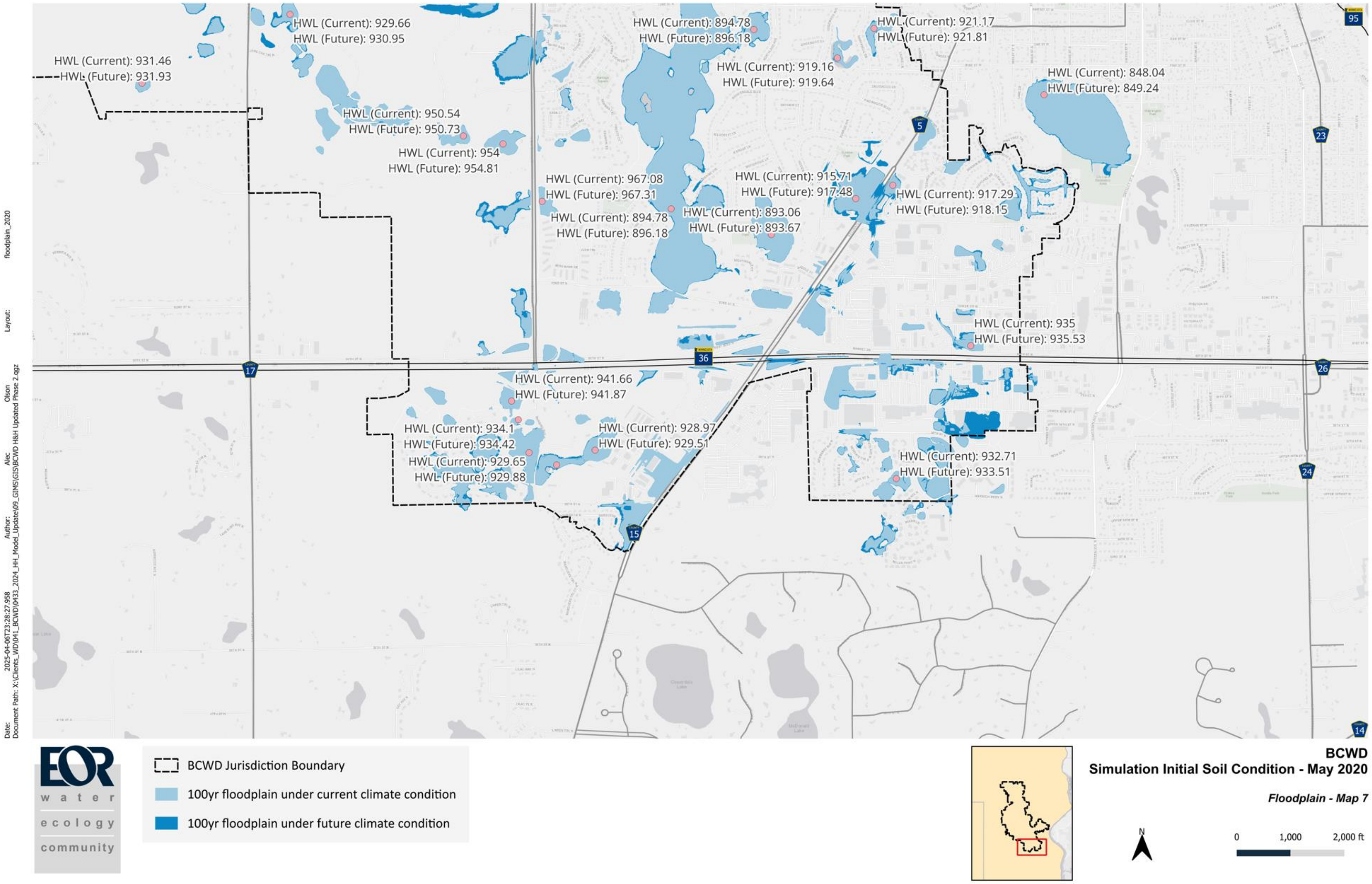

HWL (Current): 972.41
HWL (Future): 973.01
HWL (Current): 984.82
HWL (Future): 984.9
HWL (Current): 983.62
HWL (Future): 985.9
HWL (Current): 972.54
HWL (Future): 973.19
HWL (Current): 986.23
HWL (Future): 987.22
HWL (Current): 983.6
HWL (Future): 985.9
HWL (Current): 972.54
HWL (Future): 973.19
HWL (Current): 980.09
HWL (Future): 980.91
HWL (Current): 976.12
HWL (Future): 977.06
HWL (Current): 989.54
HWL (Future): 989.65
HWL (Current): 984.34
HWL (Future): 984.49
HWL (Current): 967.81
HWL (Future): 968.89
HWL (Current): 978.3
HWL (Future): 978.72
HWL (Current): 936.96
HWL (Future): 937.03
HWL (Current): 957.34
HWL (Future): 958.19
HWL (Current): 956.42
HWL (Future): 956.98
HWL (Current): 967.64
HWL (Future): 968
8
7
15
9
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain - Map 2
N
0
1,000
2,000 ft
EOR
water
ecology
community


HWL (Current): 957.34
HWL (Future): 958.19
HWL (Current): 956.42
HWL (Future): 956.98
HWL (Current): 936.96
HWL (Future): 937.03
HWL (Current): 967.64
HWL (Future): 968
HWL (Current): 946.68
HWL (Future): 947.92
HWL (Current): 954.07
HWL (Future): 954.43
HWL (Current): 963.8
HWL (Future): 964.99
HWL (Current): 942.56
HWL (Future): 943.11
HWL (Current): 933.54
HWL (Future): 934.6
HWL (Current): 956.21
HWL (Future): 956.92
HWL (Current): 955.05
HWL (Future): 955.13
HWL (Current): 947.59
HWL (Future): 947.92
HWL (Current): 910.11
HWL (Future): 910.24
HWL (Current): 986.69
HWL (Future): 987.56
HWL (Current): 997.8
HWL (Future): 998.76
HWL (Current): 986.47
HWL (Future): 987.87
HWL (Current): 929.46
HWL (Future): 929.54
HWL (Current): 901.46
HWL (Future): 902.14
HWL (Current): 904.35
HWL (Future): 904.69
HWL (Current): 960.91
HWL (Future): 960.97
HWL (Current): 939.57
HWL (Future): 939.95
HWL (Current): 991.99
HWL (Future): 993.15
HWL (Current): 943.91
HWL (Future): 944.19
HWL (Current): 940.27
HWL (Future): 940.58
HWL (Current): 960.74
HWL (Future): 961.03
HWL (Current): 956.4
HWL (Future): 956.93
HWL (Current): 907.78
HWL (Future): 908.52
9
15
96
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain - Map 3
N
0
1,000
2,000 ft


HWL (Current): 910.11
HWL (Future): 910.24
HWL (Current): 929.46
HWL (Future): 929.54
HWL (Current): 904.35
HWL (Future): 904.69
HWL (Current): 901.46
HWL (Future): 902.14
HWL (Current): 848.69
HWL (Future): 850.17
HWL (Current): 893.56
HWL (Future): 894.4
HWL (Current): 939.57
HWL (Future): 939.95
HWL (Current): 940.27
HWL (Future): 940.58
HWL (Current): 907.78
HWL (Future): 908.52
HWL (Current): 886.87
HWL (Future): 887.62
HWL (Current): 925.12
HWL (Future): 927
HWL (Current): 899.86
HWL (Future): 899.94
HWL (Current): 972.21
HWL (Future): 973.78
15
96
5
11
95
EOR
water
ecology
community
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain - Map 4
N
0
1,000
2,000 ft


HWL (Current): 991.99
HWL (Future): 993.15
HWL (Current): 960.91
HWL (Future): 960.97
HWL (Current): 939.57
HWL (Future): 939.95
HWL (Current): 940.27
HWL (Future): 940.58
HWL (Current): 943.91
HWL (Future): 944.19
HWL (Current): 960.74
HWL (Future): 961.03
HWL (Current): 907.78
HWL (Future): 908.52
HWL (Current): 956.4
HWL (Future): 956.93
HWL (Current): 970.02
HWL (Future): 970.35
HWL (Current): 966
HWL (Future): 966.15
HWL (Current): 988.95
HWL (Future): 989.39
HWL (Current): 963.96
HWL (Future): 966.91
HWL (Current): 925.12
HWL (Future): 927
HWL (Current): 977
HWL (Future): 978.89
HWL (Current): 978.09
HWL (Future): 978.71
HWL (Current): 977.76
HWL (Future): 978.94
HWL (Current): 972.21
HWL (Future): 973.78
HWL (Current): 988.77
HWL (Future): 989.88
HWL (Current): 970.66
HWL (Future): 971.09
HWL (Current): 976.63
HWL (Future): 976.76
HWL (Current): 1000.01
HWL (Future): 1000.73
HWL (Current): 936.67
HWL (Future): 937.89
HWL (Current): 931.63
HWL (Future): 932.02
HWL (Current): 935.69
HWL (Future): 935.8
HWL (Current): 894.77
HWL (Future): 896.18
HWL (Current): 929.66
HWL (Future): 930.95
HWL (Current): 929.8
HWL (Future): 931.93
HWL (Current): 931.46
HWL (Future): 931.93
HWL (Current): 950.54
HWL (Future): 950.73
HWL (Current): 954
HWL (Future): 954.81
9
96
15
12
17
EOR
water
ecology
community
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain - Map 5
N
0
1,000
2,000 ft

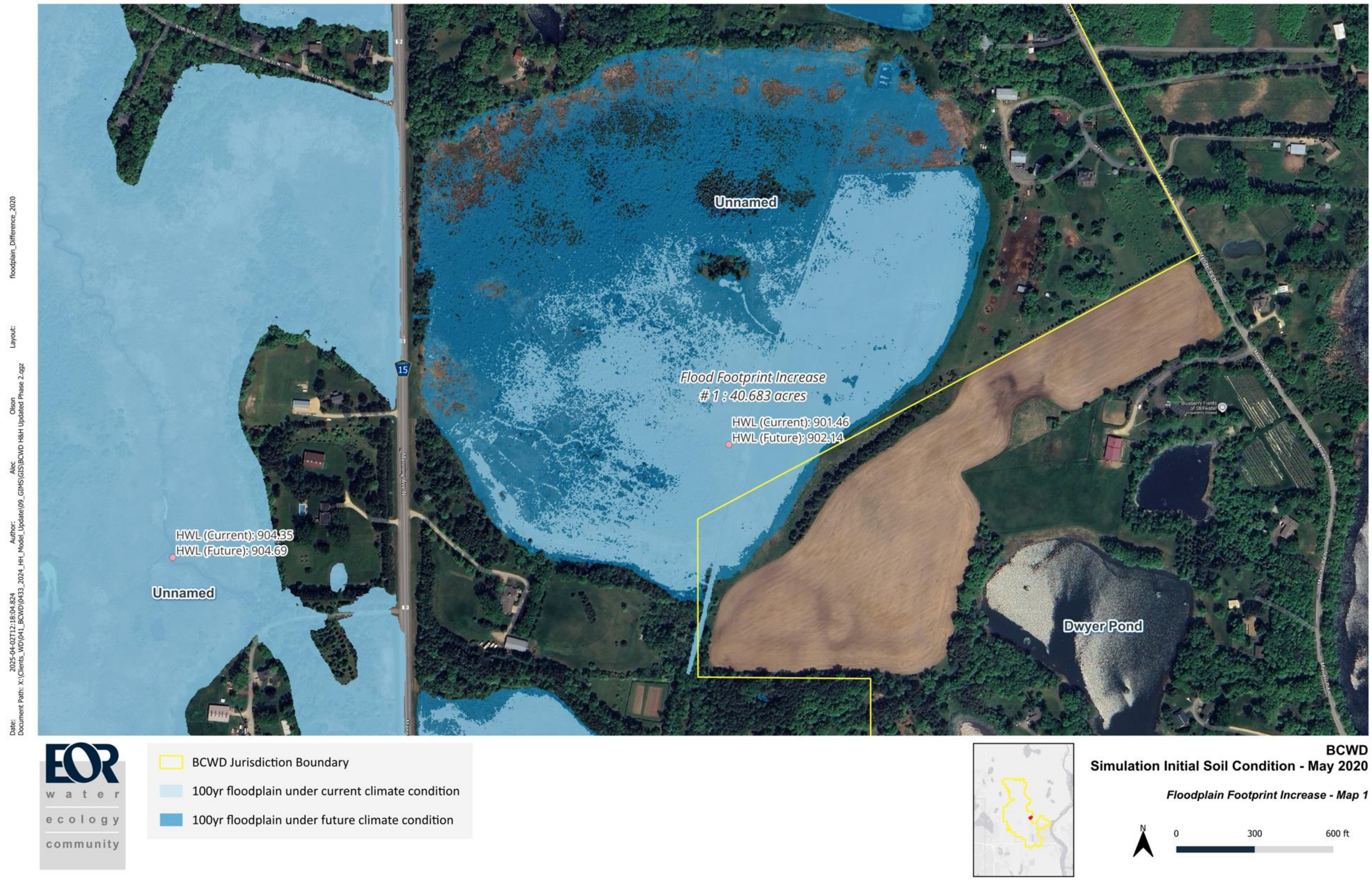

HWL (Current): 886.87
HWL (Future): 887.62
HWL (Current): 925.12
HWL (Future): 927
HWL (Current): 977.76
HWL (Future): 978.94
HWL (Current): 972.21
HWL (Future): 973.78
HWL (Current): 899.86
HWL (Future): 899.94
HWL (Current): 886.48
HWL (Future): 887.82
HWL (Current): 856.03
HWL (Future): 856.34
HWL (Current): 907.99
HWL (Future): 908.01
HWL (Current): 858.05
HWL (Future): 859.49
HWL (Current): 883.56
HWL (Future): 883.59
HWL (Current): 931.63
HWL (Future): 932.02
HWL (Current): 894.77
HWL (Future): 896.18
HWL (Current): 860.15
HWL (Future): 860.61
HWL (Current): 929.8
HWL (Future): 931.93
HWL (Current): 894.78
HWL (Future): 896.18
HWL (Current): 921.17
HWL (Future): 921.81
HWL (Current): 929.66
HWL (Future): 930.95
HWL (Current): 931.46
HWL (Future): 931.93
HWL (Current): 919.16
HWL (Future): 919.64
HWL (Current): 848.04
HWL (Future): 849.24
HWL (Current): 950.54
HWL (Future): 950.73
HWL (Current): 954
HWL (Future): 954.81
HWL (Current): 967.08
HWL (Future): 967.31
HWL (Current): 915.71
HWL (Future): 917.48
HWL (Current): 917.29
HWL (Future): 918.15
HWL (Current): 894.78
HWL (Future): 896.18
HWL (Current): 893.06
HWL (Future): 893.67
EOR
water
ecology
community
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain - Map 6
N
0
1,000
2,000 ft

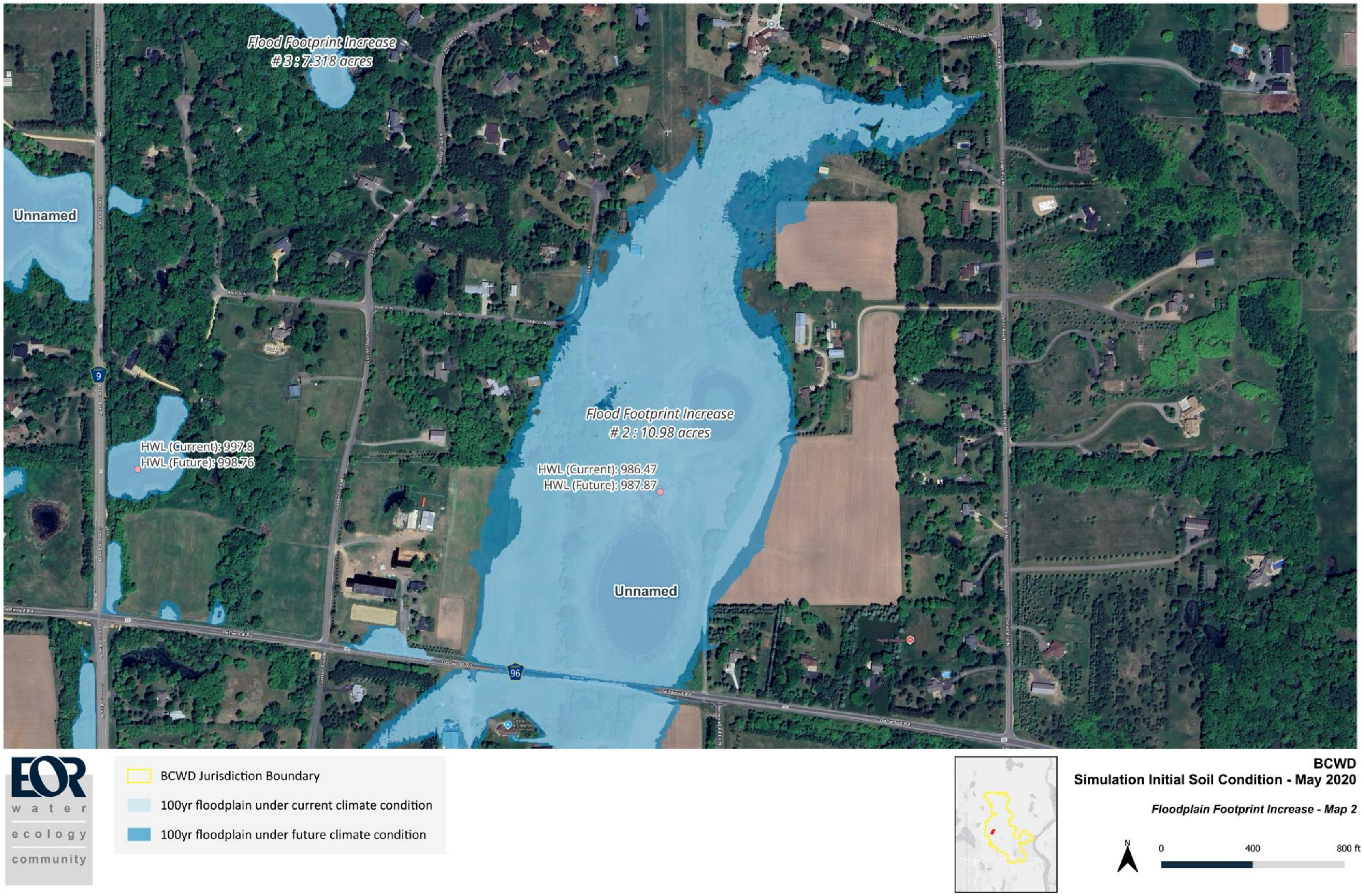

HWL (Current): 929.66
HWL (Future): 930.95
HWL (Current): 931.46
HWL (Future): 931.93
HWL (Current): 894.78
HWL (Future): 896.18
HWL (Current): 921.17
HWL (Future): 921.81
HWL (Current): 919.16
HWL (Future): 919.64
HWL (Current): 848.04
HWL (Future): 849.24
HWL (Current): 950.54
HWL (Future): 950.73
HWL (Current): 954
HWL (Future): 954.81
HWL (Current): 967.08
HWL (Future): 967.31
HWL (Current): 915.71
HWL (Future): 917.48
HWL (Current): 917.29
HWL (Future): 918.15
HWL (Current): 894.78
HWL (Future): 896.18
HWL (Current): 893.06
HWL (Future): 893.67
HWL (Current): 935
HWL (Future): 935.53
HWL (Current): 941.66
HWL (Future): 941.87
HWL (Current): 934.1
HWL (Future): 934.42
HWL (Current): 928.97
HWL (Future): 929.51
HWL (Current): 929.65
HWL (Future): 929.88
HWL (Current): 932.71
HWL (Future): 933.51
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain - Map 7
0 1,000 2,000 ft

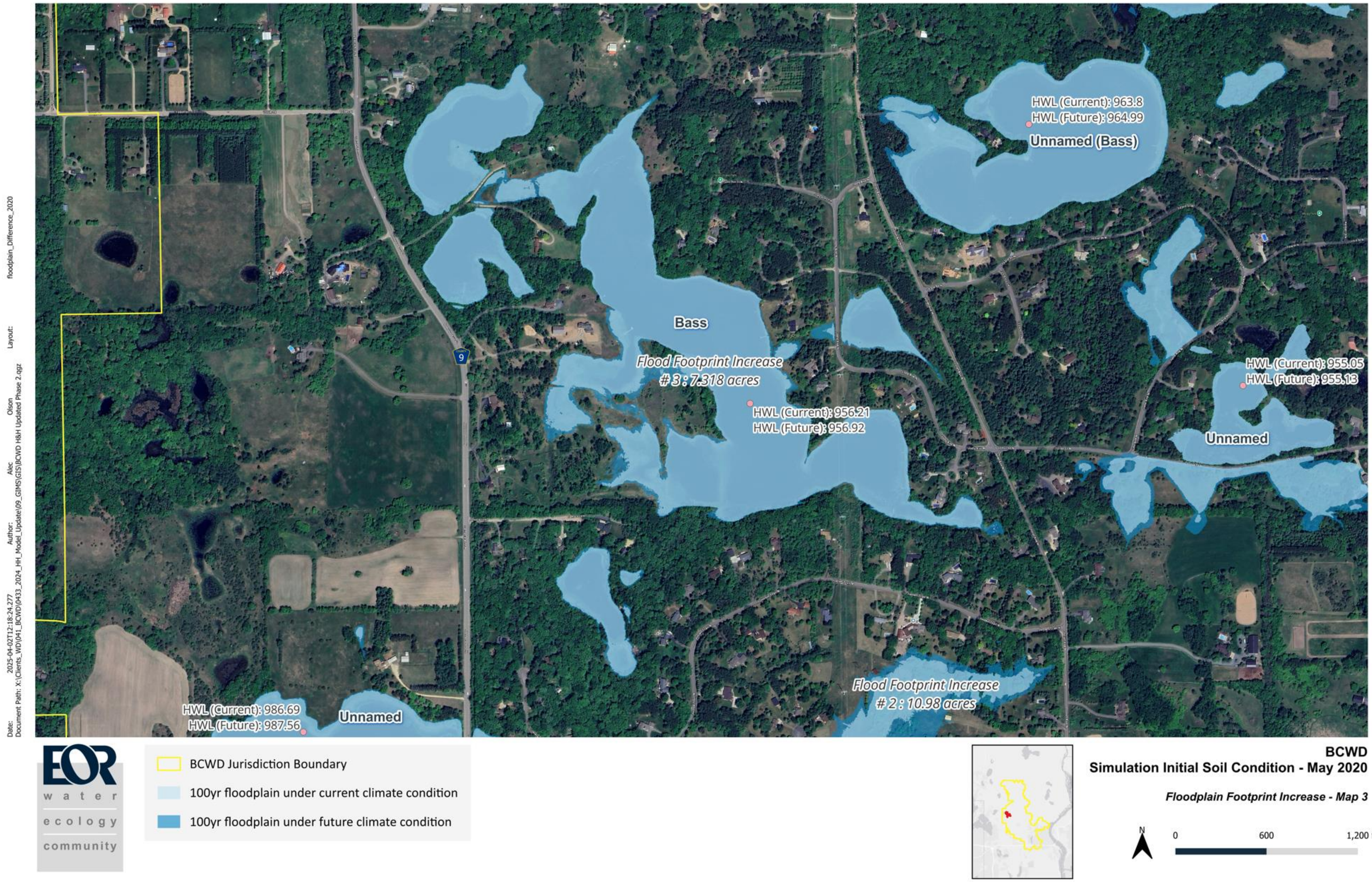
9 Appendix C: Top 10 Flood Footprint Increase for 9.5" Upper Bound 100-Year Event

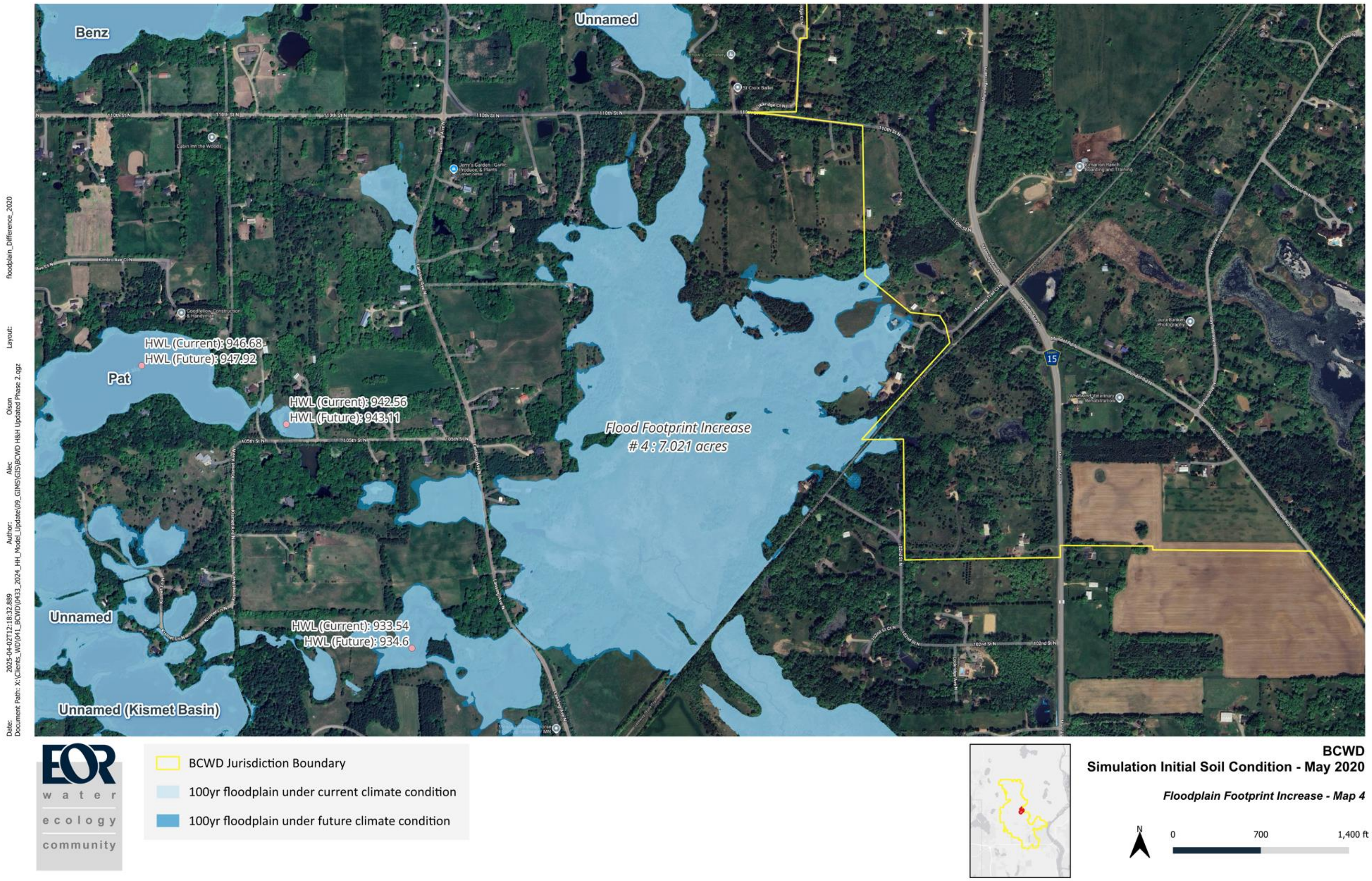
Appendix C demonstrates the maps for the 10 top area with the most flooding area increase.

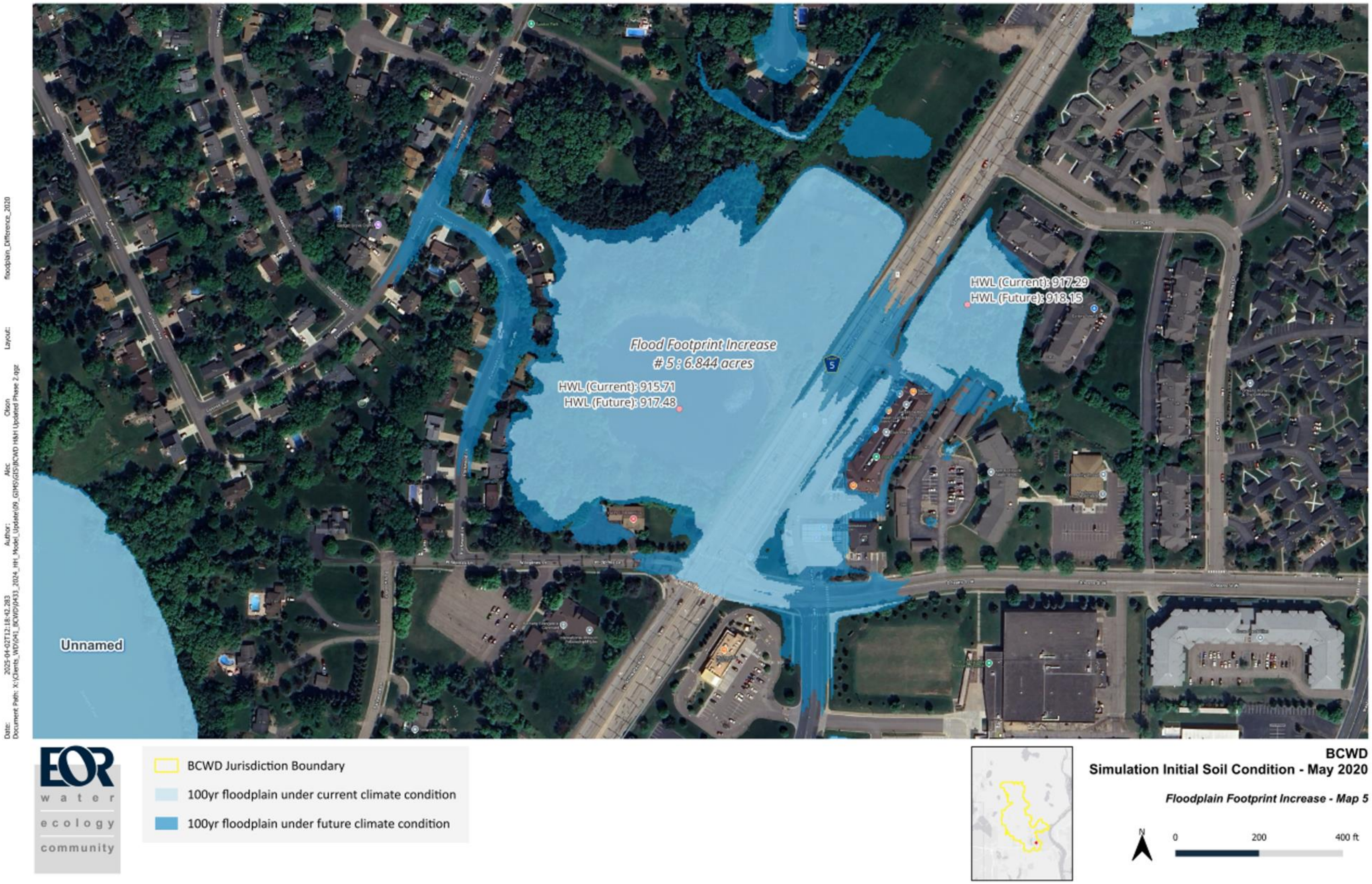
1. Mendel Wetland = +41 acres
2. Dellwood Rd. Wetland = +11 acres
3. 0.15
4. Lake West = +7 acres
5. BCWD Conservation Area = +7 acres
6. Stillwater Blvd & Orleans (Wildwood Pond) = +6.8 acres
7. Manning & Settlers Way (Grant side) = +6.6 acres
8. Long Lake = +6.5 acres
9. Manning & 115th St = +5.7 acres
10. July Avenue Pond = +5.4 acres
11. Goggins Lake = +5.2 acres


Unnamed
Flood Footprint Increase
1 : 40.683 acres
HWL (Current): 901.46
HWL (Future): 902.14
HWL (Current): 904.35
HWL (Future): 904.69
Unnamed
Dwyer Pond
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain Footprint Increase - Map 1
0
300
600 ft

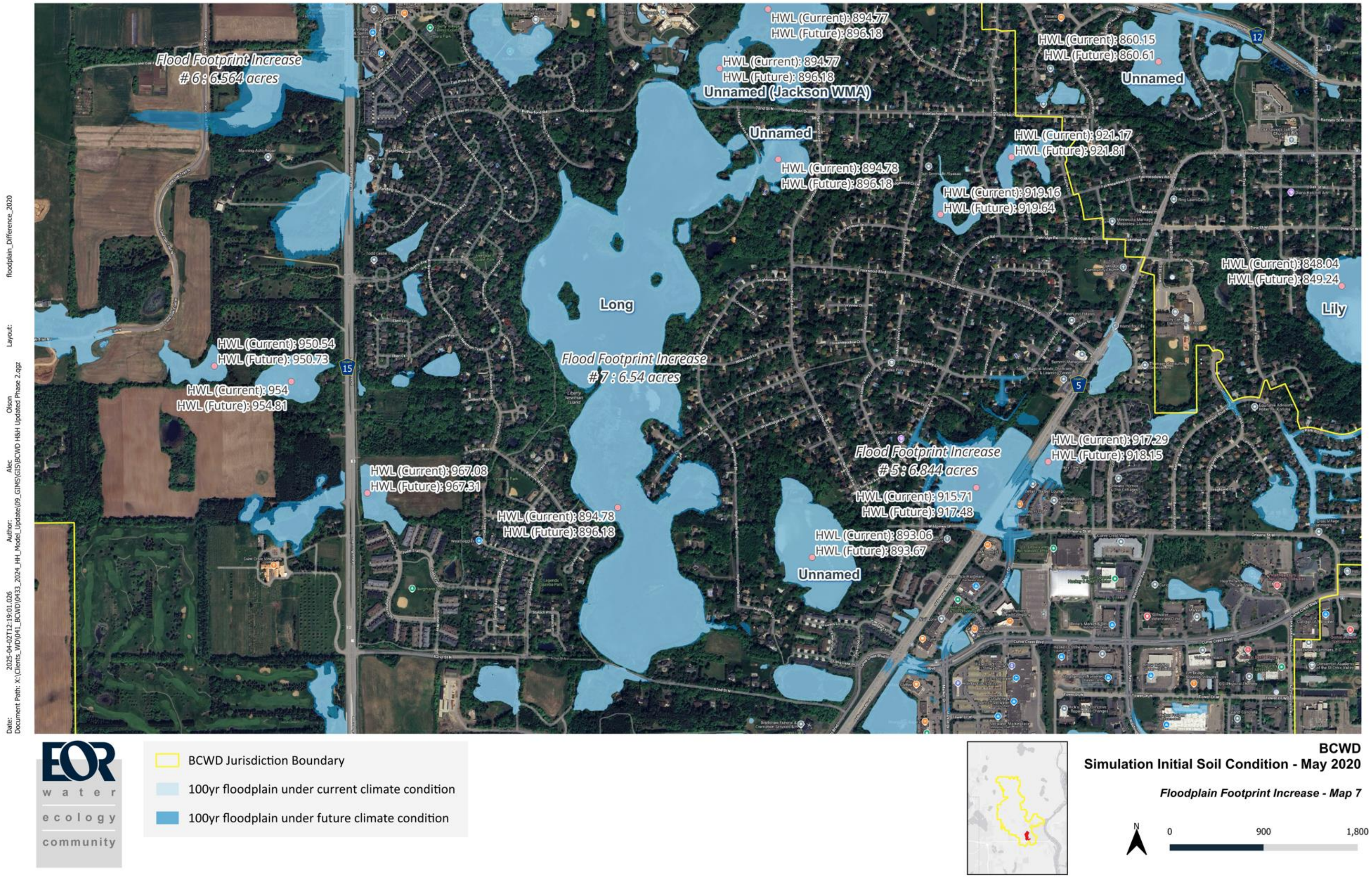

Flood Footprint Increase
3 : 7.318 acres
Unnamed
HWL (Current): 997.8
HWL (Future): 998.76
Flood Footprint Increase
2 : 10.98 acres
HWL (Current): 986.47
HWL (Future): 987.87
Unnamed
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain Footprint Increase - Map 2
0
400
800 ft


Date: 2025-04-02T12:18:24.277 Author: Alec Olson Layout: floodplain_Difference_2020
Document Path: X:\Clients_WD\041_BCWD\0433_2024_HH_Model_Update\09_GIMS\GIS\BCWD H&H Updated Phase 2.qgz
HWL (Current): 963.8
HWL (Future): 964.99
Unnamed (Bass)
Bass
Flood Footprint Increase
3 : 7.318 acres
HWL (Current): 956.21
HWL (Future): 956.92
HWL (Current): 955.05
HWL (Future): 955.13
Unnamed
9
Flood Footprint Increase
2 : 10.98 acres
HWL (Current): 986.69
HWL (Future): 987.56
Unnamed
EOR
water
ecology
community
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain Footprint Increase - Map 3
N
0
600
1,200 ft

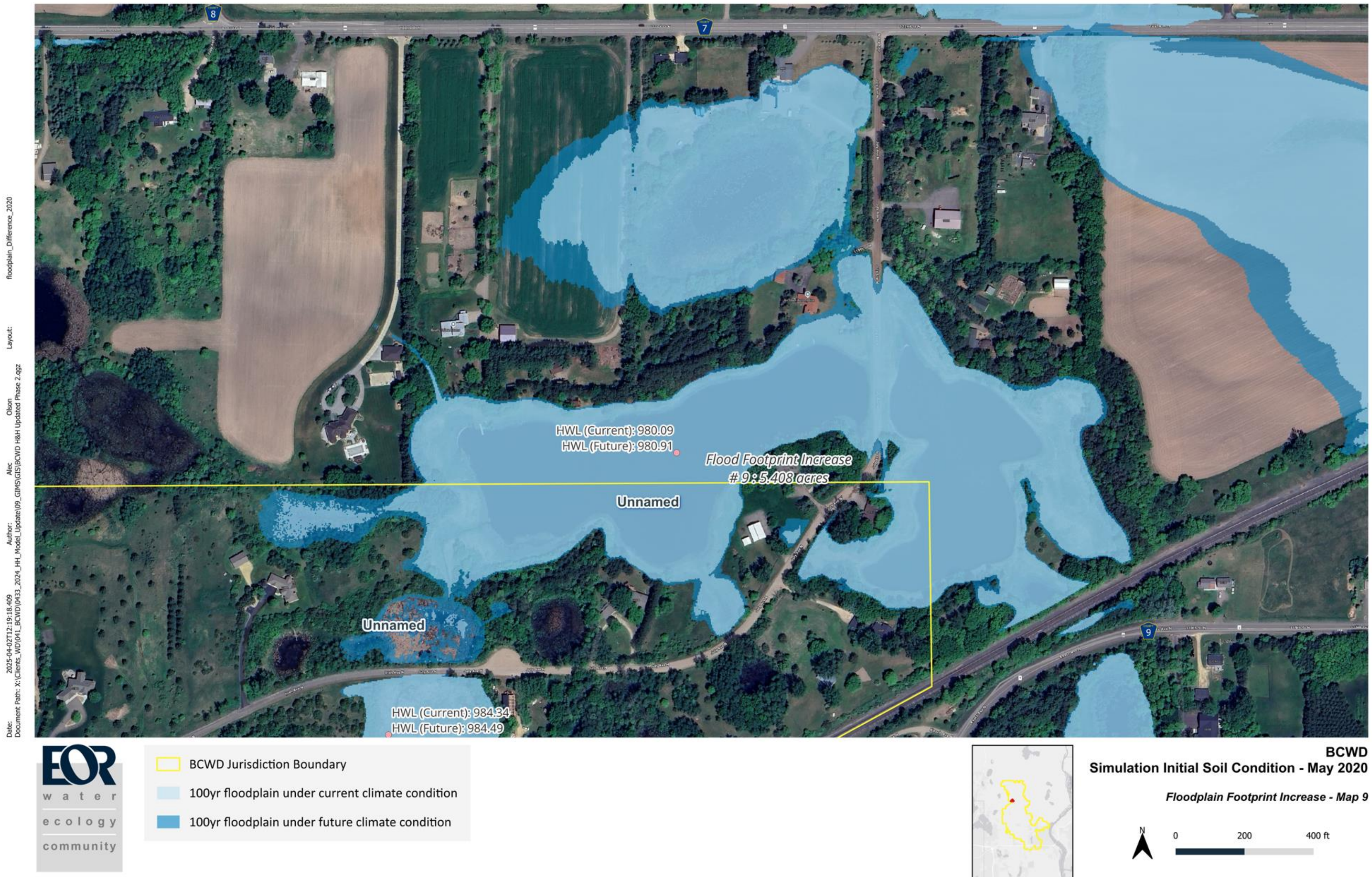

Benz
Unnamed
Pat
HWL (Current): 946.68
HWL (Future): 947.92
HWL (Current): 942.56
HWL (Future): 943.11
Flood Footprint Increase
4 : 7.021 acres
Unnamed
HWL (Current): 933.54
HWL (Future): 934.6
Unnamed (Kismet Basin)
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain Footprint Increase - Map 4
0
700
1,400 ft

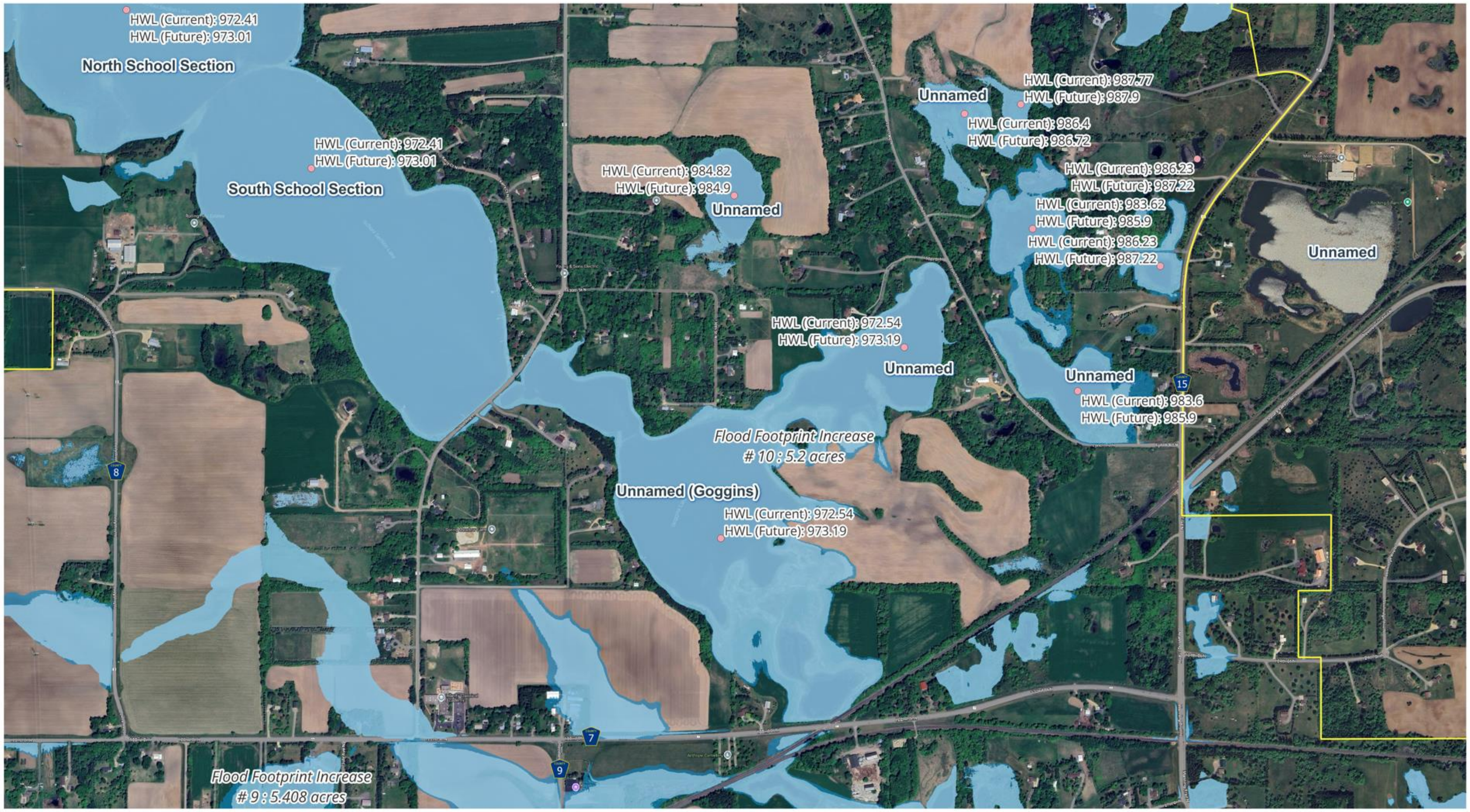

Flood Footprint Increase
5 : 6.844 acres
HWL (Current): 915.71
HWL (Future): 917.48
HWL (Current): 917.29
HWL (Future): 918.15
Unnamed
EOR
water
ecology
community
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain Footprint Increase - Map 5
N
0
200
400 ft


Flood Footprint Increase
6 : 6.564 acres
Flood Footprint Increase
7 : 6.54 acres
Long
HWL (Current): 950.54
HWL (Future): 950.73
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain Footprint Increase - Map 6
N
0
400
800 ft


Flood Footprint Increase
6 : 6.564 acres
HWL (Current): 894.77
HWL (Future): 896.18
HWL (Current): 894.77
HWL (Future): 896.18
Unnamed (Jackson WMA)
HWL (Current): 860.15
HWL (Future): 860.61
Unnamed
Unnamed
HWL (Current): 894.78
HWL (Future): 896.18
HWL (Current): 921.17
HWL (Future): 921.81
HWL (Current): 919.16
HWL (Future): 919.64
HWL (Current): 848.04
HWL (Future): 849.24
Lily
Long
HWL (Current): 950.54
HWL (Future): 950.73
Flood Footprint Increase
7 : 6.54 acres
HWL (Current): 954
HWL (Future): 954.81
HWL (Current): 917.29
HWL (Future): 918.15
Flood Footprint Increase
5 : 6.844 acres
HWL (Current): 967.08
HWL (Future): 967.31
HWL (Current): 915.71
HWL (Future): 917.48
HWL (Current): 894.78
HWL (Future): 896.18
HWL (Current): 893.06
HWL (Future): 893.67
Unnamed
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain Footprint Increase - Map 7
N
0
900
1,800


Flood Footprint Increase
8 : 5.691 acres
HWL (Current): 936.96
HWL (Future): 937.03
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain Footprint Increase - Map 8
0
300
600 ft


HWL (Current): 980.09
HWL (Future): 980.91
Flood Footprint Increase
9 : 5.408 acres
Unnamed
Unnamed
HWL (Current): 984.34
HWL (Future): 984.49
BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition
BCWD
Simulation Initial Soil Condition - May 2020
Floodplain Footprint Increase - Map 9
N
0
200
400 ft



EOR water ecology community

BCWD Jurisdiction Boundary
100yr floodplain under current climate condition
100yr floodplain under future climate condition

BCWD
Simulation Initial Soil Condition - May 2020
Floodplain Footprint Increase - Map 10

N
0 900 1,800