MEMORANDUM
Comfort Lake-Forest Lake Watershed District

Date: January 3, 2023
To: CLFLWD Board of Managers
From: Mike Kinney, District Administrator
Subject: H&H Model Update Final Report & Presentation

District Wide

Background/Discussion:

The purpose of this agenda item is for the District Engineer, Emmons & Olivier Resources (EOR), to present the final installment of the District-wide update to the hydrologic & hydraulic (H&H) computer model. This final phase entailed updates to the model in the subwatersheds of Forest Lake and Little Comfort Lake.

Recommended Motion
Proposed Motion: Manager ___________ moves to accept the H&H Model Technical Report. Seconded by Manager ___________.

Attached: EOR Technical Report

memo

Project Name |	Forest Lake & Little Comfort Lake H/H Update	**Date** |	11/18/2022
To / Contact info |	CLFLWD Board of Managers		
Cc / Contact info |			
From / Contact info |	Paul Nation, EIT; Mike Talbot, EIT; Cecilio Olivier, PE		
Regarding |	Forest Lake & Little Comfort Lake Management District H/H Model Update Documentation		

1. INTRODUCTION

The purpose of this memorandum is to outline the modeling procedures used for the development of the Forest Lake & Little Comfort Lake Hydrologic/Hydraulic (H/H) Model Update. This model update pertains to the sub-watershed draining to Little Comfort Lake upstream of Itasca Avenue and the sub-watershed draining to Forest Lake.

These modeling procedures described herein are consistent with those used in other modeling updates within the Comfort Lake-Forest Lake Watershed District (CLFLWD). Modeling was completed using PCSWMM, a proprietary platform for constructing and running the U.S. Environmental Protection Agency (EPA)'s Surface Water Management Model (SWMM).

2. KEY DATASETS

2.1. Digital Elevation Model (DEM)

County-wide DEMs, available from MnTOPO, were used. The MnTOPO data for Washington and Chisago counties was collected in November 2011 and is 1-meter resolution. As these datasets will be updated in the future to reflect changes in the land surface, future models should always use the most up-to-date version of these datasets.

2.2. Soils

Soils data was obtained from the 2020 Gridded Soil Survey Geographic (gSSURGO) database developed by the Natural Resources Conservation Service (NRCS). The gSSURGO dataset provides 10-meter resolution polygons and was used to determine the soil parameters necessary to simulate the area's hydrology using the Green-Ampt method.

2.3. Land Cover

Two datasets are available for land cover:

- The National Land Cover Dataset (NLCD) is a 30-meter resolution national dataset developed by the U.S. Geological Survey (USGS). The NLCD dataset was updated in 2019 and includes both land cover classifications and percent of impervious surfaces.
- The University of Minnesota (UMN) has also developed a 1-meter land cover dataset for the Twin Cities Metropolitan Area, Duluth, and Rochester. The UMN dataset was developed using aerial

imagery from 2009-2015 and uses similar land cover categories as the NLCD dataset. The UMN dataset was used where available and mosaicked to the NLCD dataset to cover the full extent of the area modeled. Even though the UMN dataset was developed from 2009-2015, it is reasonable to use this data for modeling purposes since there has not been a significant land use change within the modeling area since that time.

2.4. Stormwater Infrastructure

The City of Forest Lake has minimal stormwater network data in a GIS format. Most of the stormwater system is mapped, but attributes (e.g., pipes' material, size, slope, length) for the dataset are lacking. Work is currently underway to survey the entire stormwater network as part of the City's MS4 responsibilities, but this survey had not yet been entirely completed at the time of this modeling effort. The survey work completed by the City prior to model construction was incorporated in the model.

To determine key input parameters in the model, EOR collected available design and as-built plans (electronic and hardcopies) and performed additional field survey where no information was available. When necessary, pipe and other structure attributes were estimated using the best available information and a tag was added to the modeled feature noting which attributes were estimated. The following developed areas were added to the model using design and as-built plan sets.

- Third Lake Estates (as-built)
- Forest Hills Preserve (design)
- Forest Lake Preserve (as-built)
- Bridle Pass – Phase 1 (as-built)
- Bridle Pass – Phase 3 (design)
- Bridle Pass – Phase 4 (as-built)
- Bridle Pass – 5th Addition (as-built)
- Sterling Oaks (as-built)

3. NAMING CONVENTION

When constructing the model, catchment labels were kept consistent with previous H/H models except for areas that were part of the modeling area but were found not to drain to Forest Lake or Little Comfort Lake. Catchments were named with an "S" prefix, followed by two letters representing the waterbody to which the catchment drains, and finally a number representing the individual catchment (e.g., S_FL01a). Additional letters at the end of the label were added when catchments in previous H/H models had been split (e.g., S_FL01 is split into S_FL01a, S_FL01b). The following waterbody abbreviations were used.

- BCL – Birch Lake
- CBL – Cranberry Lake
- CLL – Clear Lake
- EL – Elwell Lake
- FL – Forest Lake

- GL – German Lake
- LCL – Little Comfort Lake
- LK – Lake Keewahtin
- NL – Nielsen Lake
- SCL – School Lake
- SL – Shields Lake
- TL – Twin Lake
- OT – Areas not draining to the above lakes

Nodes were labeled to match the catchment they are in, but without the "S" prefix and followed by a three-digit number (e.g., FL01a_011).

Links' names are a combination of the upstream node name and downstream node name (e.g., FL01a_082-FL01a_011). Where multiple links connect the same two nodes, an underscore with an integer is included in the name (e.g., FL53a_065-FL01a_011_1).

4. HYDROLOGY

4.1. Methodology

SWMM allows the use of different methodologies for runoff simulation. The following provides a brief description of which methods were selected for modeling the system's hydrology and the rationale behind that selection.

4.1.1. Runoff Generation – Green-Ampt

The Green-Ampt methodology was selected to simulate rainfall infiltration into the soil and generation of runoff. The Green-Ampt method is physically-based and calculates infiltration using the soil's hydraulic conductivity (i.e., soils' infiltration capacity under unsaturated conditions) and the soil's water saturation level (i.e., the amount of water in the soil at the time precipitation starts). The excess rainfall (the portion not infiltrated) is considered runoff. The Green-Ampt method performs well for both design storms (short duration, more intense storms) and continuous simulations (precipitation events for extended periods of time and typically less intense), making it ideal for model calibration, especially against year-around monitoring data.

4.2. Catchment Delineation

Delineations performed as part of previous modeling efforts were used as a starting point to define catchments. The recently delineated JD6 Ditch and Shields Lake catchments were incorporated in the model with minimal revisions. The remainder of the drainage areas were revised to provide a greater level of detail.

The average catchment size for the Forest Lake sub-watershed is 24 acres and the average for the Little Comfort Lake sub-watershed is 40 acres. These averages are very low compared to watershed modeling efforts of similar scale. This provides a level of refinement that allows for a better, more detailed characterization of the watershed's hydrology.

Delineation was done using PCSWMM's watershed delineation routine which uses a similar process to other GIS-based delineations and includes the following steps:

1. "Burn in" culverts, outlets, and streamlines to the DEM.
2. Fill sinks in DEM.
3. Delineate catchments to user-defined outlet points (major stream crossings, tributary confluences, etc.).

The process of burning in culverts to the DEM consists of editing the DEM value (elevation) at select locations where culverts, outlets, or other structures are not reflected in the surface elevation. The DEM elevation is lowered to match the surface elevation on either end of the culvert, so that the area upstream of the culvert is not considered a sink in the DEM. Because of this, the fill sinks operation is only applied to depressions that have no outlet. Filling sinks results in a DEM surface without depressions, such that flow pathways can be generated across the watershed without reaching a "dead-end" in a depression without an outlet. Finally, catchments are delineated to defined points (i.e., all land surface that drains to the flow pathway through that point is considered part of that point's catchment).

After initial delineation in PCSWMM, catchments were reviewed and revised by hand as needed. This manual revision included adjusting catchment boundaries to match adjacent catchments previously delineated for Bone Lake and Comfort Lake.

4.3. Catchment Parameters

4.3.1. Physical Parameters

Several catchment input parameters (area, width, and slope) are based on geometry and were calculated directly from GIS. 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 Little Comfort Lake sub-watershed, the maximum length flow path through each catchment was estimated by hand from the DEM. For the Forest Lake sub-watershed, flow path was estimated based on the relationship observed between area and flow path length in the Little Comfort Lake sub-watershed. For catchments larger than 50 acres, flow path length was estimated by hand. These lengths were used to estimate the width of catchments according to the following rules. Flow length was then estimated by dividing area by 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 1 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.

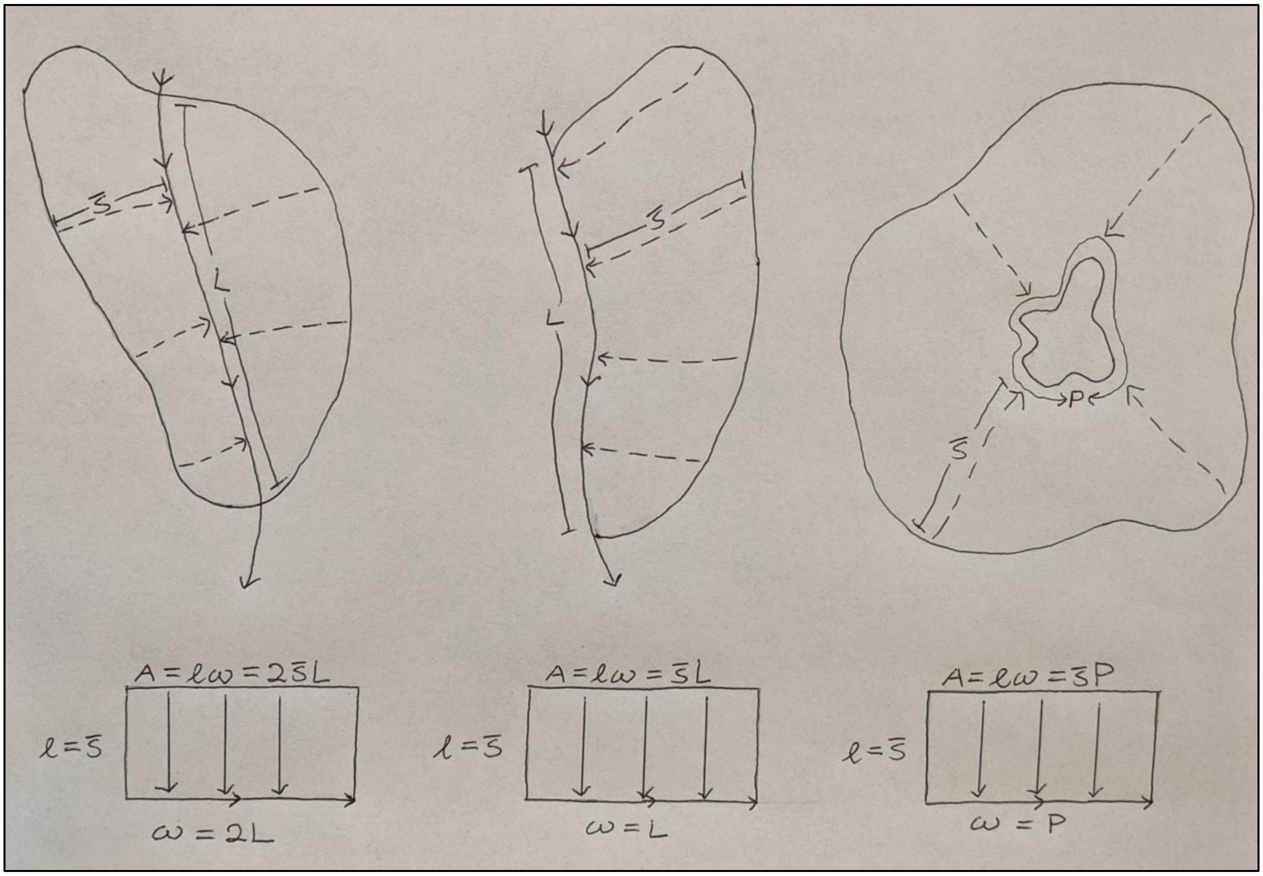


Figure 1. Width Calculations

4.3.2. Land Cover Parameters

A second set of parameters were determined based on land cover. These parameters were area-weighted to obtain an average value within each catchment. The following lookup table contains the values used for each NLCD classification, taken from a compilation of sources, and were used to assign the necessary land cover parameters to each catchment. Parameters were defined as follows.

- N Imperv – Manning's roughness for impervious surfaces (set to 0.01 regardless of surface type).
- N Perv – Manning's roughness for pervious surface.
- Dstore Imperv – Depressional storage (in) for impervious surface (set to 0.05" regardless of surface type).
- Dstore Perv – Depressional storage (in) for pervious surface.

Catchments are divided into subareas of pervious and impervious surface, with three routing options between subareas.

1. Pervious areas can be routed to impervious areas (Impervious Routing)
2. Impervious areas can be routed to pervious (Pervious Routing). An example would be rooftops routed to back/front yards).
3. Both pervious and impervious areas can be routed directly to the catchment outlet (Outlet Routing)

Table 1 provides recommendations for routing based on land cover. However, given that most of the Little Comfort Lake sub-watershed is large lot residential, wetland, and rural areas, Outlet Routing was used throughout. The urban areas of the Forest Lake sub-watershed used Pervious Routing, except for the highly impervious downtown areas west of the lake which used Impervious Routing.

Table 1. Land Cover Parameter Lookup

Land Cover Classification	Classification #	N Perv	Dstore Perv (in)	Subarea Routing	Percent Routed
Open Water (OW)	11			OUTLET	100
Developed, Open Space (DOS)	21	0.0404	0.15	PERVIOUS	100
Developed, Low Intensity (DLI)	22	0.0678	0.15	PERVIOUS	50
Developed, Medium Intensity (DMI)	23	0.0678	0.15	PERVIOUS	25
Developed, High Intensity (DHI)	24	0.0404	0.15	IMPERVIOUS	100
Barren Land (BL)	31	0.0113	0.15	OUTLET	100
Deciduous Forest (DF)	41	0.36	0.3	OUTLET	100
Evergreen Forest (EF)	42	0.32	0.3	OUTLET	100
Mixed Forest (MF)	43	0.4	0.3	OUTLET	100
Shrub/Scrub (SS)	52	0.4	0.25	OUTLET	100
Grassland/Herbaceous (GH)	71	0.368	0.25	OUTLET	100
Pasture/Hay (PH)	81	0.325	0.25	OUTLET	100
Cultivated Crops (CC)	82	0.1825	0.2	OUTLET	100
Woody Wetlands (WW)	90	0.086	0.3	OUTLET	100
Emergent Herbaceous Wetlands	95	0.1825	0.25	OUTLET	100

4.3.3. Impervious Surface & Zero Impervious

The UMN 1-meter land cover dataset was used to define the percentage of impervious surface within each catchment. This dataset has discrete land cover categories for roads, buildings, and water surface that could be directly reclassified to impervious surface. Therefore, UMN land cover was preferable to the NLCD dataset. The NLCD imperviousness raster (30-meter cells with a value from 0 to 100% impervious) was joined with the UMN raster (discrete values, each cell is either 0 or 100% impervious) and used to estimate the average impervious areas for each catchment.

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

4.3.4. Soil Parameters

Table 2 was used to assign Green-Ampt parameters to each catchment. This table is based on *Green-Ampt Infiltration Parameters from Soils Data*, a 1983 paper by Rawls et al. Soil type was obtained from gSSURGO as the "surface texture" parameter. This parameter did not line up with soil type for all soils in the modeling area. As such, engineering judgement was used to convert surface texture values to the appropriate soil type.

Since conductivity has an exponential relationship with suction head and initial water deficit (see equations below), individual soil types within a catchment were area-weighted based on the natural log of conductivity. Area-weighting on the natural log helps to prevent overestimation of conductivity for areas with predominately sandy soils. Average suction head and initial water deficit were then determined based on the conductivity assigned to each catchment. Since area-weighted conductivity will not match the values in the table for areas with heterogeneous soils, suction head and initial water deficit were calculated using the following exponential equations which were developed from the table.

$$Suction\ Head\ (in) = 3.04555 * [Conductivity\ (in/hr)]^{-0.32044}$$

$$Initial\ Deficit\ (-) = 0.05387 * [Conductivity\ (in/hr)]^{-0.38326}$$

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

Soil Type	Conductivity (in/hr)	Suction Head (in)	Initial Deficit (fraction)
Sand	4.74	1.93	0.024
Loamy Sand	1.18	2.4	0.047
Sandy Loam	0.43	4.33	0.085
Loam	0.13	3.5	0.116
Silt Loam	0.26	6.69	0.135
Sandy Clay Loam	0.06	8.66	0.136
Clay Loam	0.04	8.27	0.187
Silty Clay Loam	0.04	10.63	0.21
Sandy Clay	0.02	9.45	0.221
Silty Clay	0.02	11.42	0.251
Clay	0.01	12.6	0.265

4.4. Groundwater

Groundwater can be included in SWMM models by defining an aquifer associated with each catchment. 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. Since this information is not available, groundwater parameters were adjusted during the calibration process. Groundwater was defined for catchments that contained either large water bodies or were predominantly wetlands.

4.5. Rainfall and Climatology

4.5.1. Design Storms

Synthetic design storms for Minnesota follow the MSE3 rainfall distribution, with total depths based on Atlas 14 values for the local area. Table 3 shows the 24-hour values used in the model.

Table 3. Atlas 14 Storm Depth Values

Recurrence Interval (yr)	Depth (in)
1	2.42
2	2.80
5	3.49
10	4.14
25	5.15
50	6.01
100	6.95
200	7.98

4.5.2. Climatology

SWMM can account for evaporation from open waters surfaces (i.e., storage nodes and conduits), evaporation from depressional storage in catchments, and evapotranspiration from aquifers (where groundwater is being used). Additionally, air temperature can be used to simulate snow accumulation and melt. Climatological data is less important for short-duration design storm simulations than for long-term design storms or continuous simulations, where significant inaccuracies can be introduced into the water balance by neglecting to account for phenomena such as evaporation. Climatological parameters were applied to the model based on the nearest Automated Surface Observing System (ASOS) weather station located in Osceola, Wisconsin.

5. HYDRAULICS

5.1. Runoff Routing – Dynamic Wave

SWMM allows for three different runoff routing options: steady flow, kinematic wave, and dynamic wave. All three options solve the Saint-Venant's equations: Continuity equation (conservation of flow) and Momentum equation (conservation of momentum). Steady flow and kinematic wave are simplifications of the Saint-Venant's equations in which dynamic forces are not considered. The dynamic wave routing solves the full 1-dimensional Saint-Venant's equations and can best handle complicated flows where tailwater, reverse flows, and temporally pressurized flows are present.

5.2. Level of Detail

The level of detail for modeling hydraulics in large-scale H/H modeling is somewhat subjective and relies on engineering judgement from the modeler. For the Forest Lake and Little Comfort Lake sub-watersheds the following general guidelines were applied.

- Culverts were modeled if they were at least 24 inches in diameter.
- Driveway culverts were not included unless they were an important component of a flow pathway.
- It was assumed that stormwater networks are designed with an adequate number of inlets (catch basins) to route the design storm into the stormwater network. As such, stormwater pipe size would be the limiting factor in assessing stormwater network capacity, and inlets do not need to be modeled.
- Overflow pathways were modeled as necessary to route flows up to the 200-year, 24-hour storm event.

Additional detail may be warranted if the model is too be used to address specific or localized issues.

5.3. Link Parameters

Physical properties such as pipe geometry, length, and invert elevations were taken from survey data when available. The Description field in the model is used to note whether the parameters were taken from City surveys, EOR surveys, plan sets, or another data source. Values for Manning's roughness were obtained from standard lookup tables outlined in PCSWMM guidance.

Entry and exit loss coefficients were defined separately for culverts and for stormwater network pipes. For stormwater network pipes, entry and exit losses were input based on minor losses at structures, using the guidance from the City of Madison, Wisconsin (Table 4). Storm sewer outfalls were given an exit loss coefficient of 1.

Table 4. Entry and Exit Losses at Pipe Bends

Bend Angle (°)	Entry Loss	Exit Loss
0	0.05	0.05
45	0.25	0.25
90	0.5	0.5

For culverts, entry loss coefficients were defined using PCSWMM's standard lookup table based on culvert material and entrance geometry (projecting, mitered, etc.). Culverts' exit loss coefficient was set to 1. This applies a "culvert code" to the culvert inlet which is used to determine inlet control based on the Federal Highway Association's (FHWA) Hydraulic Design of Highway Culverts. To simplify analysis, given the number of culverts in the model and lack of information on entrance type, RCP culverts were assumed to have a grooved edge with a headwall, while CMP culverts were assumed to be mitered to slope.

When modeling open channel flows through an irregular channel, transects were generated from the DEM to define the channel cross-section. Transects were typically drawn every 30-60 feet and then averaged over the length of the conduit. Transects were extended perpendicular to the channel centerline as far as necessary to convey the 200-year, 24-hour flow. Where available, survey data was joined with transects to define the shape of the channel below the water surface. This was necessary for the tributary from Bone Lake to Little Comfort Lake. Transects were also used to define overflow pathways between catchments to better represent the overflow capacity compared to a simplified trapezoidal overflow.

5.4. Storage Parameters

Storage nodes were included in the model for all natural depressions, wetlands, stormwater ponds, and BMPs that were shown in the DEM greater than 1 foot deep or 3000 square foot surface area. For BMPs and depressions that were too small to explicitly model as a storage node, the corresponding storage volume was included as depressional storage in the catchment. An attribute was added to the catchment layer to note the volume of depressions represented in the depressional storage along with the base depressional storage value determined from land cover. The Storage Creator tool in PCSWMM was used to generate stage-storage curves and polygons representing the maximum extents of each storage node. For all storage nodes representing open water basins, the Evaporation Factor was set to a value of 1, allowing for evaporation from the basin surface.

Storage nodes that represent infiltration BMPs or naturally draining depressions can be given infiltration parameters. However, infiltration from natural depressions is difficult to estimate without specific soil information (borings) and unlikely to be a significant parameter under design event scenarios. Since natural infiltration from depressions may be more significant for long-term scenarios, infiltration was estimated implicitly by including catchment depressional storage as a calibration parameter.

5.5. Junctions

For junctions, a "ponded area" was defined to prevent loss of water from the system when water levels rise above the rim of the node (catch basin). When ponding occurs, water is temporally stored above the rim of the node within the ponded area until downstream conditions allow for the water to be released. PCSWMM will report flow losses if insufficient ponding storage is entered. All flow continuity issues in the model were addressed prior to calibration.

6. CALIBRATION & VALIDATION

6.1. Key Datasets

6.1.1. Rainfall

Often, the most intense portion of a storm falls over a relatively small area for a short period of time, and as such, local rain gauges may miss it. To account for this issue, radar-derived rainfall data was used to generate synthetic rain gauges throughout the modeled watershed. This was done by bias-correcting Next Generation Weather Radar (NEXRAD) to local rain gauges.

6.1.2. Monitoring Data

Rainfall data was paired with available 15-minute resolution monitoring data collected during previous CLFLWD diagnostic studies, projects, and routing monitoring. For the Little Comfort Lake sub-watershed, 2018 was used for the calibration year and 2020 was used for the validation year. For the Forest Lake sub-watershed, 2016 was used for the calibration year and 2021 was used for the validation year.

6.2. Error Statistics

The Nash-Sutcliffe Efficiency Coefficient (NSE) is the preferred metric for assessing success of calibration. NSE is a commonly used and widely accepted statistic for calibration of H/H models. An NSE value of 1 corresponds to a perfect match to observed data, while a value less than 0 means the modeled data is less accurate than taking the average of the observed data. While NSE values between 0 and 1 are considered acceptable, the calibration target was set to achieve model efficiencies of at least 0.5.

It should be noted that NSE is highly sensitive to errors in timing even when hydrograph's shape and volume appear to match the observed data well. This is particularly true for flashy systems where a small error in the timing of rainfall could lead to poor NSE values. Runoff volume was also used as a secondary calibration metric, with a goal of matching annual runoff volume within 20% of the observed data at all stream monitoring locations.

6.3. Calibration Methodology and Results

The Little Comfort Lake sub-watershed was calibrated by adjusting boundary conditions, initial conditions, and uncertain parameters within reason to best match observed data. Observed flow from the BL2 (Bone Lake outlet @ Lofton Ave) monitoring station was used as the upstream boundary condition.

The downstream boundary condition was set by matching water levels on either Comfort Lake or Little Comfort Lake with observed elevations from the CL1 (Comfort Lake outlet @ Wyoming Trail) monitoring station and increasing the monitoring station elevation as needed to match observed lake levels. When

Comfort Lake was used as the boundary condition, an additional boundary condition for the Sunrise River was included by inputting observed flows from the CL2 (Comfort Lake inlet @ West Comfort Drive) monitoring station. This was necessary as flow from the Sunrise River has a significant influence on water levels in Comfort Lake and running the model without this input would not reflect the natural system.

The Little Comfort Lake sub-watershed was calibrated to the following observed datasets for the growing season in 2018: Nielsen Lake elevation, Birch Lake elevation, School Lake elevation, and LC1 (Little Comfort Lake inlet @ Itasca Avenue) elevation.

The following adjustments were applied to the entire modeled sub-watershed during the calibration process:

- **Decrease depressions multiplier** – While natural depressions 5,000 square feet and greater were explicitly included in the model, depressions as small as 1,000 square feet were also included implicitly by increasing modeled pervious depressional storage for each catchment. A multiplier was applied to this depressional volume to account for inefficiencies in routing of water to these depressions. For example, a depression may have a large capacity for retaining stormwater but may have a small drainage area in which case it is under-utilized and applying the full volume would result in underestimation of runoff. The multiplier used for the calibrated sub-watershed was 0.1.
- **Decrease catchment conductivity** – Catchment conductivity was decreased by 30% throughout the sub-watershed. There are several uncertainties associated with estimating conductivity including associating natural soils into a limited number of categories and applying a uniform conductivity to every soil in that category. Some soils, such as wetland muck soils don't fit neatly into those categories. The soils data used for the model has a resolution of 10-meters. Some refinement of soil parameters is always expected with datasets this coarse.
- **Decrease pervious depressional storage** – Catchment pervious depressional storage was decreased by 30% throughout the sub-watershed. Depressional storage is initially estimated based on land cover and represents small depressions on the landscape that can retain a small amount of water before runoff occurs. Like soils data, land cover datasets have a coarse resolution, so adjustment during calibration is necessary to better reflect the specific characteristics of the watershed being modeled.
- **Increase wetland impervious** – The impervious surface percentage for catchments containing large wetland complexes was increased. This was necessary to increase runoff in these areas to better match observed data. While open water portions of wetlands are typically considered impervious, vegetated portions are not and applying an average soil conductivity over these areas can result in overestimation of runoff retention and wetland infiltration capacity. One solution is to increase the percentage of the wetland that is impervious (open water). This increase was applied to the large wetland complex immediately downstream of Bone Lake and the lakeshore fringe wetland around Birch Lake.

The Forest Lake sub-watershed was calibrated by adjusting initial conditions (both surface water and groundwater) and other key parameters within reason to best match observed data. The downstream boundary condition was set to free flow just downstream of the Sunrise River culvert crossing at Lake

Boulevard. The Forest Lake sub-watershed was calibrated to the following observed datasets for the growing season in 2016:

Flow

- FL8-D
- Ditch West
- 208th Street Pond
- FL9
- FL10
- FL17
- FL18
- FL1

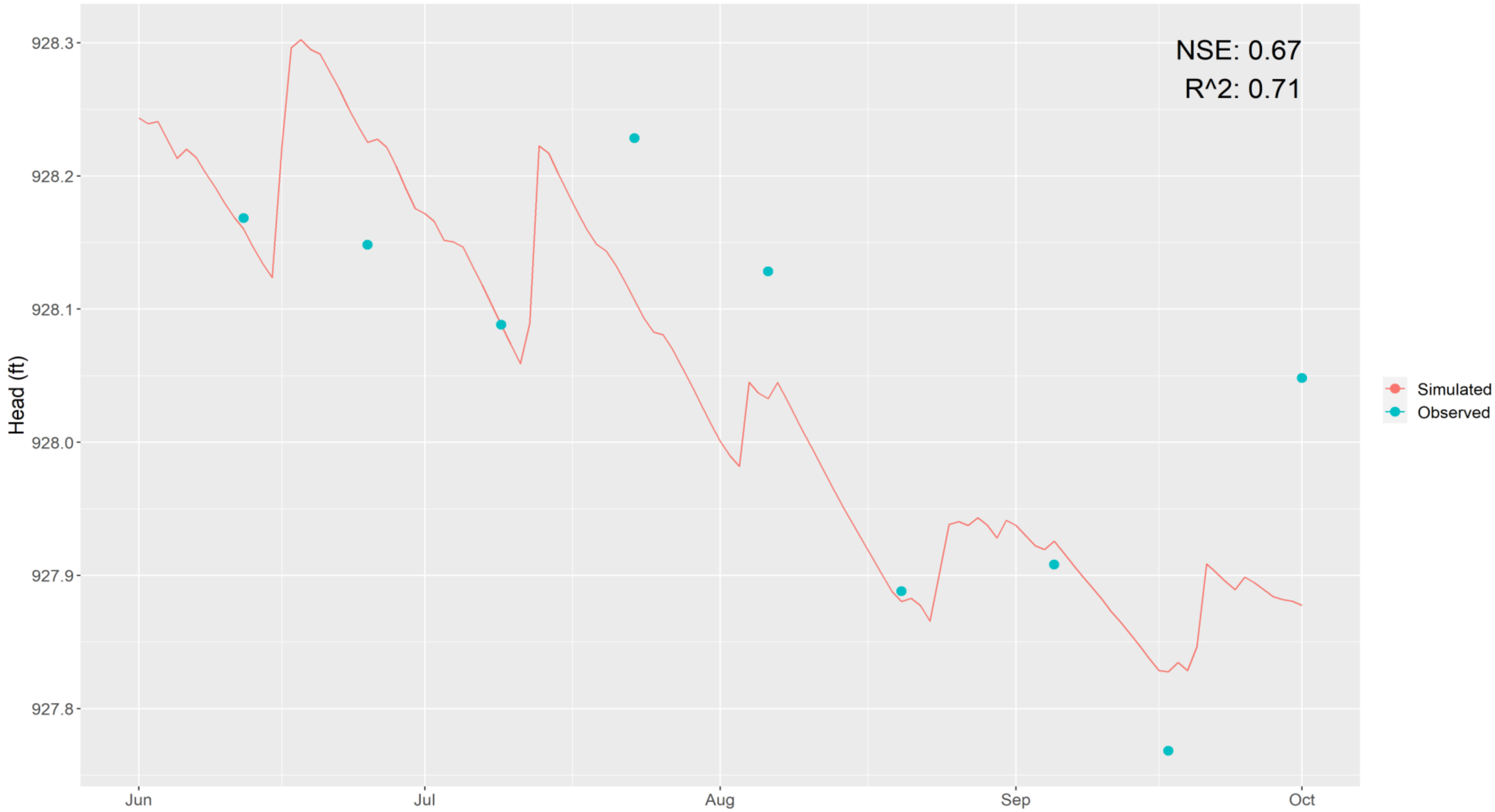
Elevation

- Lake Keewahtin
- Shields Lake
- Forest Lake

The following changes were applied to the Forest Lake sub-watershed during the calibration process.

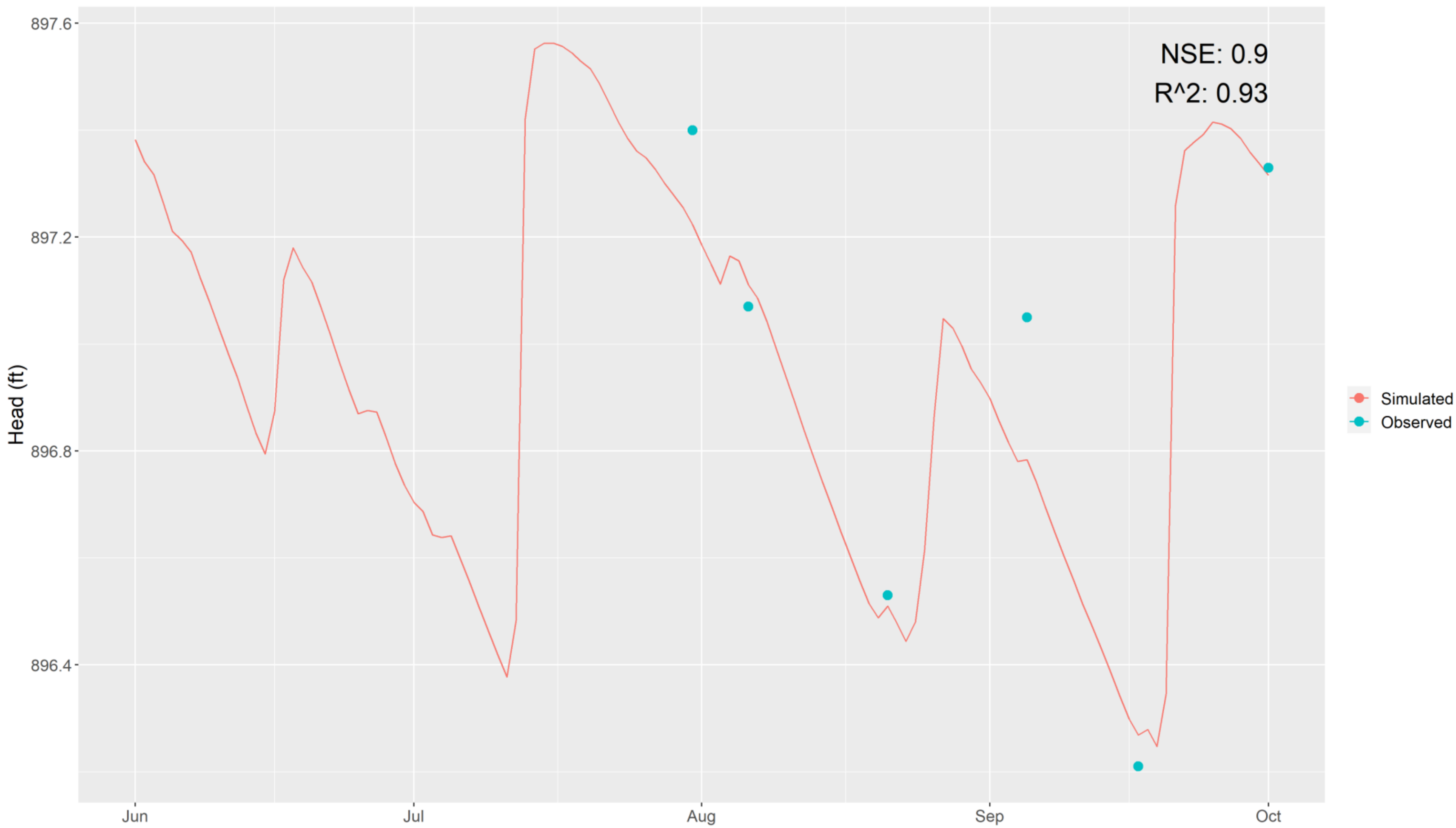
- **Decrease depressions multiplier** – While natural depressions 5,000 square feet and greater were explicitly included in the model, depressions as small as 1,000 square feet were also included implicitly by increasing modeled pervious depressional storage for each catchment. A multiplier was applied to this depressional volume to account for inefficiencies in routing of water to these depressions. For example, a depression may have a large capacity for retaining stormwater but may have a small drainage area in which case it is under-utilized and applying the full volume would result in underestimation of runoff. The multiplier used for the calibrated sub-watershed was 0.1.

6.3.1. Nielsen Lake



In addition to the general changes discussed above, seepage of water from the lake into groundwater was modeled to better reflect the observed slope of drawdown in periods of no rainfall. Since Nielsen Lake is landlocked, the only other "outlet" is evaporation of water from the lake surface which alone wasn't enough to match the drawdown in the observed data. A higher depressions multiplier (0.9) was also used to increase retention of rainfall in the large depressions located in the area surrounding the lake. The frequent, large depressions and landlocked nature of this sub-watershed gave justification for using a different multiplier than the main portion of the watershed.

6.3.2. Birch Lake

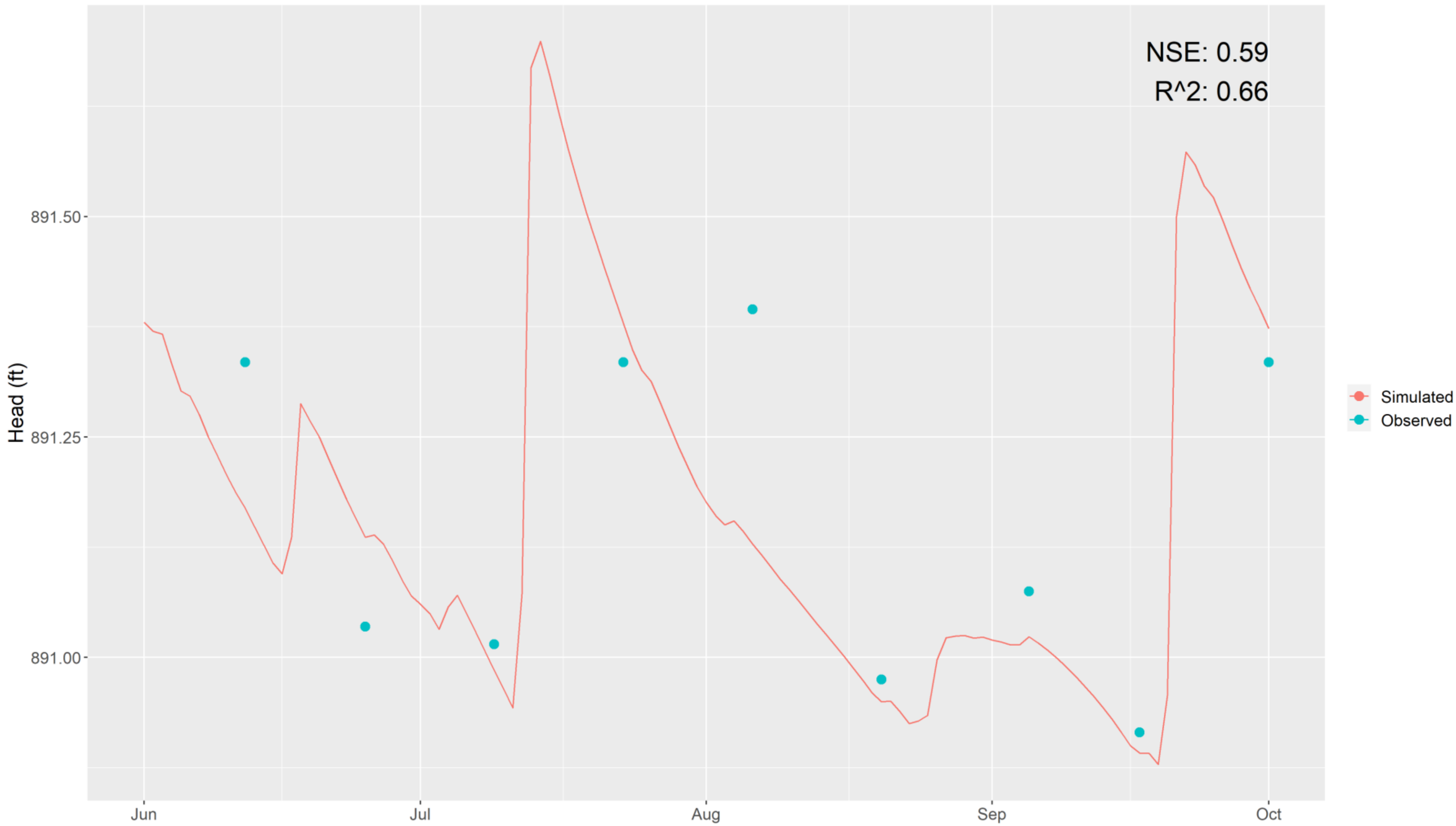


To match observed levels on Birch Lake, the modeled channel from the lake downstream to the July Avenue crossing culvert was widened by 8 feet to provide additional capacity. The original capacity was estimated based on two surveyed cross-sections located roughly 100 feet upstream of the culvert and may not have been reflective of the overall channel cross-section.

To get lake levels to bounce higher in response to rainfall as the observed data shows, a simulated obstruction was added in the channel between the Birch Lake and July Avenue. Through years, there has been anecdotal and directly observed evidence of beaver activity in this area. For instance, field notes from the monitoring of the July Avenue culvert in 2016 identified frequent beaver activity and damming of the upstream end of the culvert. Therefore, there was technical justification to include a channel obstruction as part of the model.

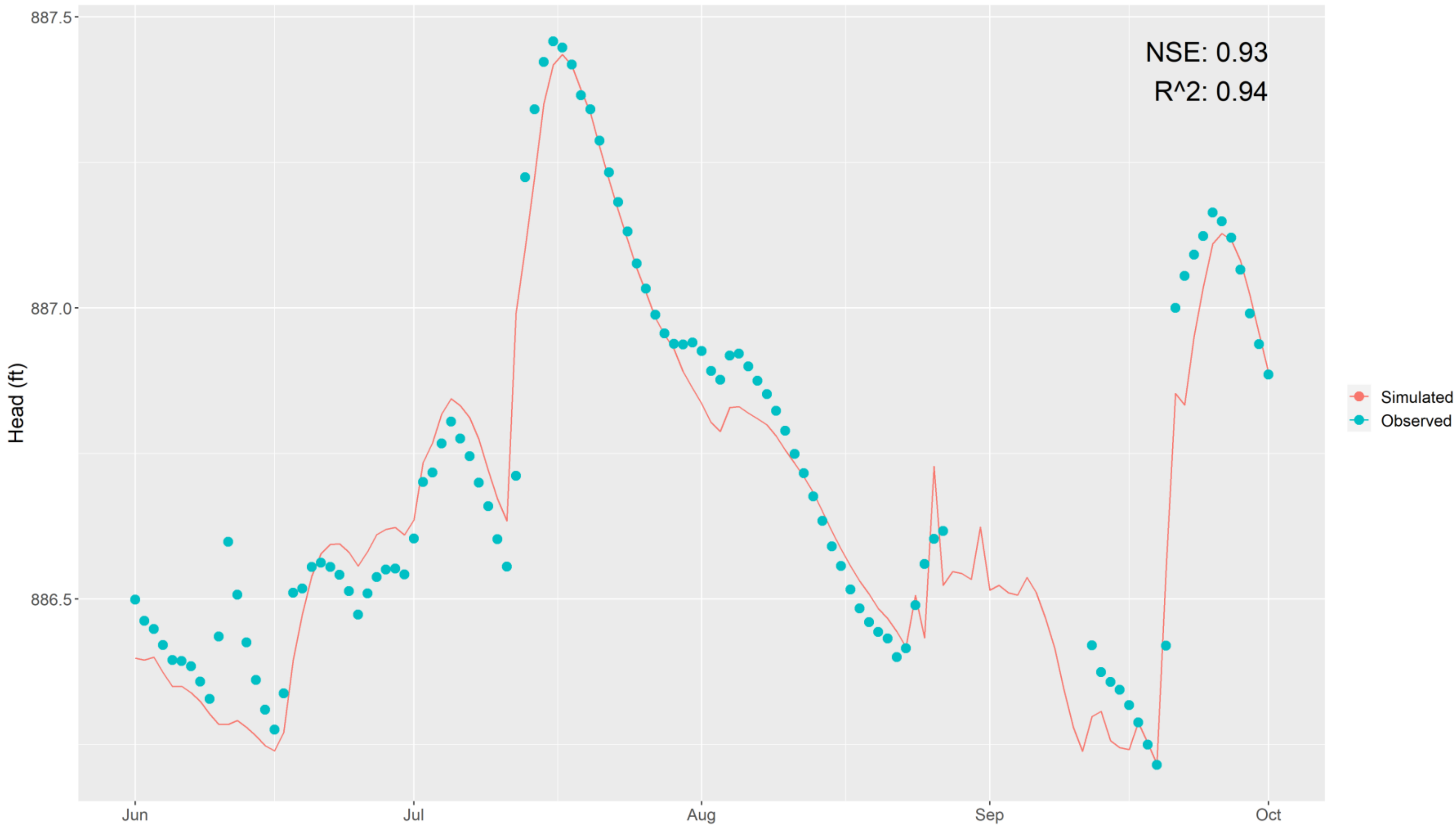
This obstruction was also needed to control Birch Lake at a higher elevation to match observed lake water elevation data. Although there are only 3 years of monitored data on Birch Lake (2017, 2018, and 2020), lake levels in 2018 were 0.9 feet higher than the other two years under similar precipitation patterns. This provides additional evidence of a restriction in the channel. Google Earth aerial imagery also indicates higher than normal water levels for Spring 2018.

6.3.3. School Lake



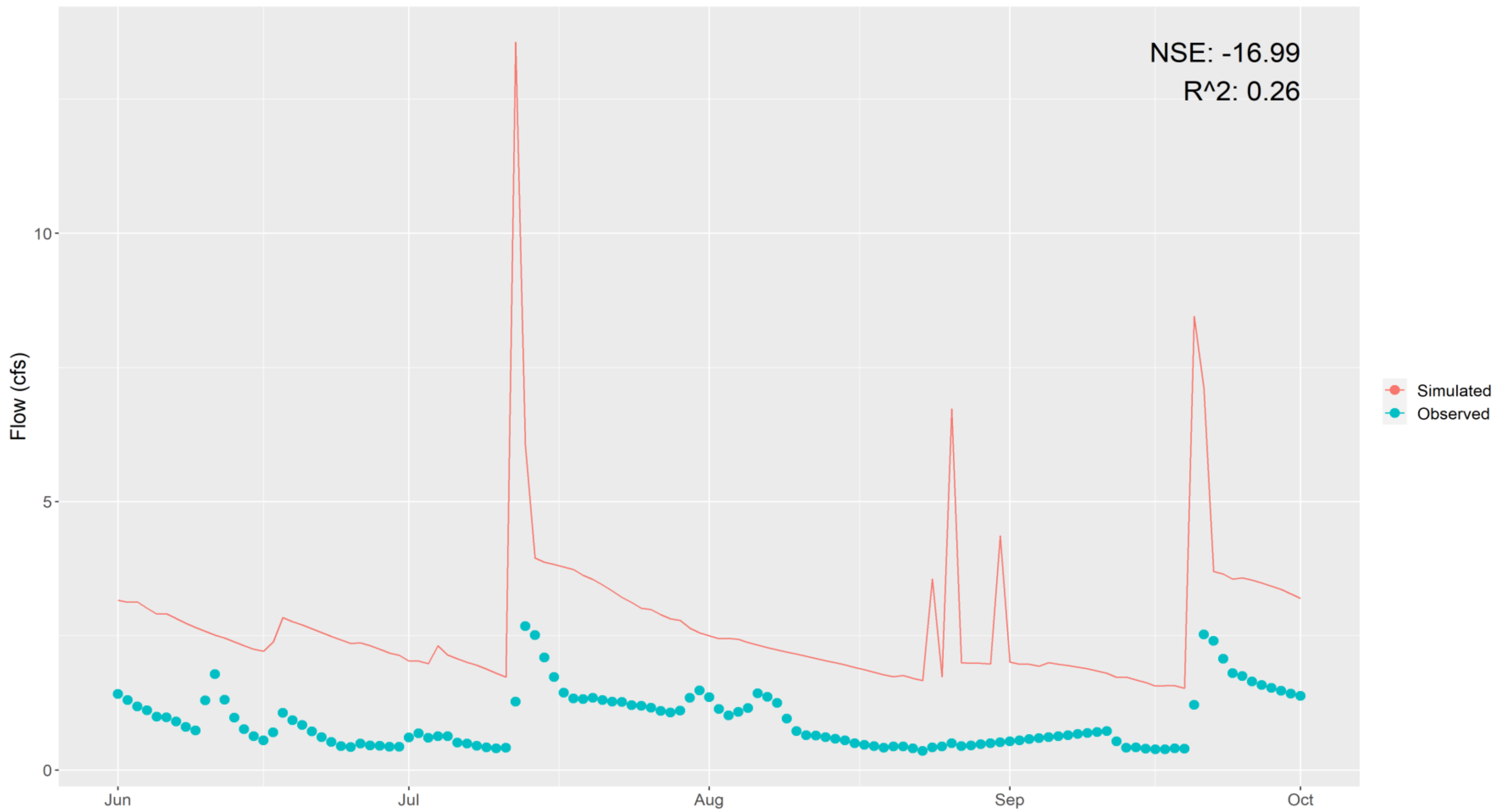
For the same reasons mentioned for Birch Lake, an obstruction at the outlet culvert from School Lake was added to better reflect the observed lake levels. Initial modeling showed School Lake drawing down much quicker than shown in the observed data. The simulated obstruction helped to lengthen the hydrograph response to rainfall to better match observed data.

6.3.4. LC1 (Little Comfort Inlet at Itasca Avenue) Head



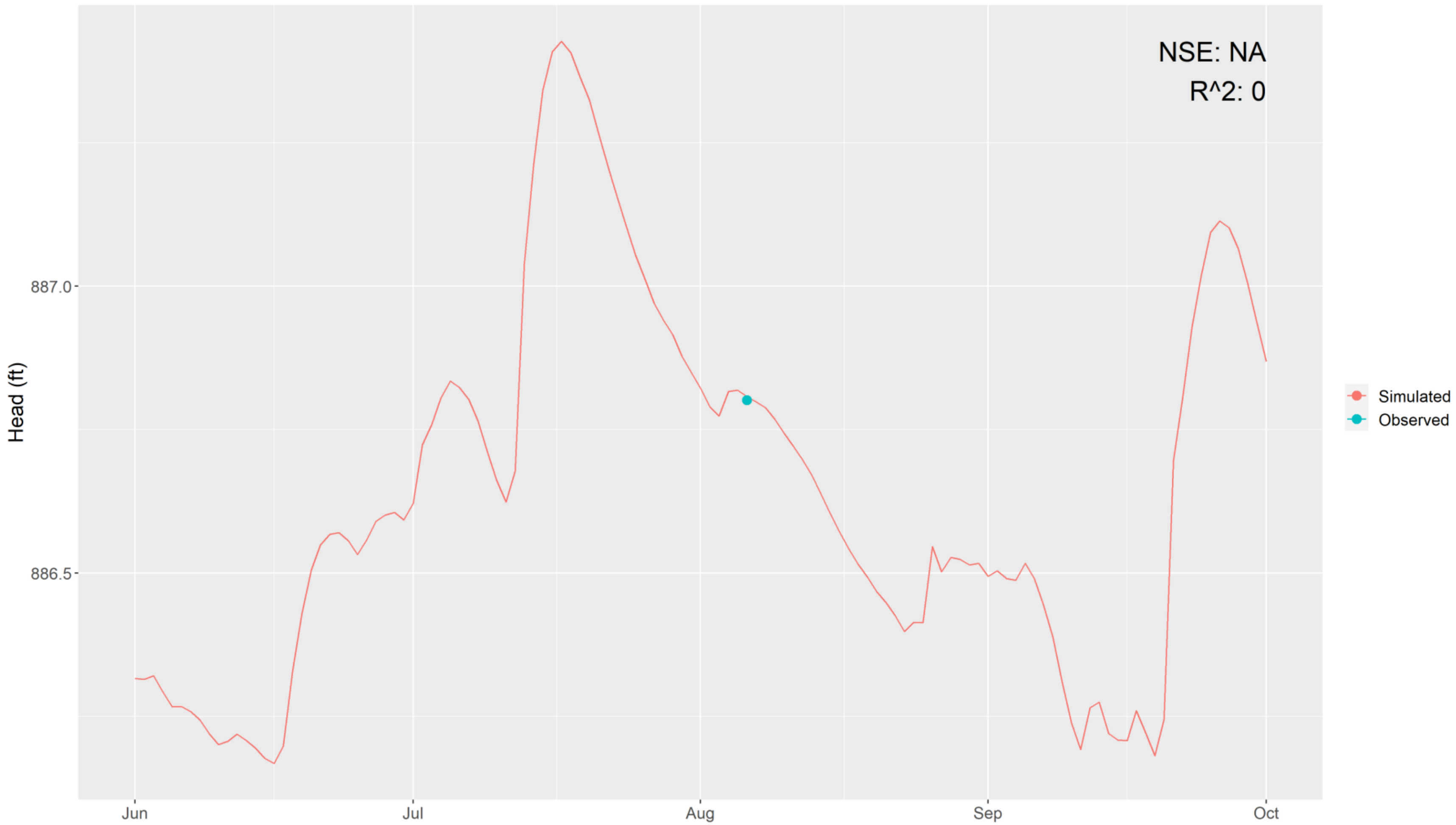
No additional changes to the model were necessary to match water surface elevation at the LC1 monitoring station. When downstream levels on Little Comfort Lake are high, tailwater from the lake impacts elevations at this monitoring site, which was the case starting in July of 2018. The monitoring station was offline from August 26 – September 12 as shown in the graphic above.

6.3.5. LC1 (Little Comfort Inlet at Itasca Avenue) Flow



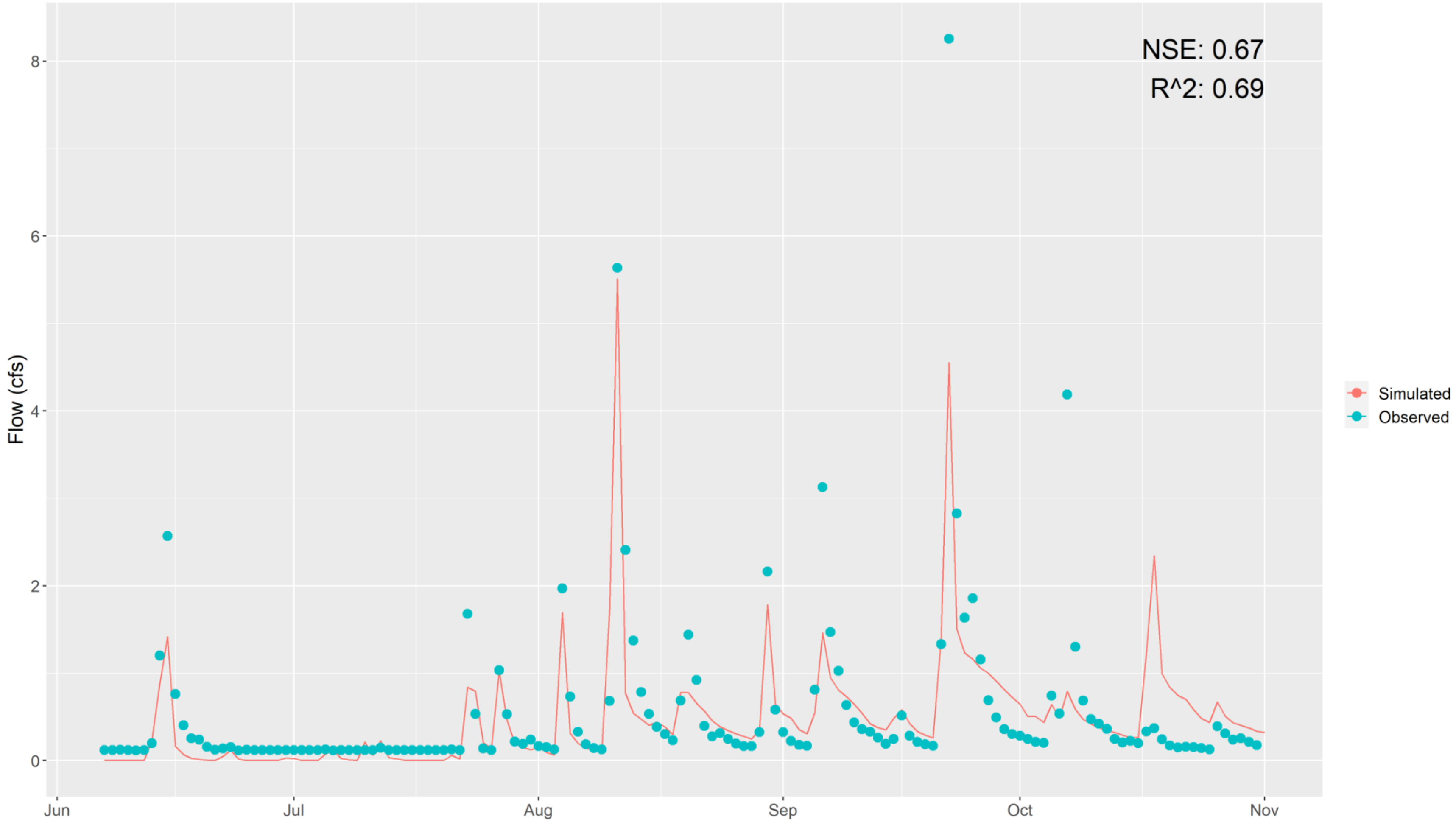
Flow rate at LC1 was not used for calibration due to problems with the monitoring methodology used for the site. Washington Conservation District (WCD) used an area-velocity sensor located in the upstream end of the culvert. This sensor measures water depth and velocity and uses the culvert shape to estimate flow. However, due to the angle at which water flows into the culvert, flow velocities measured at the center of the culvert entrance (where the sensor was located) are not representative of the velocity for the whole cross-section. The sensor missed higher velocities occurring on one side of the culvert due the flow entrance angle. This resulted in consistent underestimation of flow, as can be seen in the image above. To correct this issue, WCD switched to using a depth sensor paired with a rating curve starting in 2019.

6.3.6. Comfort Lake



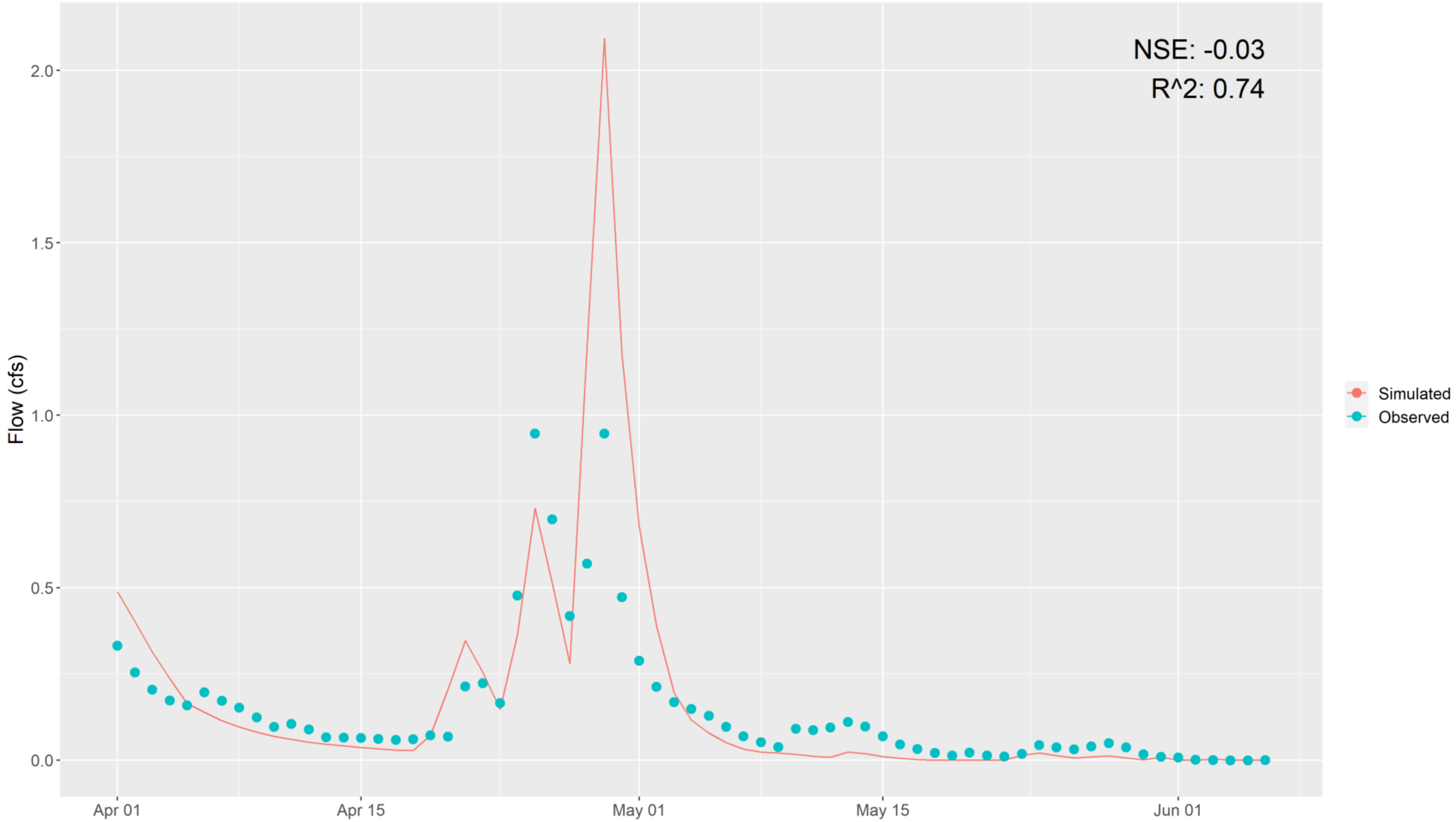
No data was available on Little Comfort Lake in 2018 to use for setting downstream boundary conditions. Instead, monitoring data from the Comfort Lake outlet @ Wyoming Trail station was adjusted to match observed levels on Comfort Lake as shown in the image above. Comfort Lake had two other data points in 2018, but both were before June 1 and excluded from the simulation period.

6.3.7. FL8-D



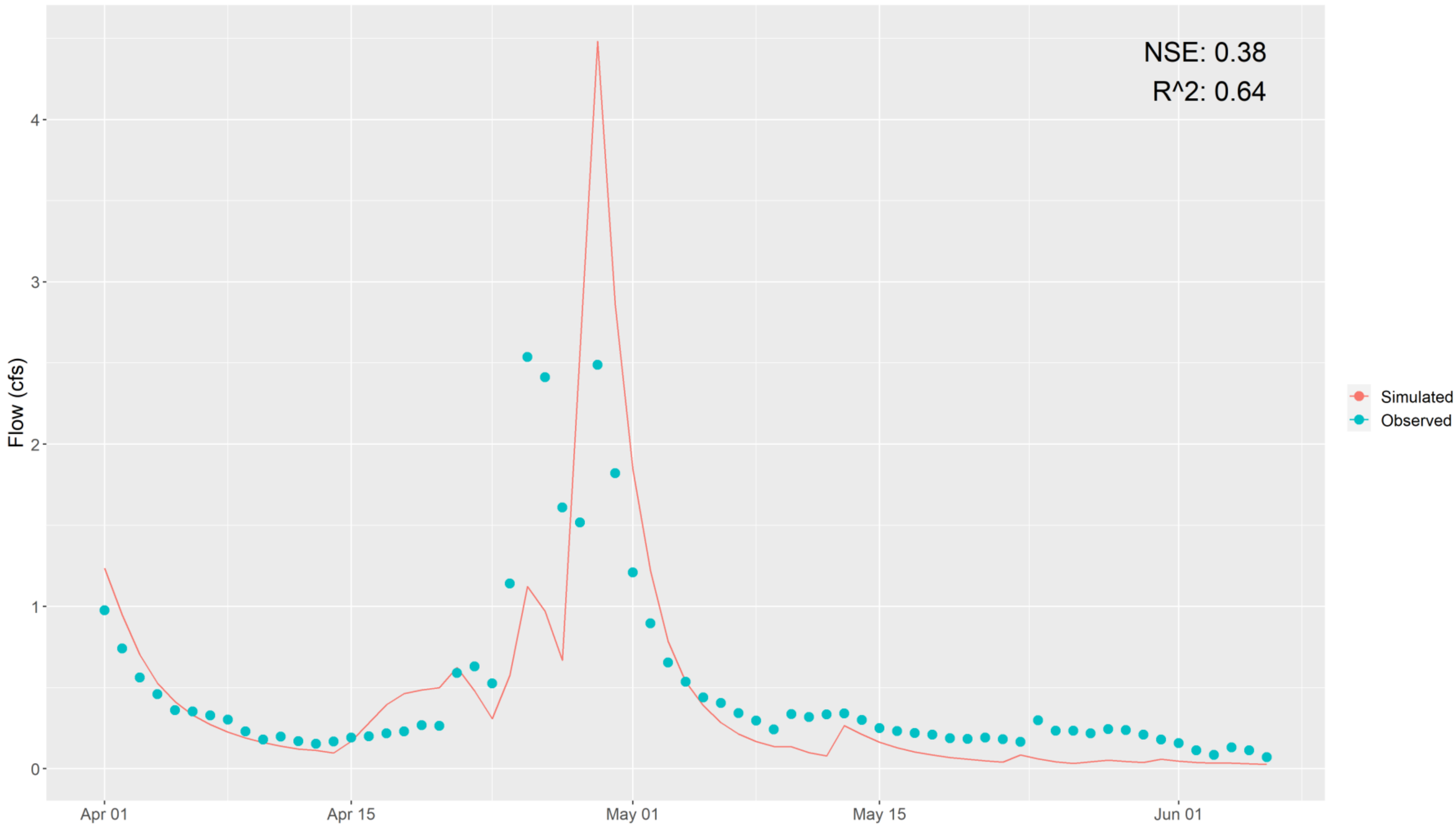
The FL8-D monitoring station is located at the downstream end of a large stream tributary, where a pipe draining the Castlewood golf course outlets into Forest Lake just east of 12th Ave SE. No additional changes to the model where necessary to match the observed data. The graphic shows small flows with a good NSE and R^2. Total volume for the model was 87% of the observed volume, which is considered a good match.

6.3.8. Ditch West



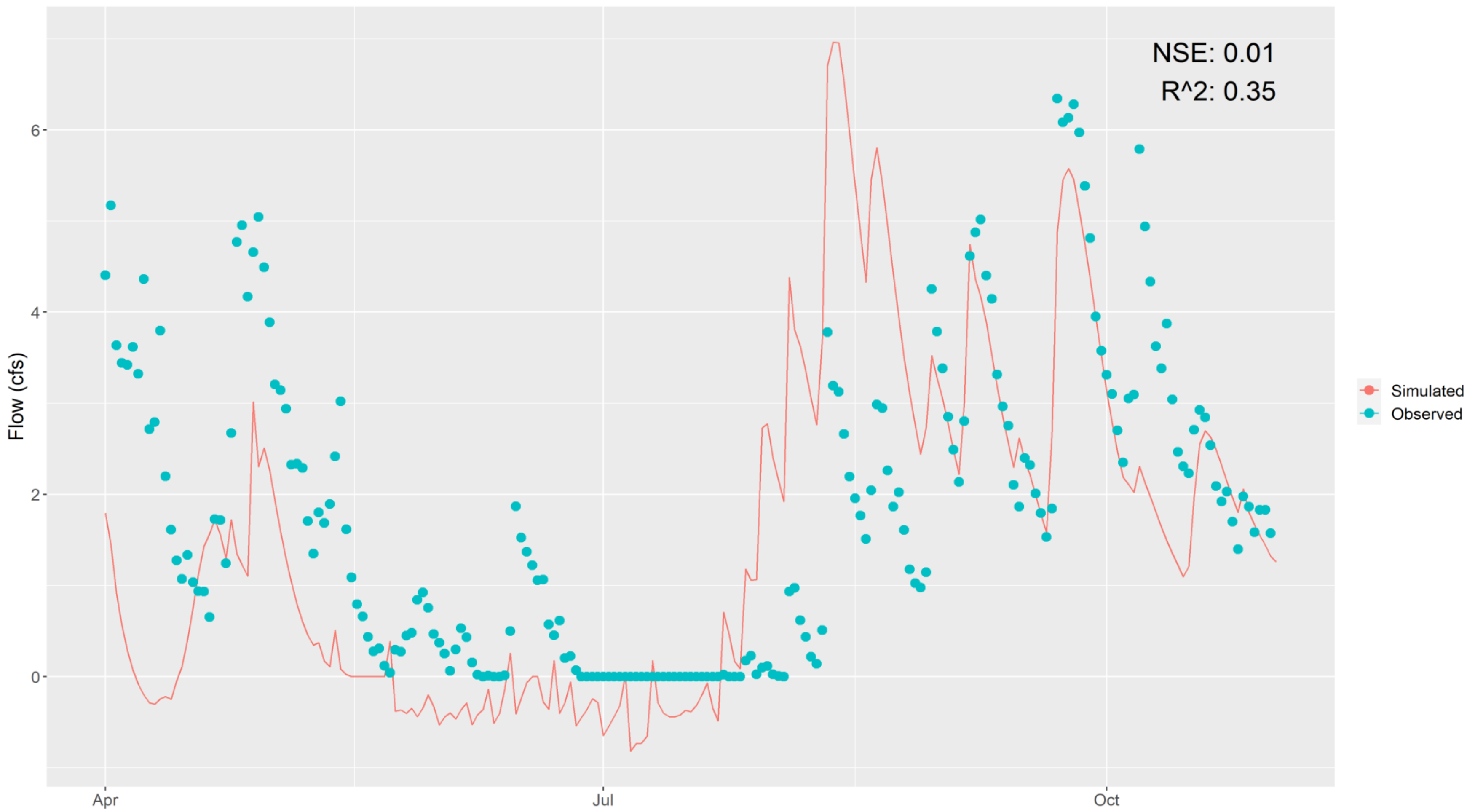
The Ditch West monitoring station is located just west of Heath Ave N, upstream of Shields Lake. This location receives piped runoff from several golf course ponds which concentrate into a ditch that then flows along 208th Street towards Shields Lake. No additional changes to the model were made to match the observed data. While the NSE value is poor for this site, the limited time scale for the observed data (2 months) makes the NSE more sensitive than the value for a longer observed dataset. Total volume for the model was 113% of the observed volume.

6.3.9. 208th Street Pond



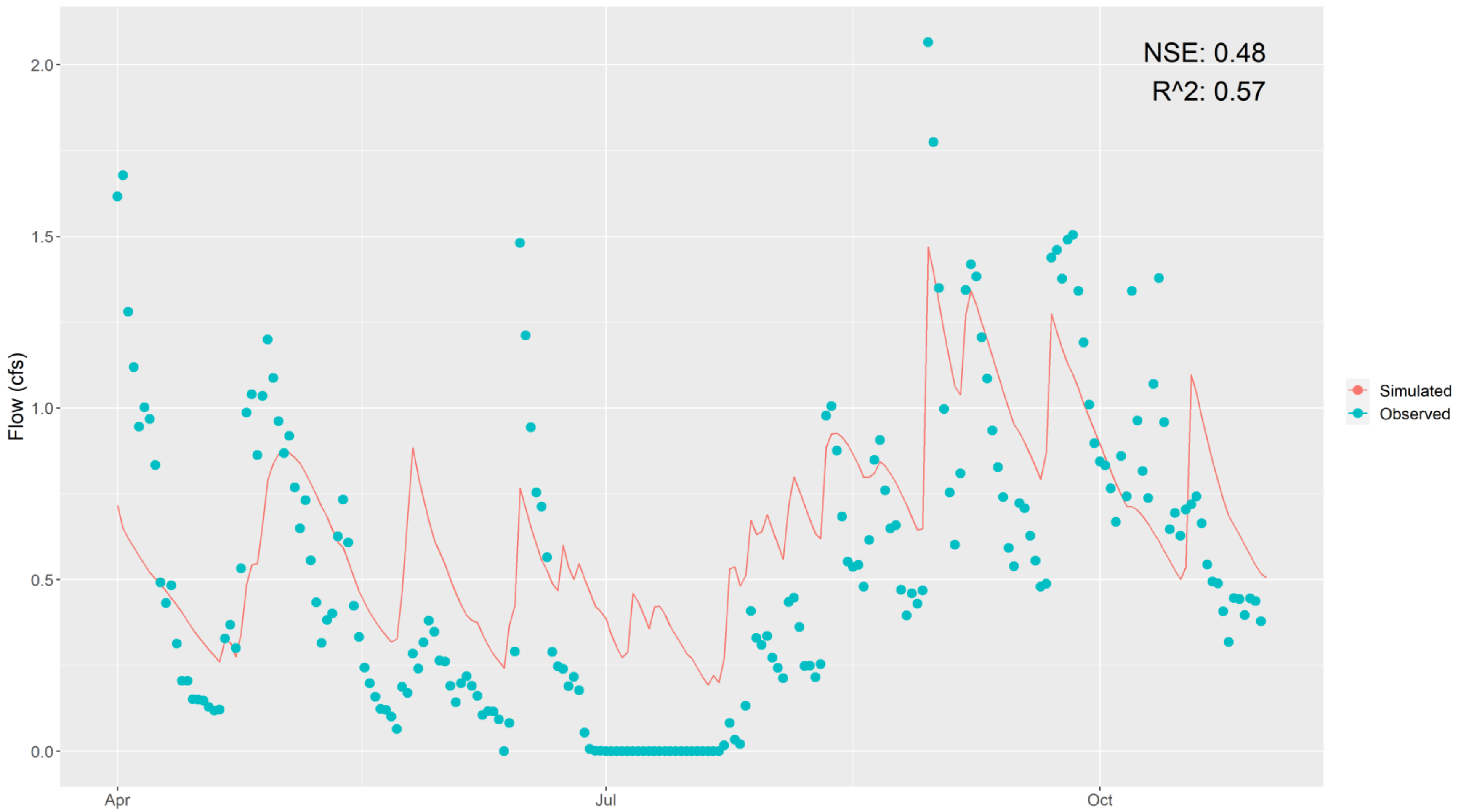
The 208th Street Pond monitoring station is located at the end of the ditch from Ditch West, at the intersection of 208th Street and 209th Street North. The outlet from this stormwater pond drains directly to Shields Lake. No additional changes to the model where necessary to match the observed data. Total volume for the model was 92% of the observed volume.

6.3.10. FL9



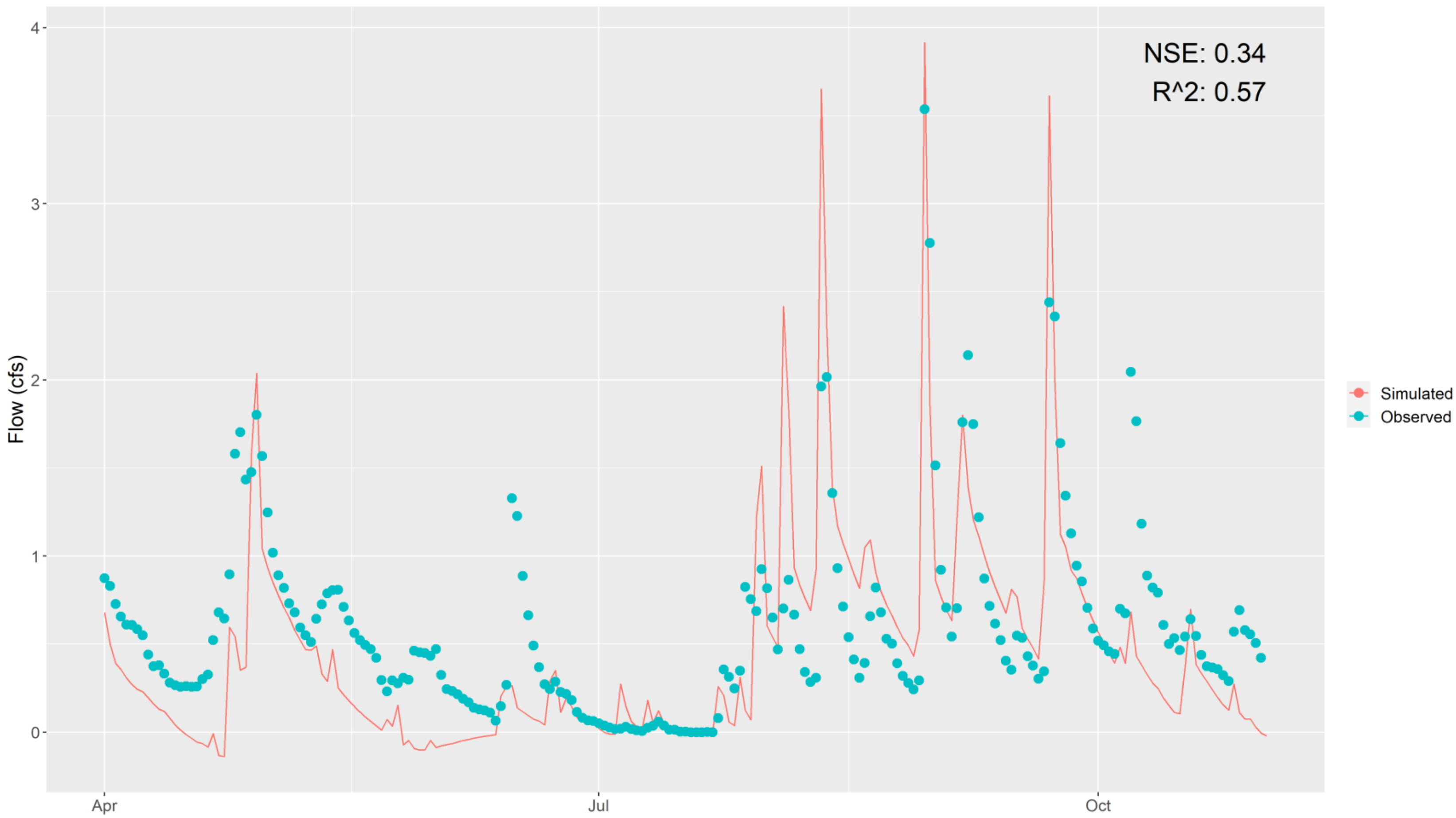
The FL9 monitoring station is located at the downstream end of the Shields Lake sub-watershed where the ditch from Shields Lake crosses Scandia Trail. Efforts to calibrate this location were largely unsuccessful. Review of the rating curve developed for this site indicates high sensitivity to changes in elevation (observed flows ranged from 0 to 9 cfs while observed stage had a range of 0.4 feet). This fact, combined with the minimal separation between culvert elevation and the normal water level of Forest Lake, likely contribute to the poor fit at this location. Total volume for the model was 83% of the observed volume, which is considered satisfactory.

6.3.11. FL17



The FL17 monitoring station is located at the outlet of Cranberry Lake where the outlet channel from the lake crosses through a culvert under North Shore Drive before continuing to Forest Lake. To match observed data, it was necessary to increase the overflow elevation from the south lobe of Twin Lake to Cranberry Lake by 0.5 feet. This limited the flow contributions from Twin Lake which initially led to high flows in September and October that were inconsistent with the observed data. The increase in overflow elevation may be due to an obstruction (vegetation, beaver dam) in the channel or it could be due to inaccuracies in the DEM elevation in this location. Total volume for the model was 122% of the observed volume.

6.3.12. FL18

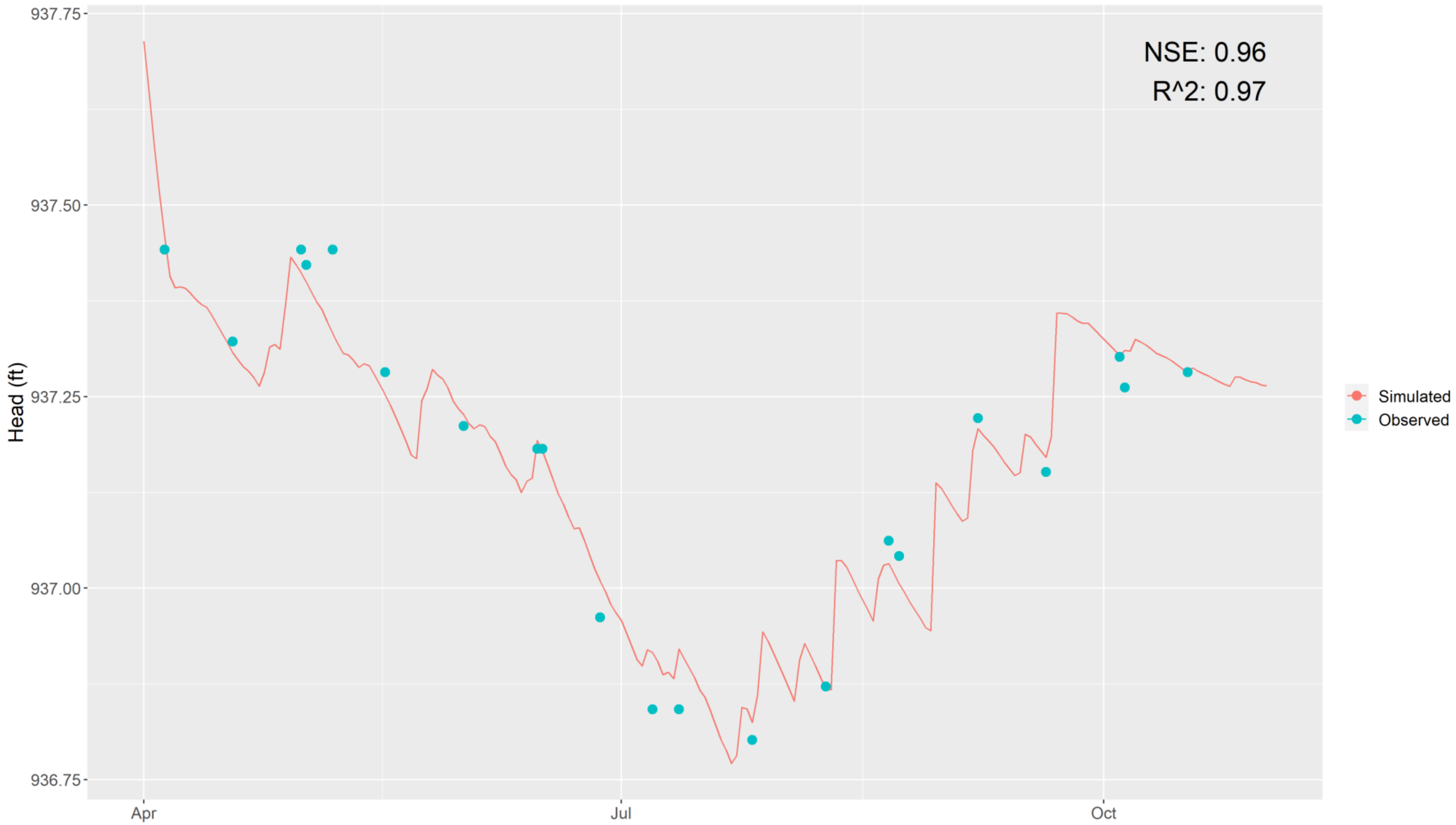


The FL18 monitoring station is located at the outlet of a large unnamed wetland located on the north side of North Shore Trail between Ivan Court and Iverson Avenue North. This wetland drains through a culvert under North Shore Trail and into Forest Lake. To match observed data, it was necessary to increase depressional storage for this wetland up to 1 inch. This suggests the vegetation throughout the wetland has a large capacity to absorb rainfall, higher than what is typically attributed to wetlands. The large size of this wetland compared to its catchment area supports tweaking parameters for this wetland separately from the more standardized parameters associated to smaller wetlands throughout the watershed. Total volume for the model was 78% of the observed volume.

6.3.13. FL1

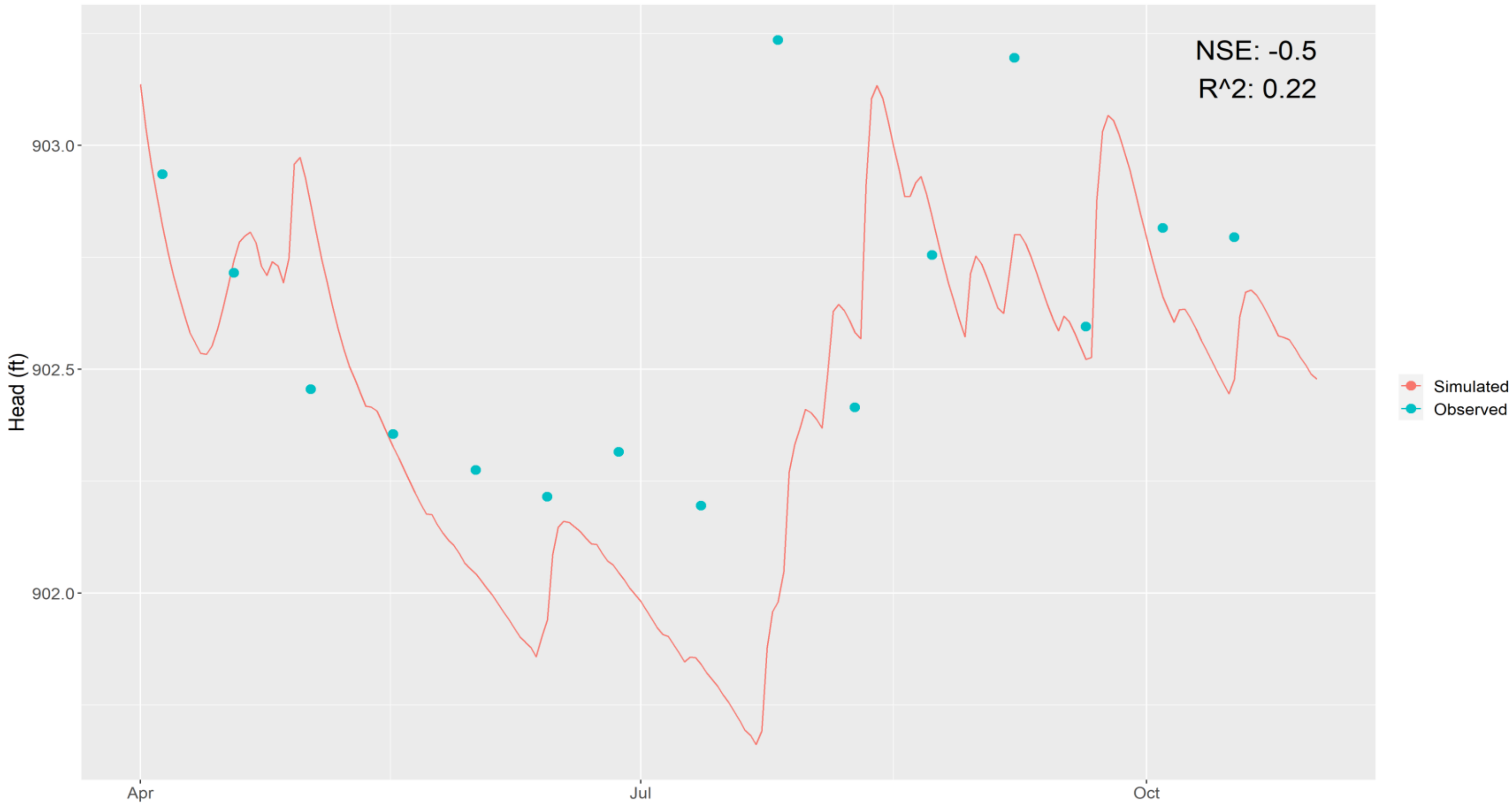
The FL1 monitoring station is located just downstream of the culvert crossing at North Shore Drive, where outflow from Forest Lake becomes the headwaters of the Sunrise River. No additional changes to the model where necessary to match the observed data. Total volume for the model was 91% of the observed volume (excludes month of June when monitoring station was offline).

6.3.14. Lake Keewahtin



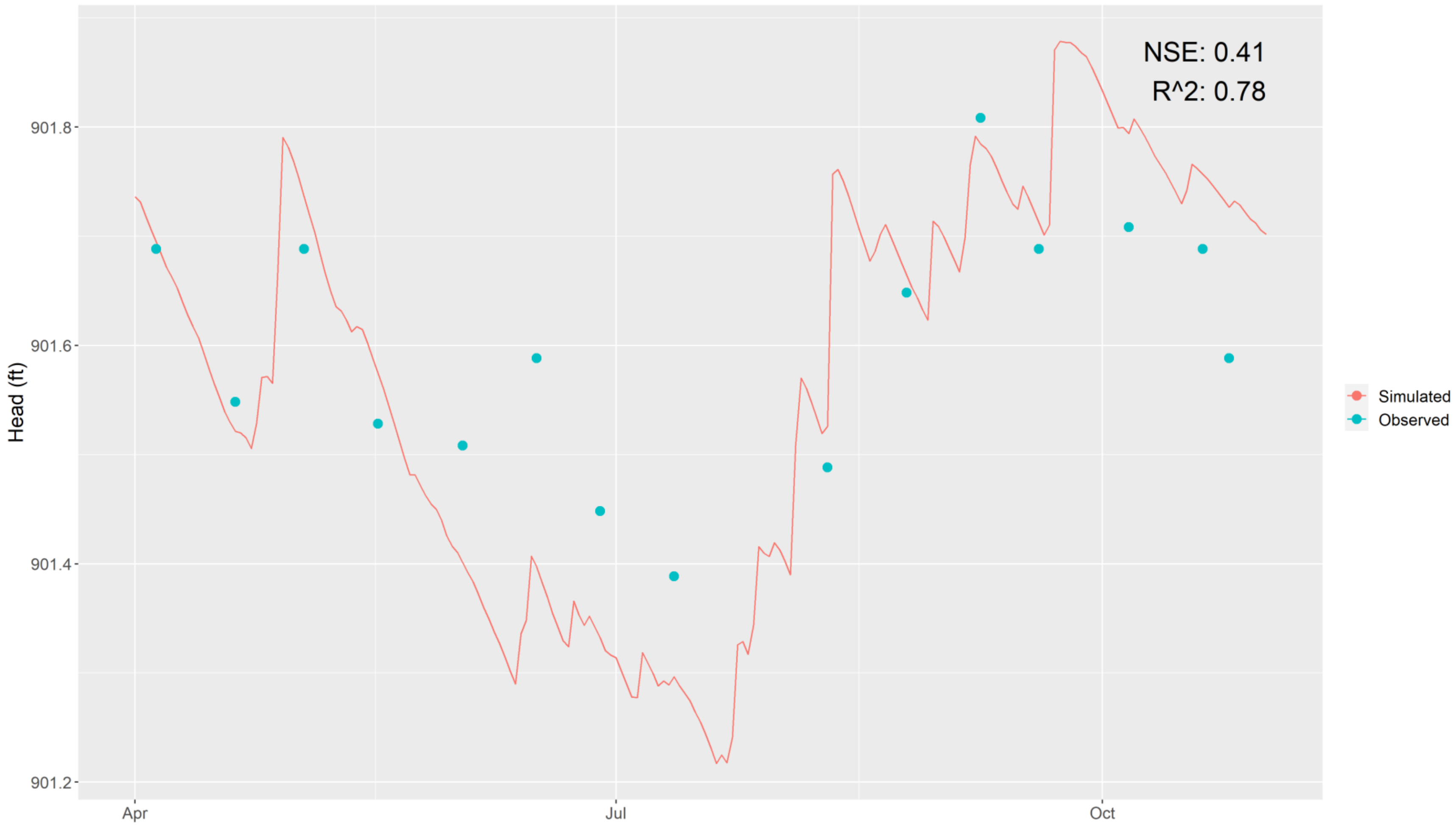
In addition to the general changes discussed above, seepage of water from Lake Keewahtin into groundwater was incorporated in the model to better reflect the observed slope of drawdown in periods of no rainfall. Since Lake Keewahtin is landlocked, the only other "outlet" is evaporation of water from the lake surface which alone wasn't enough to match the drawdown in the observed data.

6.3.15. Shields Lake



Water surface elevation on Shields Lake shows similar trends to the outflow monitoring at FL9, where elevation/flow is lower than observed for June and the first half of July. Efforts made to address this discrepancy include adjustments to outlet channel elevation and width. One possible reason for this discrepancy between modeled results and observed data is the higher Manning's roughness coefficient needed to properly simulate very shallow channel flows (sheet flow) relative to the roughness coefficient generally used for higher, deeper flows. PCSWMM does not allow utilizing multiple Manning's roughness coefficients during the same run, so the composite roughness coefficient entered for the entire channel cross-section was provably underestimated for shallow flows. Incorporating a higher roughness coefficient for shallow flows would result on a less pronounced slope on the receding part of the hydrograph in the model (see mid-April to mid-July red line).

6.3.16. Forest Lake

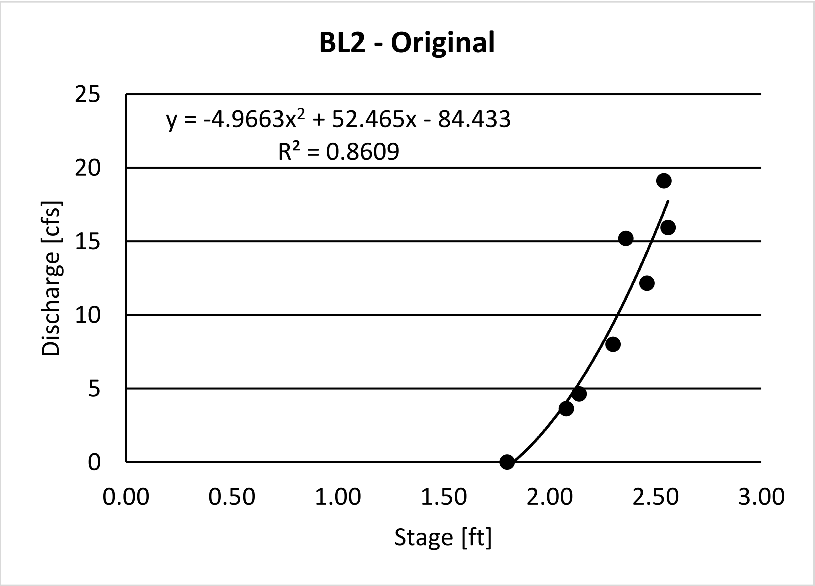


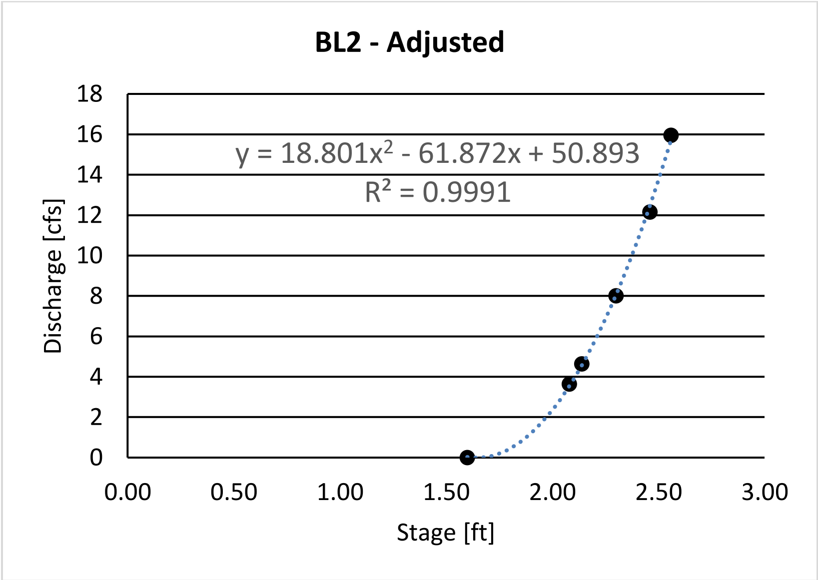
Calibrating to the upstream monitoring stations discussed above led to a good match of water levels on Forest Lake. Initial conditions for surface water and groundwater were adjusted to match observed data, but no other changes were necessary. The greatest difference between observed and modeled data is roughly 0.2 feet.

6.4. Validation Results

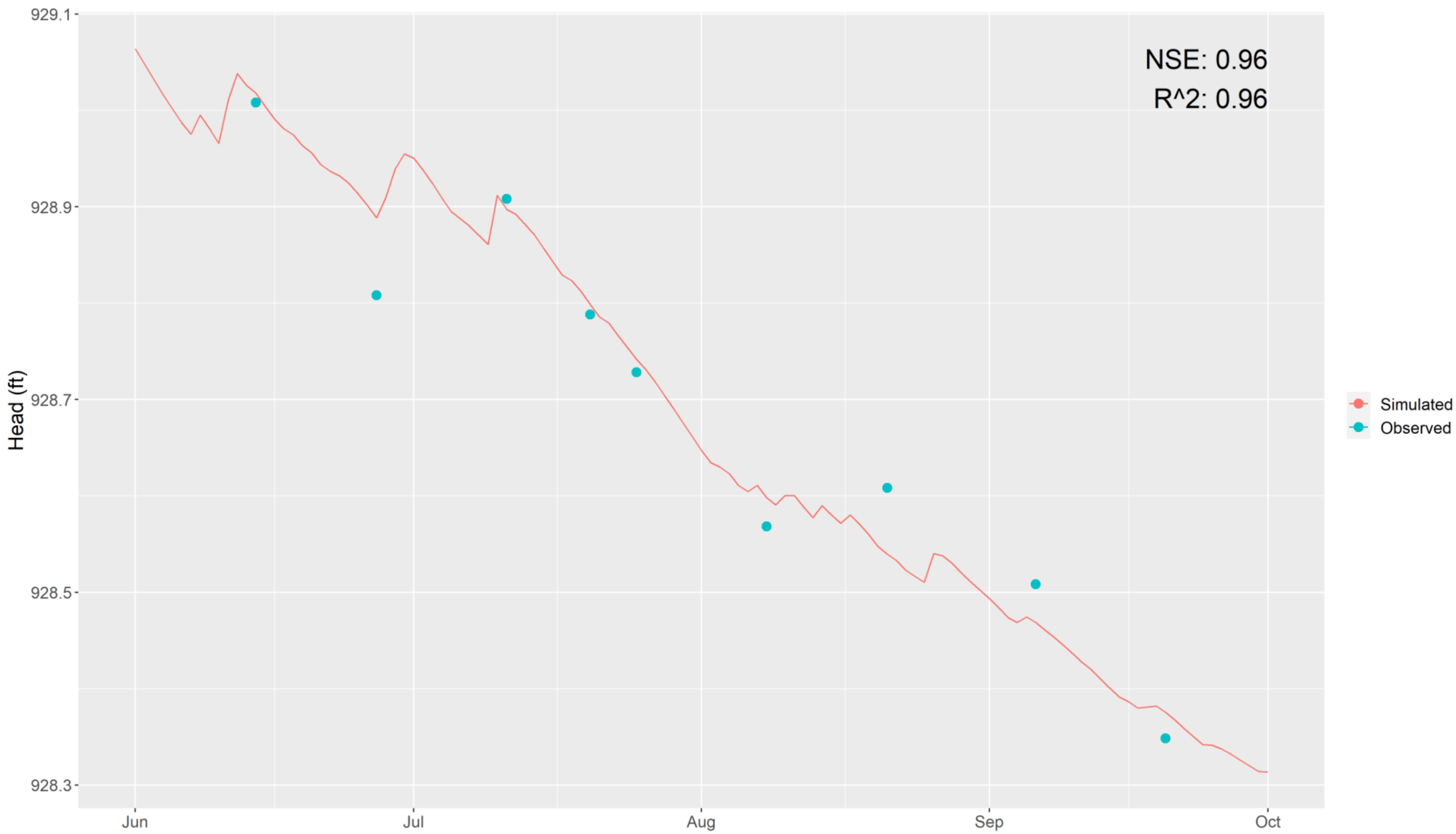
To validate the input parameters' refinement made during calibration, the model was run for a different year than the year used for calibration. The validation years were 2020 for the Little Comfort Lake sub-watershed and 2021 for the Forest Lake sub-watershed. The small number of changes made during the validation process only pertain to parameters that can change year to year, such as presence of beaver dams or other blockages or lake initial conditions. No other adjustments were performed. For direct comparison, validation was performed on the same monitoring locations as calibration where possible.

One relevant change for the Little Comfort Lake sub-watershed was to adjust the flow rating curve at BL2 by removing two outlier data points in the observed data that were questionable and potentially related to instrumentation malfunction. Removing these two data points resulted in an improved curve fit (see change in R-squared values in the graphics below). In addition, removing these data points increased discharge values at lower flow depths, which better fit observed data for 2020. Using the original rating curve resulted in no discharge from Bone Lake in late August. This was inconsistent with downstream lake level measurements that showed minimal elevation change from August to September. Adjusting the rating curved helped to solve this inconsistency.



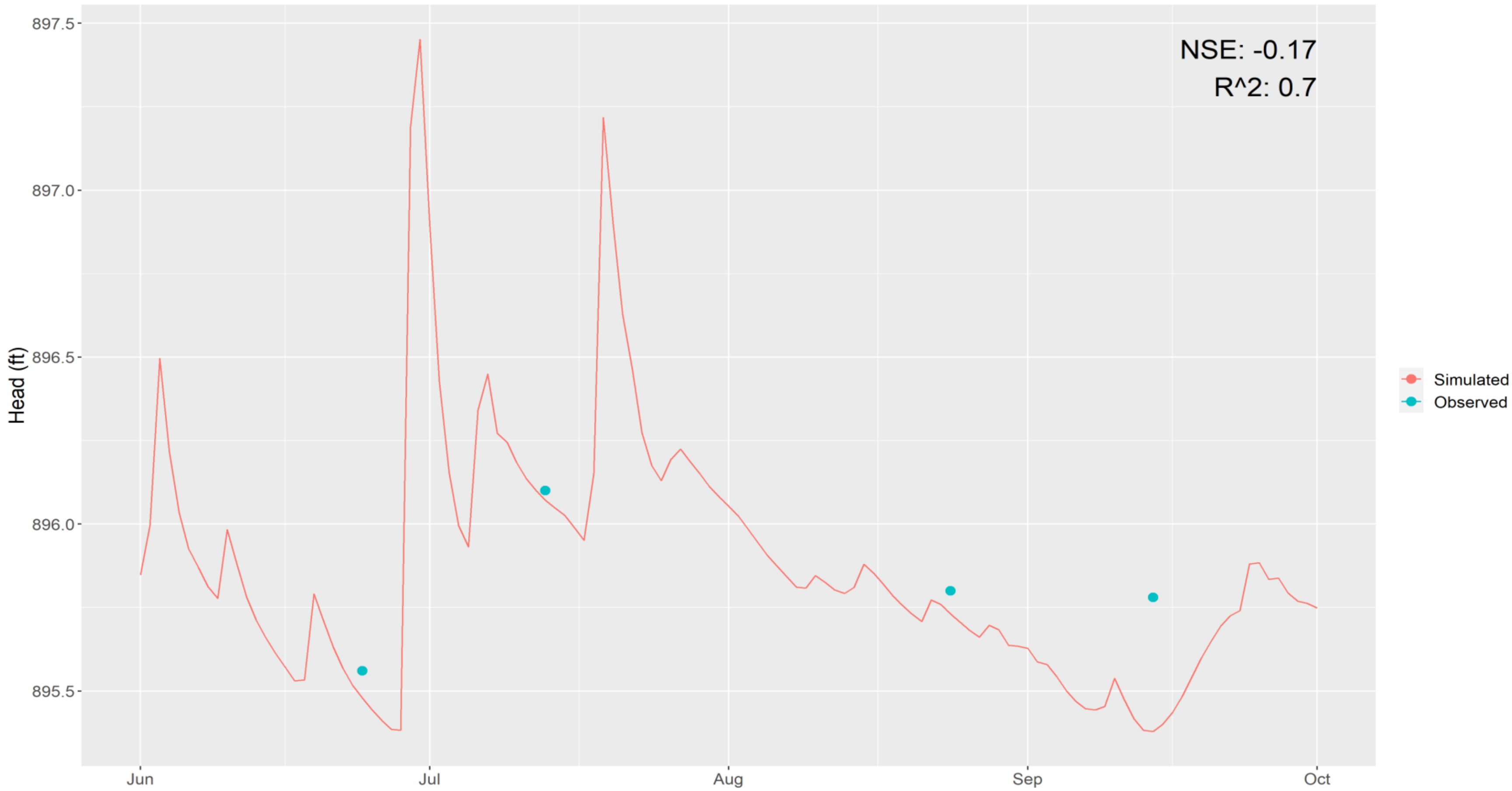


6.4.1. Nielsen Lake



Nielsen Lake was not monitored in 2020, so validation was done instead on lake levels in 2017. Outside of setting the initial lake level, no changes were necessary to match observed data.

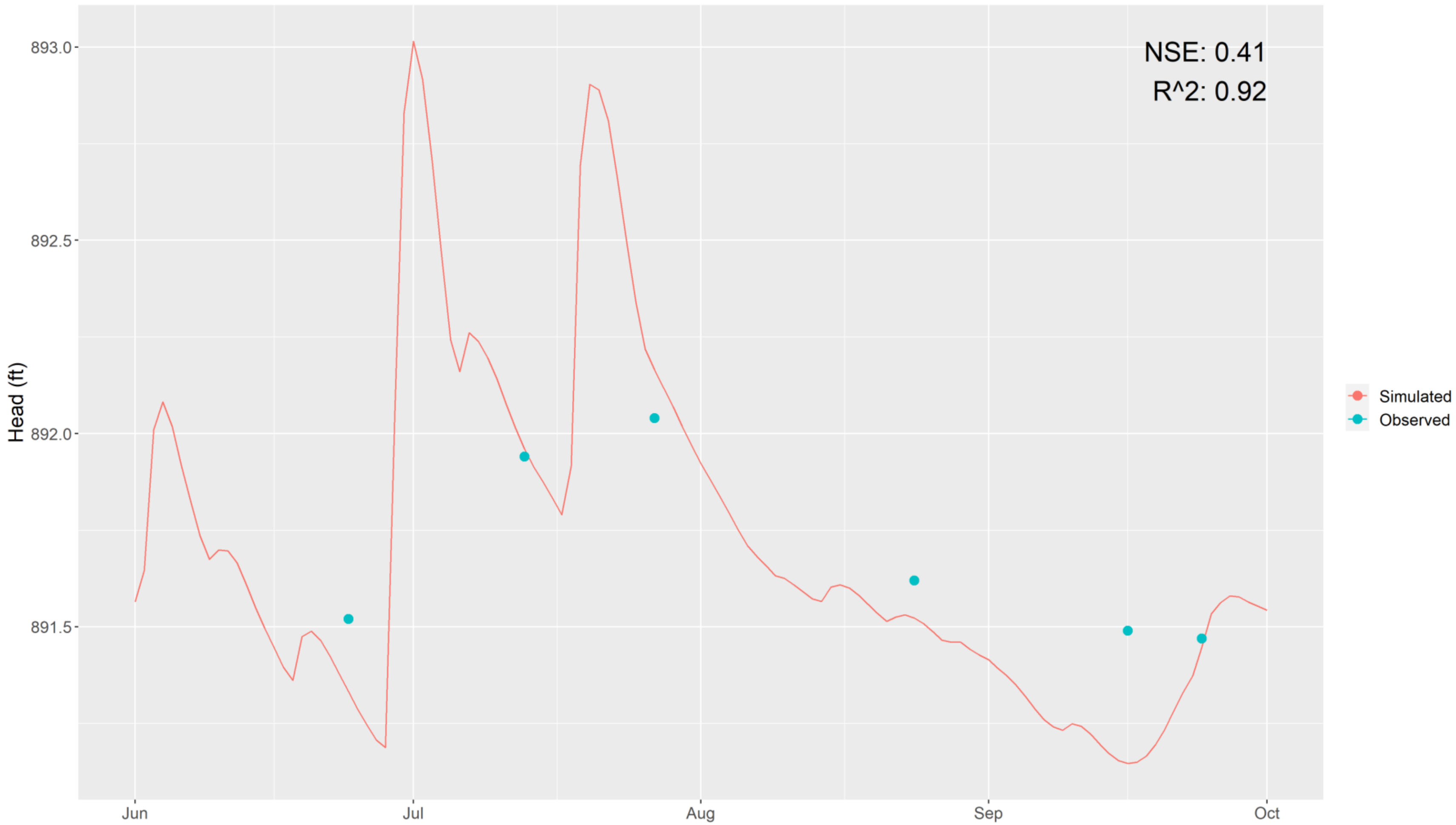
6.4.2. Birch Lake



No beaver dams were simulated for the validation year between Birch Lake and July Avenue. Although, the NSE value is poor due to the limited number of observed data points, lake levels in the model match observed levels well (within roughly 2 inches of each other) except for the point on September 14. This data point is questionable as only 1.5" of rainfall fell in the 3 weeks between the observed data points on August 24 and September 14. Lake level would be expected to drop noticeably during this time.

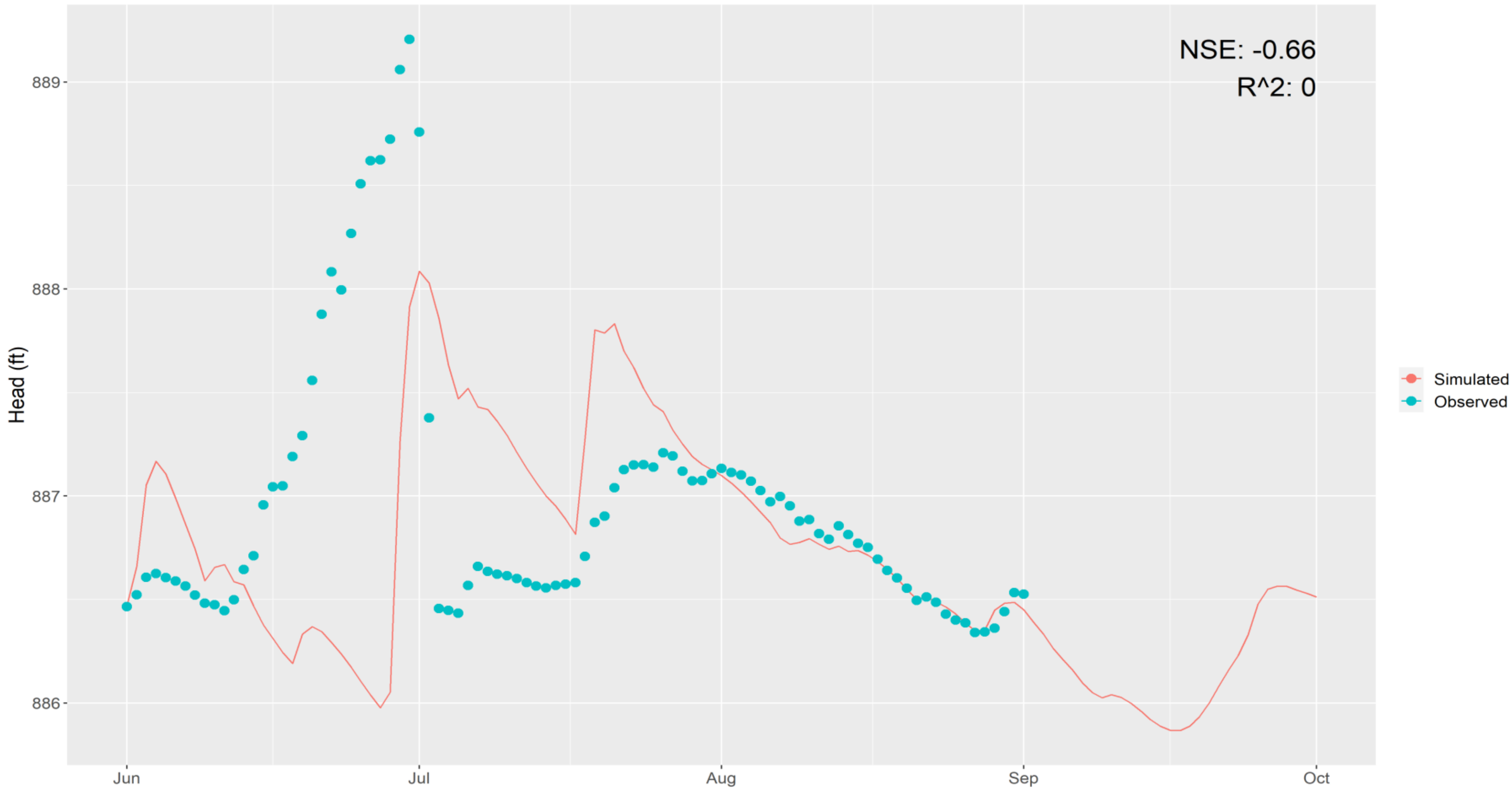
As noted in the Birch Lake calibration section, the channel width downstream of the lake was increased during calibration. This increased capacity controlled the lake level at a lower elevation and helped to better fit the validation data as it did the calibration data.

6.4.3. School Lake



The only change made to School Lake during validation was to adjust the level of obstruction at the outlet culvert relative to the obstruction considered during calibration. The amount of obstruction due to clogging or beaver activity is expected to change year to year and decreasing the depth of obstruction resulted in a better match with observed data.

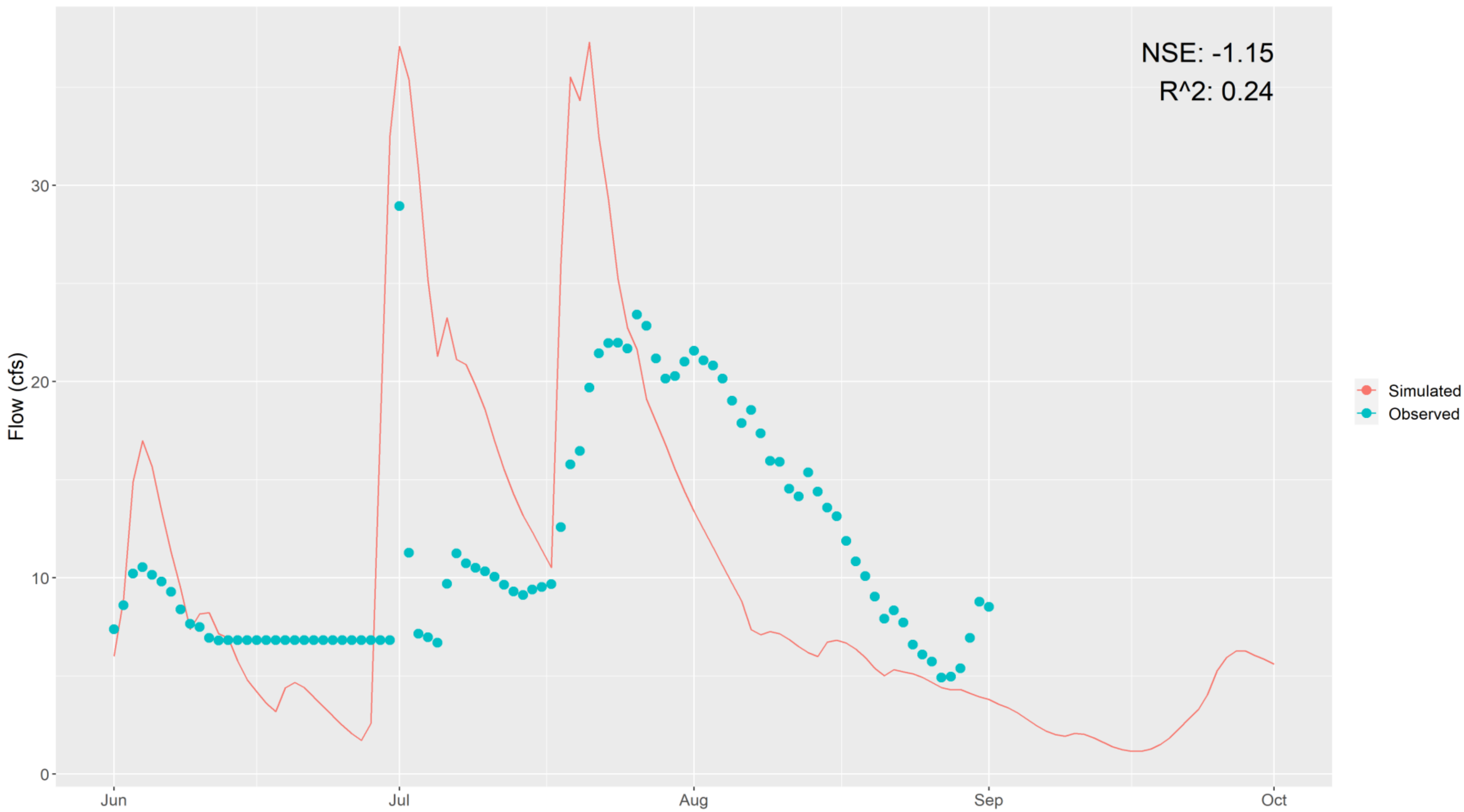
6.4.4. LC1 (Little Comfort Inlet at Itasca Avenue) Head



A beaver dam was observed on June 12 and was cleared on July 1, resulting in the large increase in elevation in mid-June and then sudden drop when the dam was removed (see graphic above). Removal of the beaver dam impacted the sensor's response to a large rainfall event occurring June 28-30. The monitored data in the graphic shows a sudden drop in elevation instead of a more logical and expected days-long drop in water elevation as water levels peak and then slowly recede from the storm.

The model appears to overpredict the stormwater response from another large storm on July 18 but matches observed data well in August. The LC1 monitoring station was pulled at the end of August, so no data was available for further validation in September.

6.4.5. LC1 (Little Comfort Inlet at Itasca Avenue) Flow

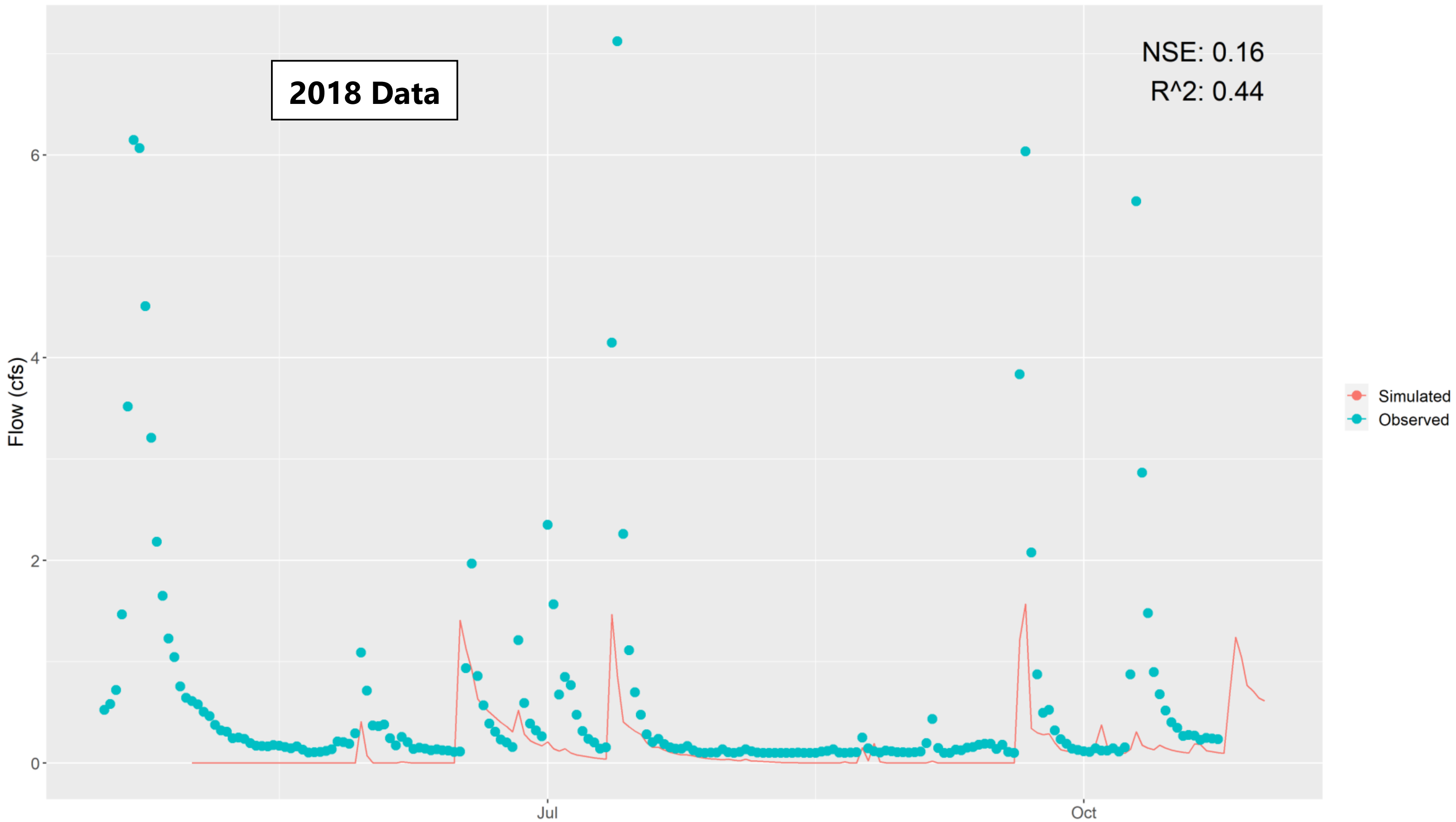


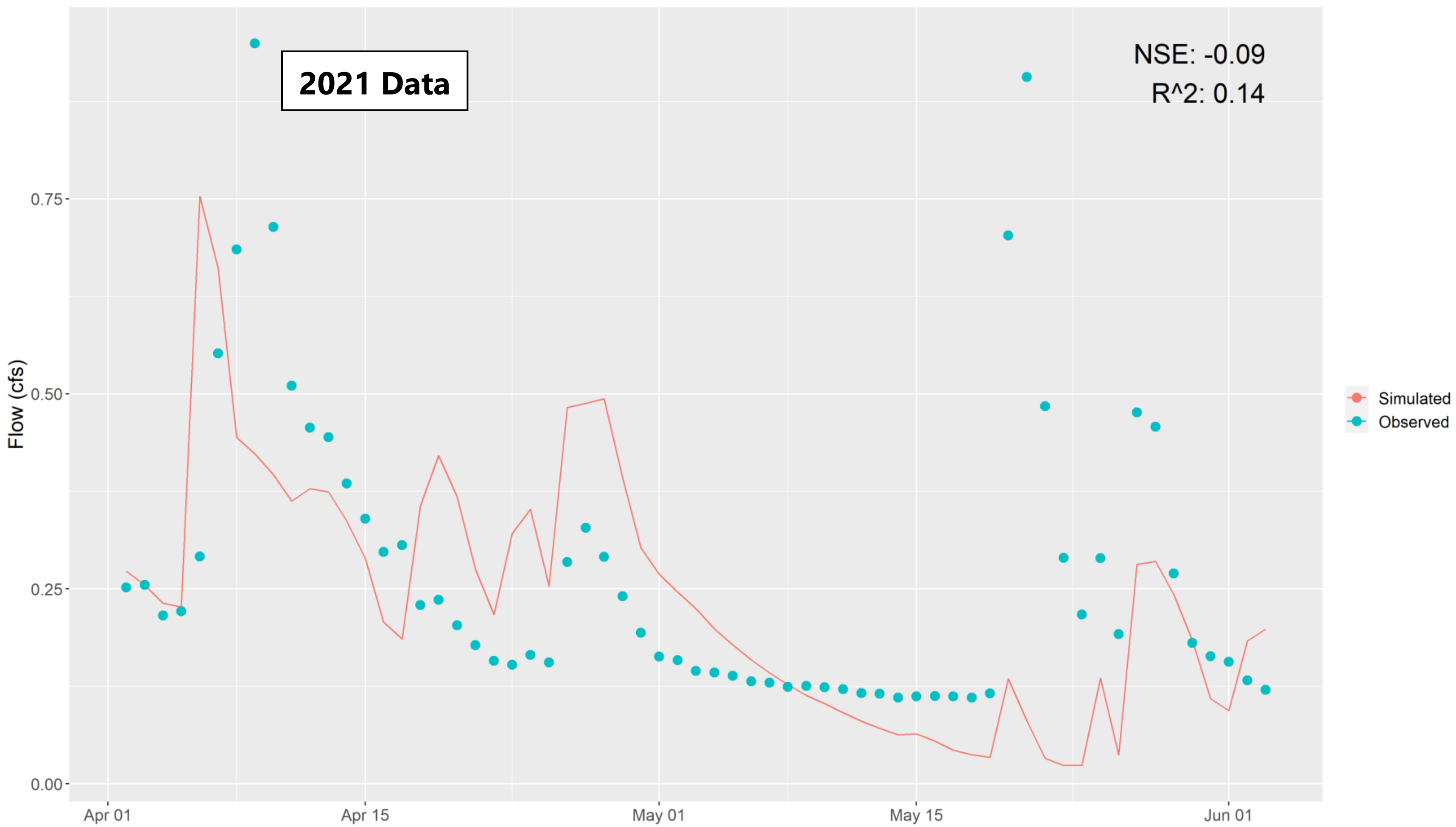
Unlike the calibration year, flow monitoring in the validation year used a depth sensor paired with a rating curve and was able to predict flow more accurately at the monitoring station. Like the elevation graph, the flow graph shows that peak flows were overpredicted in response to rain events. Despite the differences in peak flow rate and shape of the hydrograph, the model predicts a total flow volume of 1902 acre-feet from June through September (excluding the period the beaver dam was in place) compared with an observed total flow volume of 1780 acre-feet, a difference of only 6 percent.

6.4.6. Little Comfort Lake

For the validation year, elevations at Little Comfort Lake were used since there were 5 data points available to use in the validation, instead of just one on Comfort Lake.

6.4.7. FL8-D

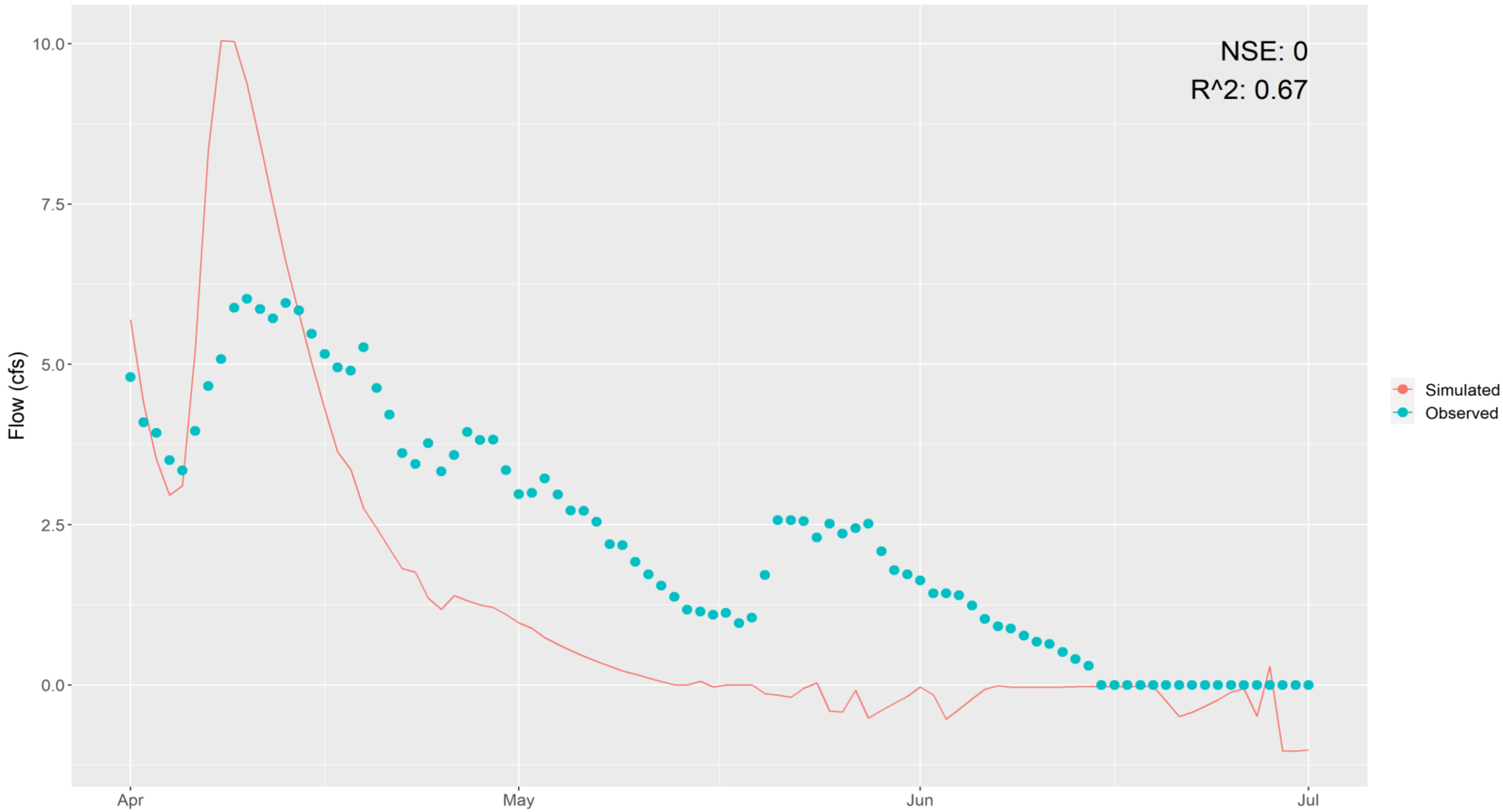

2018 Data
NSE: 0.16
R^2: 0.44
Flow (cfs)
0
2
4
6
Jul
Oct
Simulated
Observed



Flow monitoring data at FL8-D was available for both 2018 and 2021. 2018 is a poor match with only 34% of the measured runoff volume and with some peak flows lower than observed values. The low runoff volume in the modeling results is partially due to a significant snowmelt event at the beginning of the year, that was not incorporated into the model because of the difficulty in modeling snowmelt events. As the ground thaws in the spring, soil infiltration capacity increases, starting at frozen ground conditions where no infiltration is possible to fully thawed conditions where snowmelt and rainfall infiltrate into the soil. Since SWMM uses a single, static soil conductivity value for each catchment, modeling of snowmelt would require assuming an average conductivity over the snowmelt period. Because of these complexities, snowmelt events are not typically modeled.

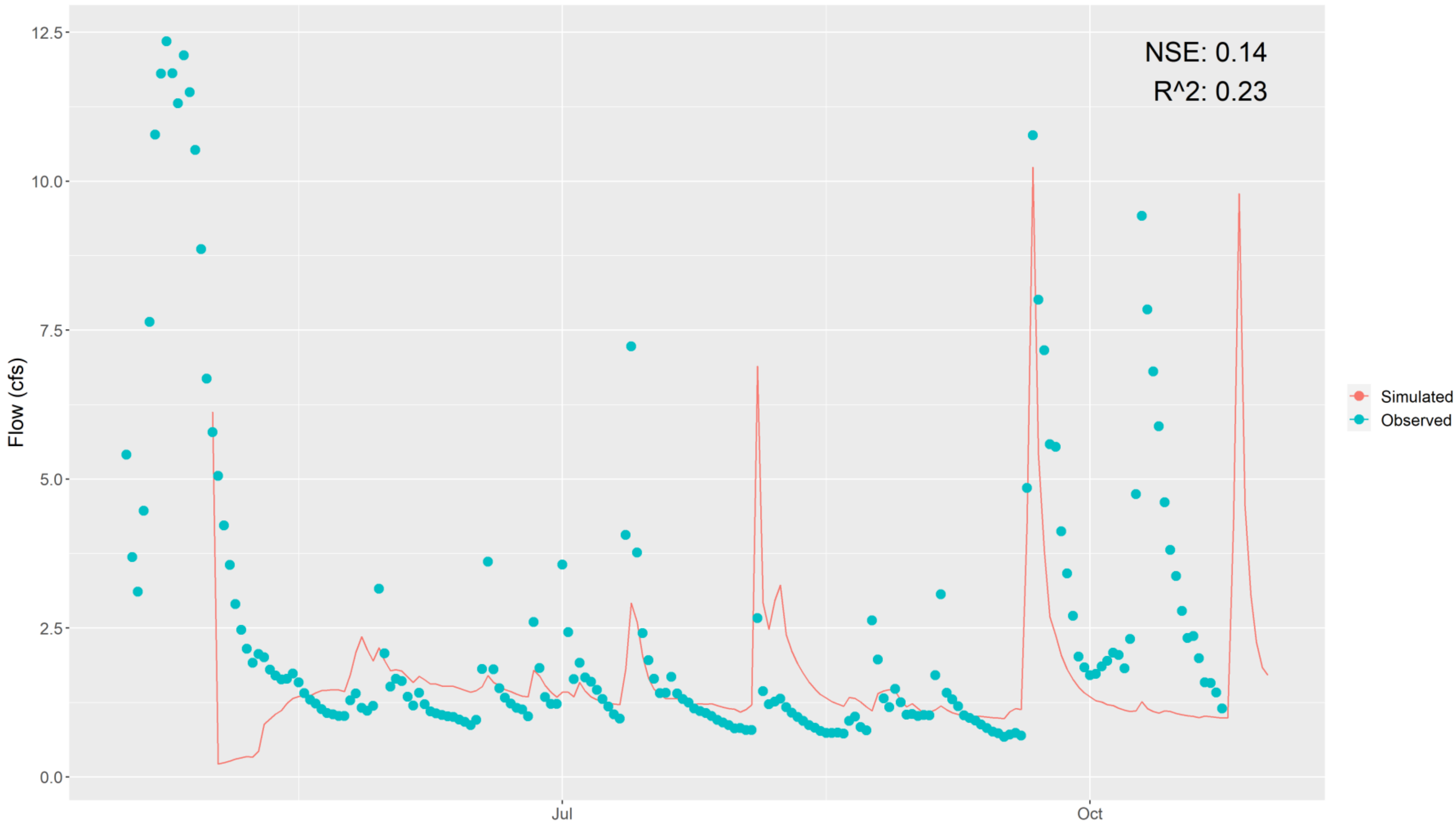
2021 is a better match for total runoff volume (86% of the measured volume), but still shows some issues with matching the overall shape of the observed hydrograph.

6.4.8. FL9



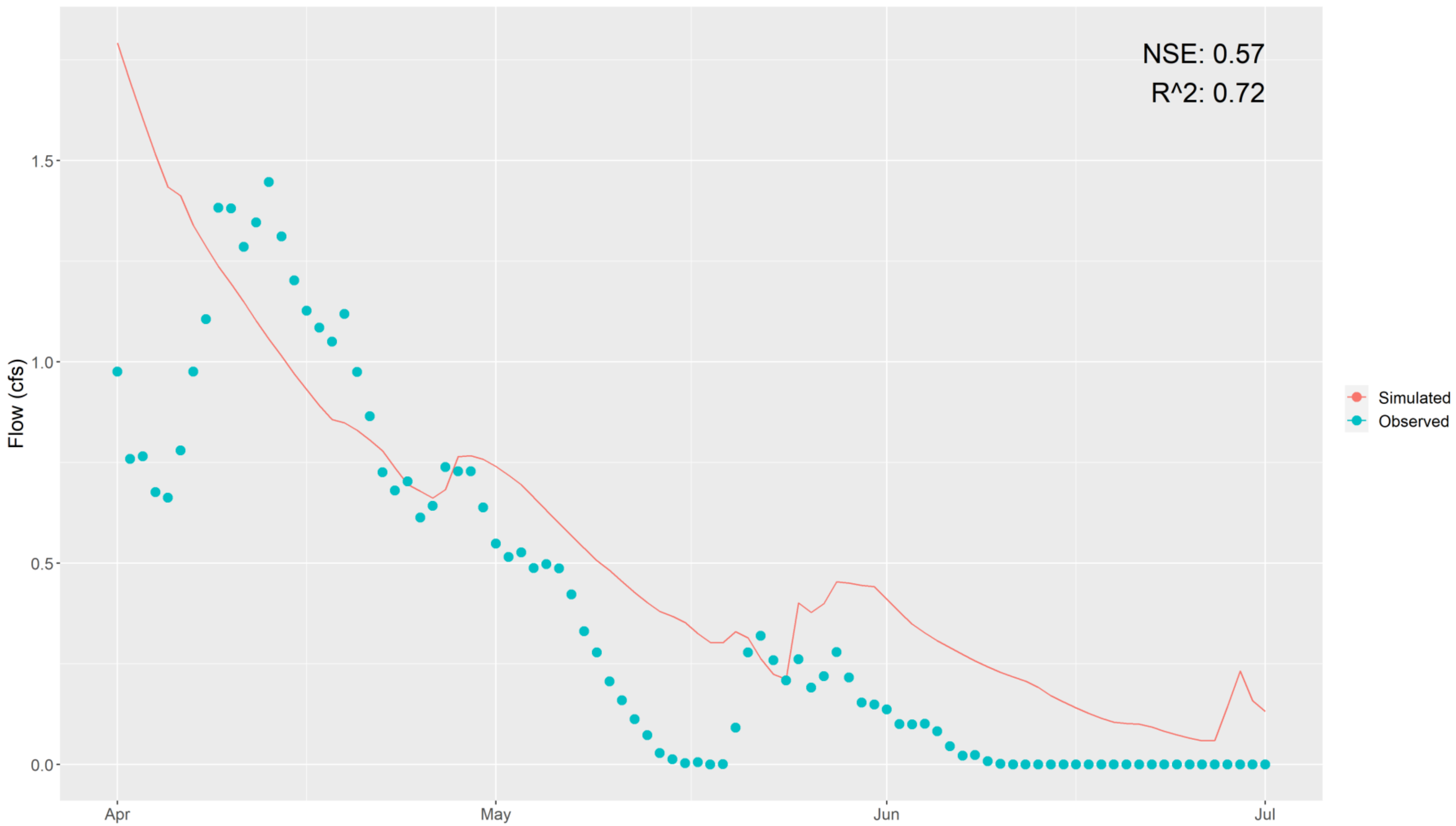
The validation for FL9 shows a poor fit between observed and simulated flow data. In early Spring, the model shows a peakier hydrograph than the observed data, but lower flows than observed for the rest of the modeling season. As discussed in the Shields Lake calibration section, one possible reason for this flow discrepancy between modeled and observed results is the higher Manning's roughness coefficient needed to properly simulate very shallow channel flows (sheet flow) relative to the roughness coefficient generally used for higher, deeper flows. PCSWMM does not allow utilizing multiple Manning's roughness coefficients during the same run, so the composite roughness coefficient entered for the entire channel cross-section was provably underestimated for shallow flows. Incorporating a higher roughness coefficient for shallow flows would result on a less pronounced slope on the receding part of the hydrograph in the model (see mid-April to May red line). Regardless, the total runoff volume shown in the model is only 58% of the observed, so the underestimation of the Manning's roughness coefficient for shallow flows is not the only reason for the poor validation results.

6.4.9. FL10



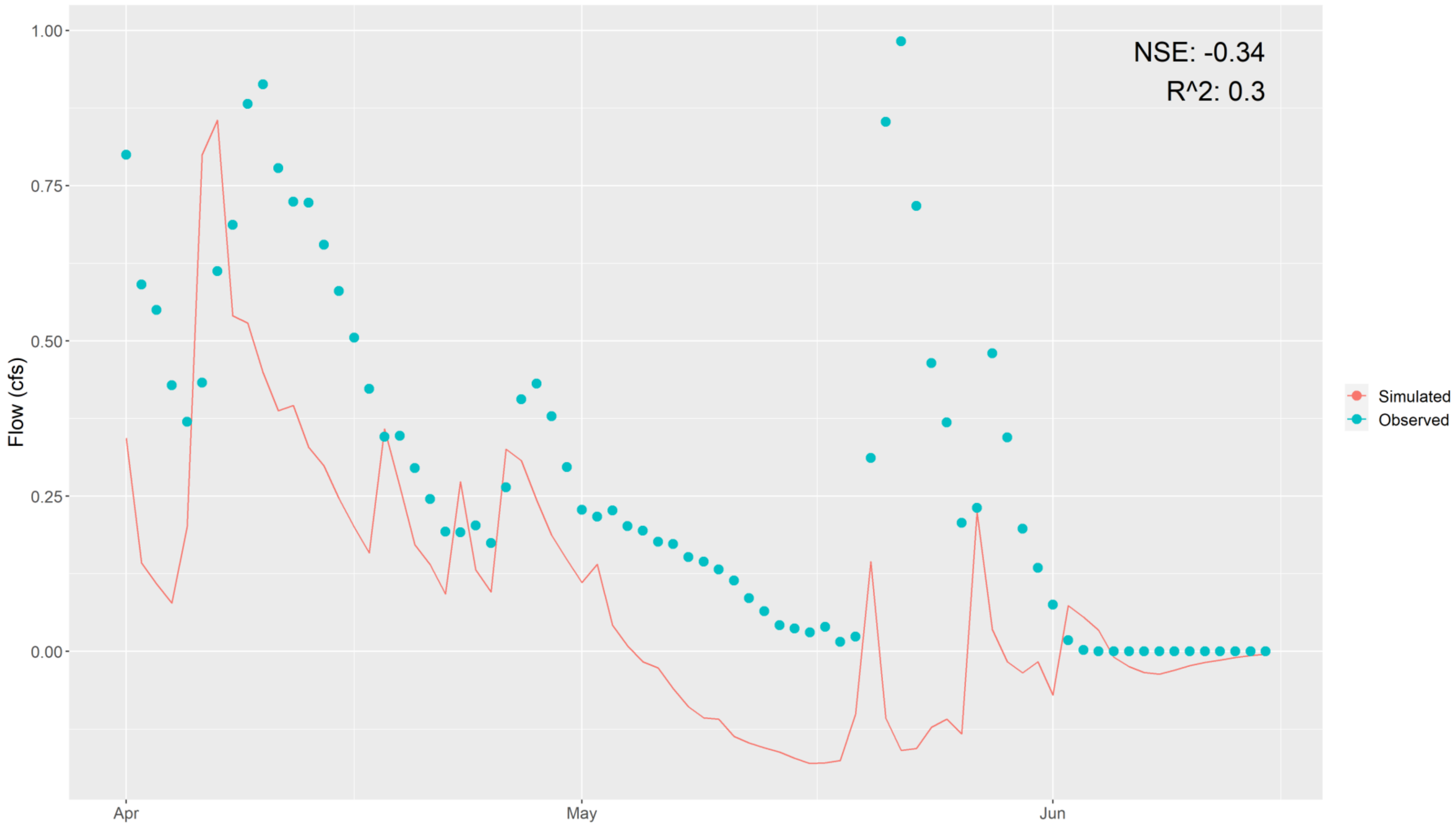
The FL10 monitoring station is located at the downstream end of the JD6 ditch system where the ditch crosses Scandia Trail N. No data was available for this monitoring station in 2016, so 2018 was used as a validation year with no adjustments made to the tributary catchments. Total runoff volume for the model was 92% of the observed volume.

6.4.10. FL17



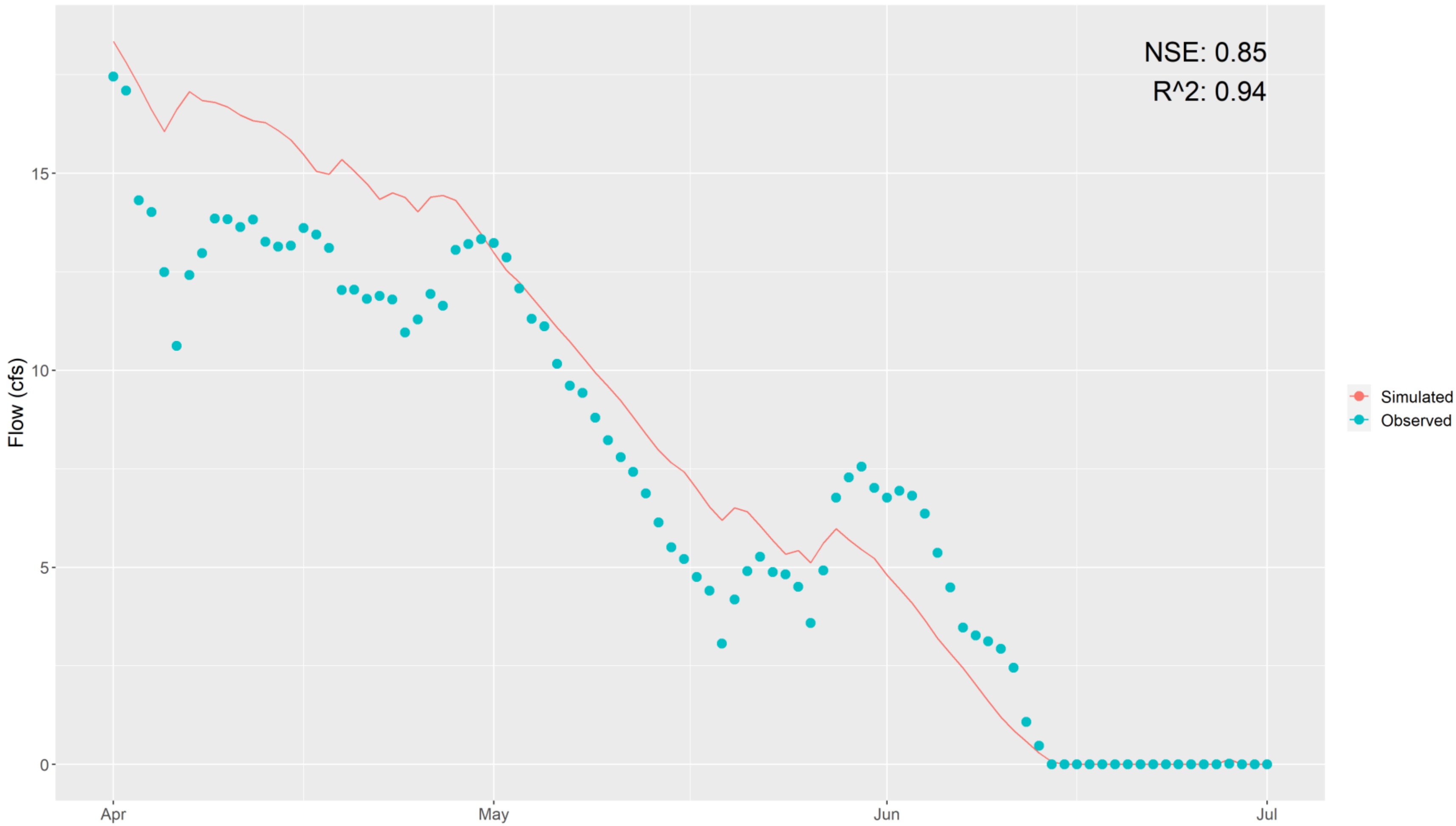
FL17 shows a good NSE value despite a poor fit of the observed data due to the general decrease in flow during 2021. The observed rise in flow in late April is likely due to snowmelt and isn't reflected in the model. Total runoff volume for the model was 140% of the observed volume.

6.4.11. FL18



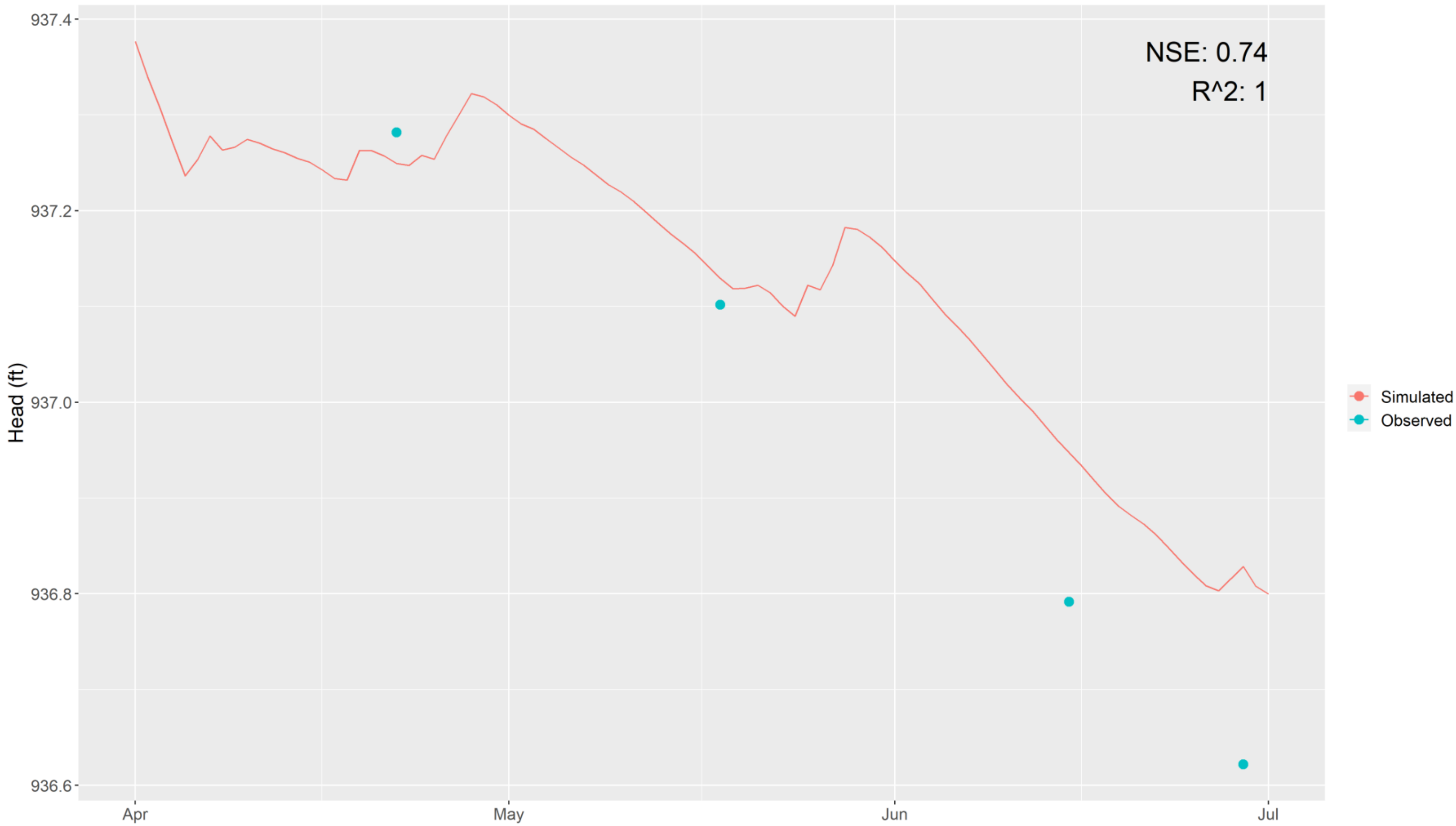
FL18 shows lower flows than observed flows. These differences are likely exaggerated due to the low peak flows in 2021. For the calibration year in 2016, peak flows were as high as 4 cfs, compared to 1 cfs for 2021. Total runoff volume for the model was 36% of the observed volume.

6.4.12. FL1



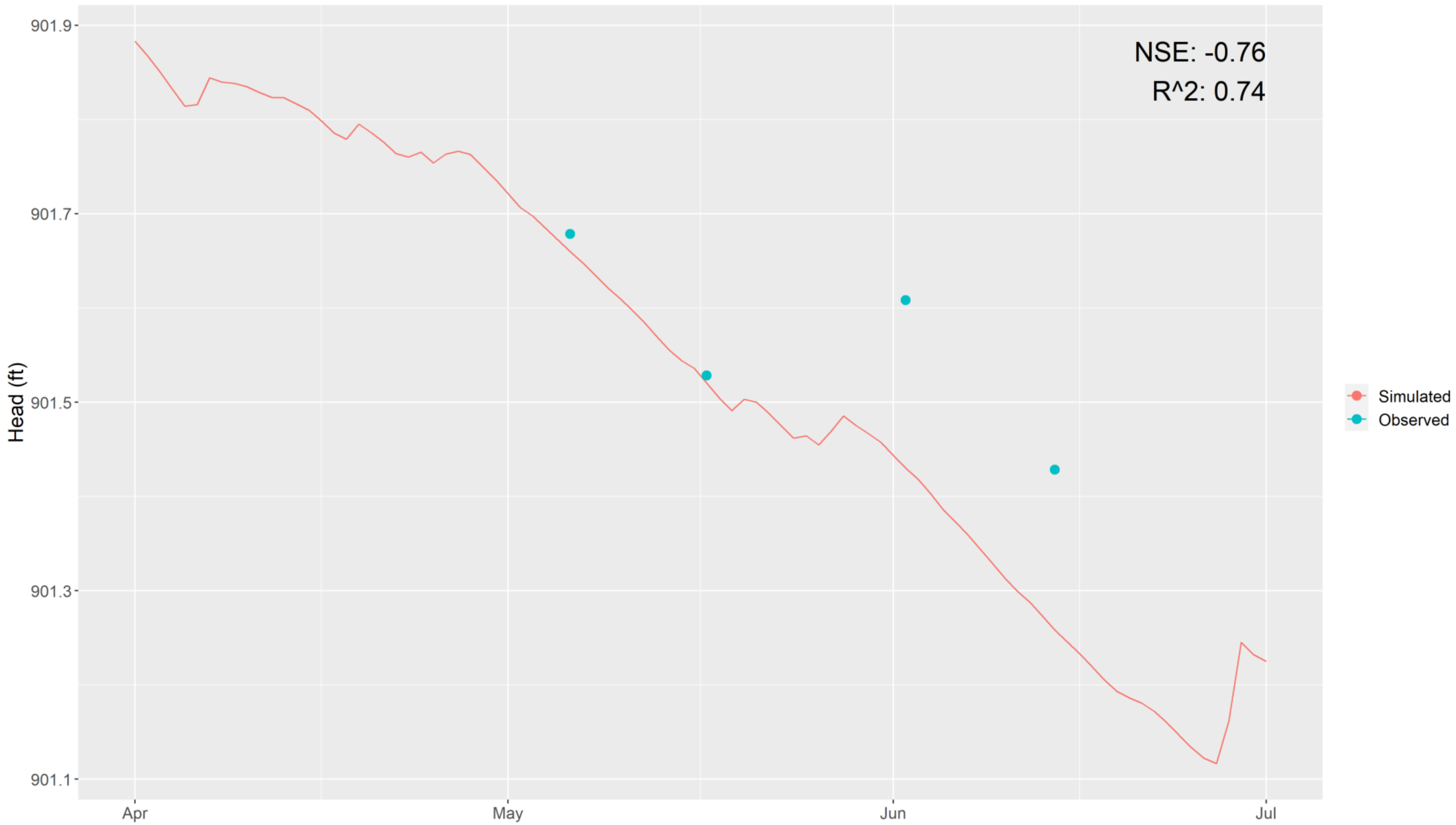
FL1 shows a good NSE value due to the general downward trend observed in 2021. Snowmelt and rainfall early in the year were not enough to maintain water levels on Forest Lake, so outflow from the lake is largely driven by channel capacity and lake levels. Total runoff volume for the model was 113% of the observed runoff volume.

6.4.13. Lake Keewahtin



Very few observed data points were available for Lake Keewahtin in 2021, but the modeled and observed water levels match fairly well with the maximum difference in elevation roughly 0.2 feet.

6.4.14. Forest Lake



Like Lake Keewahtin, only four observed data points were available for Forest Lake in 2021 and the maximum difference in elevation between observed lake water elevations and modeled elevations is roughly 0.2 feet.