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Mare Brook Watershed Hydrologic & Hydraulic Study

Brunswick, Maine

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Executive Summary

The Town of Brunswick retained GEI Consultants, Inc., to perform a hydrologic and hydraulic (H&H) study of the Mare Brook Watershed. The purpose of this work was to provide the Town with information to help prioritize a sequence of culvert replacements and geomorphic stream restoration projects recommended in the Mare Brook Watershed Management Plan 2022-2032 (WMP).

The WMP was prepared by the Cumberland County Soil and Water Conservation District with input from WMP Steering Committee members. Funding for the plan was provided in part by the U.S. Environmental Protection Agency under Section 604B of the Clean Water Act. In February 2022, Brunswick Town Council voted to adopt the WMP. The plan included a series of recommended stream restoration projects to improve the ecological health of the brook and reduce inland flooding. The plan also identified several specific culverts in need of hydrologic and hydraulic (H&H) analyses to inform culvert replacement options.

GEI's work on this project included the development of a 2-dimensional (2D) rain-on-grid hydraulic model of the Mare Brook watershed to simulate the 2-, 10- and 25-year annual recurrence interval design storms. The model was developed to represent the watershed's existing conditions based on detailed information from survey of existing culverts, dams, and GEI's temporary monitoring equipment. The model was used to estimate flood conditions, peak water elevations, and peak flow at several key stream crossings for the design storm events. GEI performed the H&H modeling using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center - River Analysis System (HEC-RAS) (USACE, 2022a).

The model was calibrated/validated to three observed precipitation events. Adequate comparison between observed and simulated results confirmed the model is suitable in providing reasonable estimates of peak water levels and peak flows during the design storm events (i.e., 2-, 10-, 25-year storms) at key stream crossings within the watershed.

To evaluate the vulnerability of the watershed under climate change and sea level rise conditions and to ensure stream restoration projects provide a healthier, more resilient ecosystem, GEI offers a few possible areas of additional analysis for Brunswick's consideration:

- The Town may want to consider performing a climate change vulnerability analysis to assess impacts to the watershed caused by rising sea levels and increased frequency, depth, and intensity of precipitation events.

- GEI recommends performing an H&H analysis for the 50-year and 100-year annual recurrence interval storm events. The Maine Bridge Design Guide (MaineDOT, 2003) indicates that bridges and minor spans should be designed for the 50-year event and checked for the 100-year event. In certain cases, analysis of the 500-year flood event may be warranted. For culvert design, MaineDOT indicates that the ratio of headwater (depth above the invert) to structure depth (culvert diameter) should be approximately equal to or less than 0.9 (i.e., flow depth at 90% full) for the 50-year event.

  When outlet conditions control culvert flow, a minimum of 1 foot of freeboard is required for the 100-year event. Performing H&H analysis under the 50-year and 100-year flood conditions will provide the Town of Brunswick with an understanding of culvert design relative to the state guidelines.

- GEI created the HEC-RAS model to facilitate design of future culvert replacements. Proposed culverts may be added to the model to assess flood conditions and downstream impacts under proposed designs. GEI recommends consideration of the State of Maine Aquatic Resource Management Strategy (ARMS) Stream Smart Road Crossing Guide when designing replacement and new culverts (MaineDOT, 2023). The web-based guide provides information for "installing and replacing crossings in an effective and cost-efficient manner while meeting goals of restoring and maintaining stream habitat connectivity and enhancing the stability of roads and culvert crossings."

- The hydraulic model was developed for use in evaluating extreme events (i.e., 2-, 10- and 25-year events) and was calibrated to three observed storms on the order of 1- to 2-year annual recurrence interval. Analyzing channel velocities and water depths under low flow conditions may be of interest for the design of future stream restoration projects. If the Town is interested in evaluating low flow conditions, additional work may be required to refine the model such as the collection of detailed stream channel bathymetry (to supplement the detailed LiDAR terrain data), water level monitoring, calibration during low flows, and evaluation of ground water discharge to the brook during low flow periods.

1. Introduction

The purpose of the H&H study was to provide the Town of Brunswick with information to prioritize culvert replacements and geomorphic stream restoration projects recommended within the Mare Brook Watershed Management Plan (WMP) 2022–2032 (CCSWCD, 2022).

Work on this project included the development of a 2-dimensional (2D) rain-on-grid hydraulic model of the Mare Brook watershed to simulate the 2-, 10- and 25-year annual recurrence interval design storm events. The model was used to estimate flood conditions, peak water elevations, and peak flows at several key stream crossings during the design storm events. GEI performed this evaluation using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center – River Analysis System (HEC-RAS) software, Version 6.3.0 (USACE, 2022a). GEI deployed five water level sensors within the watershed from July to October 2022 to capture changes in water elevations during significant precipitation events. The water level data was used for model calibration to demonstrate that the hydraulic model was a reasonable characterization of observed conditions.

Critical to model development was the compilation of terrain data to represent topographic features of the watershed. The model terrain was compiled from three 1-meter digital elevation models (USGS, 2021a, b, and c). GEI also subcontracted Little River Land Surveying, Inc. to collect elevation data at key river crossings.

The North American Vertical Datum of 1988 (NAVD88) was the reference datum for elevations in this report and the hydraulic model.

GEI completed the analysis for the Town of Brunswick in accordance with GEI's Proposal dated April 29, 2022. The following GEI personnel were primarily responsible for performing the hydraulic analysis for this report:

Project Manager:	Lissa Robinson, P.E. (ME)
Water Resource Engineer:	Marc Chmura, E.I.T (MA)
Quality Assurance/Control Lead:	Amanda Barnett, E.I. (ME)
Engineering Field Lead:	Dan Pelletier, E.I., (ME)

2. Project Background

In February 2022, the Town of Brunswick with help from the Cumberland County Soil and Water Conservation District completed the Mare Brook Watershed Plan 2022-2032 (WMP). Mare Brook, a Maine Class B stream, is currently listed by the Maine Department of Environmental Protection (Maine DEP) as impaired due to poor macroinvertebrate sampling results and habitat (CCSWCD, 2022). Maine's water classification system, in place since the 1950's, establishes water quality goals for the state. Mare Brook is also considered an Urban Impaired Stream under Maine's Stormwater Management Law.

The primary goal of the WMP is to meet the Maine State-designated Class B standards by 2037. Land use activities and impervious cover within the watershed are two of several stressors that reportedly contribute to the impairment of Mare Brook. This has led to erosion, loss of habitat, and poor water quality. GEI conducted this H&H study to help the Town of Brunswick evaluate the existing stream system and to provide the Town with a tool for assessing future culvert replacement and stream restoration projects.

Mare Brook is a 5.7-mile stream with a 6.02-square-mile drainage area located entirely within the Town of Brunswick (Fig. 1). The headwaters of the brook begin in the northwest area of the watershed in a dense residential area. The brook flows east through neighborhoods, and into Coffin's Ice Pond, which is impounded by a small dam just upstream of Harpswell Road. The brook continues to flow past several culverts including a more than 3,000-foot-long culvert under the runway of the Brunswick Executive Airport and continues downstream to its confluence with the Merriconeag Stream, Mare Brook's main tributary.

Merriconeag Stream begins in the northeast area of the watershed and flows into Picnic Pond, which is impounded by a small dam just upstream of Purington Road. Downstream of the confluence with Merriconeag Stream, Mare Brook continues south for less than a mile through forested land where it discharges to Harpswell Cove.

3. Field Survey

The GEI Team performed several field visits throughout the watershed to confirm existing conditions, observe road crossings and associated culverts, measure culvert and dam dimensions, observe potential obstructions to flow, and record approximate channel widths and depths. The information gathered during GEI's site visits was used to develop the HEC-RAS model and ensured that the model would reasonably represent conditions at the time of the study.

To further improve model accuracy, GEI retained Little River Land Surveying, Inc. to collect elevation data at key river crossings. The survey was focused on locations critical for the accuracy of the H&H model such as culverts, water level sensor elevations, bank locations, weir elevations at dams, and top of road elevations at culvert crossings. This site-specific survey data was used to supplement the publicly available digital elevation model (DEM) at the critical hydraulic structure locations. Locations of surveyed structures are shown in Fig. 2.

The crossings selected for the survey were based on the following: (1) location along the main stem of Mare Brook, (2) importance to hydraulic conveyance, and (3) identification in the WMP as requiring an H&H model to inform culvert replacement design.

4. Water Level Sensor Installation and Monitoring

GEI installed water level sensors to collect depth measurements at key locations during rainfall events in summer and fall of 2022. This information was critical for calibration of the hydraulic model to ensure the model was appropriate for use in simulating flows for the design storms identified for the study (2-, 10-, and 25-year events). To GEI's knowledge, no prior streamflow or water level data exist for Mare Brook or its tributaries.

GEI deployed five water level sensors upstream of the following five structures:

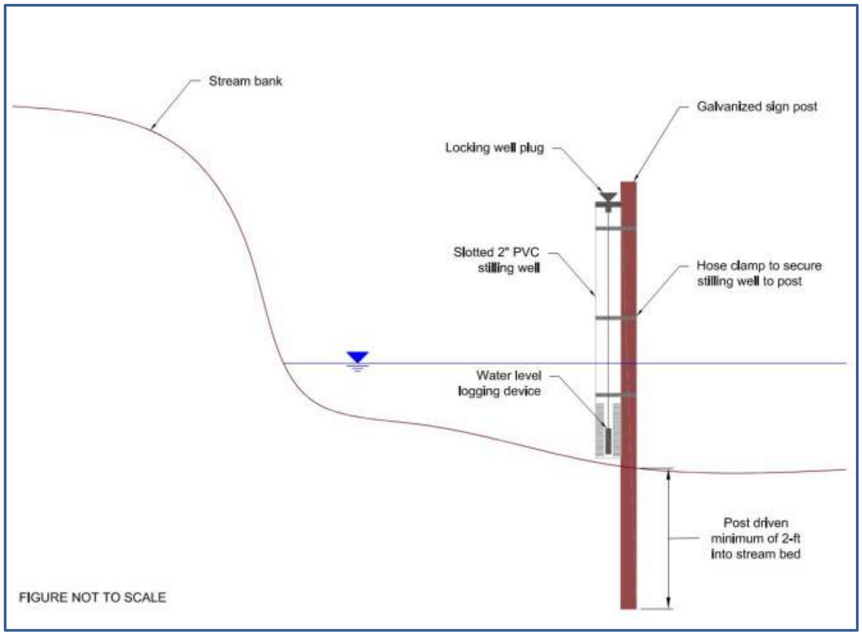
1. Meadowbrook Road Culvert
2. Picnic Pond Dam
3. Airport Runway Culvert
4. Coffin's Ice Pond Dam
5. Liberty Crossing Culvert

The locations of these water level sensors are shown in Fig. 2. Graphs of water depth at each sensor are provided in Appendix A. Consistent with water level logging practices, the sensors were set above the channel bottom and therefore "depth" represents the depth of water above the sensor. GEI converted water depth measurements to elevations (NAVD88) by adding the recorded depth to the known sensor elevation surveyed by Little River Land Surveying, Inc.

Water level loggers require adjustment to account for changes in barometric pressure. GEI recorded atmospheric pressure at a barometer installed upstream of the Meadowbrook Road Culvert. The barometric data was used to adjust water level readings using Solinst Levelogger Software. Water level and barometric data was continuously collected from July 9, 2022 to October 28, 2022 at 5-minute intervals.

To estimate streamflow, GEI developed stage discharge rating curves for the culverts and dams located immediately downstream of the sensors. The rating curves for culverts were created using HY-8 Culvert Hydraulic Analysis software published by the Federal Highway Administration (FHWA, 2021). Rating curves at the two dams were developed using standard weir equations. Using the rating curves, GEI was able to estimate streamflow for each recorded water elevation. The estimated streamflow data was used to support model calibration.

The water level monitoring equipment consisted of a water level logger in the form of a pressure transducer installed within a 2-inch-diameter slotted PVC stilling well that was secured to a driven galvanized post. The monitoring equipment included five (5) Solinst Levelogger 5 sensors and one (1) Solinst Barologger 5 barometer. Graphic 1 shows a schematic of GEI's temporary stilling well and water level logger installation. GEI field personnel periodically checked the water level loggers to download data and perform maintenance. The equipment was removed on October 28, 2022.



Graphic 1. Water Level Logger Installation Schematic

5. Hydraulic Model Setup

To perform the hydrologic and hydraulic analysis, GEI developed a 2-dimensional (2D) rain-on-grid HEC-RAS model of the Mare Brook watershed. GEI developed this model using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center – River Analysis System (HEC-RAS) software, Version 6.3.0 (USACE, 2022a).

The model was used to simulate watershed conditions for the 2-, 10- and 25-year annual recurrence interval design storm events. The focus of this study was to evaluate crossings on the main stem of the Mare Brook River that were previously identified as needing a H&H analysis in the WMP.

The model was developed to represent existing conditions in the watershed. Modifications may be made to the model to facilitate design and analysis of future stream modification projects, dam rehabilitation or removal, land use build-out, and/or culvert replacement projects. A spreadsheet will be provided containing water depths recorded by GEI.

5.1 Terrain

A terrain model is a 3-D representation of the watershed's topography that affects the movement of water through the floodplain. The terrain was based on one-meter resolution Digital Elevation Models (DEMs) available from the USGS 3D Elevation Program (USGS 2021a, b, and c). The DEMs were merged, converted from meters to feet, and projected to Maine State Plane West Zone NAD83. The files used to create the DEM reference a publish date of January 21, 2021.

5.2 Watershed Delineation

GEI used the terrain and ArcGIS watershed analysis tools (ESRI, 2020) to delineate the Mare Brook watershed boundary. GEI also reviewed stormwater infrastructure data provided by Brunswick and refined the watershed boundary where existing stormwater infrastructure diverts surface runoff out of Mare Brook's natural watershed. Brunswick also provided a previous watershed delineation performed by Maine DEP in the form of a GIS shapefile. This prior watershed delineation was used to verify and amend the watershed limits estimated by GEI, as applicable and appropriate. In general, GEI found good agreement between the Maine DEP watershed and the GEI watershed. Differences between the two may be due to GEI's use of a more recent and higher resolution DEM. Fig. 1 presents the GEI-delineated watershed.

5.3 2D Flow Area

Using the HEC-RAS 2D flow area editor, GEI generated a computational mesh to represent the 6.02 square-mile watershed. The cell size, shape, and orientation were input to describe the terrain and changes in water surface slope in the 2D areas. A cell size of 100 ft by 100 ft was selected as the default cell size. Smaller cell sizes were input for model stability and additional detail along the main channel and at key geometric features such as culverts, reservoirs, and dams. Breaklines were added to the 2D flow area mesh to reduce cell size, re-orient the cells to align with geometric features and the primary direction of flow, and to capture “high” features in the terrain.

5.4 Land Cover and Manning’s n-value

Land cover data for the watershed was obtained from the Maine Land Cover Dataset (MLCD), downloaded from Maine GeoLibrary (2004) as a GIS shapefile. A map of the land cover for the watershed, as classified in the MLCD, is provided in Fig. 3. The land cover categories include types of development for urbanized areas and natural vegetation cover types for undeveloped areas. The distribution of land cover as a percent of total watershed area is presented in Table 1.

Table 1. Distribution of Land Cover

Land Cover	Area (Square miles)	Area Percentage
Developed, High Intensity	0.55	9.05%
Developed, Medium Intensity	0.48	7.93%
Developed, Low Intensity	0.80	13.33%
Developed, Open Space	1.36	22.51%
Cultivated Crops	0.01	0.15%
Pasture/Hay	0.10	1.63%
Grassland/Herbaceous	0.03	0.51%
Deciduous Forest	0.16	2.64%
Evergreen Forest	0.92	15.21%
Mixed Forest	1.00	16.53%
Shrub/Scrub	0.05	0.80%
Wetland Forest	0.20	3.25%
Wetlands	0.13	2.09%
Roads – Runway	0.21	3.50%
Unconsolidated Shore	0.01	0.13%
Open Water	0.03	0.51%
Blueberry Field	0.00	0.00%
Light Partial Cut	0.01	0.15%
Heavy Partial Cut	<0.01	0.05%
Forest Regeneration	<0.01	0.02%

Land cover within the 2D model was associated with Manning's n-values to establish roughness coefficients in the model. GEI assigned Manning's n-values to land cover groups based on Chow (1959), NRCS (2010), and our engineering judgement. A high-resolution GIS shapefile representing impervious areas including roads, sidewalks, buildings, runways, and parking lots was provided by the Town of Brunswick. This detailed shapefile was superimposed over the MLCD so that Manning's n-values could be refined in areas containing impervious surfaces.

5.5 Infiltration

GEI used the deficit and constant loss method in HEC-RAS to estimate surface runoff volume and precipitation loss due to soil infiltration. In this method, precipitation is stored within the soil layer until the soil becomes fully saturated and can no longer accept water. Once the soil is fully saturated, additional precipitation loss due to percolation out of the bottom of the soil layer can occur. The rate of percolation is modeled as a constant rate and is determined by the properties of the soil and landcover. In general, soils consisting of clay and silt have lower percolation rates compared to sand and gravel soils. The amount of rainfall that occurs in excess of the percolation rate represents the volume of direct surface runoff. Total runoff in areas with impervious surfaces are reduced based on the average percent of impervious area within a model cell.

The parameters required to use the deficit and constant loss method within HEC-RAS include:

- Initial Deficit (inches)
- Constant Rate (in/hr)
- Maximum Deficit (inches)

5.5.1 Initial Deficit

Initial deficit represents the "initial loss" and is the amount of water required to bring the soil layer from a dry state to full saturation. In other words, it is the portion of precipitation that is immediately lost to the unsaturated voids or openings in the subsurface soil/rock before precipitation contributes to surface runoff. For modeling of design storms, the initial loss was assumed to be 0. This is a conservative assumption (produces more runoff) and represents fully saturated conditions prior to a design storm event.

For modeling of actual observed storm events, the initial loss was input based on precipitation observations leading up to the selected storm and refined based on model calibration. Further discussion of initial loss calibration is included in Section 6.

5.5.2 Constant Rate

When the soil is fully saturated, the amount of loss (i.e., infiltration) is defined by a constant rate. This rate was estimated based on published information for the watershed including soil type, land cover, drainage classification, depth to ground water table, and hydrologic soil group (HSG). HSG is a published classification that provides an estimate of runoff potential for a given soil type. The Natural Resources Conservation Service (NRCS) defines four hydrologic soil groups (HSGs) of A, B, C, or D. Minimum infiltration rates for each soil group are show in Table 2 reproduced by the USACE (2022b) from Skaggs and Khaleel (1982). The ranges provided represent minimum infiltration rates and actual observed rates may be and often are higher than these minimum published values.

Table 2. Hydrologic Soil Group Minimum Infiltration Rates

Hydrologic Soil Group	Description	Minimum Loss Rate (in/hr)
A	Deep sand, deep loess, aggregated silts	0.30 – 0.45
B	Shallow loess, sandy lam	0.15 – 0.30
C	Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay	0.30 – 0.15
D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00 – 0.05

Soil data including soil classification, soil texture, drainage classification, HSGs and other parameters were downloaded from the U.S. Department of Agriculture (USDA) website (USDA, 2022). The data obtained for this project represents information compiled in the Soil Survey for Cumberland County, Maine.

The percent distribution of hydrologic soil groups across the Mare Brook watershed are shown in Table 3. A map of the watershed displaying hydrologic soil groups is provided in Fig. 4. GEI used engineering judgment to select an appropriate HSG in areas where the soil survey did not assign a HSG classification or areas that were assigned dual classifications (A/D, C/D, etc.). GEI also consulted Maine Geological Survey Surficial Geology Maps (MGS, 1999) for additional information regarding the presence and extent of significant sand and gravel aquifers in the Mare Brook watershed.

Table 3. Percent Distribution of Hydrologic Soil Groups

Hydrologic Soil Group	Area (Square miles)	Area Percentage
A	3.84	63.9%
B	<0.00	0.04%
C	0.79	13.2%
D	1.38	22.9%

Most of the watershed (63.9%) was estimated to fall under HSG A, indicating the watershed consists mostly of soils that provide relatively high infiltration rates.

5.5.3 Maximum Deficit

The maximum deficit determines the total amount of water the soil layer can hold. Unlike initial deficit, this value is not affected by antecedent moisture conditions. Instead, the maximum deficit represents the driest the soil can become under the influence of gravity, evaporation, and transpiration. This parameter is a function of effective porosity, wilting point, and an assumed active layer depth (Rawls, Brakensiek, and Miller, 1983). GEI performed sensitivity testing by varying the maximum deficit estimate and found that the parameter had no measurable effect on model results. This is because maximum deficit is typically used to account for evapotranspiration that happens between storm events and sets a limit on the amount of water that is required to bring the soil from a dry state to a fully saturated condition. Because the model is used to simulate single storm events under saturated conditions, the maximum deficit does not influence the results. Therefore, the maximum deficit was set to zero (0) during design storm simulations or was set equal to the estimated initial deficit during simulation of observed storms.

5.6 Boundary Conditions

The boundary condition downstream of the watershed was set using a stage hydrograph to represent fluctuations of tides in Harpswell Cove. Tide data was obtained from the NOAA Portland ME Tide Station (Station ID 8418150) and downloaded from tidesandcurrents.noaa.gov (NOAA, 2022). The downstream boundary was placed at the confluence of Mare Brook and Harpswell Cove. For modeling of design storms, average high tide was set to occur when flow through the Liberty Crossing culvert (the most downstream culvert) was at its peak. This is a conservative measure resulting in higher water surface elevations in the downstream areas of the model.

Inflow hydrographs were used as upstream boundary conditions in various areas of the model to represent base flow. Water levels recorded during dry weather conditions were converted to flow using GEI's estimated rating curves. Base flows were then adjusted as necessary during model calibration to best match recorded initial river and pond levels.

Detailed bathymetric data in ponds and deeper sections of the brook were not available and a bathymetric survey was outside the scope of work. For storm event modeling the bathymetric data is not as critical as it would be for low flow modeling. Initial reservoir elevations of Coffin's Ice Pond Dam and Picnic Pond Dam were set to the average normal pool water elevations recorded by GEI's water sensors (47.6 ft and 23.3 ft, respectively) for the period of monitoring from July 2022 through October 2022.

5.7 Culvert Crossings and Control Structures

Structures were built within the model to represent the geometry of culverts and other stream crossings. Culvert invert elevations recorded during survey were directly input into the model. Other culvert input parameters included culvert length, material, slope, Manning's n-value, and entrance and exit loss coefficients. If a culvert was observed in the field to be clogged with debris or partially collapsed, GEI used the depth blocked parameter in HEC-RAS to account for the flow restriction. For culverts that were not surveyed either due to access restrictions or because they were less critical to model development, culvert geometry was based on documented information in the culvert and outfall inspection datasheets provided in Appendix B of the Mare Brook WMP. Inverts of culverts not surveyed were estimated based on photographs and the LiDAR surface in the area of the culvert.

GEI also modeled the geometry of Picnic Pond Dam and Coffin's Ice Pond Dam. The model includes elevations and lengths of embankments, spillways, and other hydraulic controls. The dimensions and elevations were based off measurements recorded during site-survey and GEI's field observations. Fig. 5 contains a map identifying stream crossings and culverts included in the 2-D hydraulic model.

6. HEC-RAS Model Calibration

Model calibration was performed to demonstrate the model can reasonably replicate observed stream and pond conditions. The process involved comparing simulated model results with observed conditions and refining inputs to optimize the model's replication of observed data. The goal of calibration was to achieve an overall "best match" to the observed data by replicating the timing, water level elevation, and discharge in the model.

6.1 Selection of Calibration and Validation Storms

GEI reviewed observed water level data and chose two calibration storms based on dates when high water levels were recorded by GEI's water level sensors. Two separate storms were selected for calibration to account for possible anomalies in the observed precipitation or water level data. The first storm of interest occurred on October 14, 2022. This storm produced the greatest amount of rainfall and the highest water levels compared with other events during the monitoring period from July to October 2022. On average about 2.7 inches of rainfall fell across the watershed in 24 hours. A review of historic rainfall data indicated the October storm would be on the order of a 1- to 2-year annual recurrence interval storm event. The second storm of interest occurred on July 25, 2022 when an average of 1.2 inches of rain fell over the watershed within 10 hours.

To verify the model would produce repeatable results, a third event was selected to serve as the model's validation storm. The third storm occurred over three days from September 18 to September 20, 2022 when an average of 2.3 inches of rain fell over the watershed. The September storm resulted in the second highest water levels recorded by GEI's water level sensors.

6.2 Precipitation Data

To accurately model observed storm events, it is critical to have reliable, high resolution precipitation data. During a storm event, rainfall intensity and duration can vary significantly from one end of a watershed to the other. Therefore, it's helpful to obtain rain gage data from multiple points within the watershed to capture the storm's path and timing.

Rainfall modeling methods typically guide selection of precipitation data. GEI elected to use the more detailed direct rainfall method included in the HEC-RAS software, referred to as "rain-on-grid." This method allowed for the simulation of the temporal and spatial variability of the observed storms allowing for more accurate results compared to average basin methods, where rainfall would typically be averaged across the entire watershed.

GEI consulted two precipitation data sources, Multi-Radar Multi-Sensor, and Weather Underground, to develop the gridded rainfall data.

(1) Multi-Radar Multi-Sensor (MRMS) – a system originally developed by NOAA's National Severe Storms Laboratory that produces gridded precipitation data as a time series. The automated system compiles data from Next Generation Weather Radar (NEXRAD) stations, satellite observations, and numerical weather prediction models to generate gridded data records for the United States.

    The MRMS data for this project was downloaded from Iowa State University's Iowa Environmental Mesonet (IEM) as Multi-Sensor Quantitative Precipitation Estimation (QPE) Pass 2 data (NOAA NSSL, 2022). The data set was downloaded in GRIB file format and represented 1-hour precipitation estimates at an approximate 1100x800 meter grid resolution. GEI used the U.S. Army Corps of Engineers HEC Hydrologic Modeling System (HEC-HMS) version 4.10.0 (USACE, 2022b) to convert the raw gridded precipitation data into a DSS file for input to HEC-RAS. The precipitation files were projected to align with the hydraulic model's coordinate system and time zone, and were clipped to the Mare Brook watershed boundary.

(2) Weather Underground (wunderground.com) – is website containing meteorological data from a network of weather stations maintained by meteorologists and members with personal weather stations. The site provides access to recorded weather data including 5-minute incremental precipitation. Rainfall data was obtained from 10 weather stations located within and around the Mare Brook watershed. A map of the selected weather stations is provided in Fig. 6.

    The precipitation data from each station along with the station's respective coordinates were entered into the HEC-RAS program. GEI used HEC-RAS to create an interpolated precipitation grid using a two-step process. First, the Thiessen Polygon method was used to determine which rain gage should be used as the representative storm pattern for a give cell within the 2D grid. Next, the Inverse Square of the Distance method was used to estimate the weighted rainfall total for each individual cell. This approach resulted in the compilation of precipitation data representing the spatial and temporal distribution of the given storms at 5-minute intervals.

Precipitation data from MRMS and Weather Underground were compared to determine an appropriate precipitation estimate for each storm event. GEI used engineering judgment to determine which source provided the most appropriate data for the three storms under consideration for this study. In general, MRMS data can provide higher resolution precipitation estimates in areas of low weather station density. While there were several weather stations located around the watershed, only one station was within the watershed boundary (See Fig. 6). Therefore, the MRMS data was the preferred option because the data provided relatively higher spatial resolution. For the July calibration model run, the MRMS precipitation estimates compared favorably with Weather Underground rain gage measurements in both magnitude and timing, thus, the MRMS data was chosen as the precipitation estimate for this storm.

While MRMS can produce higher resolution precipitation estimates, the NEXRAD data used to develop the estimates can be prone to error. These errors can stem from beam blockages, improper algorithms, range degradation and other mechanisms inherent in the process of estimating precipitation. Thus, NEXRAD data benefits from comparison with point gage data to verify the magnitude and timing of a rainfall event. Upon GEI's review, it was determined the MRMS data significantly overestimated the depth of rainfall during the October and September storms when compared to rain gage measurements from Weather Underground. Therefore, Weather Underground was used as the precipitation data source for the October calibration and the September validation model runs.

6.3 Calibration Adjustments

Several refinements were made to the HEC-RAS model inputs until the simulated model results compared favorably with the observed data. The "time step" (the frequency at which the model's calculations are performed) was tested for sensitivity. GEI determined a "variable" 5 second timestep (i.e., an automatically adjusted time step based on the Courant Condition) provided the best combination of runtime speed and stability. The model's sensitivity to Manning's n-values was also evaluated. However, modifying the Manning's n-values did not result in significant variations to model flows or water surface elevations. Therefore, initial values were determined to be appropriate. Initial base flows were also adjusted until water levels in the model matched recorded water elevations observed prior to the storm events. Other modifications included adding breaklines, adjusting impervious area infiltration percentages, and decreasing cell size in high flow areas. By performing these refinements, GEI was able to develop optimum inputs and model configurations that improved the agreement between observed and simulated model results.

6.4 Infiltration Rate Calibration

GEI's model sensitivity testing revealed that soil infiltration rates had the greatest influence on model results. Infiltration directly affects the amount of surface runoff calculated by the model. After making preliminary calibration runs, it became apparent that the volume of water flowing in the stream was too high compared to observed measurements. GEI determined that initial infiltration estimates were too low causing excessive runoff. The need for higher infiltration rates was attributed to two primary factors: drought conditions and soil types.

6.4.1 Drought Conditions

Cumberland County, Maine experienced drought conditions during the monitoring period from July through October 2022 (NOAA, 2023). NOAA and the U.S. Drought Monitor use a

5-category system to classify drought: abnormally dry, moderate drought, severe drought, extreme drought, and exceptional drought. Cumberland County was classified as abnormally dry in May and June, moderate drought in July, severe drought in August and September, and moderate drought in October.

These conditions likely resulted in high infiltration potential reducing the volume of direct runoff compared to rain events during periods when soils are saturated prior to the onset of a storm event. While the drought resulted in potentially increased short term infiltration potential, it is likely that the drought conditions in Maine in the summer of 2022 were not so severe as to result in "hydrophobic" conditions where the soil would repel precipitation and infiltration. This assumption is based on the observation of no significant vegetation die-off during the stream monitoring period suggesting the presence of moisture in the soil.

6.4.2 Soil Types

In addition to a review of NRCS soil characteristics, GEI reviewed published geology maps to further evaluate infiltration potential. Maine Geological Survey maps show that sand and gravel aquifers cover a significant area of the watershed (MGS, 1999). Research by Gerber and Hebson (Gerber and Hebson, 1997) indicate sand and gravel materials in Maine exhibit the greatest recharge potential (50% to 60% of average annual precipitation) when compared with other geologic materials like till, clay, and bedrock, which range from 2% (clay and bedrock) to 20% (sandy till) of average annual precipitation. In *Introduction to Soil Physics* (Hillel, 1982) the infiltration rate for sand and gravel is estimated to be 0.8 inches/hour or greater, loams 0.2 to 0.4 inches/hour, and clays 0.04 to 0.2 inches/hour. These infiltration rates are nearly twice the minimum infiltration rates reproduced by USACE (2022b) based on Skaggs and Khaleel (1982) which were used in GEI's preliminary model runs (see Table 2). In GEI's opinion, increasing the infiltration rates within the model was appropriate based on the available soil information, published maps, research on Maine soils, and the water level data recorded during significant storm events.

The July and October storms were independently calibrated. To achieve reasonable model accuracy, the July storm required a slightly lower infiltration rate to achieve a best match compared to the October storm. The average calibrated infiltration rates between the October and July storms were used in model validation and final design storm model runs.

6.5 Model Calibration Results

GEI compared observed water level data with the water levels simulated by the model at each of the five sensor locations. Peak observed and simulated water levels for the October and July storm events are shown in Table 4 and Table 5, respectively. Graphs summarizing simulated and observed results are included in Appendix B.

Table 4. October 14, 2022 Model Calibration Results

Location	Peak Water Surface Elevation (ft, NAVD88)		
	Observed	Simulated	Difference
U/S of Meadow Brook Rd. Culvert	50.8	51.0	+0.2
Coffin's Ice Pond	48.4	48.5	+0.1
U/S of Runway Culvert	27.8	28.1	+0.3
Picnic Pond	25.4	25.2	-0.2
U/S of Liberty Crossing Culvert	6.0	6.2	+0.2

Note: "U/S" indicates "upstream."

Table 5. July 25, 2022 Model Calibration Results

Location	Peak Water Surface Elevation (ft, NAVD88)		
	Observed	Simulated	Difference
U/S of Meadow Brook Rd. Culvert	51.3	50.6	-0.8
Coffin's Ice Pond	48.3	48.1	-0.2
U/S of Runway Culvert	27.4	27.3	-0.1
Picnic Pond	24.0	24.0	0.0
U/S of Liberty Crossing Culvert	5.1	4.9	-0.2

Note: "U/S" indicates "upstream."

Modeled peak water surface elevations during the October event were within 0.3 ft or less of observed levels. For the July calibration storm event, modeled results were within 0.2 feet or less at four out of five sensors. These results indicate very good agreement between the observed data and simulated results.

At the Meadowbrook Road culvert, the model results for the July calibration event were 0.8 ft lower than the observed peak water elevation of 51.3 ft. This event produced the highest recorded water level at the Meadowbrook sensor during the observation period. The peak recorded during the July storm (51.3 ft) was about half of a foot higher than the peak recorded during the larger October storm (50.8 ft). This result for Meadowbrook Road culvert was somewhat unexpected because nearly half as much rain fell during the July storm compared to the October storm. One possible explanation for the high water surface is that the culvert may have become blocked from debris during the July storm event reducing flow and causing water levels upstream of the culvert to rise. Another possibility is an intense but short microburst may have passed over the area upstream of the Meadowbrook culvert which may not have been captured in the observed precipitation data.

Aside from the minor anomaly identified at the Meadowbrook Road culvert in July, these results indicate that the model provided an accurate estimation of peak water levels for both calibration storm events. Also, the graphs provided in Appendix B show the model accurately simulates the timing of peak water surface, arriving at about the same time as the GEI observed peak water levels.

6.6 Model Validation Results

To validate the model, a third storm was compared with observed water levels. The third storm occurred over three days from September 18 to September 20, 2022. The September storm resulted in the second highest water levels recorded by GEI's water level sensors.

Peak simulated and observed water levels for the September storm event are shown in Table 6. Graphs summarizing the simulated and observed results are included in Appendix C.

Table 6. September 18 – 20, 2022 Model Validation Results

Location	Peak Water Surface Elevation (ft, NAVD88)		
	Observed	Simulated	Difference
U/S of Meadow Brook Rd. Culvert	50.7	50.6	-0.1
Coffin's Ice Pond	48.4	48.3	-0.1
U/S of Runway Culvert	27.7	27.8	+0.1
Picnic Pond	24.8	24.7	-0.1
U/S of Liberty Crossing Culvert	5.2	5.7	+0.5

Again, the model showed accurate results compared to observed conditions with four out of five sensors coming within 0.1 feet of observed elevations. The graphs in Appendix C also show very good timing of peak water elevation and flow volume.

The model accurately simulated observed conditions for three separate storm events. In GEI's opinion, the model is suitable for its intended use in providing reasonable estimates of peak water levels and peak flows during the design storm events (i.e., 2-, 10-, 25-year storms) at key stream crossings within the watershed.

7. Design Storm Analysis

7.1 Annual Recurrence Storm Estimation

GEI modeled the 24-hour 2-, 10-, and 25-year annual recurrence interval precipitation events also referred to as “design storms.” Respectively, these events have a 50%, 10%, and 4% chance of occurring in any given year. To select the precipitation associated with these recurrence intervals, GEI compared precipitation estimates from the National Oceanic and Atmospheric (NOAA) Atlas 14 Precipitation Frequency Data Server (PFDS) with precipitation estimates published by Northeast Regional Climate Center (NRCC) Extreme Precipitation in New York and New England (NOAA PFDS, 2022 and NRCC, 2022). Estimates from each source are presented in Table 7.

Table 7. Precipitation Estimates (inches) for Design Storm Events

	2-Year		10-Year		25-Year	
Duration	Atlas 14	NRCC	Atlas 14	NRCC	Atlas 14	NRCC
5-min	0.351	0.32	0.54	0.43	0.654	0.51
10-min	0.497	0.49	0.76	0.67	0.926	0.81
15-min	0.584	0.61	0.90	0.85	1.09	1.04
30-min	0.790	0.80	1.21	1.16	1.47	1.43
60-min	0.995	1.01	1.53	1.51	1.86	1.89
2-hr	1.33	1.28	2.04	1.94	2.48	2.45
3-hr	1.57	1.49	2.40	2.26	2.91	2.86
6-hr	2.05	1.90	3.12	2.86	3.79	3.61
12-hr	2.62	2.42	3.96	3.60	4.81	4.52
24-hr	3.16	3.10	4.81	4.51	5.84	5.60

The 24-hour precipitation estimates from NOAA Atlas 14 were greater than estimates from NRCC for each of the three design storm events. As a conservative measure, GEI used the greater precipitation estimates from NOAA Atlas 14.

GEI estimated rainfall distribution curves using the NRCC web tool (NRCC, 2022). The tool develops a dimensionless 24-hour hyetograph and incorporates storms of smaller duration from 5-minutes through 24-hours that have a consistent exceedance probability. The dimensionless 24-hour hyetograph is represented as cumulative rainfall at 6-minute intervals. GEI multiplied the 24-hour NOAA Atlas 14 precipitation estimate by the by the dimensionless hyetograph to create cumulative precipitation curves for each design storm event.

7.2 Results

Results for the 24-hour 2-, 10-, and 25-year annual recurrence interval precipitation events are provided in Appendix D. The results include peak upstream water elevation, peak flow, and headwater depth versus structure depth ratio (HW/D). Results are provided for Coffin's Ice Pond Dam, Picnic Pond Dam, and the culverts identified in the Mare Brook WMP as needing an H&H analysis. These culverts are included in Table 8, listed from upstream to downstream.

Table 8. Key Culverts listed in MWP

Location	Culvert ID	Total Cross Sectional Flow Area (ft^2)	WMP Recommendation
Baribeau Drive	Cul04 & Cul05	15	1) Remove culverts, 2) Restore channel 3) Replace with open bottom culvert
Barrows Street	Cul10	16	1) Remove undersized culverts, restore channel 2) Replace with larger opening
Macmillan Drive	Cul14	16	1) Remove culverts, restore channel 2) Replace open bottom culvert
Maine Street	Cul16	19	1) Remove culverts, restore channel 2) Replace open bottom culvert
Meadowbrook Road	Cul17	13	1) Remove culvert, restore channel 2) Upsize culvert
Harpswell Road	Cul23	20	1) Remove culvert, restore channel 2) Replace with open bottom culvert
*Sparwell Lane	Cul18	5	1) Upsize culvert 2) Rebuild road

- *Sparwell Lane crossing is located on a tributary of Mare Brook between Meadowbrook Road and Harpswell Road

The majority of these culverts were identified in the WMP as undersized and nearing the end of their design lives. The WMP also indicated these culverts offered little opportunity for aquatic organism passage. In general, the culverts were recommended to be replaced with a larger, open bottom culvert or bridge.

GEI's H&H model indicated significant ponding upstream of the culverts listed in Table 8. Road crossings at the culvert locations were not overtopped in GEI's 25-year design storm analysis. However, each culvert barrel was fully submerged for the 25-year storm, and debris carried by flood water could restrict flow increasing the risk of roadway overtopping during future storm events.

The model also identified limitations in the existing capacity of other hydraulic structures within the watershed. Several culverts were overtopped along the tributary at the Mid Coast Senior Health Center. The WMP identified these culverts as Cul09, Cul08 and Cul07. The WMP indicated these culverts were undersized and/or partially blocked with debris.

Culvert Cul28 located downstream of Picnic Pond Dam was overtopped during the 10 and 25-year storm events. This road was closed to the public at the time of preparing this report and may not be critical to Brunswick's restoration plan. It is not clear if road overtopping at this location from the low recurrence interval storm would result in instability and/or potential failure of the road. Stability analysis was not performed for this study.

Based on GEI's H&H analysis, Coffin's Ice Pond Dam and Picnic Pond Dam would be at risk of overtopping for storm events of similar order of magnitude as the 2-year storm or greater. Table 9 presents estimates of overtopping/freeboard depth at the non-overflow embankment sections during the modeled design storm events.

Table 9. Overtopping/Freeboard Depth at Picnic Pond and Coffin's Ice Pond Dams

Dam	Freeboard (-), Overtopping (+), (ft)		
	2-yr	10-yr	25-yr
Coffin's Ice Pond Dam	-0.1	+0.5	+1.4
Picnic Pond Dam	0.0	+1.0	+1.5

The dams appeared to be earthen embankments, which are highly susceptible to erosion from overtopping. Loss of Coffin's Ice Pond Dam would likely have ecological and social repercussions, though consideration for either is beyond the scope of this analysis and requires further consideration by the Town of Brunswick.

The Environmental Protection Agency (EPA) placed the Picnic Pond area on the Superfund program's National Priorities List in 1987. Wastes generated by the U.S. Navy when the base was active have contaminated soil and ground water in areas upstream of the pond. The Navy has and continues to perform cleanup in the Picnic Pond area, which is closed to the public. Loss of Picnic Pond Dam could potentially cause a release of contaminated sediment into the downstream reach of Mare Brook.

7.3 Conclusions

The conclusions and recommendations presented in this section are based on GEI's engineering judgment and their interpretation of the study's results. The recommendations in this section are meant to assist Brunswick develop a strategy for restoring the Mare Brook watershed. The recommendations made are considered suggestions and, in some cases, further analysis and public outreach may be necessary to determine the best action moving forward. In Section 8, Next Steps, GEI includes specific recommended studies that will further help Brunswick make decisions to meet their goals in accordance with published state guidelines.

Mare Brook, a Maine Class B stream, is currently listed by the Maine Department of Environmental Protection as impaired due to poor macroinvertebrate sampling results and habitat. Brunswick's WMP has a goal to meet the State-designated Class B standards in Mare Brook by 2037 by performing stream restoration and culvert replacement projects. These projects seek to improve stream health while reducing risk of inland flooding. Several of the existing culverts are undersized and in poor condition as indicated in the WMP. Most of the culverts will likely need to be replaced prior to 2037.

GEI recommends Brunswick identify design storms to use in culvert replacements and dam rehabilitation based on an appropriate level of risk and consistent with state guidelines while also considering potential effects of climate change and sea level rise.

It is critical that culverts/dams be replaced/rehabilitated in an order that does not cause increased flooding downstream. Therefore, culvert replacement should generally progress from downstream to upstream especially for culvert replacements that are proposed to increase capacity. The 2D hydraulic model created by GEI is capable of analyzing the culverts as a system rather than individually. This allows future modeling efforts to analyze the effects a new culvert will have on the watershed as whole. Ideally, all culverts proposed for replacement should be designed concurrently. This is done so that each culvert is designed to account for the increased flow expected once all upstream culverts are replaced.

GEI recommends the Town of Brunswick address spillway capacity at Coffin's Ice Pond Dam prior to replacing culverts upstream of the dam. Coffin's Ice Pond Dam is at risk of overtopping during storm events greater than the 2-year annual recurrence interval and overtopping of the earthen embankment could lead to failure. The WMP suggests exploring removal as a possible remedial action, though it acknowledges this action would require further consideration and analysis of potential ecological and social impacts prior to implementation. Regarding the pond's social value, the WMP suggests establishing a "Coffin's Ice Pond Stakeholder Working Group, [tasked with establishing] a definitive charge and timeline to weigh [the] benefit of dam removal and/or restoration to stream health versus community and ecological benefits to provide a [final] recommendation to the Mare Brook Leadership Team." While GEI would be able to provide assistance as it pertains to modeling the effect of removal versus non removal, final determination as to how to mitigate stressors in either scenario would require further analysis and consideration by the Mare Brook Leadership Team, as would establishing a public outreach program to educate the community on the possible rehabilitation or removal of dam before taking action.

The WMP suggests "day lighting" the more than 3,000-ft-long culverts that run under the airport runways. Though this action would have significant benefit to the overall ecological health of the stream, daylighting the culverts would likely be the most challenging and costly modification in the culvert portfolio. While it is recommended that culvert replacement take place starting from downstream and moving upstream, prioritizing the runway culvert, and associated remedial options suggested within the WMP, may not be immediately necessary. Currently, the runway's existing culvert system has significantly more conveyance capacity compared to other culverts in the watershed; further analysis would be required to confirm airport culvert capacity relative to that of anticipated remediation efforts further upstream, with the need for further analysis contingent on design storms selected by the Town. Given the challenges associated with this culvert, time and more calculated effort concerning planning and securing funding would be necessary in the event of such an undertaking; as such, while the system does not appear to require immediate attention, additional modeling efforts to assess shifts in the collective impact of (a) suggested remedial actions within the WMP, and (b) replacements and updates implemented, would be beneficial for the purpose of evaluating the performance of this culvert in relation to the overall systems flow and hydrology.

8. Next Steps

To help evaluate the vulnerability of the watershed under potential climate change and sea level rise impacts and to ensure stream restoration projects provide a healthier more resilient ecosystem, GEI offers a few possible areas of additional analysis for Brunswick's consideration. These suggested analyses are model-based scenarios by which Brunswick may examine the impact of potential policy changes, construction efforts and improvements, or other climate-based scenarios as they pertain to the WMP and the betterment of Mare Brook. These suggestions are as follows:

- The Town may want to consider performing a climate change vulnerability analysis to assess impacts to the watershed caused by rising sea levels and increased frequency, depth, and intensity of precipitation events.

- GEI recommends performing an H&H analysis for the 50-year and 100-year annual recurrence interval storm events. The Maine Bridge Design Guide (MaineDOT, 2003) indicates that bridges and minor spans should be designed for the 50-year event and checked for the 100-year event. In certain cases, analysis of the 500-year flood event may be warranted. For culvert design, MaineDOT indicates that the ratio of headwater (depth above the invert) to the structure depth (culvert diameter) should be approximately equal to or less than 0.9 (i.e., flow depth at 90% full) for the 50-year event.

  When outlet conditions control culvert flow, a minimum of 1 foot of freeboard is required for the 100-year event. Performing H&H analysis under the 50-year and 100-year flood conditions will provide the Town of Brunswick with an understanding of culvert design relative to the state guidelines.

- GEI created the HEC-RAS model to facilitate design of future culvert replacements. Proposed culverts may be added to the model to assess flood conditions and downstream impacts under proposed designs. GEI recommends consideration of the State of Maine Aquatic Resource Management Strategy (ARMS) Stream Smart Road Crossing Guide when designing replacement and new culverts (MaineDOT, 2023). The web-based guide provides information for "installing and replacing crossings in an effective and cost-efficient manner while meeting goals of restoring and maintaining stream habitat connectivity and enhancing the stability of roads and culvert crossings."

- The hydraulic model was developed for use in evaluating extreme events (i.e., 2-, 10- and 25-year events) and was calibrated to three observed storms on the order of 1- to 2-year annual recurrence interval. Analyzing channel velocities and water depths under low flow conditions may be of interest for the design of future stream restoration projects. If the Town is interested in evaluating low flow conditions, additional work may be required to refine the model such as the collection of detailed stream channel bathymetry (to supplement the detailed LiDAR terrain data), water level monitoring, calibration during low flows, and evaluation of ground water discharge to the brook during low flow periods.

9. Limitation of Liability

This report presents analyses and results of a site-specific hydrologic and hydraulic study of the Mare Brook watershed. GEI developed a hydrologic and hydraulic model of the Mare Brook watershed to access flood conditions during the 2-, 10- and 25-year annual recurrence interval storm events. The hydrologic and hydraulic model was created using GEI's best judgment and to be comprehensive and conservative in the development of infiltration rates, design storm precipitation, and other parameters presented in this study. This study also relied on data developed by others.

This study included limited hydraulic analysis and does not include an evaluation of the structural integrity of culverts, bridges, dams, and other appurtenances. If a storm event occurs in the watershed, actual conditions, peak flows, and peak water surface elevations will vary from those presented in this report. Because the methods, procedures, and assumptions used to develop the analysis are approximate, the results should be used only as guidance. Actual flood inflow volumes, water surface elevations, and flood timing may differ from the results presented in this report.

The HEC-RAS model was developed to provide reasonably accurate results along the main branch of Mare Brook, Picnic Pond Dam, Coffin's Ice Pond Dam, and at crossings identified in the Mare Brook Management Plan as needing a H&H analysis. With any complex hydraulic model, a balance must be struck between model stability, accuracy, and run-time speed. GEI structured the model so that flood conditions could be estimated with reasonable accuracy in locations where needed while still maintaining optimal model performance. Use of the model to extrapolate results from locations not prioritized in this study including Mare Brook's tributaries and un-surveyed culverts may provide comparatively less accurate results.

The hydraulic model was developed and calibrated to evaluate watershed characteristics and approximate hydraulic capacity of river crossings and dams for the storm events presented. Assessing Mare Brook and its tributaries under low flow conditions was not the objective of this study. Evaluation of the Mare Brook under low flow conditions would require calibration and additional analyses.

Reuse of this report for any other purposes, in part or in whole, is at the sole risk of the user.

10. References

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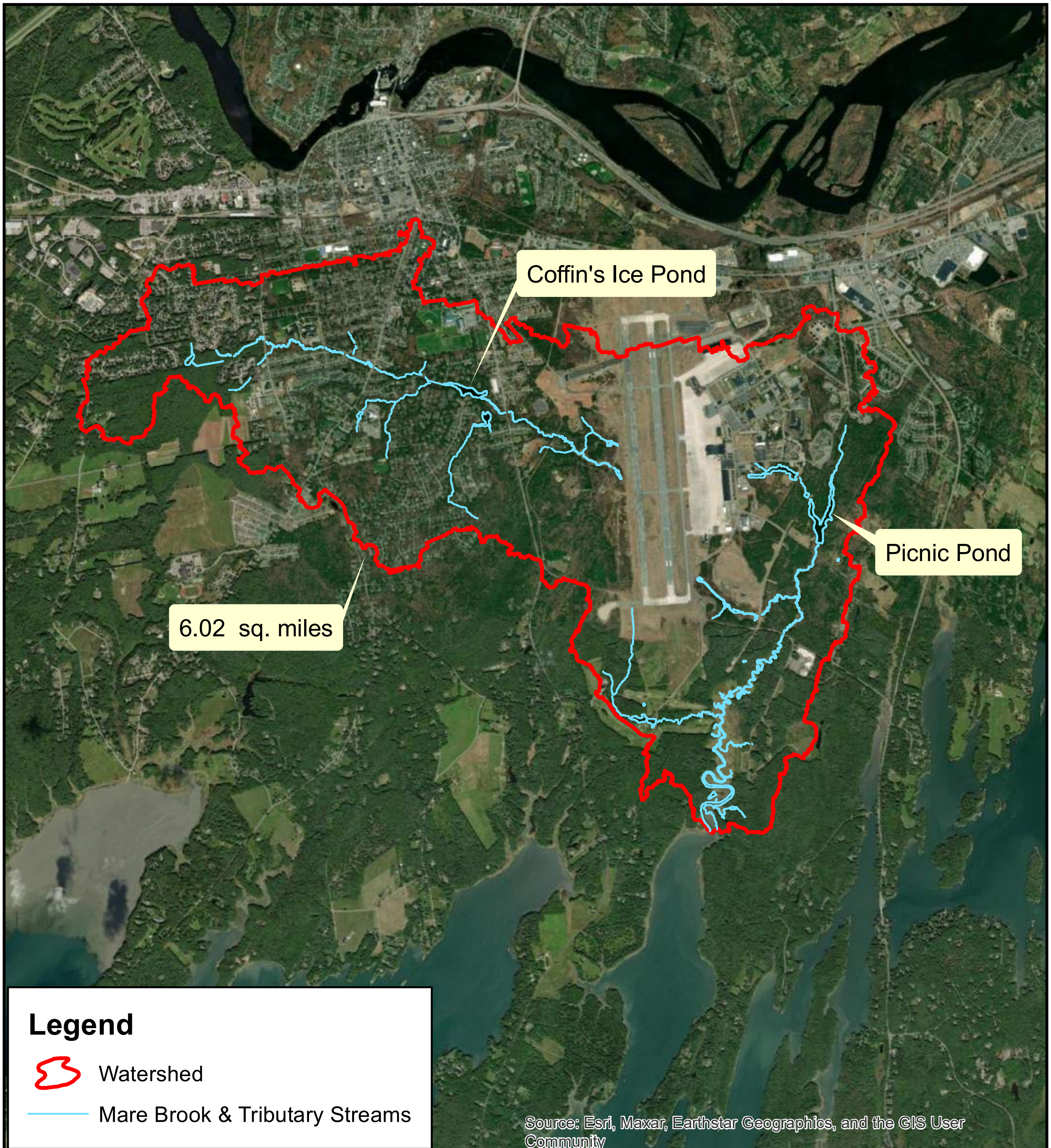
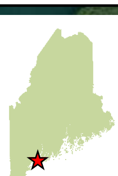
Figures





Mare Brook Watershed Hydrologic & Hydraulic Study Brunswick, Maine	GEI Consultants	WATERSHED AREA MAP
Town of Brunswick, Maine Department of Planning and Development	Project 2202137	March 2023 Fig. 1

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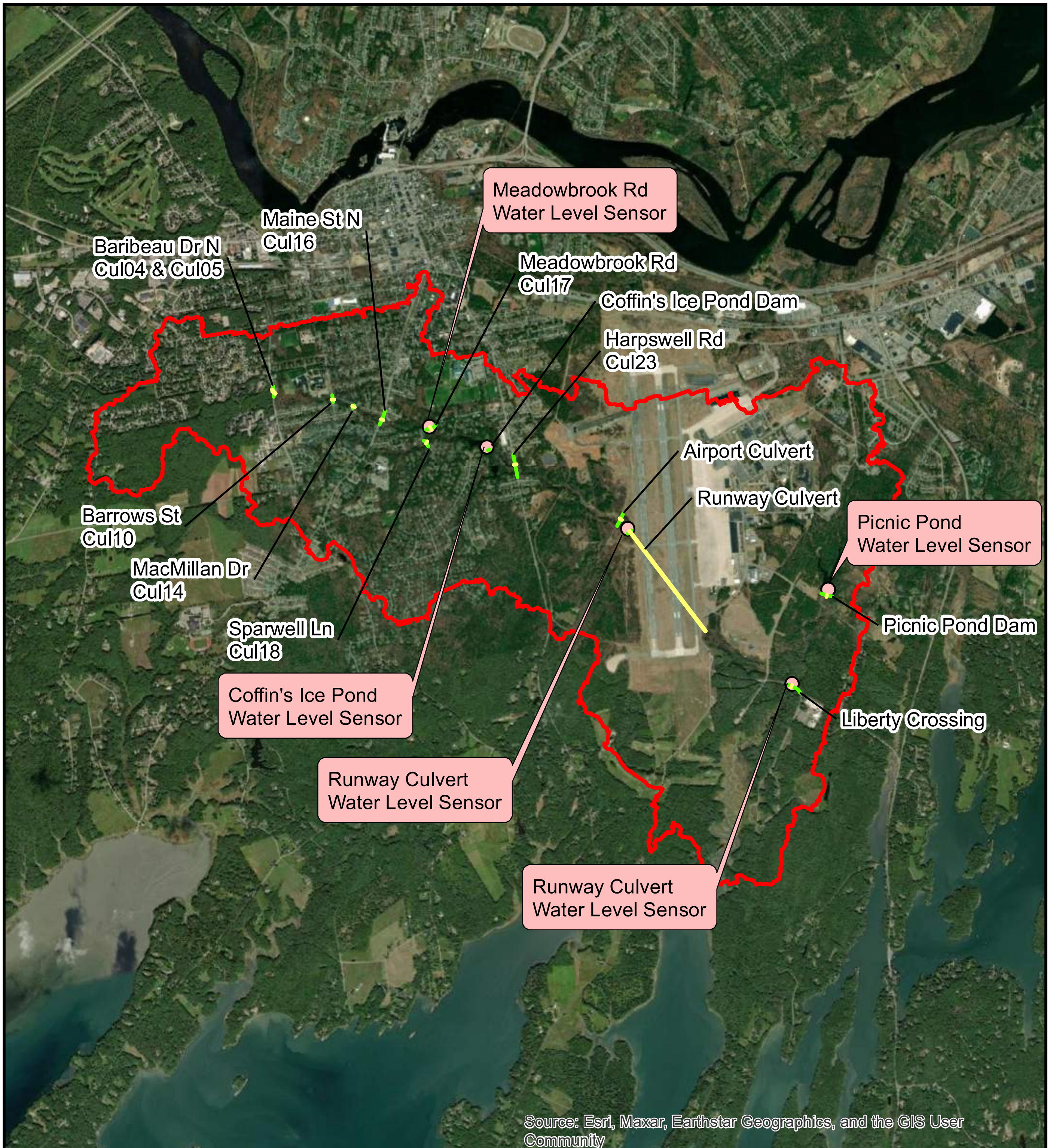

Legend

Cuvert Surveyed

Crossing Surveyed

Water Level Sensor

Watershed

N

0 2,000 4,000 8,000

Feet

Mare Brook Watershed Hydrologic & Hydraulic Study Brunswick, Maine	GEI Consultants	SURVEYED CROSSINGS AND WATER LEVEL SENSOR LOCATIONS
Town of Brunswick, Maine Department of Planning and Development	Project 2202137	March 2023 Fig. 2

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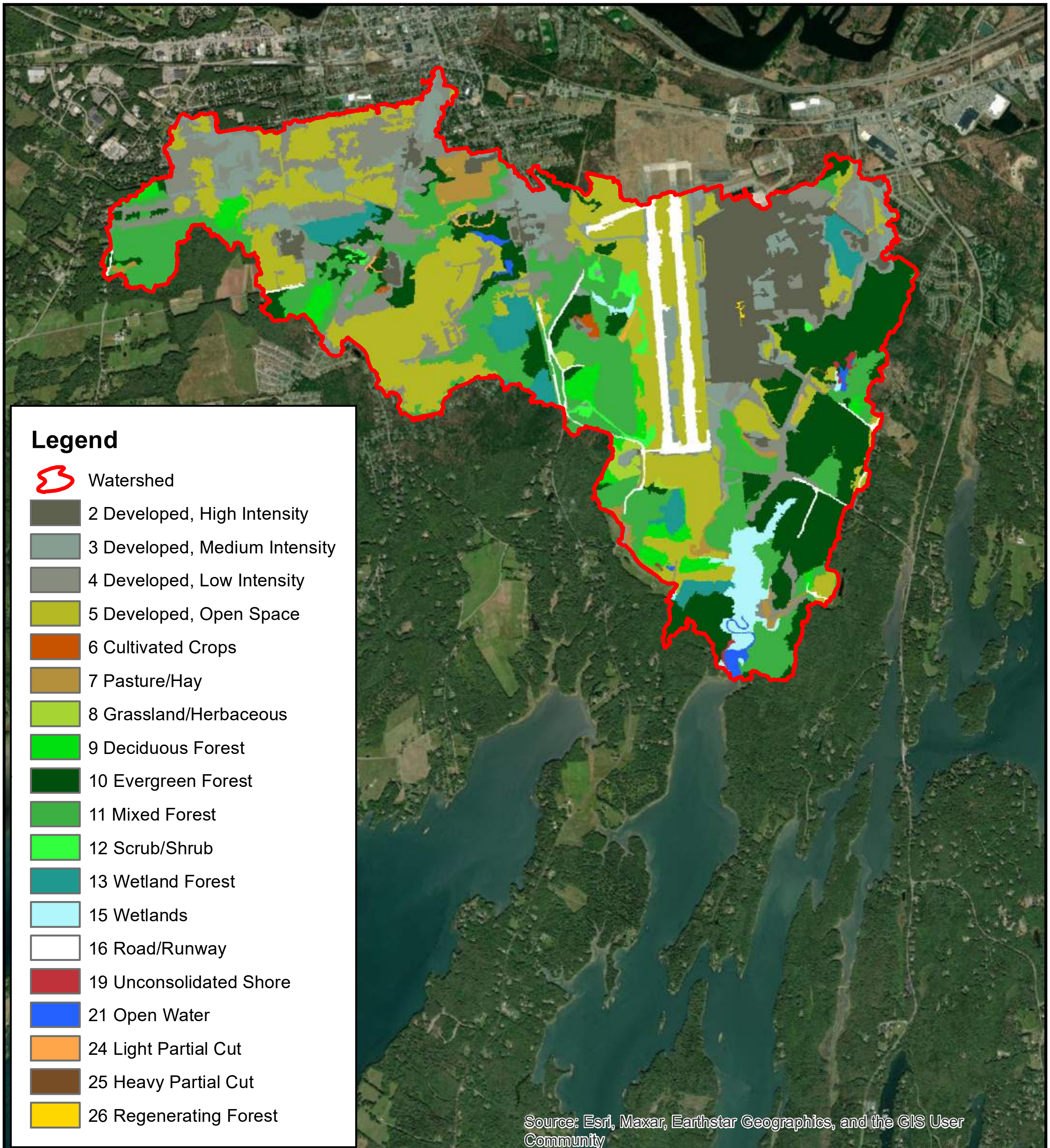

Land cover data for the Mare Brook Watershed was obtained from the Maine Land Cover Dataset (2004), downloaded from Maine GeoLibrary.

Mare Brook Watershed Hydrologic & Hydraulic Study Brunswick, Maine	GEI Consultants	LAND COVER MAP
Town of Brunswick, Maine Department of Planning and Development	Project 2202137	March 2023 Fig. 3

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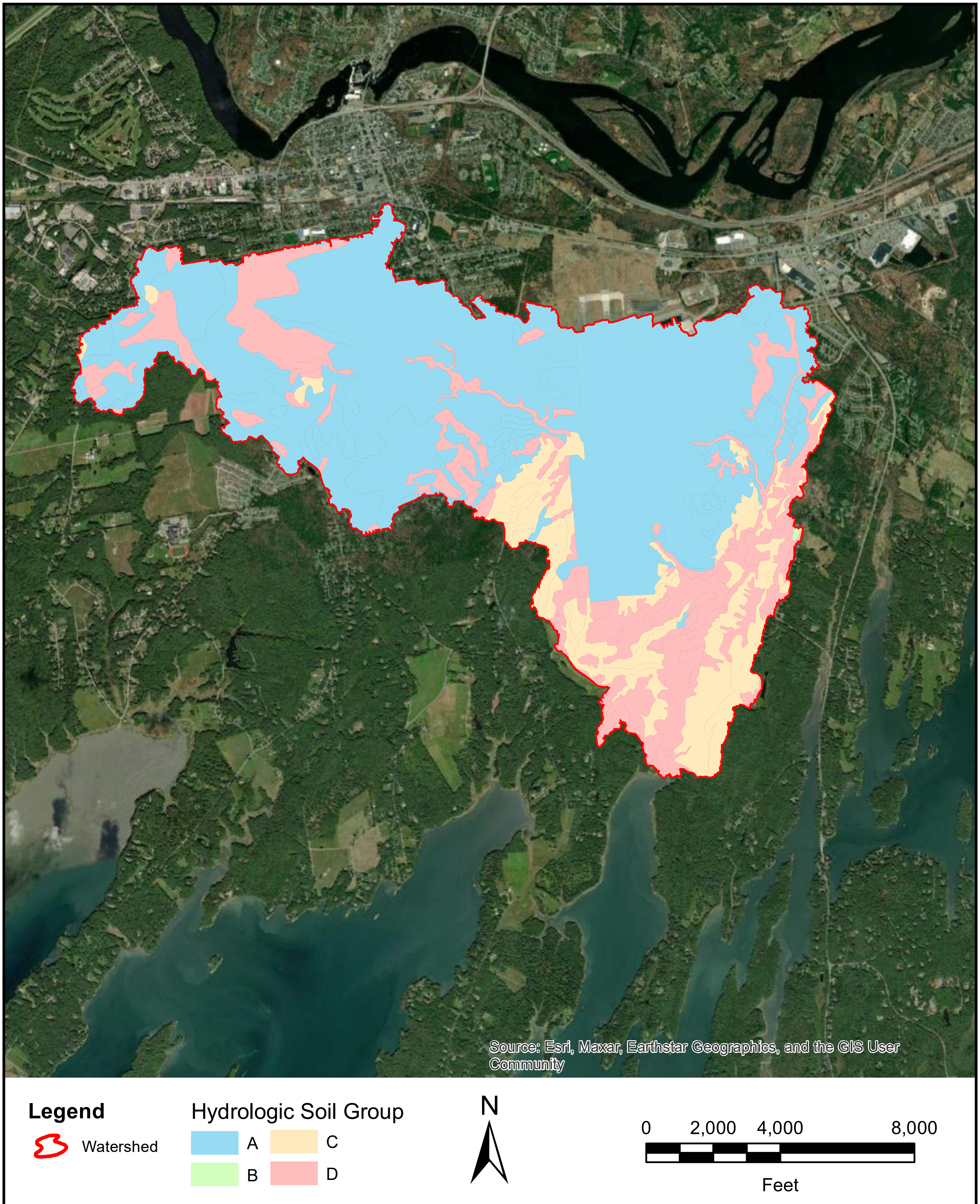

Mare Brook
Watershed Hydrologic & Hydraulic Study
Brunswick, Maine

Town of Brunswick, Maine
Department of Planning and Development

GEI Consultants

HYDROLOGIC SOIL GROUP MAP

Project 2202137

March 2023

Fig. 4

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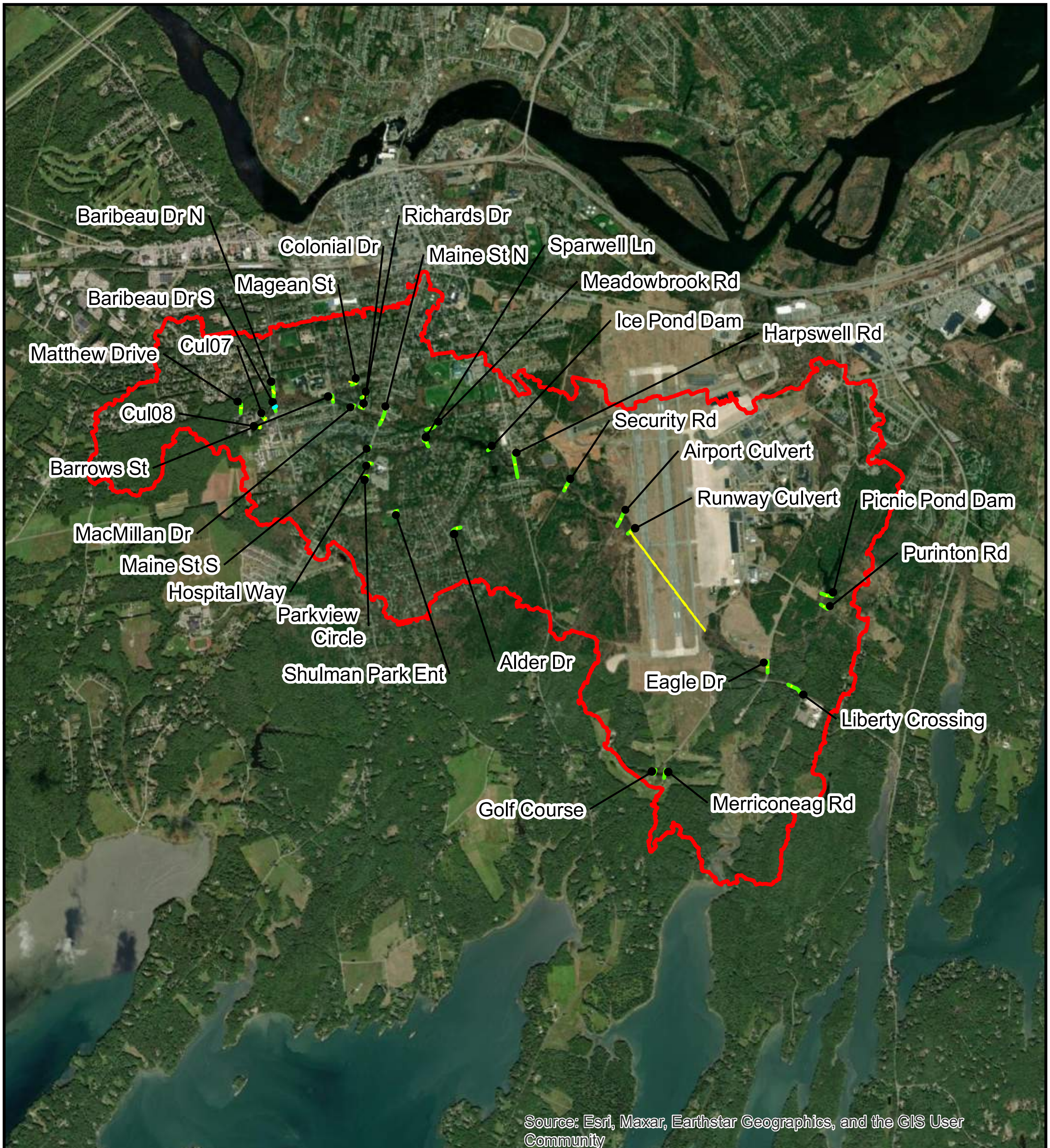


Legend

HECRAS Culverts

HECRAS Crossings

Watershed

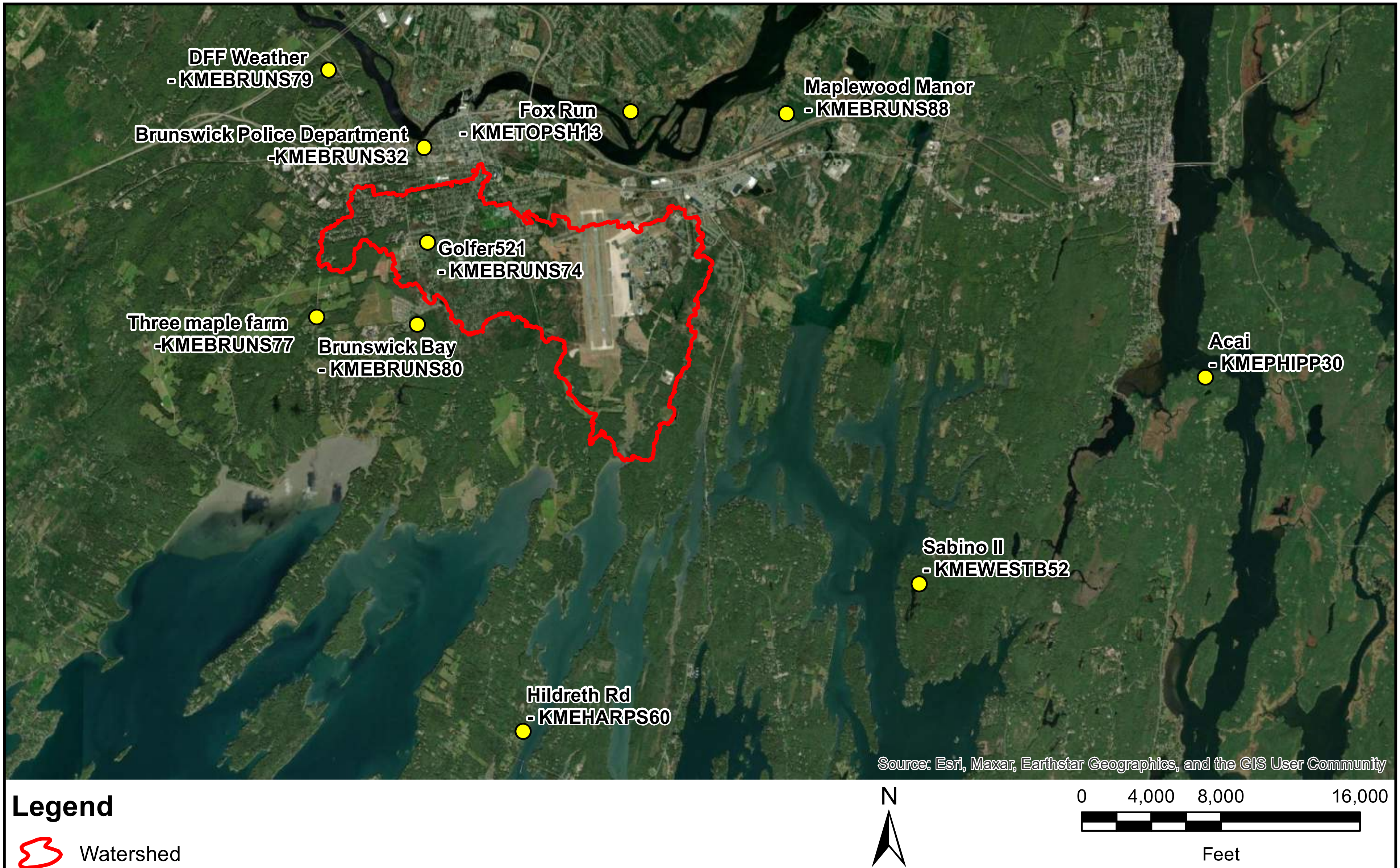
N

0 2,000 4,000 8,000

Feet

Mare Brook Watershed Hydrologic & Hydraulic Study Brunswick, Maine	GEI Consultants	MODELED STREAM CROSSINGS
Town of Brunswick, Maine Department of Planning and Development	Project 2202137	March 2023 Fig. 5

Y:\SHARED\PROJECTS\2022\2202137_Mare Brook H_H\GIS\Figures\Fig5_Modeled_Stream_Crossings.mxd



Legend

Watershed

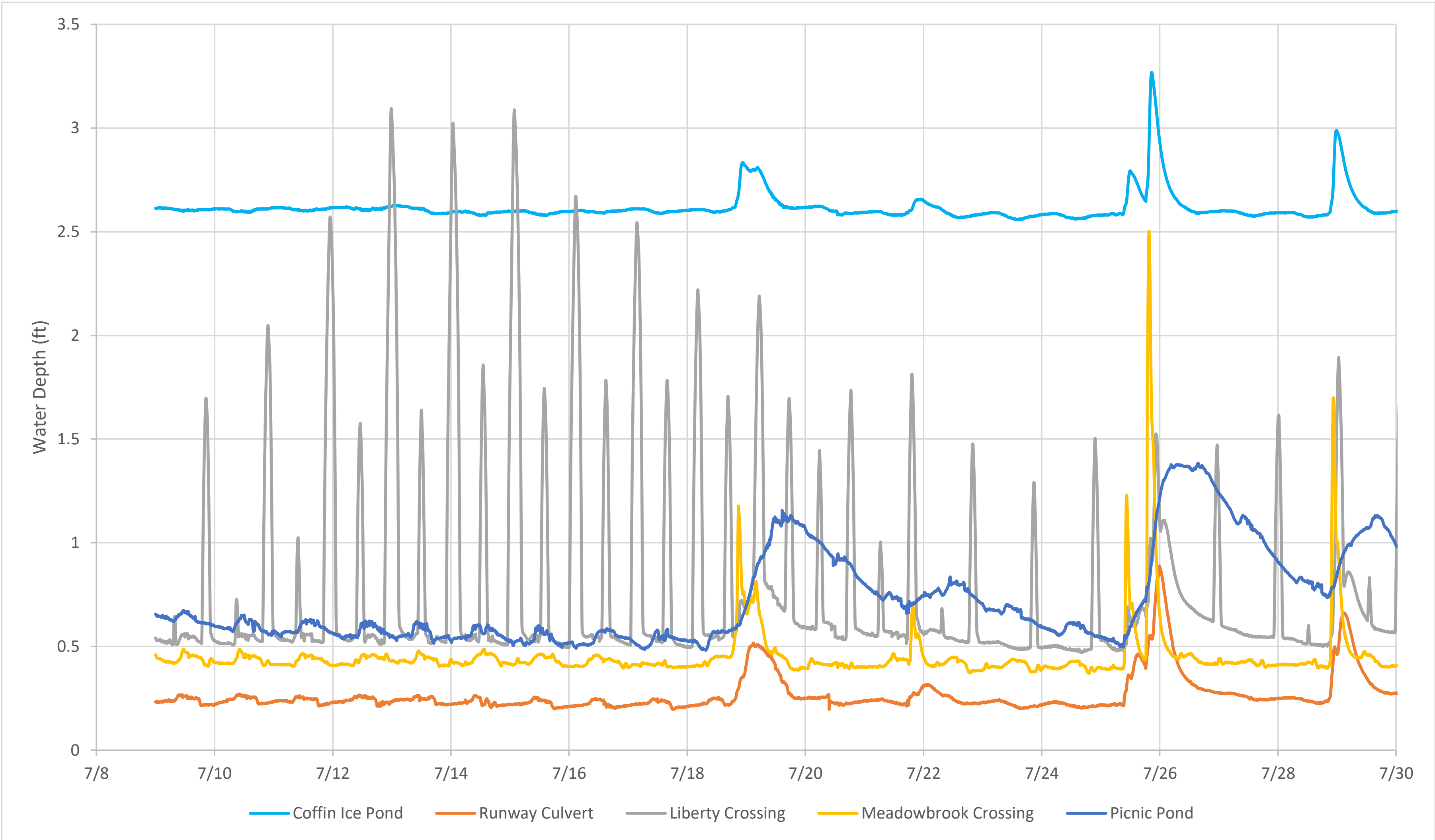
Precipitation Gages

Mare Brook Watershed Hydrologic & Hydraulic Study Brunswick, Maine	GEI Consultants	WEATHER STATION MAP	
Town of Brunswick, Maine Department of Planning and Development	Project 2202137	March 2023	Fig. 6

Y:\SHARED\PROJECTS\2022\2202137_Mare Brook H_H\GIS\Figures\Fig6_Weather_Station_Map.mxd

Appendix A

Mare Brook Water Depth Graphs



Note:
Water level data recorded by GEI. "Depth" represents water depth as measured from the bottom of sensor to water level and does not represent actual depth of water. Provided data compensates for barometric pressure at time of measurement.

Mare Brook Watershed
Hydrologic & Hydraulic Study

GEI Consultants

MARE BROOK WATER DEPTHS
July 2022

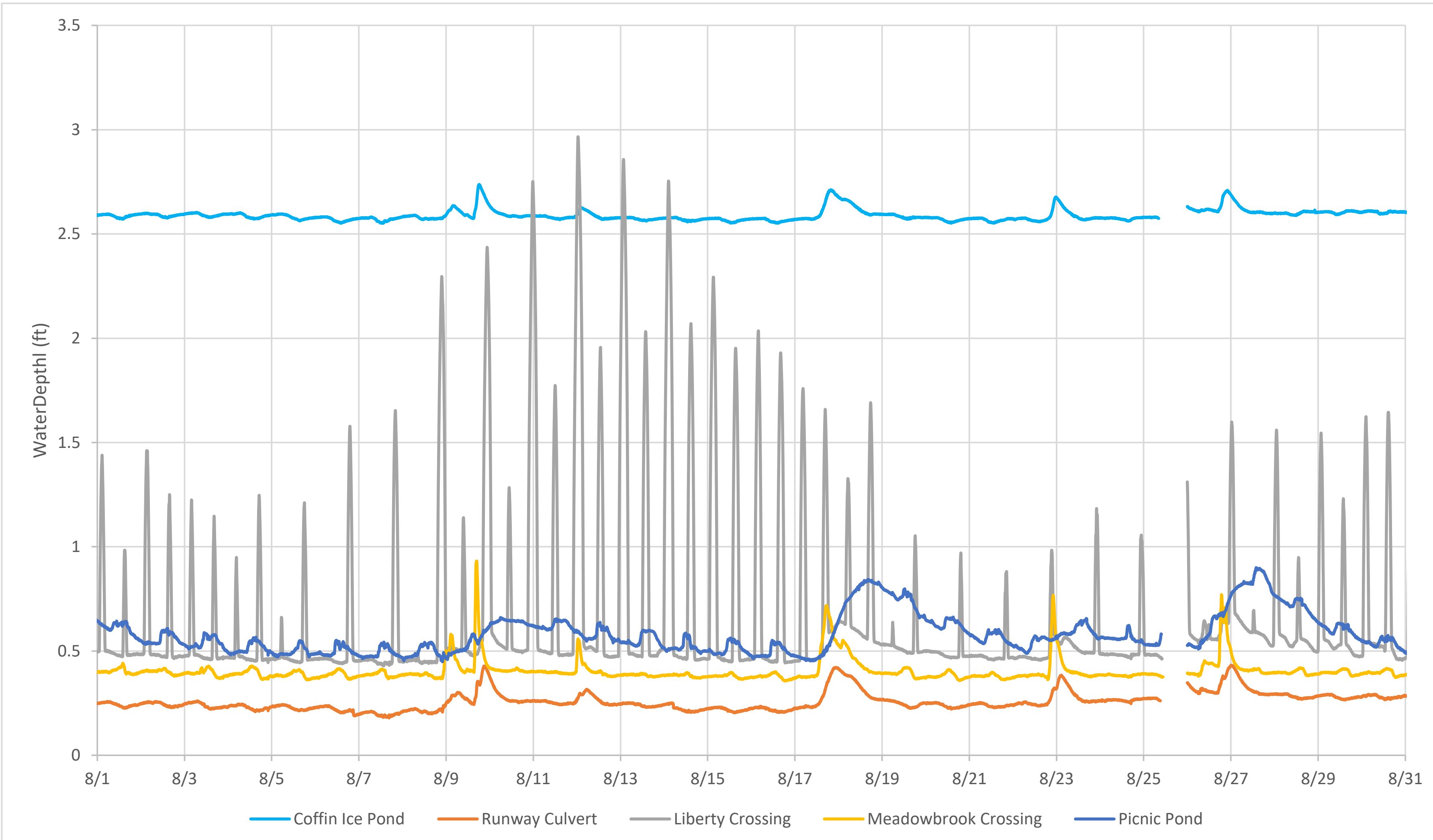
Town of Brunswick, Maine
Department of Planning and Development

Project 2202137

December 2022

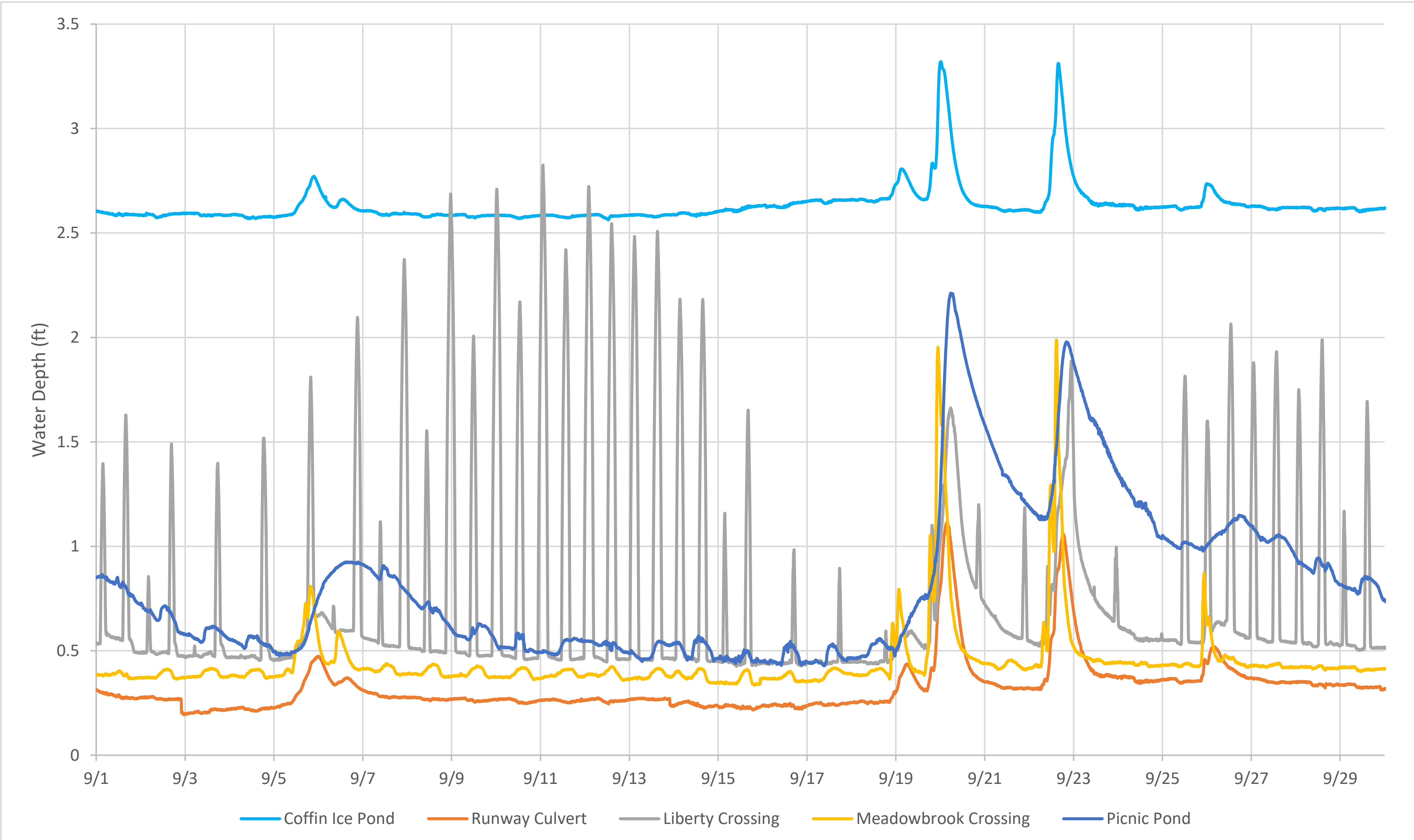
Appx. A
Fig. 1

\\geiconsultants.com\data\Data_Storage\Working\BRUNSWICK ME, TOWN OF\2202137 Mare Brook H_H\05_FIELD\Sensor Data\MareBrookData_0709to1028.xlsx



Note: Water level data recorded by GEI. "Depth" represents water depth as measured from the bottom of sensor to water level and does not represent actual depth of water. Provided data compensates for barometric pressure at time of measurement.	**Mare Brook Watershed** **Hydrologic & Hydraulic Study**	GEI Consultants	**MARE BROOK WATER DEPTHS** **August 2022**
	Town of Brunswick, Maine **Department of Planning and Development**	**Project 2202137**	**December 2022** **Appx. A Fig. 2**

\\geiconsultants.com\data\Data_Storage\Working\BRUNSWICK ME, TOWN OF\2202137 Mare Brook H_H\05_FIELD\Sensor Data\MareBrookData_0709to1028.xlsx



Note:
Water level data recorded by GEI. "Depth" represents water depth as measured from the bottom of sensor to water level and does not represent actual depth of water. Provided data compensates for barometric pressure at time of measurement.

Mare Brook Watershed
Hydrologic & Hydraulic Study

GEI Consultants

MARE BROOK WATER DEPTHS
September 2022

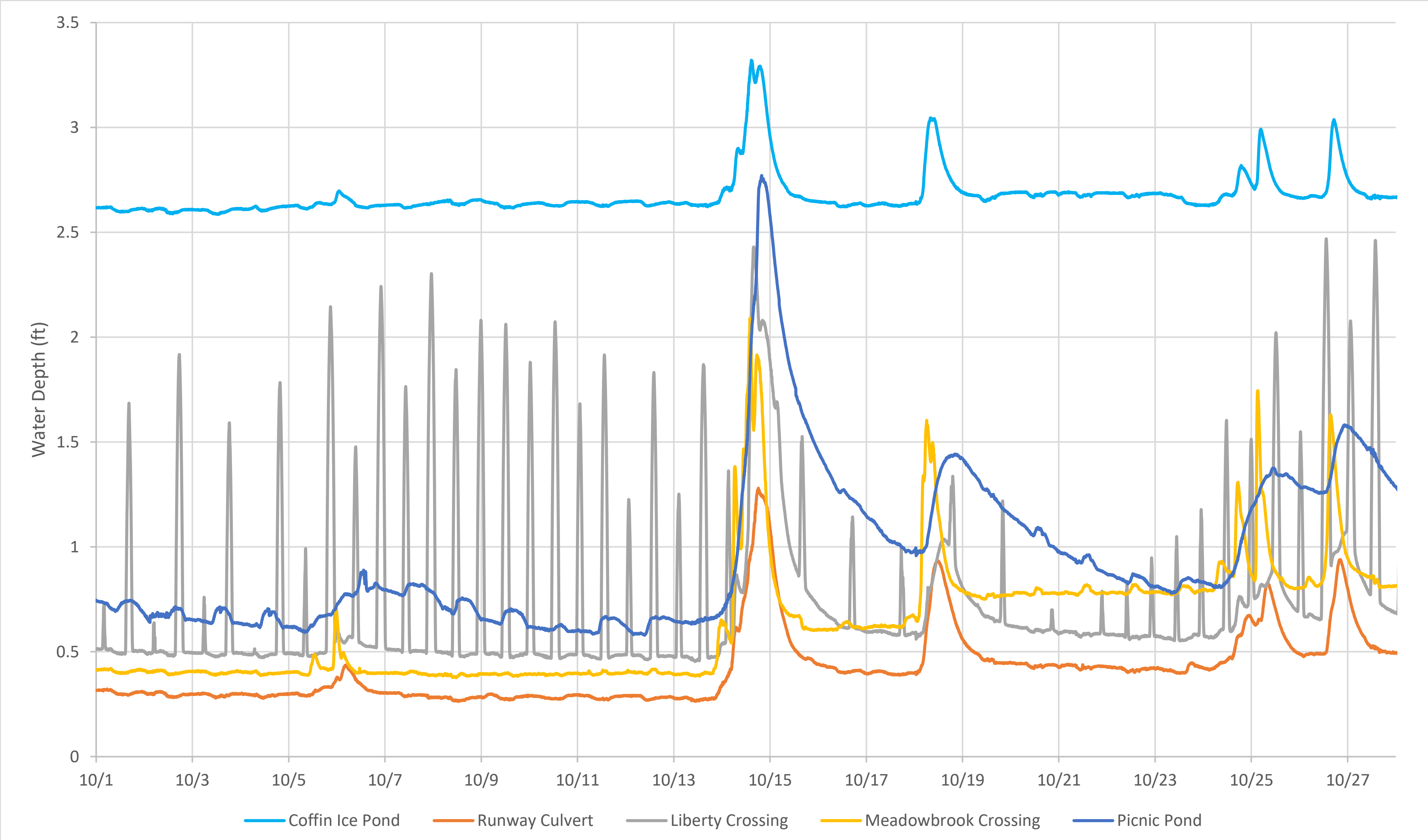
Town of Brunswick, Maine
Department of Planning and Development

Project 2202137

December 2022

Appx. A
Fig. 3

\\geiconsultants.com\data\Data_Storage\Working\BRUNSWICK ME, TOWN OF\2202137 Mare Brook H_H\05_FIELD\Sensor Data\MareBrookData_0709to1028.xlsx

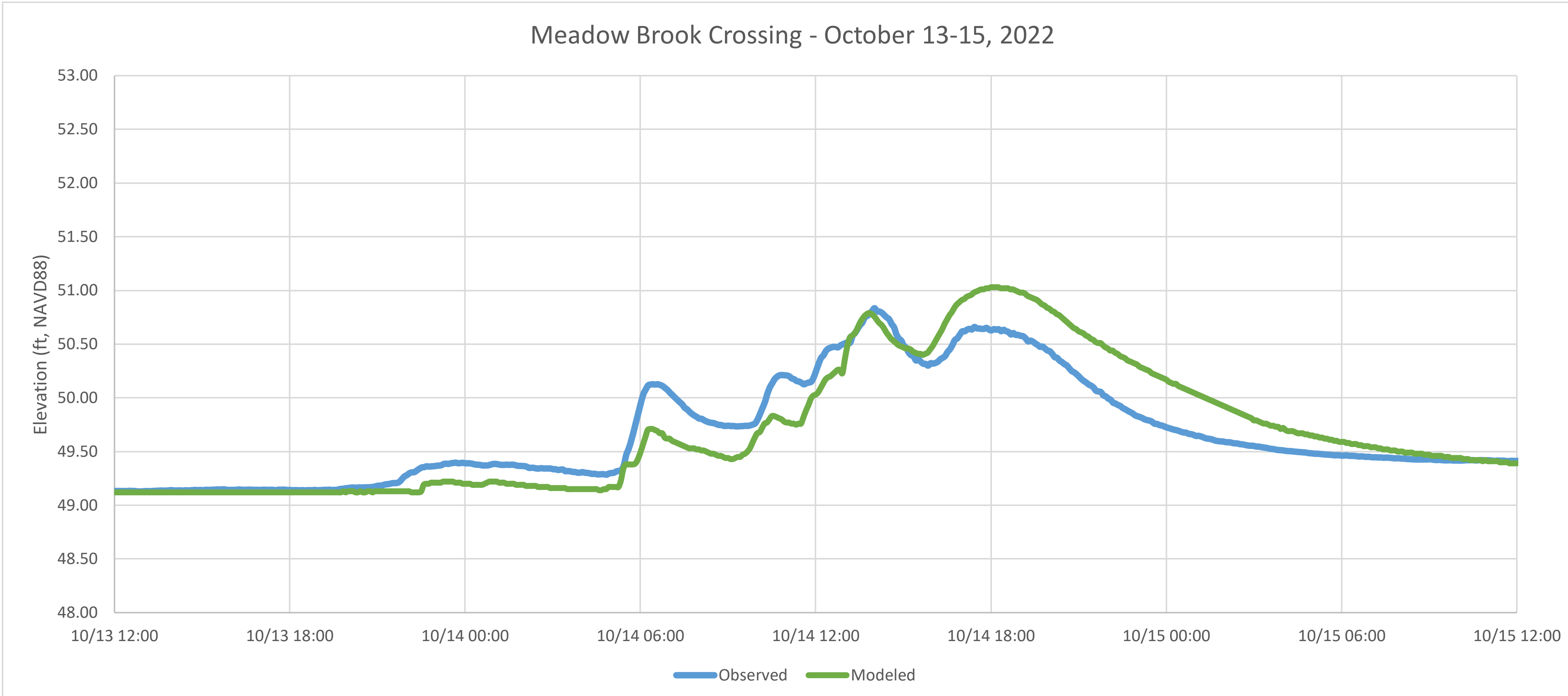


Note: Water level data recorded by GEI. "Depth" represents water depth as measured from the bottom of sensor to water level and does not represent actual depth of water. Provided data compensates for barometric pressure at time of measurement.	**Mare Brook Watershed** **Hydrologic & Hydraulic Study**	GEI Consultants	**MARE BROOK WATER DEPTHS** **October 2022**
	Town of Brunswick, Maine **Department of Planning and Development**	**Project 2202137**	**December 2022** **Appx. A Fig. 4**

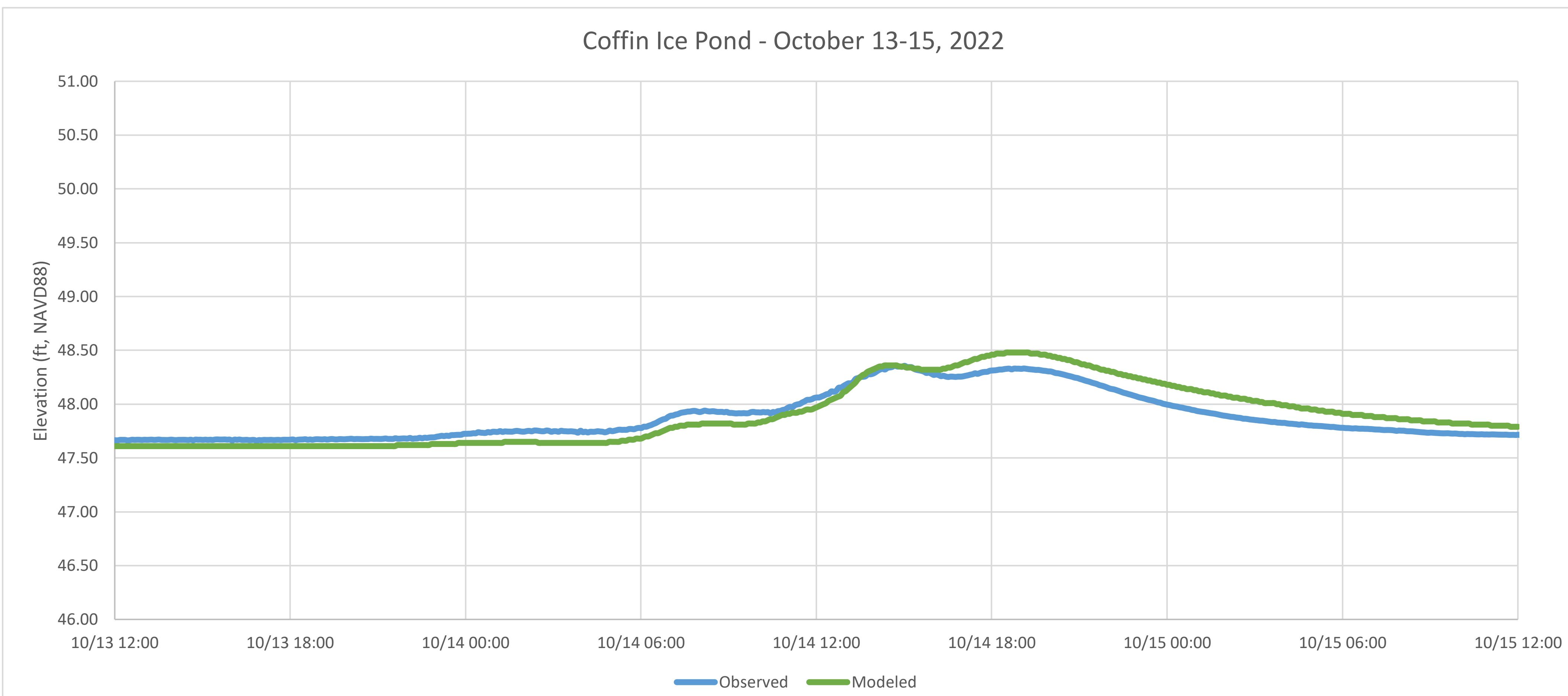
\\geiconsultants.com\data\Data_Storage\Working\BRUNSWICK ME, TOWN OF\2202137 Mare Brook H_H\05_FIELD\Sensor Data\MareBrookData_0709to1028.xlsx

Appendix B

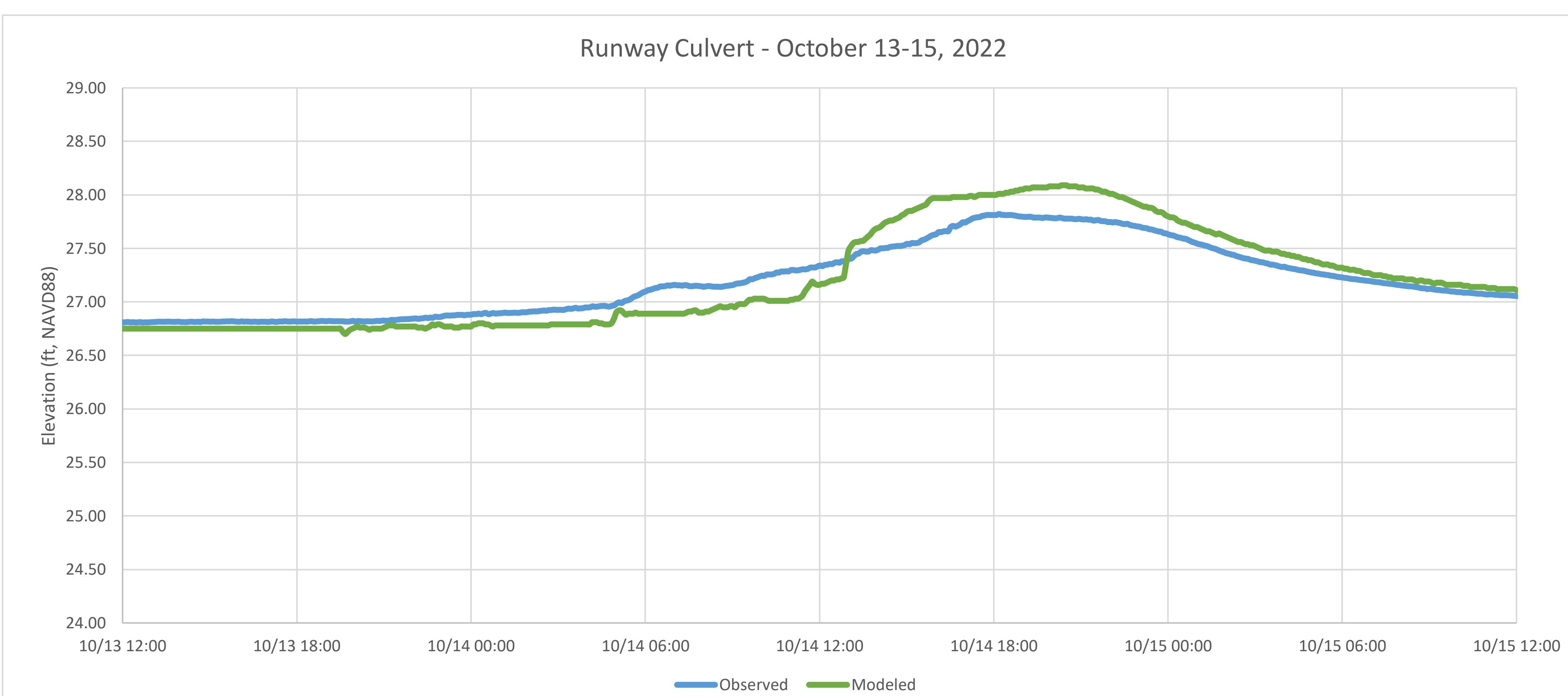
Model Calibration Graphs – October 14, 2022 Storm



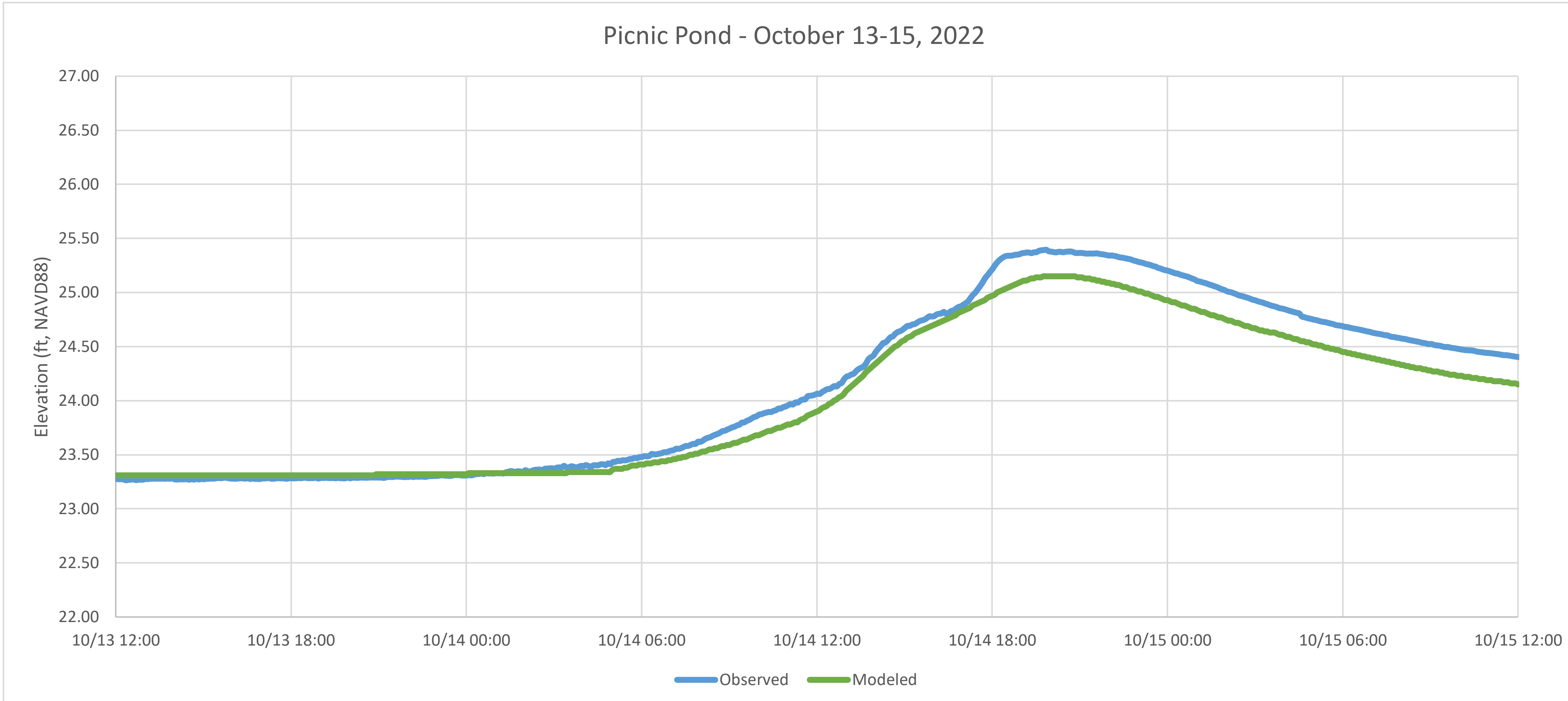
Meadow Brook Crossing - October 13-15, 2022
Elevation (ft, NAVD88)
53.00
52.50
52.00
51.50
51.00
50.50
50.00
49.50
49.00
48.50
48.00
10/13 12:00
10/13 18:00
10/14 00:00
10/14 06:00
10/14 12:00
10/14 18:00
10/15 00:00
10/15 06:00
10/15 12:00
Observed
Modeled

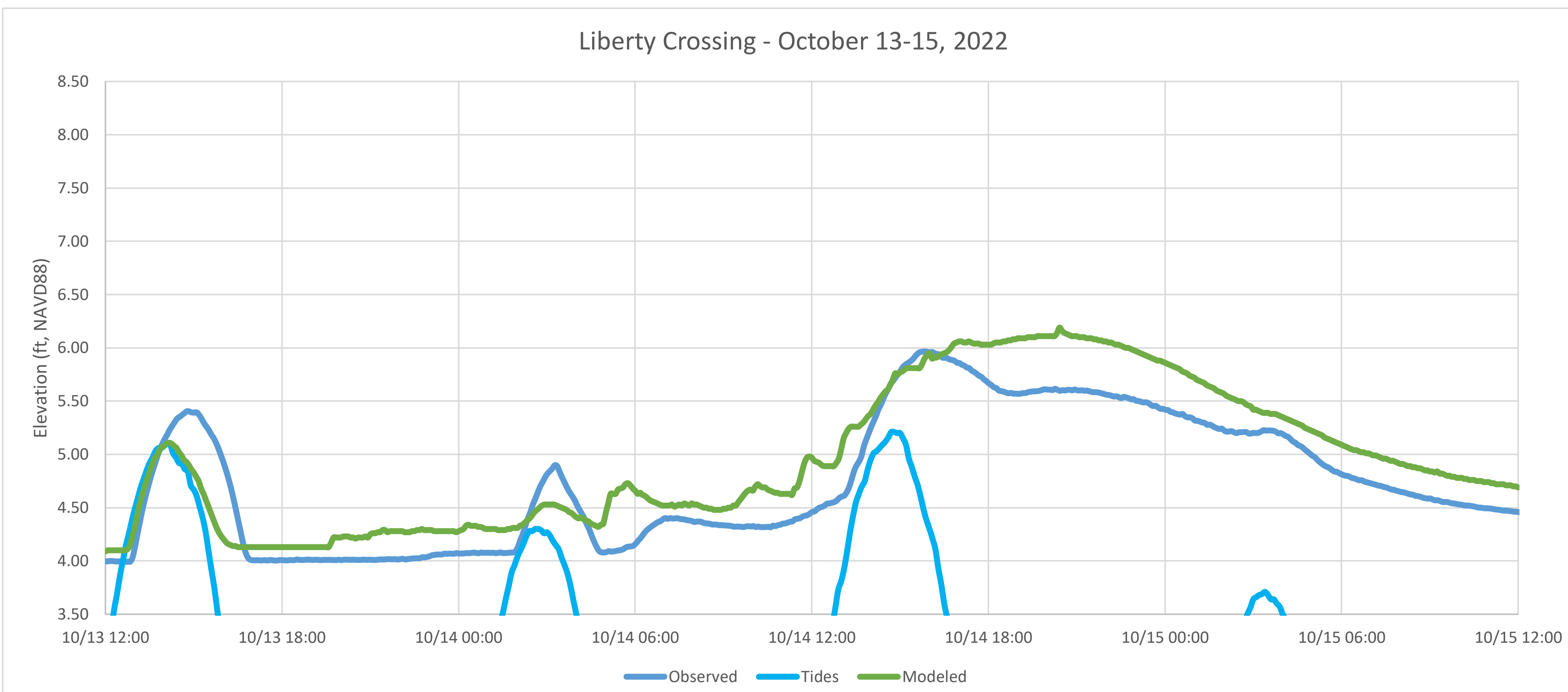


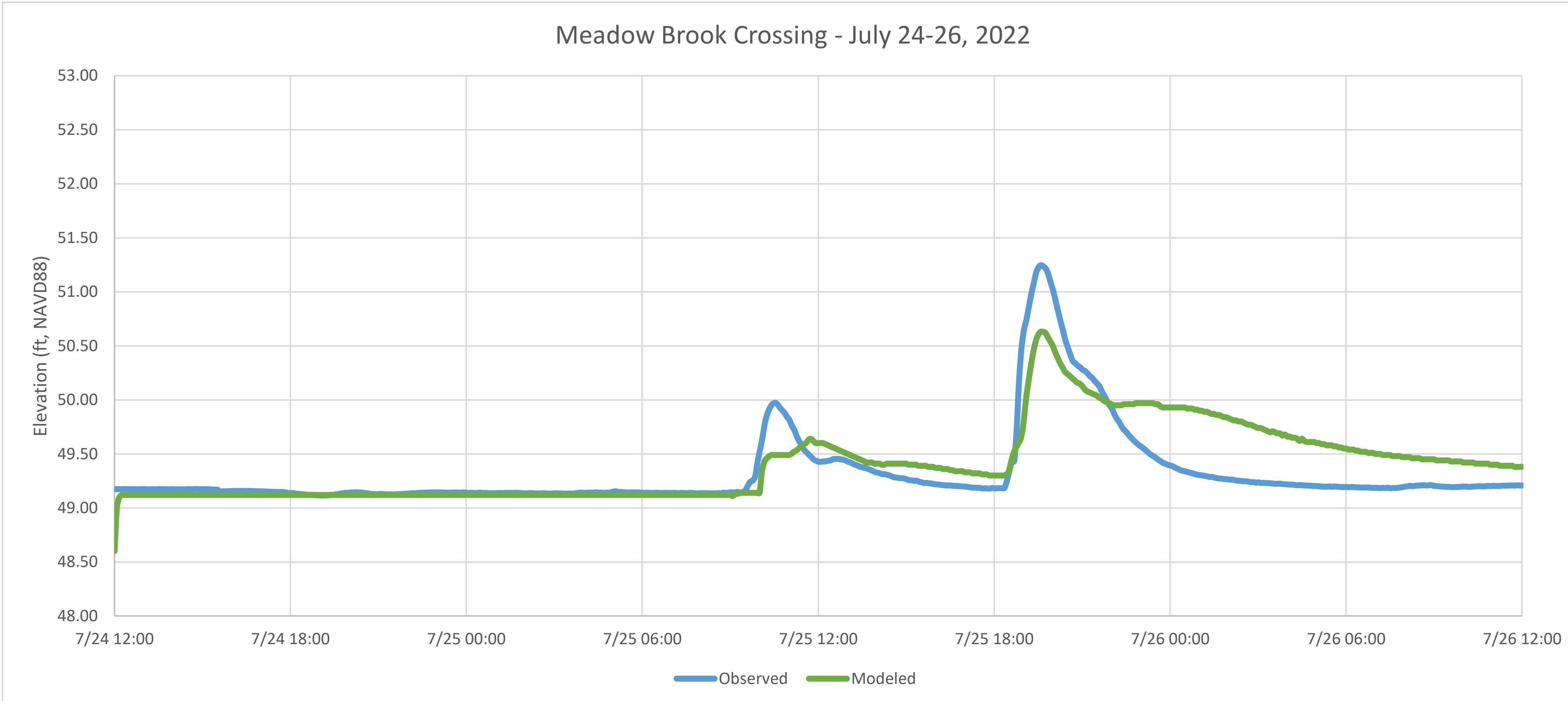
Coffin Ice Pond - October 13-15, 2022
Elevation (ft, NAVD88)
51.00
50.50
50.00
49.50
49.00
48.50
48.00
47.50
47.00
46.50
46.00
10/13 12:00
10/13 18:00
10/14 00:00
10/14 06:00
10/14 12:00
10/14 18:00
10/15 00:00
10/15 06:00
10/15 12:00
Observed
Modeled

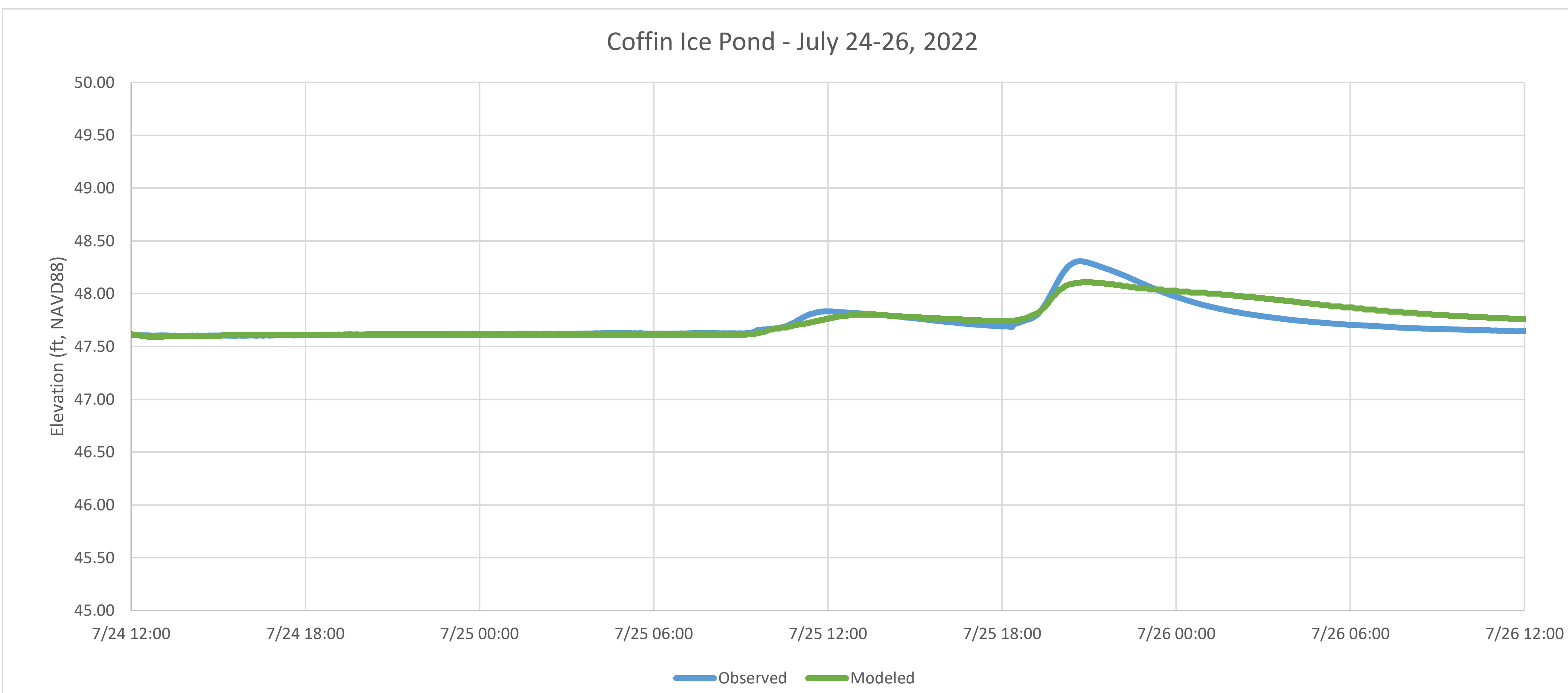


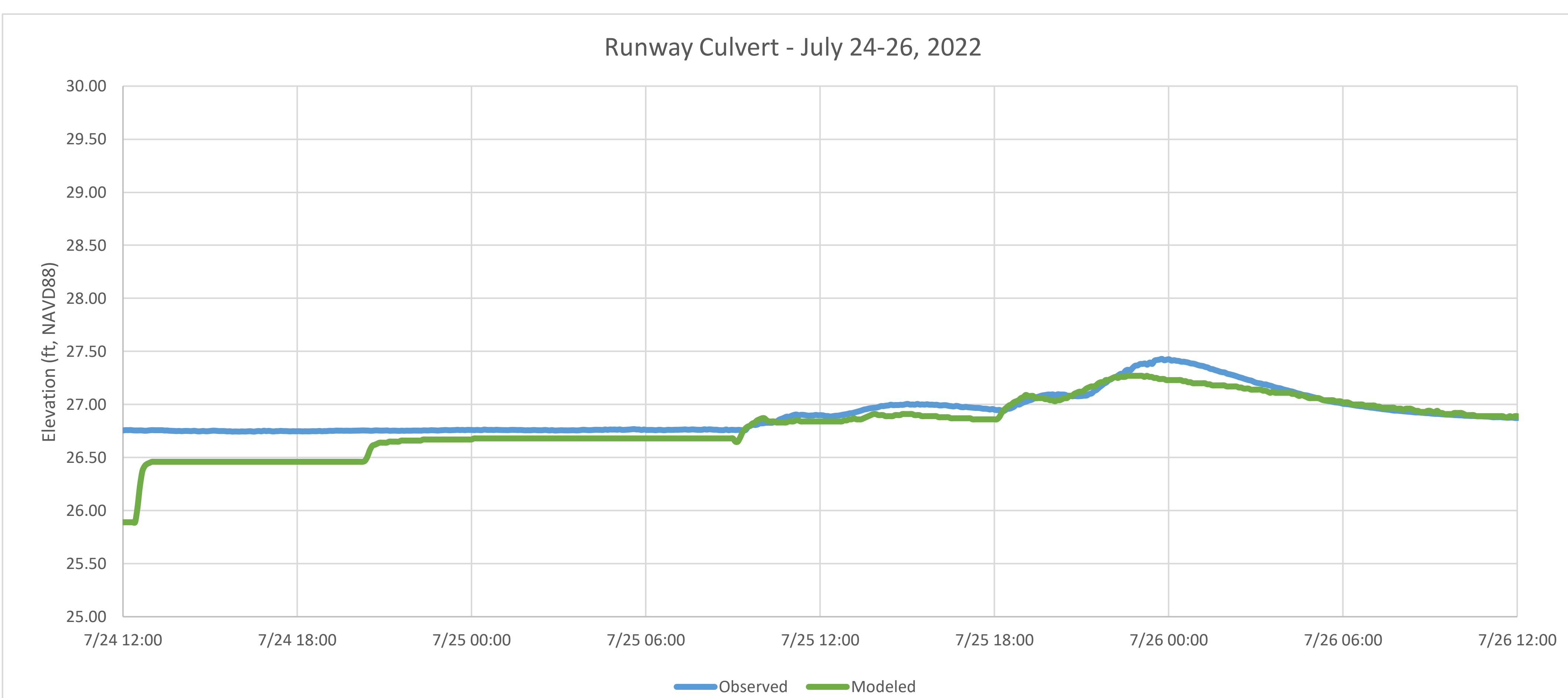
Runway Culvert - October 13-15, 2022
Elevation (ft, NAVD88)
29.00
28.50
28.00
27.50
27.00
26.50
26.00
25.50
25.00
24.50
24.00
10/13 12:00
10/13 18:00
10/14 00:00
10/14 06:00
10/14 12:00
10/14 18:00
10/15 00:00
10/15 06:00
10/15 12:00
Observed
Modeled

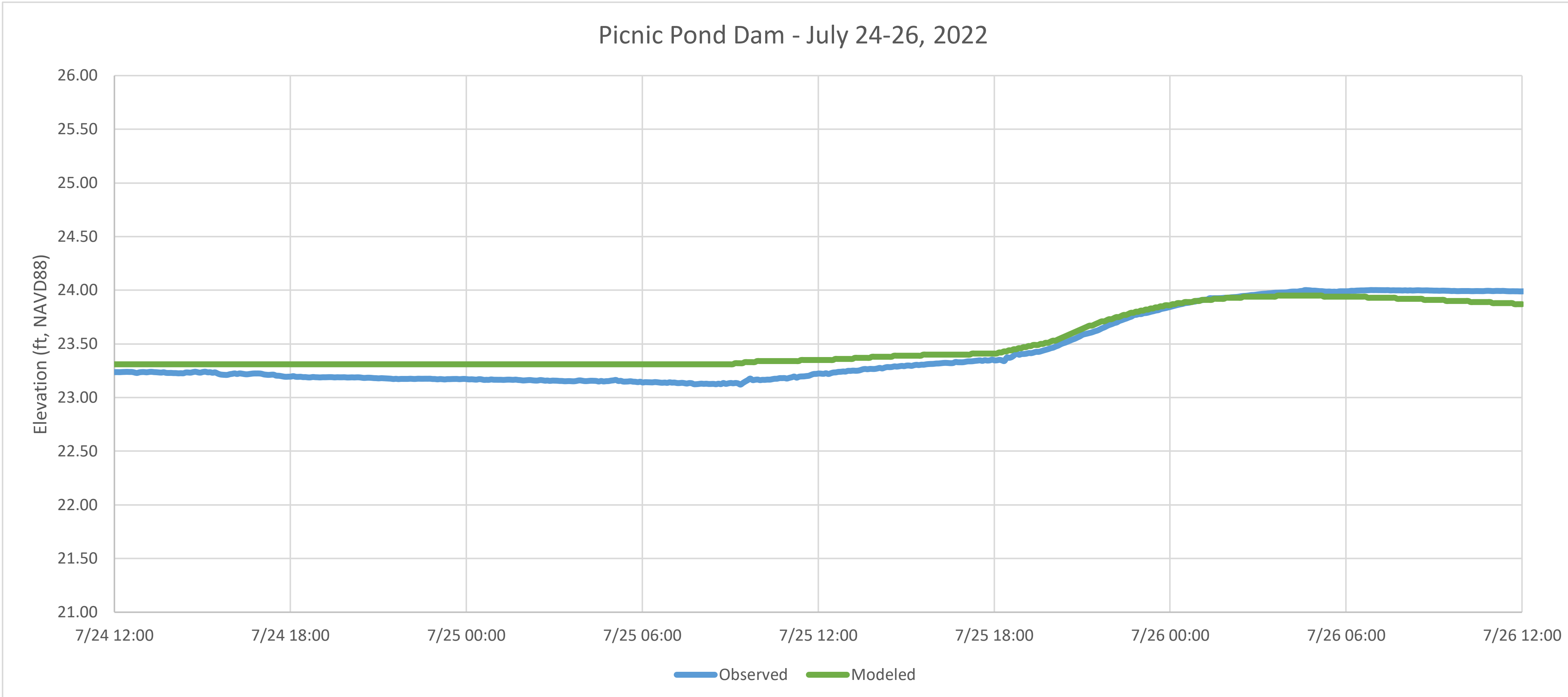

Picnic Pond - October 13-15, 2022
Elevation (ft, NAVD88)
27.00
26.50
26.00
25.50
25.00
24.50
24.00
23.50
23.00
22.50
22.00
10/13 12:00
10/13 18:00
10/14 00:00
10/14 06:00
10/14 12:00
10/14 18:00
10/15 00:00
10/15 06:00
10/15 12:00
Observed
Modeled

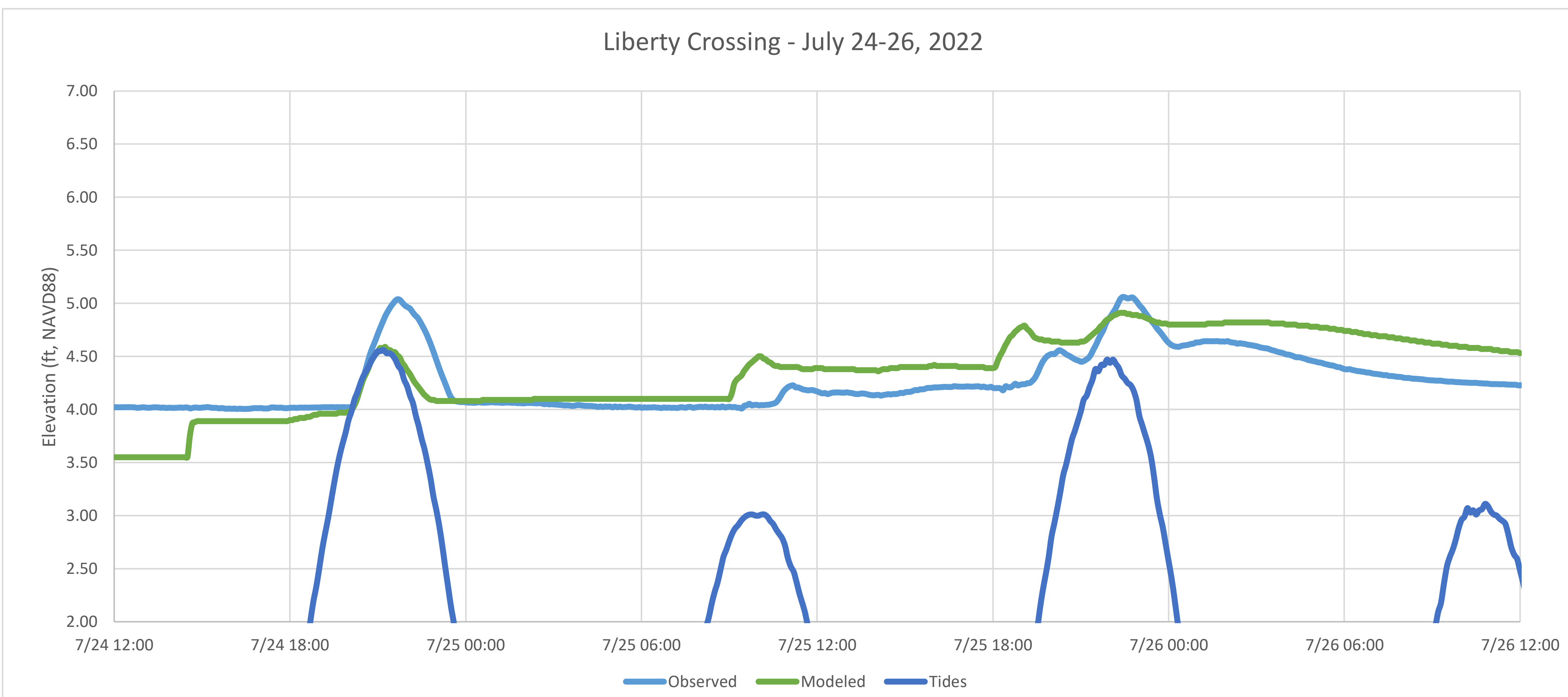

Liberty Crossing - October 13-15, 2022
Elevation (ft, NAVD88)
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
10/13 12:00
10/13 18:00
10/14 00:00
10/14 06:00
10/14 12:00
10/14 18:00
10/15 00:00
10/15 06:00
10/15 12:00
Observed
Tides
Modeled


Meadow Brook Crossing - July 24-26, 2022
Elevation (ft, NAVD88)
53.00
52.50
52.00
51.50
51.00
50.50
50.00
49.50
49.00
48.50
48.00
7/24 12:00
7/24 18:00
7/25 00:00
7/25 06:00
7/25 12:00
7/25 18:00
7/26 00:00
7/26 06:00
7/26 12:00
Observed
Modeled


Coffin Ice Pond - July 24-26, 2022
Elevation (ft, NAVD88)
50.00
49.50
49.00
48.50
48.00
47.50
47.00
46.50
46.00
45.50
45.00
7/24 12:00
7/24 18:00
7/25 00:00
7/25 06:00
7/25 12:00
7/25 18:00
7/26 00:00
7/26 06:00
7/26 12:00
Observed
Modeled

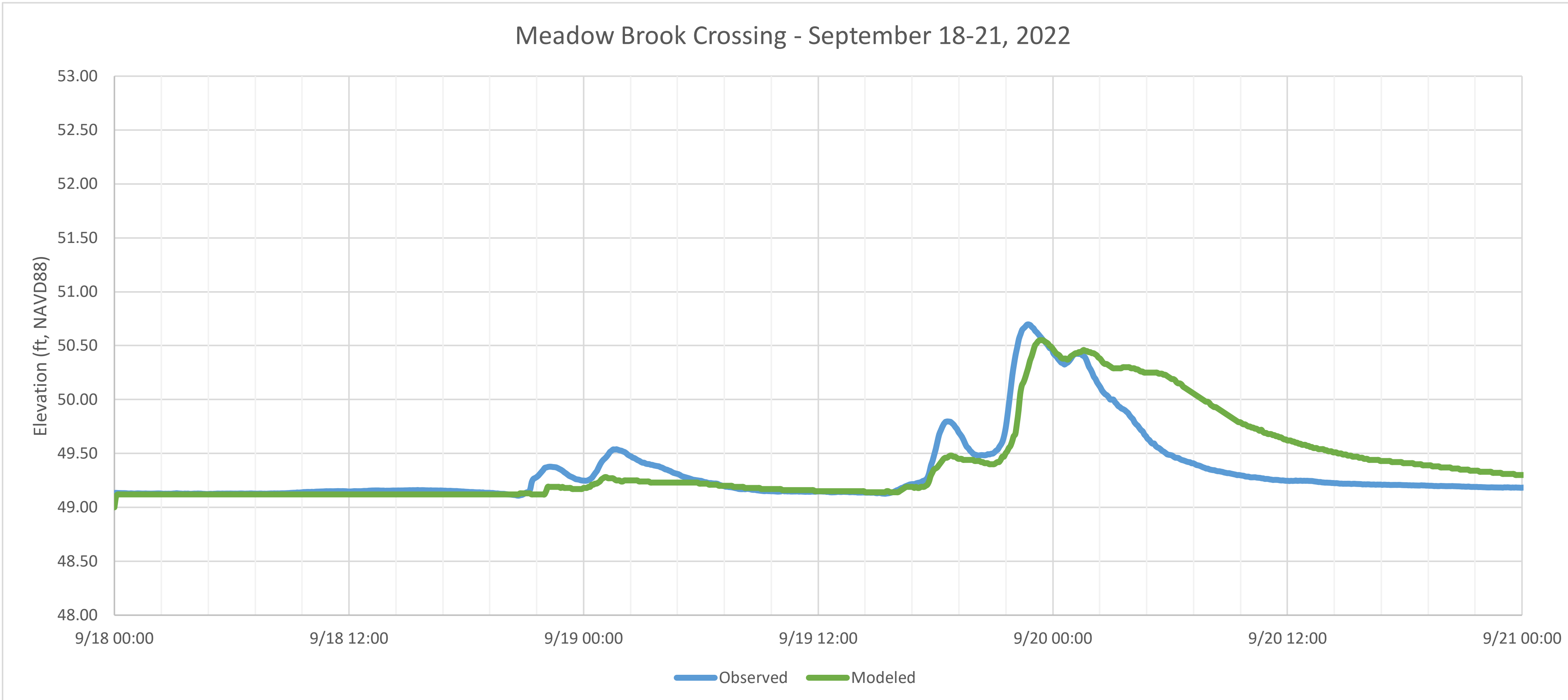

Runway Culvert - July 24-26, 2022
Elevation (ft, NAVD88)
30.00
29.50
29.00
28.50
28.00
27.50
27.00
26.50
26.00
25.50
25.00
7/24 12:00
7/24 18:00
7/25 00:00
7/25 06:00
7/25 12:00
7/25 18:00
7/26 00:00
7/26 06:00
7/26 12:00
Observed
Modeled

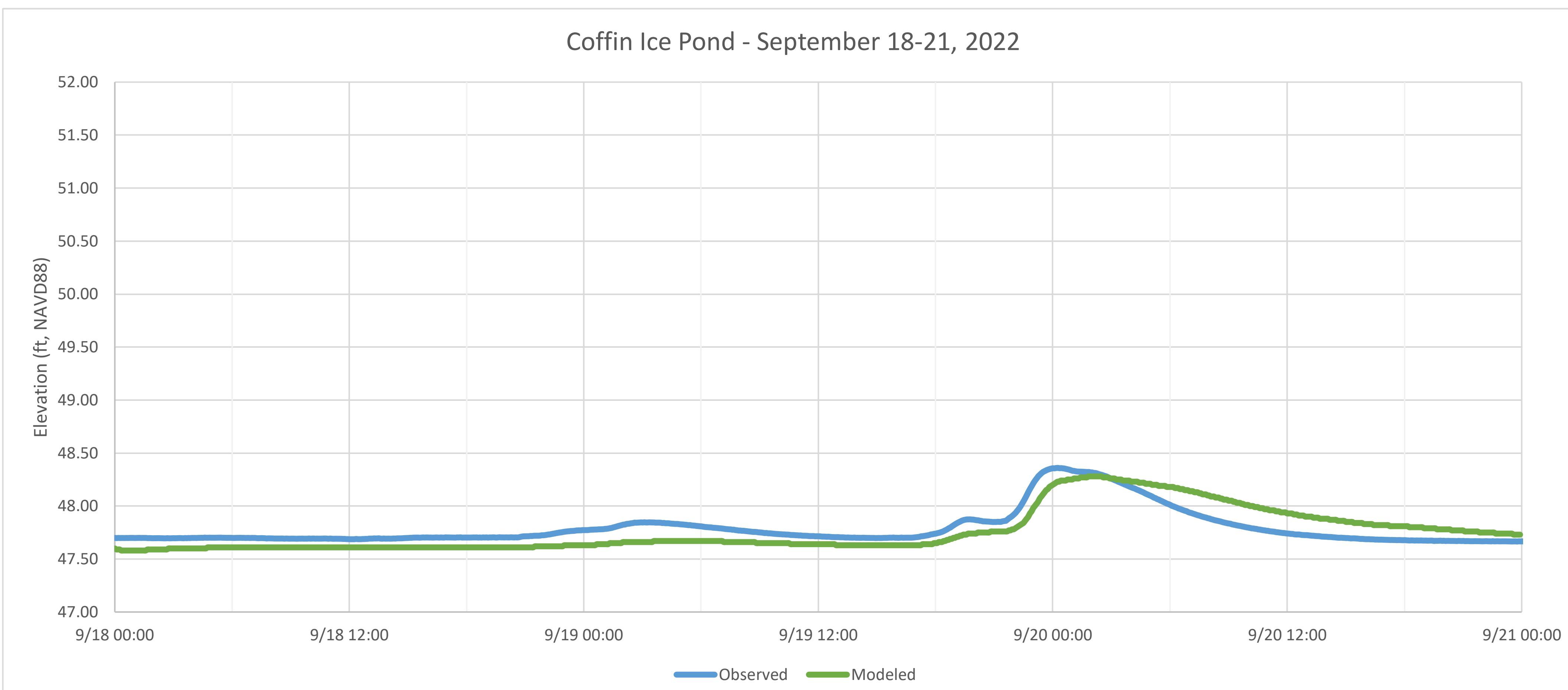

Picnic Pond Dam - July 24-26, 2022
Elevation (ft, NAVD88)
26.00
25.50
25.00
24.50
24.00
23.50
23.00
22.50
22.00
21.50
21.00
7/24 12:00
7/24 18:00
7/25 00:00
7/25 06:00
7/25 12:00
7/25 18:00
7/26 00:00
7/26 06:00
7/26 12:00
Observed
Modeled

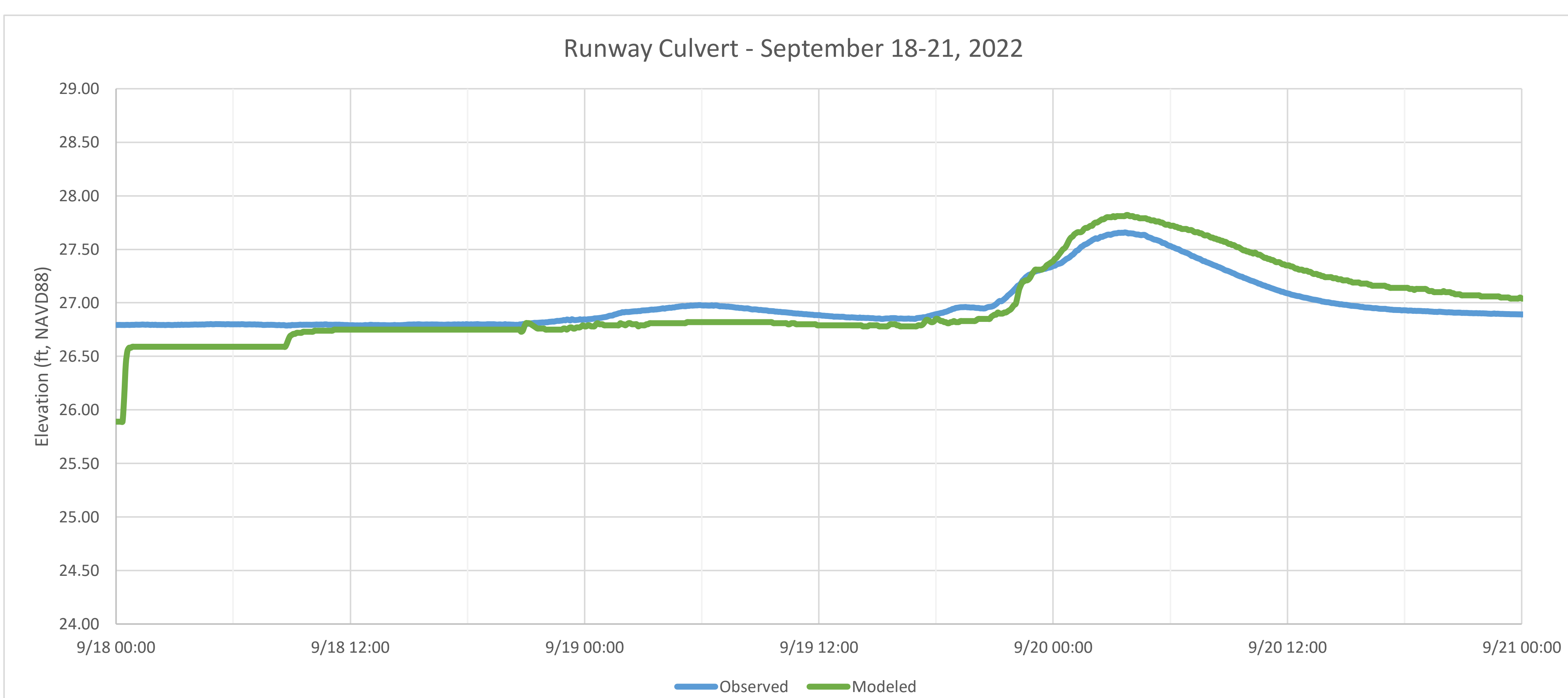

Liberty Crossing - July 24-26, 2022
Elevation (ft, NAVD88)
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
7/24 12:00
7/24 18:00
7/25 00:00
7/25 06:00
7/25 12:00
7/25 18:00
7/26 00:00
7/26 06:00
7/26 12:00
Observed
Modeled
Tides

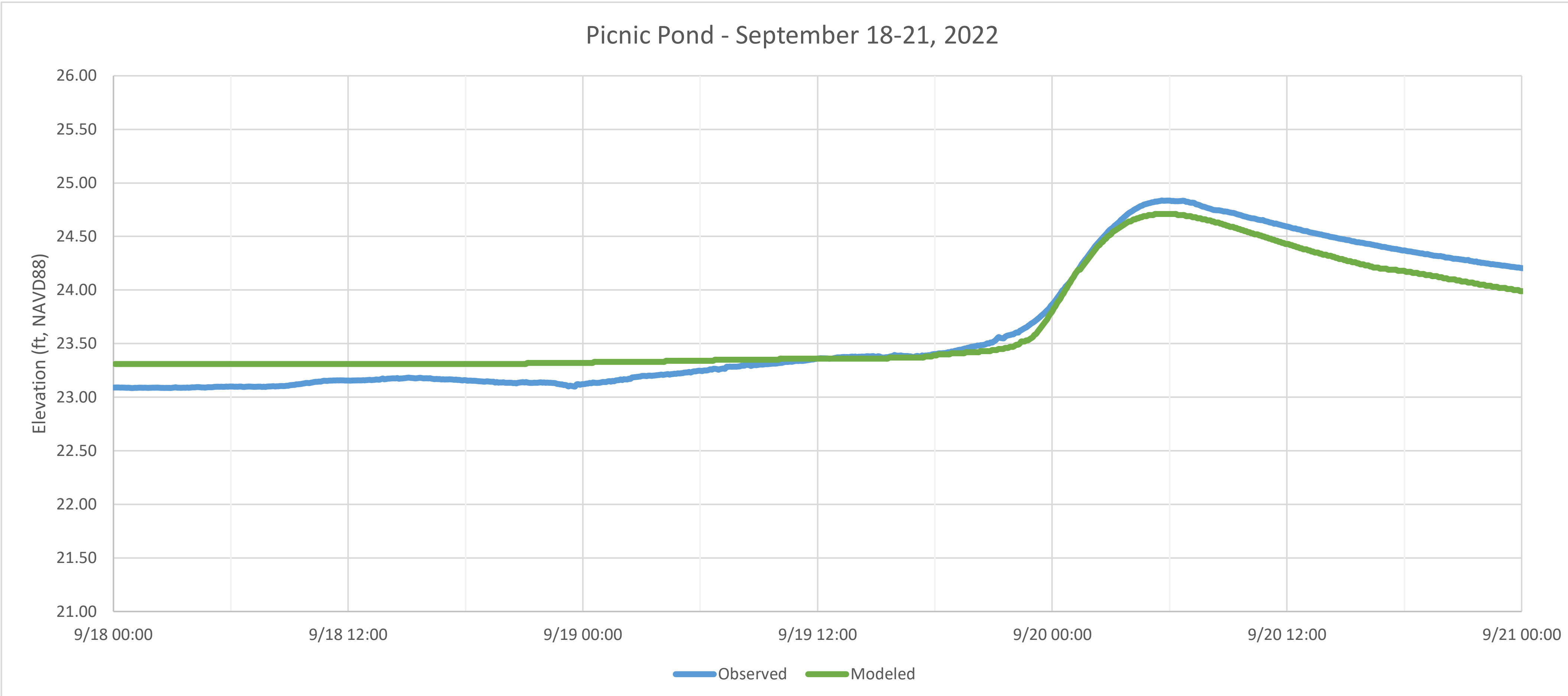
Appendix C

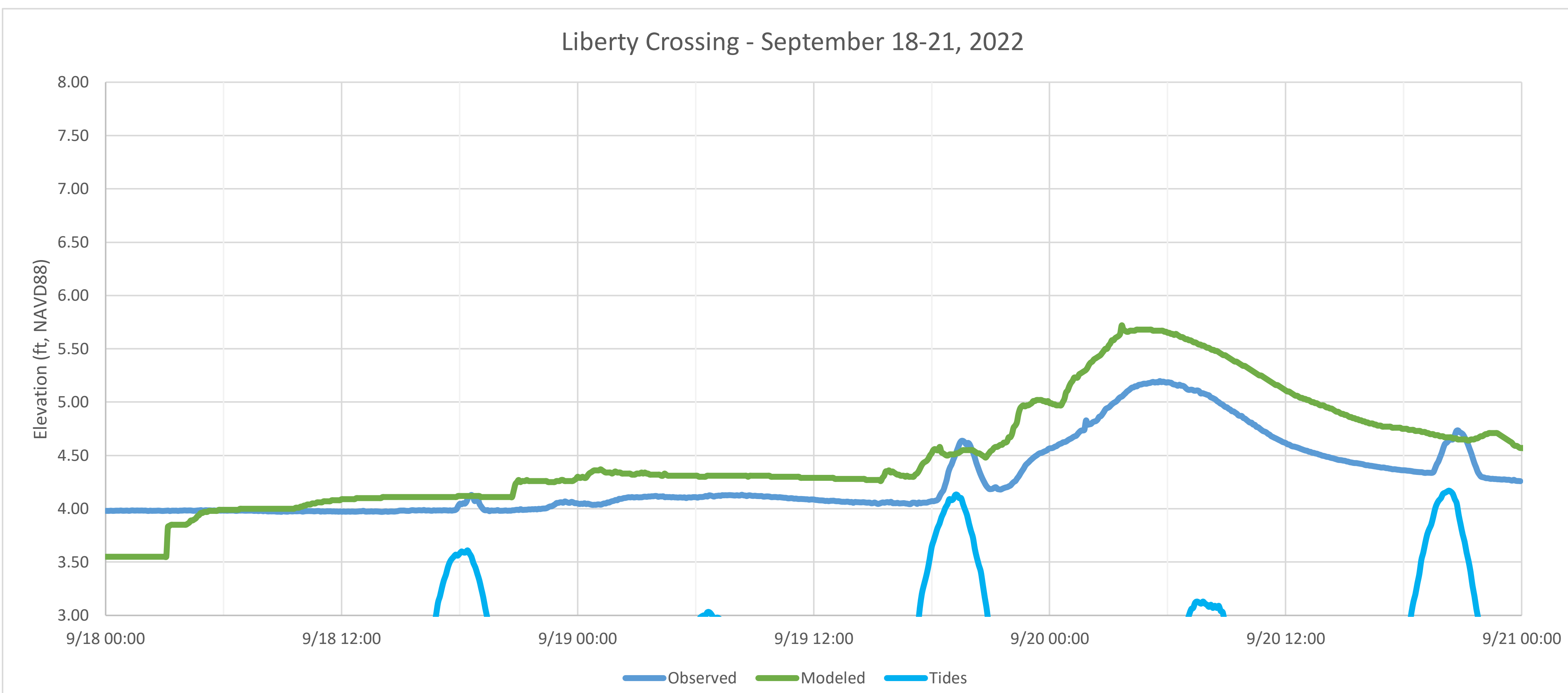
Model Validation Graphs – September 25, 2022 Storm


Meadow Brook Crossing - September 18-21, 2022
Elevation (ft, NAVD88)
53.00
52.50
52.00
51.50
51.00
50.50
50.00
49.50
49.00
48.50
48.00
9/18 00:00
9/18 12:00
9/19 00:00
9/19 12:00
9/20 00:00
9/20 12:00
9/21 00:00
Observed
Modeled


Coffin Ice Pond - September 18-21, 2022
Elevation (ft, NAVD88)
52.00
51.50
51.00
50.50
50.00
49.50
49.00
48.50
48.00
47.50
47.00
9/18 00:00
9/18 12:00
9/19 00:00
9/19 12:00
9/20 00:00
9/20 12:00
9/21 00:00
Observed
Modeled


Runway Culvert - September 18-21, 2022
Elevation (ft, NAVD88)
29.00
28.50
28.00
27.50
27.00
26.50
26.00
25.50
25.00
24.50
24.00
9/18 00:00
9/18 12:00
9/19 00:00
9/19 12:00
9/20 00:00
9/20 12:00
9/21 00:00
Observed
Modeled


Picnic Pond - September 18-21, 2022
Elevation (ft, NAVD88)
26.00
25.50
25.00
24.50
24.00
23.50
23.00
22.50
22.00
21.50
21.00
9/18 00:00
9/18 12:00
9/19 00:00
9/19 12:00
9/20 00:00
9/20 12:00
9/21 00:00
Observed
Modeled


Liberty Crossing - September 18-21, 2022
Elevation (ft, NAVD88)
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
9/18 00:00
9/18 12:00
9/19 00:00
9/19 12:00
9/20 00:00
9/20 12:00
9/21 00:00
Observed
Modeled
Tides

Appendix D

H&H Results

2-Year Storm								
ID#	**Location**	**Culvert Size (in)**	**Invert Elev. (ft)**	**Peak U/S Elev. (ft, NAVD88)**	**Top of Road/Dam (ft, NAVD88)**	**Overtopping (+), Freeboard (-) (ft)**	**Peak Flow (cfs)**	**Headwater / Depth***
Cul04	Baribeau Drive Crossing Flood Control	30''	73.8	74.8	77.9	-3.1	15	0.4
Cul05	Baribeau Drive Crossing Main Pipe	Twin 30''	73.7					0.4
Cul10	Barrows Street Crossing	24''	64.2	66.6	70.8	-4.2	35	1.2
		48''	64.2					0.6
Cul14	Macmillan Drive Crossing	24''	60.4	62.4	69.2	-6.8	41	1.0
		48''	59.5					0.7
Cul16	Maine Street Crossing	84''W x 42''H (Ellipse)	57.7	60.3	64.8	-4.5	53	0.7
Cul17	Meadowbrook Road Crossing	48''	48.7	52.6	61.1	-8.5	63	1.0
Cul18	Sparwell Lane Tributary Crossing	30''	50.4	53.8	61.5	-7.7	29	1.4
Cul23	Harpswell Road Crossing	60''	38.8	44.5	57.3	-12.8	85	1.1
	Dams							
	Coffin Ice Pond Dam	NA	NA	49.0	49.1	-0.1	85	NA
	Picnic Pond Dam	NA	NA	25.5	25.5	0	23	NA

*Headwater / Depth ratio is equal to the peak water surface elevation minus culvert invert elevation divided by culvert height (ft)

10-Year Storm								
ID#	Location	Culvert Size (in)	Invert Elev. (ft)	Peak U/S Elev. (ft, NAVD88)	Top of Road/Dam (ft, NAVD88)	Overtopping (+), Freeboard (-) (ft)	Peak Flow (cfs)	Headwater / Depth*
Cul04	Baribeau Drive Crossing Flood Control	30''	73.8	75.5	77.9	-2.4	35	0.7
Cul05	Baribeau Drive Crossing Main Pipe	Twin 30''	73.7					0.7
Cul10	Barrows Street Crossing	24''	64.2	67.8	70.8	-3	68	1.8
		48''	64.2					0.9
Cul14	Macmillan Drive Crossing	24''	60.4	64.1	69.2	-5.1	79	1.9
		48''	59.5					1.2
Cul16	Maine Street Crossing	84''W x 42''H (Ellipse)	57.7	62.1	64.8	-2.7	111	1.3
Cul17	Meadowbrook Road Crossing	48''	48.7	56.4	61.1	-4.7	126	1.9
Cul18	Sparwell Lane Tributary Crossing	30''	50.4	56.8	61.5	-4.7	44	2.6
Cul23	Harpswell Road Crossing	60''	38.8	48.6	57.3	-8.7	153	2.0
	Dams							
	Coffin Ice Pond Dam	NA	NA	49.6	49.1	0.5	168	NA
	Picnic Pond Dam	NA	NA	26.5	25.5	1	94	NA

*Headwater / Depth ratio is equal to the peak water surface elevation minus culvert invert elevation divided by culvert height (ft)

25-Year Storm								
ID#	**Location**	**Culvert Size (in)**	**Invert Elev. (ft)**	**Peak U/S Elev. (ft, NAVD88)**	**Top of Road/Dam (ft, NAVD88)**	**Overtopping (+), Freeboard (-) (ft)**	**Peak Flow (cfs)**	**Headwater / Depth***
Cul04	Baribeau Drive Crossing Flood Control	30''	73.8	76.0	77.9	-1.9	53	0.9
Cul05	Baribeau Drive Crossing Main Pipe	Twin 30''	73.7					0.9
Cul10	Barrows Street Crossing	24''	64.2	69.7	70.8	-1.1	110	2.8
		48''	64.2					1.4
Cul14	Macmillan Drive Crossing	24''	60.4	67.1	69.2	-2.1	115	3.4
		48''	59.5					1.9
Cul16	Maine Street Crossing	84''W x 42''H (Ellipse)	57.7	63.9	64.8	-0.9	153	1.8
Cul17	Meadowbrook Road Crossing	48''	48.7	60.0	61.1	-1.2	152	2.8
Cul18	Sparwell Lane Tributary Crossing	30''	50.4	59.2	61.5	-2.3	54	3.5
Cul23	Harpswell Road Crossing	60''	38.8	50.4	57.3	-6.9	177	2.3
	Dams							
	Coffin Ice Pond Dam	NA	NA	50.5	49.1	1.4	201	NA
	Picnic Pond Dam	NA	NA	27.0	25.5	1.5	173	NA

*Headwater / Depth ratio is equal to the peak water surface elevation minus culvert invert elevation divided by culvert height (ft)