TRANSCANADA HYDRO NORTHEAST INC.

ILP Study 4
Hydraulic Modeling Study

Study Report

In support of Federal Energy Regulatory Commission Relicensing of:

Wilder Hydroelectric Project (FERC Project No. 1892-026)
Bellows Falls Hydroelectric Project (FERC Project No. 1855-045)
Vernon Hydroelectric Project (FERC Project No. 1904-073)

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EXECUTIVE SUMMARY

The goal of this study was to develop a hydraulic model to simulate routing of river flow on the mainstem of the Connecticut River in support of Federal Energy Regulatory Commission (FERC) relicensing efforts by TransCanada Hydro Northeast Inc. (TransCanada) for the Wilder Hydroelectric Project (FERC Project No. 1892), Bellows Falls Hydroelectric Project (FERC No. 1855) and the Vernon Hydroelectric Project (FERC No. 1904). The study area includes the three project impoundments and associated downstream riverine sections. The model provides information in the form of rating curves to express the relationships between hydraulic variables such as flows, water surface elevations, and velocities for the study area and at locations of interest ("nodes" or "econodes") identified in other ILP studies. The results of the hydraulic model on its own and in conjunction with the Operations Modeling Study (Study 5) inform resource consultants regarding the effects of project operations on aquatic, terrestrial, and geologic resources.

Steps to develop the hydraulic model included calibration, validation, and a comparison of modeled to field-measured velocity. Calibration is a process to demonstrate that the simulated hydraulic model is a reasonable characterization of observed river conditions. The results of calibration demonstrate that the hydraulic model compares very favorably with the observed data. Validation performed as part of this study confirmed the suitability of the model for its intended use. The velocity comparison at seven locations similarly verified that the simulated velocities compare very well with the observed velocity data.

Two primary work products derive from this study: rating curves and lag time. The rating curves are being used by numerous other ILP studies (2, 3, 8, 9, 14, 15, 16, 21, 24, 25, 26, 27, 28, 29, 31, 32, and 33) to screen resources for potential project effects. Rating curves allow screening for potential project effects by comparing the resource critical flows and water surface elevations noted in the field with simulated flows and water surface elevations. For locations where project effects are unlikely, no further analysis of the resource would be warranted (i.e., project operations were identified as having no effect). Resources potentially affected by project operations would undergo further examination using the hydraulic model and/or the operations model (Study 5) to evaluate potential effects and to assess alternatives to mitigate project effects, as applicable. The rating curves developed in this study were also used by Study 5 for operations model refinement. The results of the screening, alternatives analysis, and operations model are discussed in other ILP study reports.

Lag time results were developed from the hydraulic model and provided to Study 5 to refine operations model routing. To develop lag time results, flow pulses were routed in the hydraulic model to calculate the time intervals between nodes of interest.

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List of Abbreviations

cfs	cubic feet per second
CRWC	Connecticut River Watershed Council
DEM	Digital elevation model
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Power Resources
ft	Feet or foot
ft/s	feet per second
FWS	U.S. Department of Interior, Fish and Wildlife Service
GEI	GEI Consultants, Inc.
GIS	geographic information system
HEC-RAS	Hydrologic Engineering Center River Analysis System
ILP	Integrated Licensing Process
LiDAR	Light Detection and Ranging
NAVD 88	North American Vertical Datum of 1988
NGS	National Geodetic Survey
NGVD 29	National Geodetic Vertical Datum of 1929
NHDES	New Hampshire Department of Environmental Services
NHFGD	New Hampshire Fish and Game Department
NRCS	Natural Resources Conservation Service
Normandeau	Normandeau Associates, Inc.
RSP	Revised Study Plan
SPD	Study Plan Determination
TNC	The Nature Conservancy
TransCanada	TransCanada Hydro Northeast Inc.
TU	Trout Unlimited
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geologic Survey
VANR	Vermont Agency of Natural Resources

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1.0 INTRODUCTION

This report presents the results of the Hydraulic Modeling Study (ILP Study 4) conducted in support of Federal Energy Regulatory Commission (FERC) relicensing efforts by TransCanada Hydro Northeast Inc. (TransCanada) for the Wilder Hydroelectric Project (FERC Project No. 1892), Bellows Falls Hydroelectric Project (FERC No. 1855) and the Vernon Hydroelectric Project (FERC No. 1904). TransCanada has initiated the Integrated Licensing Process (ILP) for these projects in order to extend the term of their operating licenses beyond the current expiration date of April 30, 2019 for each project.

In their study requests, the FERC, U.S. Department of the Interior-Fish and Wildlife Service (FWS), New Hampshire Department of Environmental Services (NHDES), New Hampshire Fish and Game Department (NHFGD), Vermont Agency of Natural Resources (VANR), Connecticut River Watershed Council (CRWC), The Nature Conservancy (TNC), and Trout Unlimited (TU) indicated an interest in understanding the effects on environmental resources of changing flows and water surface elevations at the Wilder, Bellows Falls, and Vernon Projects.

This study involved the development of a hydraulic model to simulate the routing of river flow and to derive the resulting hydraulic indices and parameters (in the form of rating curves) such as water surface elevations, velocities, and flows across the study area and at locations of interest ("nodes" or "econodes") identified in other ILP studies. The results of the hydraulic model on its own and in conjunction with the Operations Modeling Study (Study 5) inform resource consultants regarding the effects of project operations on aquatic, terrestrial, and geologic resources.

The Revised Study Plan (RSP) for this study was modified by FERC in its September 13, 2013 Study Plan Determination (SPD) with the following specific changes:

- Consult with NHDES and FWS, (and presumably with VANR) to establish a process and schedule for selecting the appropriate number and locations of velocity transects, and the appropriate range of calibration flows, and file that information with FERC by December 12, 2013. TransCanada requested, and FERC subsequently approved, an extension of time for that filing.

- File a modified study plan that details the process for selection of velocity transects and calibration flows in consultation with the agencies.

TransCanada filed the modified study plan on March 28, 2014. On April 9, 2014 FERC issued a letter approving the modified study plan.

2.0 STUDY GOALS AND OBJECTIVES

The goal of this study was to develop a hydraulic model that would simulate routing of river flow on the mainstem of the Connecticut River for the three project impoundments (Wilder, Bellows Falls, and Vernon) and associated riverine sections downstream of each project dam. The model was used to derive hydraulic indices and parameters such as water surface elevations, velocities, and flows across the study area and at locations of interest identified in other ILP studies.

The objectives of this study were to:

- Develop rating curves to provide information about the relationships between hydraulic variables such as water levels and flows throughout the project impoundments and affected downstream reaches; and

- Provide information regarding specific relationships at econodes of interest to the Operations Modeling Study (Study 5). The study requests also identified an interest in understanding how operations at the three TransCanada projects affect operations of the FirstLight projects (Northfield Mountain Pumped Storage [FERC No. 2485] and Turners Falls [FERC No. 1889]), which is beyond the scope of TransCanada's hydraulic and operations models and is the responsibility of FirstLight to develop that determination. TransCanada provided FirstLight with information in the form of outflow at Vernon dam. This information will serve as the upstream inflow in the model FirstLight develops to assess the effect of its operations on resources of interest at the FirstLight projects.

3.0 STUDY AREA

The study area includes three TransCanada project impoundments on the mainstem of the Connecticut River (Wilder, Bellows Falls, and Vernon) and associated downstream riverine sections (Figure 3-1). The hydraulic model extends from McIndoes dam (FERC No. 2077) downstream to Turners Falls dam. Turners Falls dam, owned and operated by FirstLight, was included in the hydraulic model to account for potential effects of the Turners Falls Project and Northfield Mountain Pump Storage Project on the riverine section associated with TransCanada's Vernon Project.

Within the hydraulic model study area are model reaches developed to represent the impounded and riverine segments of the Wilder, Bellows Falls, and Vernon projects. The impoundment associated with Wilder extends approximately 45 miles upstream of Wilder dam and the impoundments associated with the Bellows Falls and Vernon dams are each approximately 26 miles long. Riverine segments consist of an approximate 17-mile segment downstream of Wilder dam, an approximate 6-mile segment downstream of Bellows Falls dam, the approximately 3,500-foot long Bellows Falls bypassed reach, and an approximate 1.5-mile segment downstream of Vernon dam.

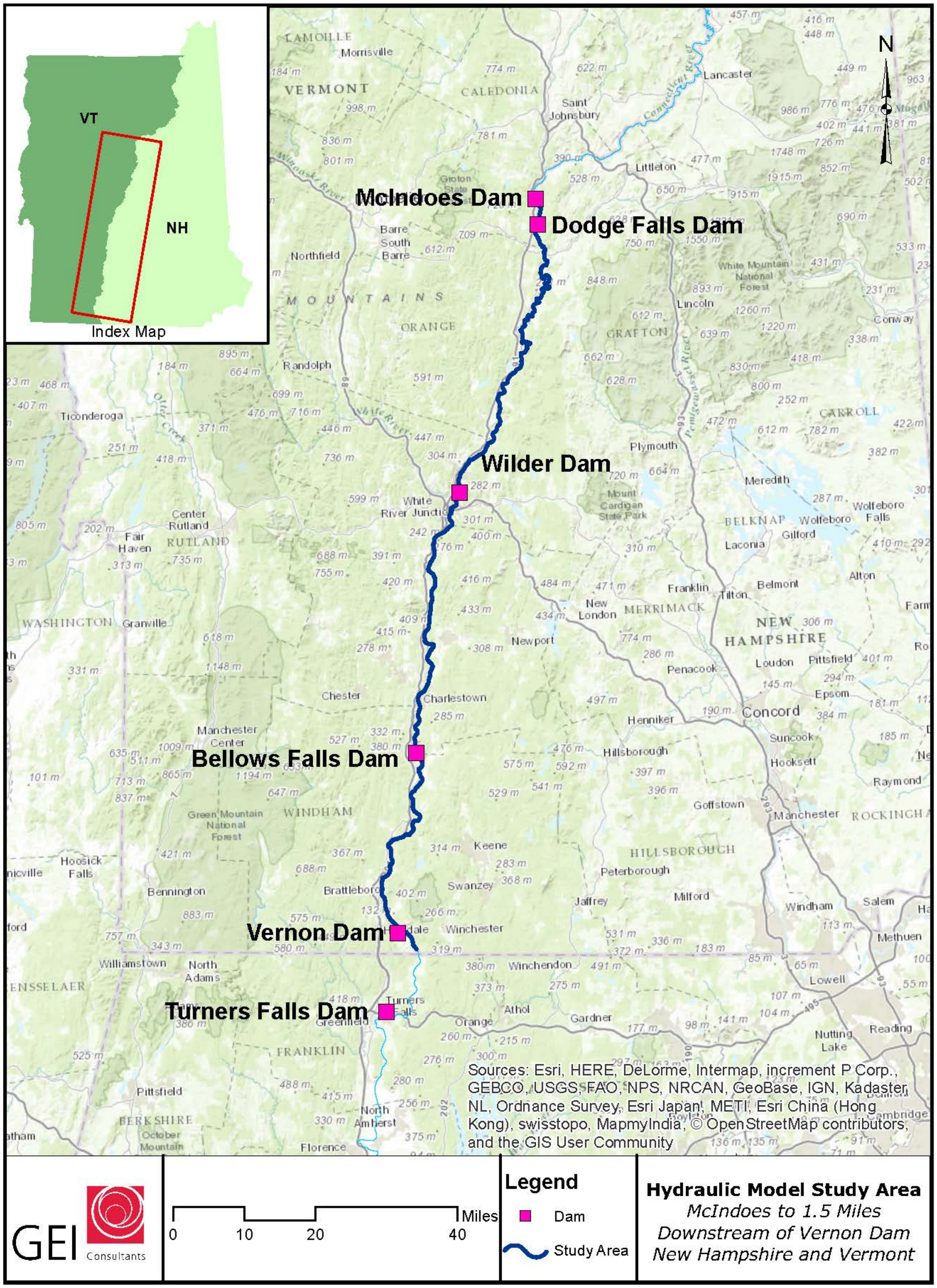

Figure 3-1. Hydraulic model study area.

4.0 METHODS

The hydraulic model simulates routing of river flow along the mainstem of the Connecticut River from McIndoes dam to about 1.5 miles downstream of Vernon dam. River flow routing includes the three project impoundments (Wilder, Bellows Falls, and Vernon) and the associated downstream riverine sections. This model was used to develop relationships between water levels and flows throughout the project impoundments and downstream reaches.

Sections 4.1, 4.2, and 4.3 describe the steps undertaken to set the model up and demonstrate that the model is a reasonable characterization of observed river conditions. Section 4.1 presents the steps involved in the hydraulic model setup. Section 4.2 contains model calibration methods along with a summary comparison of simulated and observed river conditions. Section 4.2 also contains a summary of validation methods to substantiate the suitability of the model for its intended use. Section 4.3 includes a comparison of velocities measured in the field with velocities computed by the hydraulic model.

Sections 4.4, 4.5 and 4.6 present the methods involved in running the hydraulic model to develop results for use by other ILP studies. Section 4.4 presents the methods used to develop lag time estimates for the operations model (Study 5). Section 4.5 presents information on sub-hourly flow and elevation rate-of-change model inputs used to develop information for Studies 3, 8, and 9. Section 4.6 includes methods used to develop rating curves for other ILP studies.

4.1 Hydraulic Model Setup

The hydraulic model was developed using U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center - River Analysis System (HEC-RAS) software Version 4.1.0 (USACE, 2010a) with geographic information system (GIS) based cross sections. The USACE designed the HEC-RAS software program to perform 1-dimensional hydraulic calculations for natural and human-made channels. HEC-RAS is widely used and accepted by the engineering community and regulatory agencies. The model is standard for USACE projects; FEMA has accepted HEC-RAS for performing national flood insurance studies; the Natural Resources Conservation Service (NRCS) has adopted HEC-RAS as its main river hydraulics model; the Federal Highway Administration has accepted it for use on hydraulics studies; and many state and local agencies across the country have adopted the use of HEC-RAS.

HEC-RAS model setup requires the designation of a vertical datum for each project and input of parameters to characterize the physical channel and flow conditions for hydraulic modeling as described in more detail in the following sub-sections.

4.1.1 Vertical Datum

The North American Vertical Datum of 1988 (NAVD 88) is the reference datum for elevations in this study. The topographic data developed from the Light Detection and Ranging (LiDAR) and bathymetric surveys provided by U.S. Imaging and

Normandeau Associates (Normandeau), respectively, were in NAVD 88. Similarly, level logger data provided from Study 2 (Riverbank Transect Study) and Study 7 (Aquatic Habitat Mapping Study) were in NAVD 88.

Several data sources were provided in National Geodetic Vertical Datum of 1929 (NGVD 29) including TransCanada impoundment water surface elevations, Hatch hourly headpond levels, and USGS stream gage water surface elevations. Information provided by FirstLight for the reach from Vernon dam to Turners Falls dam were also in NGVD 29 including the bathymetry, water level logger data, and impoundment water surface elevations upstream of the Turners Falls dam.

For this study, NGVD 29 was converted to NAVD 88 by subtracting 0.4 ft from NGVD 29 elevation data based on the online height conversion tool VERTCON developed by the National Geodetic Survey (NGS, 1994). As an example, a water surface elevation at Wilder impoundment of 385.0 ft NGVD 29 converts to approximately 384.6 ft NAVD 88.

4.1.2 Cross Sections

Cross sections were input to the hydraulic model to characterize the Connecticut River channel geometry for flow routing. Cross sections were developed using the digital elevation model (DEM) provided by Normandeau. Normandeau developed the DEM from high resolution LiDAR data acquired by U.S. Imaging between April 26 and May 8, 2013 (U.S. Imaging, 2013) and bathymetry data acquired by Normandeau from July through September 2013 (Normandeau Associates, 2015b). Downstream of Vernon dam, channel geometry was developed from bathymetry data provided by FirstLight within the Connecticut River channel and the U.S. Imaging LiDAR outside the river channel. Bathymetry refers to the topography of land in the river channel beneath the water surface.

LiDAR survey data acquisition was initiated in 2013 and conducted by U.S. Imaging, Inc. Surveys. The LiDAR survey was performed from April 6 through May 8, 2013, over an approximately 1-mile-wide swath that was centered on the study reach of the Connecticut River. To perform the LiDAR survey, the river system was flown for 34.2 hours at a height of approximately 1,066 meters above ground level and at a speed of 120 knots traveling from south to north. The LiDAR system settings and flight parameters yielded a density of 3.8 points per square meter on a single flight line with 35 percent overlap for a resulting density of about 5 points per square meter.

The LiDAR data acquisition performed for TransCanada provided a highly detailed representation of the land surface elevations but did not record elevations beneath the water surface. The river channel beneath the water surface was characterized based on bathymetric data provided by Normandeau in the TransCanada project impoundments and based on bathymetric data provided by FirstLight for the Turners Falls impoundment.

Normandeau collected bathymetry survey data by boat between the dates of July 8 through July 25, 2013 in Vernon impoundment, July 26 through August 2, 2013 in

Bellows Falls impoundment and August 7 through September 5, 2013 in Wilder impoundment. Additional bathymetric data was collected by Normandeau on foot from shallow water tributary and backwater confluence areas during September 2013 within all three project impoundments. A more detailed description of the Normandeau bathymetry survey is provided in the ILP Study 7 Final Report (Normandeau Associates, 2015a).

Information about the FirstLight bathymetric data is provided in FirstLight Relicensing Study 3.2.2, Hydraulic Study of Turners Falls Impoundment, Bypass Reach and Below Cabot (Gomez and Sullivan, March 2015).

To characterize the Connecticut River, 1,207 cross section locations were selected using the Environmental Systems Research Institute (ESRI) Geographic Information System (ArcGIS) Version 10.1 (ESRI, 2012), HEC-GeoRAS Version 10 (USACE, 2013), and the digital elevation models created from the LiDAR and bathymetry data. Cross section locations were primarily based on river morphology and were placed to capture changes in channel and floodplain width, slope, storage and ineffective flow areas.

To address gaps in available river channel elevation data in riverine areas due to high velocity flows, shallow water, and other access and safety issues encountered during the 2013 surveys, additional bathymetry and transect data were provided by Normandeau and Field Geology Services as part of surveys performed for Studies 2, 7, and 9 (Instream Flow Study). Additional data collection included 92 transect locations in Wilder, Bellows Falls, and Vernon riverine segments. Normandeau also provided bathymetric data in the vicinity of Johnston Island, Sumner Falls, Chase Island, and the Bellows Falls bypassed reach. The hydraulic model also includes river channel data provided by the USGS for gage 01138500 CONNECTICUT RIVER AT WELLS RIVER, VT.

4.1.3 Manning's n-values

Manning's n-value is a roughness coefficient used in hydraulic equations to account for energy loss in an open channel (i.e., river, stream, or canal). In general, energy loss in a river can be due to friction, contraction, and expansion. Friction energy loss in particular can be due to the channel shape, and channel bank and bottom material (sand, gravel, boulders, vegetation, debris, etc.) as well as the amount, depth, velocity, and sinuosity of the flow in a channel. Manning's n-value is applied in the hydraulic equations to account for friction losses. A lower n-value represents a more efficient channel (less friction losses). A higher n-value represents greater friction losses.

Estimation of Manning's n-value is subjective and requires engineering judgement due to its empirical nature (based on observation or experiment). Manning's n-value is best quantified when compared with observed water level and flow data rather than solely relying on technical references, although such references provide a reasonable starting point for parameter estimation.

This study included a review of Manning's n-values published in readily available references such as the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for towns and counties along the Connecticut River in Vermont and New Hampshire (FEMA, 2008) and standard hydraulic and hydrologic references (Chow, 1959; Barnes, 1967). Manning's n-values contained in the references reviewed for this study ranged from 0.02 to 0.10 for the Connecticut River Channel and 0.01 to 0.17 in the overbanks of the Connecticut River. To put these values in perspective, a Manning's n-value of 0.02 is indicative of a clean, straight channel with no rifts, large boulders or deep pools. An n-value of 0.10 in a river channel is indicative of a reach with large boulders or dense brush in the channel. Similarly, an overbank value of 0.06 suggests pasture and light brush along a river's edge and an overbank value of 0.17 indicates a heavy stand of timber with river flow through thick, dense tree branches. Appendix A contains a summary of Manning's n-values reviewed from these data sources (FEMA, multiple).

Manning's n-values were initially entered based on these references and engineering judgement during model setup and adjusted during calibration based on a comparison of simulated and observed data to optimize the model's replication of observed data.

The Manning's n-values in the hydraulic model ranged from 0.025 to 0.048 for the channel with an average value of 0.030. For the overbanks, the Manning's n-values were set to 0.060. The flows generally remained in the channel of the Connecticut River for the hydraulic simulations performed for this study. These Manning's n-values are within the ranges referenced for the Connecticut River in Vermont and New Hampshire (FEMA, multiple).

4.1.4 Expansion and Contraction Coefficients

Contraction and expansion of flow occurs when water is forced into and out of constrictions causing the water to speed up, slow down, or flow in rapidly varying directions and speeds. Sudden changes in velocity at such constrictions result in energy losses. The HEC-RAS program computes energy losses as part of the internal flow calculations and allows for the input of expansion and contraction coefficients for each model cross section. Coefficients of contraction and expansion of 0.1 and 0.3, respectively, were assigned to cross sections for this study. These values, the model defaults, are appropriate for the flow conditions observed in the Connecticut River.

4.1.5 Boundary Conditions

The HEC-RAS model requires boundary conditions to perform hydraulic routing calculations. A river system characterized by subcritical flows requires input of downstream boundary conditions and supercritical flows require the input of upstream boundary conditions. For mixed flow, the condition selected for calibration and verification of the hydraulic model, the input of both upstream and downstream boundary conditions is required.

The fundamental hydraulic equations that govern the type of 1-dimensional flow analysis performed for this study include the continuity equation, energy equation and flow resistance equation. For the energy equation, the total energy at any point along a river channel is a function of the river bed elevation, the flow depth, and the velocity.

Generally, subcritical flow conditions occur in rivers with slower velocities and supercritical flow conditions occur in rivers with faster velocities. These flow conditions can be observed by tossing a pebble into a river: concentric rings that move both upstream and downstream from the pebble indicate subcritical flow. Rings that progress only downstream indicate supercritical flow. “Mixed flow” simply means that the flow conditions can fluctuate between subcritical and supercritical. Model analysis for this study indicates that the Connecticut River exhibits subcritical flow conditions along the study area. When mixed flow is selected, the model produces the same results.

The modeling for this study was performed across four individual project reaches with dams representing the upstream and downstream boundary of each individual reach. This allowed development of downstream boundary conditions based on actual observed hourly impoundment water surface elevations just upstream of the dams and upstream boundary conditions based on outflows from the projects. Individual reaches modeled as part of this study are as follows:

M_W	McIndoes dam to Wilder dam
W_B	Wilder dam to Bellows Falls dam
B_V	Bellows Falls dam to Vernon dam
V_T	Vernon dam to Turners Falls dam

The water surface elevations at Wilder, Bellows Falls, and Vernon impoundments (just upstream of the dams) were input as the downstream boundary condition based on hourly elevations for 2013 and 2014 provided by TransCanada. Upstream flows entering the model were input based on hourly project discharges in 2013, 2014, and 2015 provided by TransCanada for McIndoes, Wilder, Bellows Falls, and Vernon projects. The impoundment water surface elevations and project flows provided by TransCanada include a range of impoundment elevations and project discharges in accordance with conditions established in the current FERC licenses.

The reach from Vernon dam to Turners Falls dam relied on water surface elevations provided by FirstLight for Turners Falls dam to establish the downstream boundary condition for that reach.

4.1.6 Model Flows

The model flow inputs included hourly project discharge data (upstream boundary conditions) and tributary inflows during 2013, 2014, and 2015. Model flow data was compiled as part of this study to perform model calibration and validation. A more detailed report on hydrology was developed as part of Study 5.

In addition to the model inflows input as boundary conditions from the hourly project discharge data, tributary inflows for model calibration were input along the Connecticut River from readily available data sources. Table 4.1 below summarizes tributary inflow data compilation.

Table 4-1. Dams, gages, and tributary locations.

Location	HEC-RAS River Station	HEC-RAS Node	Description
Mainstem - MCINDOES DAM	135.222	1335	McIndoes Dam, TransCanada
Mainstem – USGS Gage	126.603	1251	USGS gage 01138500
Tributary - Wells River, VT	126.567	1250	USGS gage 01139000
Tributary - Waits River, VT	107.991	1126	Bradford Dam, Green Mountain Power
Tributary - Ompompanoosuc, VT	85.554	955	Union Dam, USACE
Mainstem - WILDER DAM	77.731	870	Wilder Dam, TransCanada
Tributary - White River, VT	76.364	853	USGS gage 01144000
Tributary - Mascoma River, NH	75.004	844	Mascoma Lake Dam, NHDES
Tributary - Ottauquechee River, VT	71.012	803	USGS gage 01151500
Tributary - Sugar River, NH	56.299	667	USGS gage 01152500
Tributary - Black River, VT	44.089	571	North Springfield Dam, USACE
Tributary - Williams River, VT	37.636	534	USGS gage 01153550
Mainstem - BELLOWS FALLS DAM	34.772	512	Bellows Falls Dam, TransCanada
Canal - Bellows Falls Powerhouse	34.120	499	Powerhouse
Tributary - Saxton River, VT	33.583	490	USGS gage 01154000
Tributary – Cold River, NH	33.033	480	Based on Sugar River flows
Tributary - West River, VT	9.919	186	Townshend Dam, USACE
Mainstem - VERNON DAM	2.442	46	Vernon Dam, TransCanada
Tributary - Ashuelot River, NH	17.933	111	USGS gage 01161000
Tributary – Millers River, MA	3.845	19	USGS gage 01166500

The input of tributary inflows for model calibration followed a hierarchical framework with first priority given to the USGS gage data closest to the Connecticut River. The timing of the USGS gage data (15-minute intervals) was maintained in the HEC-RAS input for these tributary inflows. After flows were input from USGS gages, remaining tributaries were evaluated for available discharge records at existing dams closest to the confluence with the Connecticut River. Dam discharge data were input based on the timing provided by the data sources, which was typically based on hourly increments. Finally, inflow for tributaries without USGS gages or dam discharge records (less than 10% of watershed area as indicated in Table 4-2 below) was accounted for based on an evaluation of the hydraulic model volume (flow x time) compared to the volume calculated from TransCanada discharge data at each dam. Lateral inflow, flow entering the river from sources other than major tributaries such as from smaller tributaries, overland flow, and groundwater discharge to the river, was input to each model reach to balance the total inflow and outflow volume over the calibration period.

This study diverged from the original study plan in the use of flow data at the TransCanada dams and USGS gages in 2013, 2014, and 2015, rather than using the hydrology data set developed through operations model back routing as described in the study plan. The dam and gage flow data were selected as inputs to the hydraulic model because the data were recorded during the same time period and under similar increment (sub-daily) as the level logger data used in model calibration and validation. This variation to the study plan was communicated with stakeholders during the ILP Study 4 Modeling Consultation call on July 20, 2015.

Model calibration results, presented in Section 5.0 of this report, indicate this approach to model hydrology is reasonable and acceptable. Furthermore, sensitivity analysis of the ungaged tributary inflows indicates a negligible impact of ungaged tributary flow on model calibration due to the small flow contribution from ungaged tributaries compared to recorded flows for gaged drainage areas at dams, mainstem gages, and larger tributary gages. Table 4-2 presents the percent of drainage area accounted for by gaged flow data for the river reaches modeled.

Table 4-2. Gaged drainage areas.

Location	Drainage area (sq mi)	Gaged Drainage Area (%)
WILDER DAM	3375	90%
BELLOWS FALLS DAM	5414	92%
VERNON DAM	6266	94%
TURNERS FALLS DAM	7163	99%

Figures 4-1 through 4-4 present the gaged drainage areas and show the portions of the drainage areas that are ungaged for each reach.

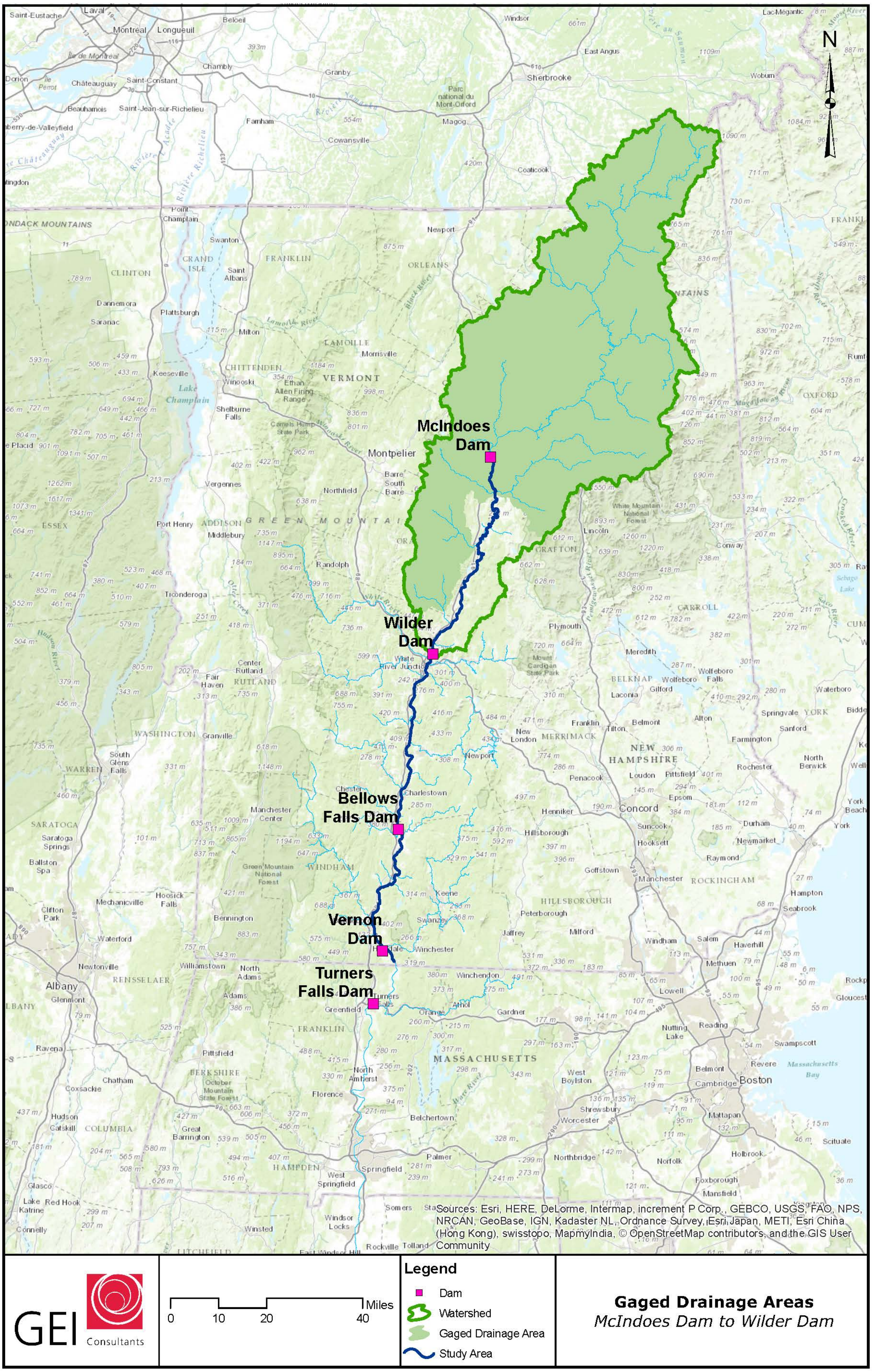

Figure 4-1. Gaged drainage areas – McIndoes dam to Wilder dam.

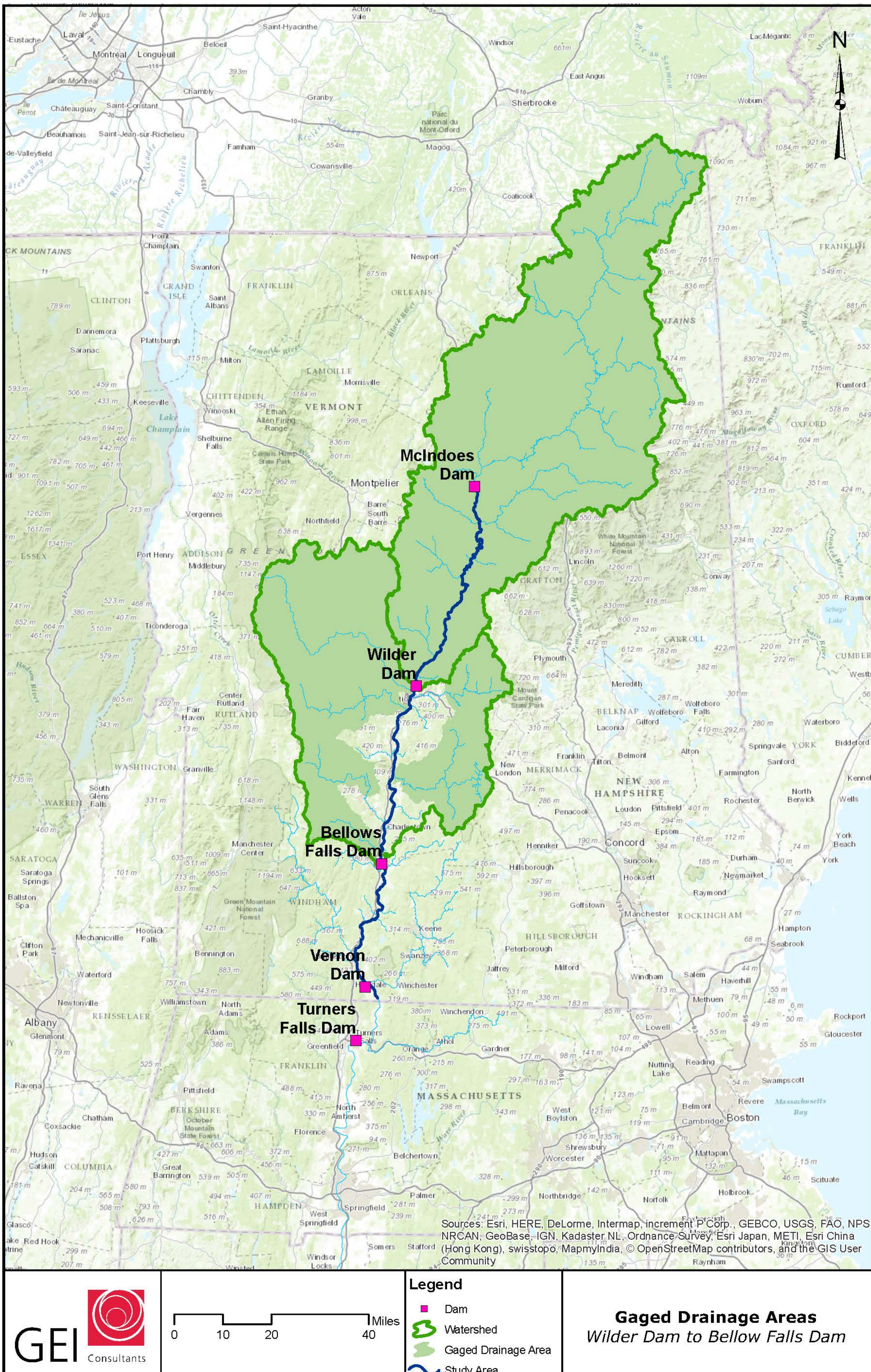

Figure 4-2. Gaged drainage areas –Wilder dam to Bellows Falls dam.

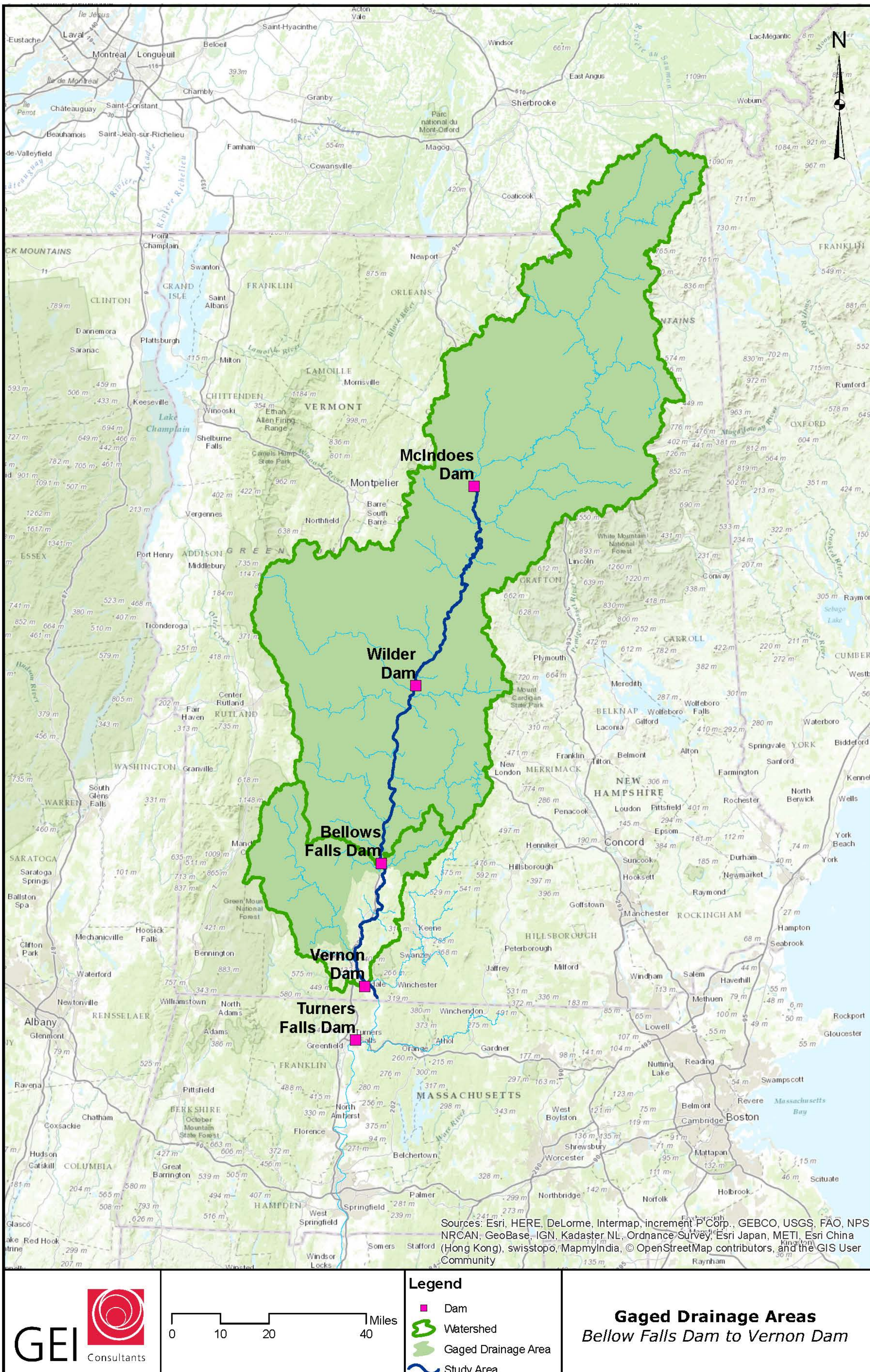

Figure 4-3. Gaged drainage areas – Bellows Falls dam to Vernon dam.

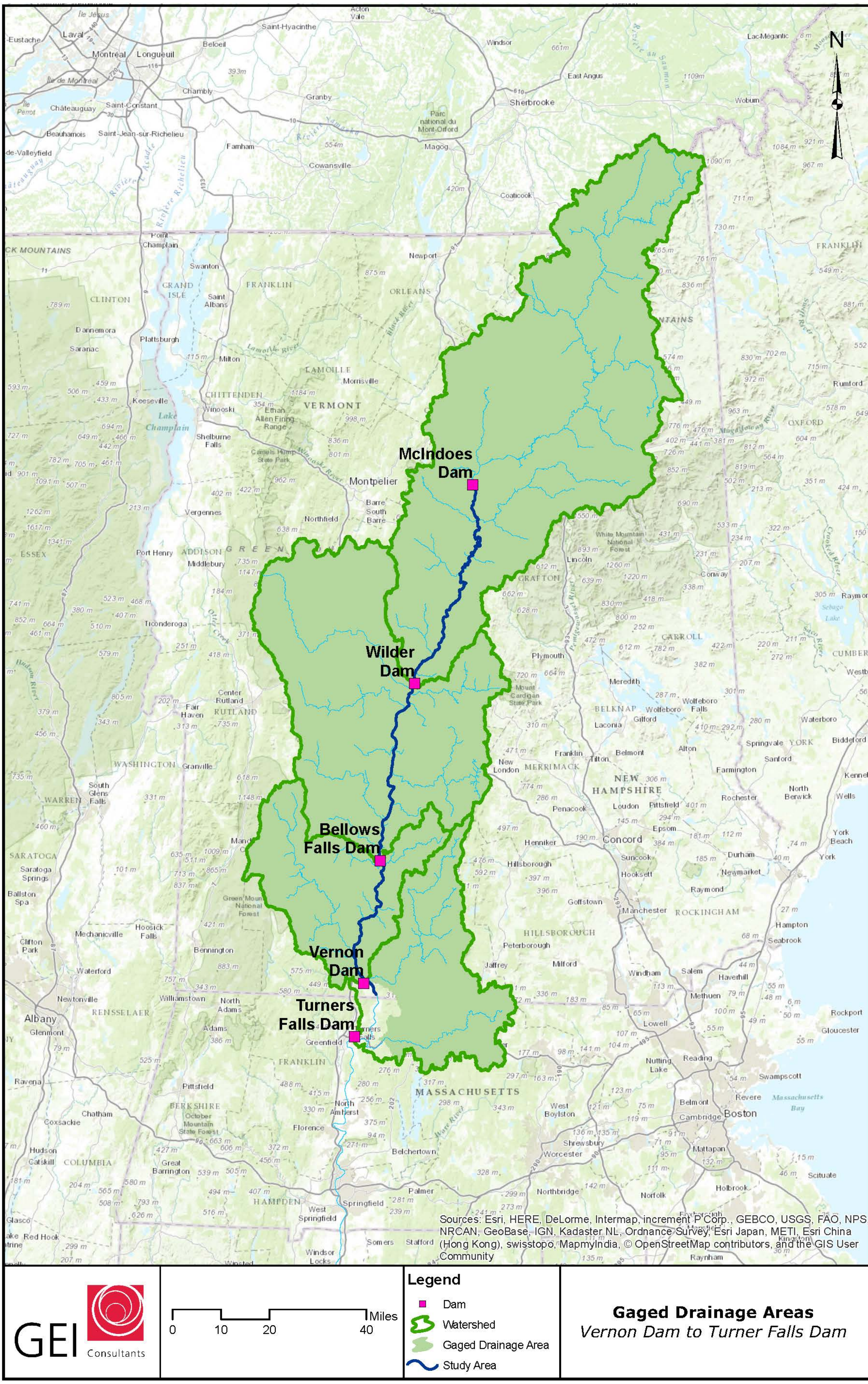

Figure 4-4. Gaged drainage areas – Vernon dam to Turner Falls dam.

4.1.7 Bridges

The hydraulic model did not explicitly evaluate the hydraulic effects of bridge crossings. The LiDAR data represents the earthen terrain in the vicinity of bridges in detail. The flows and water surface elevations simulated in the hydraulic model are generally within the river channel and therefore would not be affected by bridge abutments. Furthermore, the bridges were likely designed to pass at least the 100-year flow event without significant hydraulic impacts.

4.2 Hydraulic Model Calibration and Validation

Hydraulic model calibration is a process to demonstrate that the model is a reasonable characterization of observed river conditions. The process involves comparing simulated model results with observed conditions and refining inputs to optimize the model's replication of observed data.

Model calibration was performed from a comparison with USGS gage rating curves (elevation vs flow) for observed and simulated conditions, and using time series of water surface elevation data (elevation vs time) from data recorded at active USGS gages, level loggers deployed in 2014 for Study 2, and level logger data available from FirstLight. Gage and level logger information is summarized in the tables below. The location of USGS gages, Study 2 level loggers, and FirstLight level loggers are shown in Figure 4-5a and b.

Table 4-3. Connecticut River USGS gage information.

USGS Station	HEC-RAS River Station	HEC-RAS Node
USGS 01138500 CONNECTICUT RIVER AT WELLS RIVER, VT	126.603	1251
USGS 01144500 CONNECTICUT RIVER AT WEST LEBANON, NH	75.962	849
USGS 01154500 CONNECTICUT RIVER AT NORTH WALPOLE, NH	33.583	490

Table 4-4. TransCanada Study 2 level loggers.

Study 2 Logger ID	HEC-RAS River Station	HEC-RAS Node	Reach Description
02-W02	113.468	1166	Wilder impoundment
02-W03	110.171	1143	Wilder impoundment
02-W07	96.907	1040	Wilder impoundment
02-W09	91.611	999	Wilder impoundment
02-W10	89.809	985	Wilder impoundment
02-W12	81.919	919	Wilder impoundment

Study 2 Logger ID	HEC-RAS River Station	HEC-RAS Node	Reach Description
02-WR01	77.415	864	Wilder impoundment
02-WR-05	71.012	801	Wilder riverine
02-WR-08	62.963	730	Wilder riverine
02-WR09	60.380	703	Bellows impoundment
02-B01	58.717	686	Bellows impoundment
02-B03	52.634	632	Bellows impoundment
02-B07	41.168	552	Bellows impoundment
02-B09	35.959	523	Bellows impoundment
02-BR01	33.976	496	Bellows riverine
02-BR05	31.165	460	Vernon impoundment
02-V02	21.658	377	Vernon impoundment
02-V03	21.300	373	Vernon impoundment
02-V06	10.236	194	Vernon impoundment
02-VR01	VR19.925	VR148	Vernon riverine
02-VR02	VR18.914	VR123	Vernon riverine

Table 4-5. FirstLight level loggers.

FirstLight Logger ID	HEC-RAS River Station	HEC-RAS Node	Description
US Stebbins	19.500	135	Just upstream Stebbins Island (same as logger 73)
DS Stebbins	17.724	108	Just downstream Stebbins Island
Stateline	13.766	80	MA and VT/NH Stateline
DS Pauchaug	13.259	76	Just downstream confluence of Pauchaug Brook
Rt. 10 Br	10.965	61	Route 10 Bridge
US Northfield Tailrace	7.477	39	Upstream of Northfield Tailrace
NF Tailrace GSE	5.237	27	Northfield Tailrace
FrenchK	2.978	13	Downstream French King Gorge
TF Dam	0.000	1	Upstream Turners Falls dam

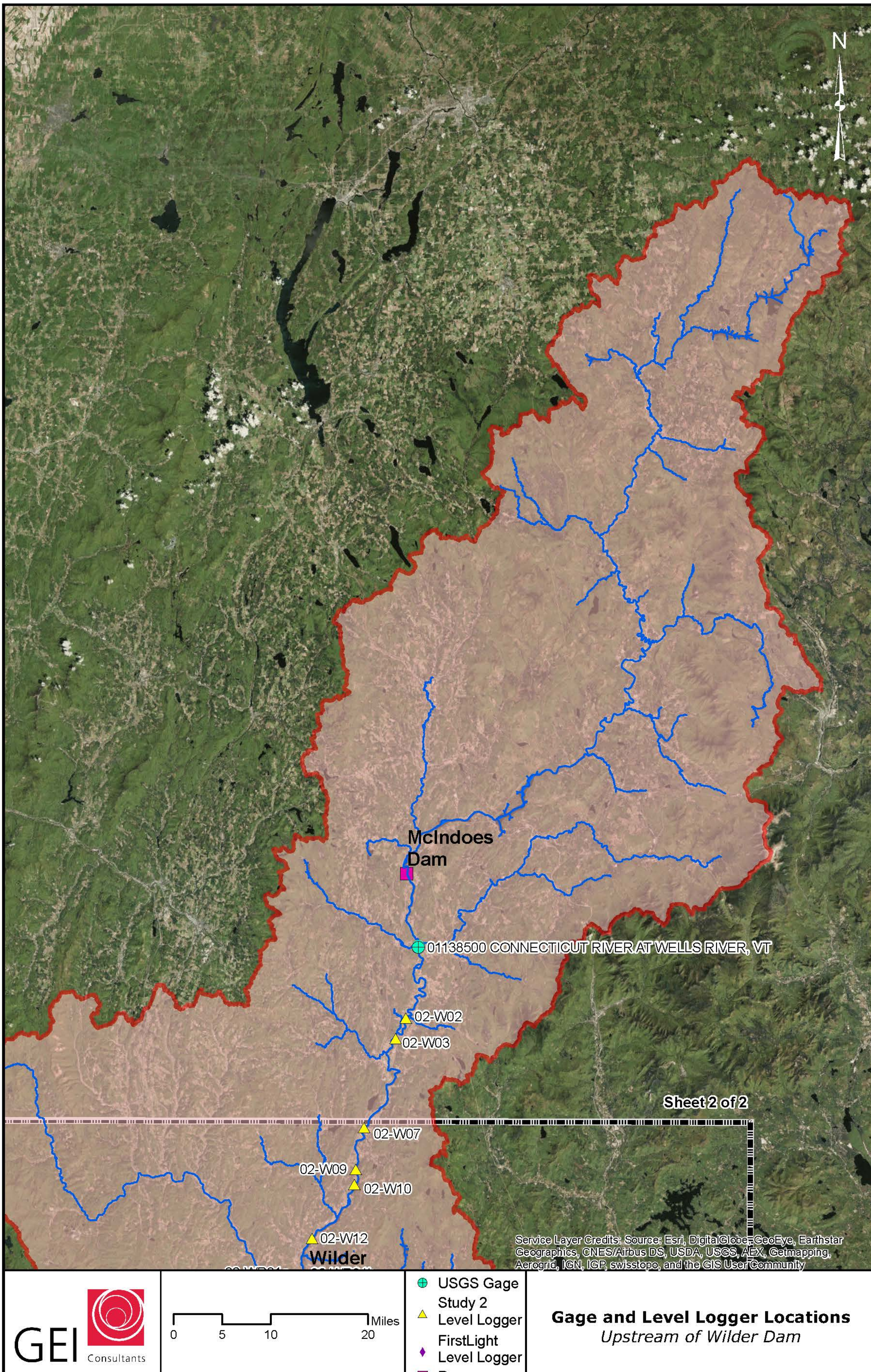

Figure 4-5a. Gage and level logger locations – upstream of Wilder dam.

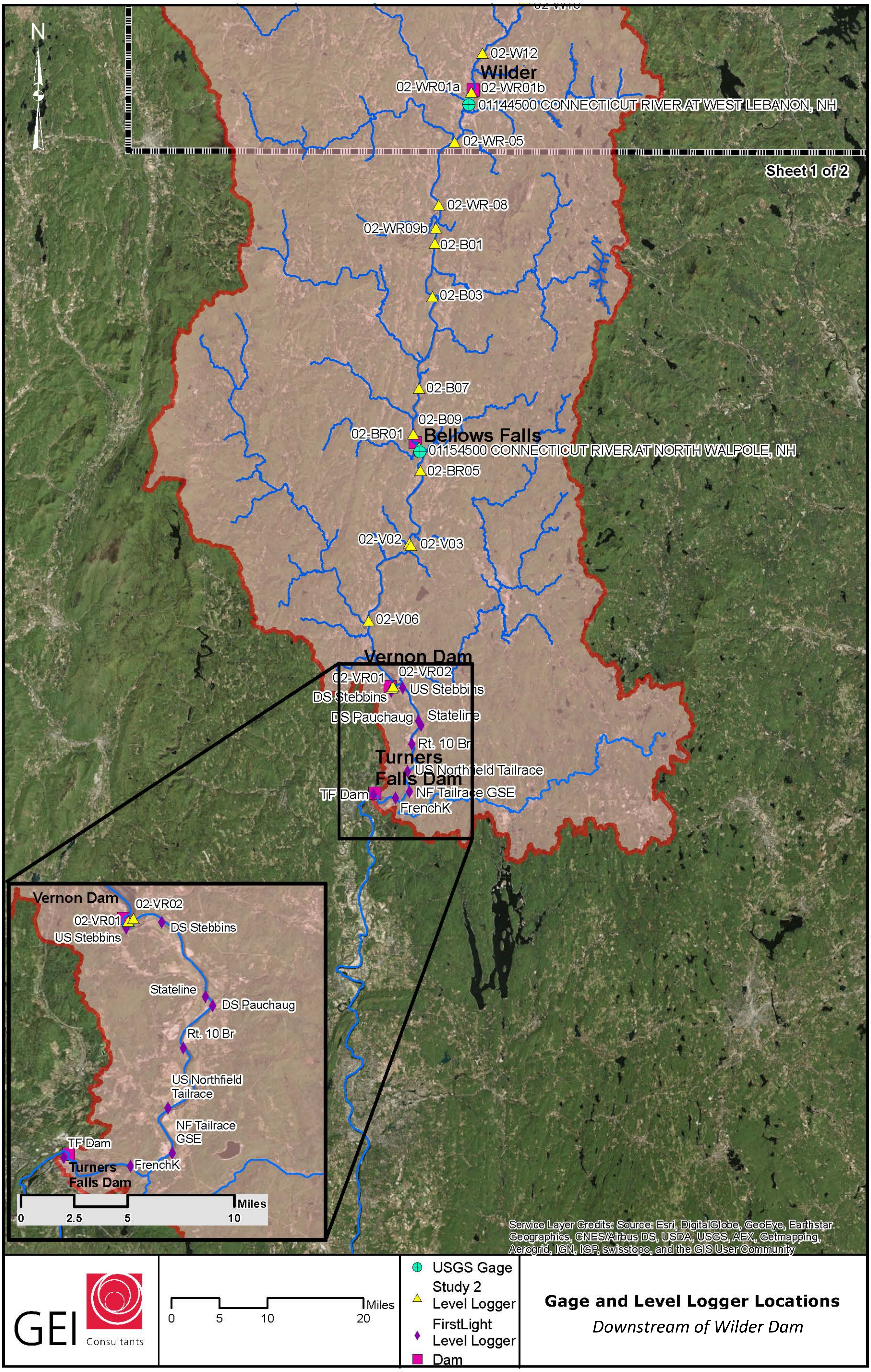

Figure 4-5b. Gage and level logger locations – downstream of Wilder dam.

The goal of model calibration was to achieve an overall "best match" to the observed data to replicate the timing and elevation of water levels in the river system related to typical project operations and to a spill event. Figure 4-6 below summarizes what is meant by "timing" and "elevation" data matching. Before model refinement, the water level logger data was reviewed for potential issues such as vandalism, placement in river (to make sure the logger was sufficiently placed to capture low river flows), logger clock settings, logger barometric pressure correction factors, and logger elevation surveys.

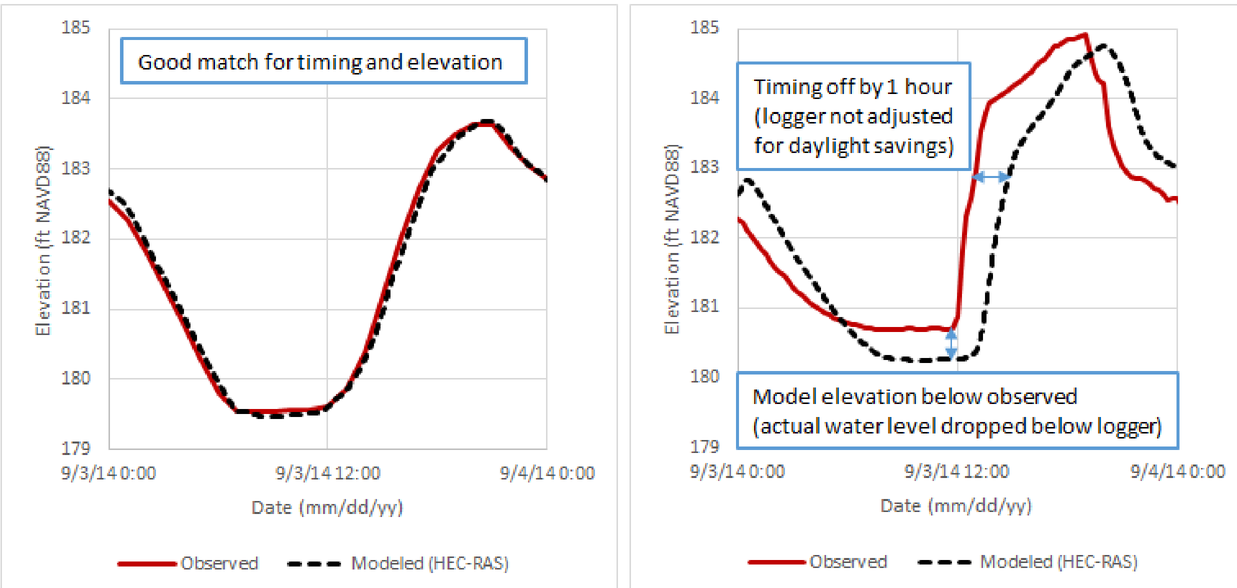

Figure 4-6. Examples of calibration match for timing and elevation.

Study 2 consultants were responsible for Study 2 logger deployment, and data collection and management. Information regarding the Study 2 logger program may be reviewed in the Study 2 report (not yet available). Similarly, information regarding the FirstLight logger program may be reviewed in the FirstLight Relicensing Study 3.2.2 report (Gomez and Sullivan, 2015).

After working with Study 2 consultants regarding logger deployment, data collection and data management, the hydraulic model calibration efforts focused on minimizing differences between observed and simulated water surface elevations by adjusting Manning's n-value.

Calibration was conducted across a range of flows over a period of about 5 to 7 days in 2014 for one typical operations event and one spill event. Operation and spill events were selected based on availability of valid logger data (i.e., free of issues such as vandalism, ice formation, or out-of-water loggers) and the periods selected were reviewed by TransCanada to confirm that the flows were representative of operations and spill conditions.

The hydraulic model was developed as four reaches to establish upstream boundaries based on project discharge records and downstream boundaries based on impoundment stage at the Wilder, Bellows Falls, Vernon, and Turners Falls dams. In the Wilder reach, the calibration was routed from USGS gage 01138500 (Connecticut River at Wells River, VT) to Wilder dam. The USGS gage was selected as the upstream boundary of the Wilder reach for model calibration based on several factors. The areas of interest to other resource studies and level loggers are located downstream of this gage, there is a well-established record of flows and water surface elevations at this gage, and this approach minimized the need to estimate inflows at upstream ungaged tributaries such as the Ammonoosuc River. A description of these reaches and the schedule of flow events for the calibration process are presented in the following table.

Table 4-6. Hydraulic model calibration periods.

Reach	Reach Description	Operations Calibration Period 2014	Spill Calibration Period 2014
Wilder (M_W)	USGS gage 01138500 to Wilder Dam	8/1 to 8/7	6/24 to 7/1
Bellows Falls (W_B)	Wilder Dam to Bellows Falls Dam	9/13 to 9/18	7/28 to 7/30
Vernon (B_V)	Bellows Falls Dam to Vernon Dam	9/15 to 9/20	7/28 to 8/2
Turners Falls (V_T)	Vernon Dam to Turners Falls Dam	8/30 to 9/6	7/3 to 7/7

Calibration results are discussed in Section 5.0. Appendix B contains graphs summarizing the comparison of the observed and modeled results. The calibration was performed using actual project outflows, impoundment water surface elevations, and tributary flow data for unsteady flow conditions. Unsteady modeling allows a comparison of both the timing and elevations rather than just the elevations as would be the case in a steady state calibration. The calibration results are presented as rating curves (elevation vs flow) at USGS gages and time series of water surface elevation data (elevation vs time) at level loggers for one operations and one spill event at the reaches identified in Table 4-6.

Validation is a process to substantiate the suitability of the model for its intended use, that is, to simulate the routing of river flow with the goal of developing rating curves at econodes of interest. Validation was conducted using level logger data collected in 2013 and 2015 as part of Study 7. The intent was to select loggers deployed as part of a separate study and use data from a different time period than the data used in calibration. Validation results are included in Appendix C. The validation periods are provided in the table below.

Table 4-7. Hydraulic model validation periods.

Reach	Description	Validation Period
Wilder (M_W)	USGS gage 01138500 to Wilder Dam	10/9 to 10/14/2013
Bellows Falls (W_B)	Wilder Dam to Bellows Falls Dam	10/2 to 10/6/2013
Vernon (B_V)	Bellows Falls Dam to Vernon Dam	10/20 to 10/23/2013
Turners Falls (V_T)	Vernon Dam to Turners Falls Dam	5/14 to 5/16/2015

4.3 Velocity Comparison

Velocities measured in the field at selected transects were compared to average velocities computed by the HEC-RAS model. The velocity comparison methods and the proposed locations were discussed at the study consultation conference call with FWS, VANR, and NHDES on July 20, 2015.

A total of seven velocity comparisons were performed: one in each of three riverine reaches (Wilder, Bellows Falls, and Vernon), three in project impoundments (two in Wilder and one in Bellows Falls), and one USGS gage location (USGS 01154500 CONNECTICUT RIVER AT NORTH WALPOLE, NH). A summary of velocity comparisons is provided in Section 5.0. Figure 4-7 shows the velocity comparison locations.

Table 4-8. Velocity comparison locations.

Reach	Velocity Location ID	Date of Velocity Measurement	HEC-RAS River Station	HEC-RAS Node	Description
McIndoes dam to Wilder dam (M_W)	EMW3-ADCP	8/6/2015	110.171	1143	Wilder Impoundment
McIndoes dam to Wilder dam (M_W)	EMW9-ADCP	8/6/2015	91.611	999	Wilder Impoundment
Wilder dam to Bellows Falls dam (W_B)	WR1-3	5/9/2015	77.415	864	Wilder Riverine
Wilder dam to Bellows Falls dam (W_B)	EMB7	8/6/2015	41.168	552	Bellows Falls Impoundment
Bellows Falls dam to Vernon dam (B_V)	BF3	5/13/2015	33.624	491	USGS gage 01154500
Bellows Falls dam to Vernon dam (B_V)	BF17	5/13/2015	31.165	460	Bellows Riverine
Downstream of Vernon dam (V_T)	VR8LC	5/14/2015	18.914	VR123	Vernon Riverine

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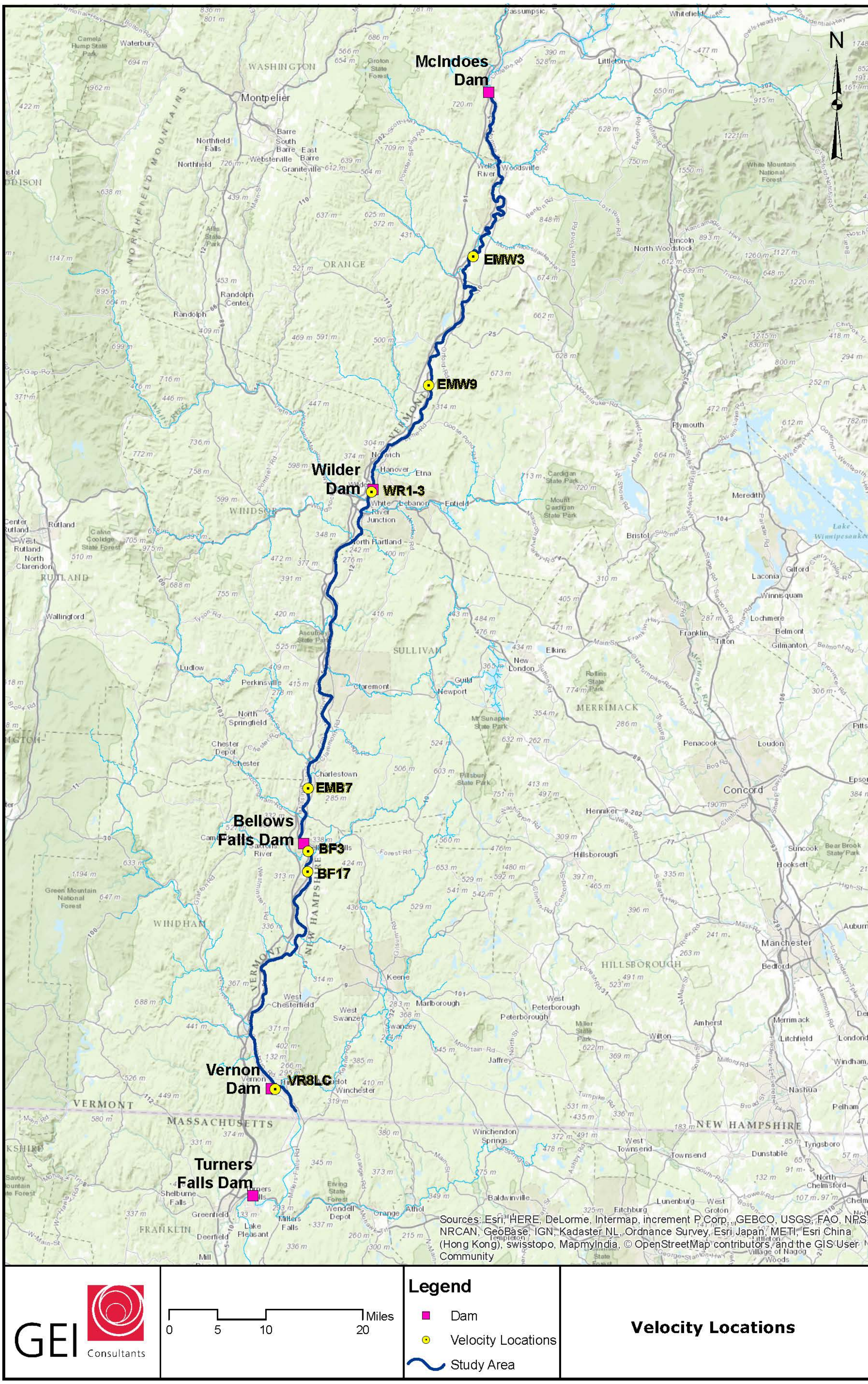

Figure 4-7. Velocity comparison locations.

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4.4 Lag Time

The lag time was estimated and provided to the operations modeling consultants for operations model routing as part of Study 5. The hydraulic model was used to derive hydrographs from the routing of typical flow pulses for the following river segments: McIndoes dam to Wilder dam, Wilder dam to Bellows Falls dam, and Bellows Falls dam to Vernon dam. Hydrograph data was exported to a spreadsheet where the lag time was estimated from the time interval between the hydrograph centers of mass at river cross sections (i.e., nodes) of interest. The operations modelers provided the location of nodes to report lag time estimates as summarized in the following table. At the request of the operations modelers, the average impoundment elevation under the current license was input as the downstream boundary condition in the hydraulic model for the estimation of lag time.

Table 4-9. River reach locations to estimate lag time for Operations Model (Study 5).

Reach	Operations Model ID
McIndoes dam to Dodge Falls dam	MCDT_DOFJ
Dodge Falls dam to Woodsville Junction	DOFJ_WODJ
Woodsville Junction to Wilder dam	WODJ_WLDR
Wilder dam to White River	WLDT_WHRJ
White River to Bellows Falls dam	WHRJ_BEFR
Bellows Falls dam to Vernon dam	BERT_VERR

In addition to these locations of interest, the locations of one-hour lag time increments were also provided to the operations modelers.

4.5 Sub-hourly Flow and Elevation Rate-of-Change

The hydraulic model will be used to compute sub-hourly flow and elevation rate-of-change at locations of interest. Operations modelers will provide hydraulic modelers with up-ramp and down-ramp flows across a 24-hour period for 5 scenarios. Hydraulic modelers will perform sub-hourly HEC-RAS model runs to compute the flows and water surface elevations at locations of interest for each scenario. The hydraulic modelers will then provide the sub-hourly time-series flows and water surface elevations to Studies 3, 8, and 9, and for other studies if required, for five scenarios of 24 hours each.

Work on sub-hourly flow and elevation rate-of-change will be based on discussions with stakeholders after the results of applicable ILP studies are available.

4.6 Rating Curves

The hydraulic model was used to compute rating curves for resource consultants and operations modelers. Using the calibrated and validated hydraulic model, a family of flow versus stage rating curves was developed for each model cross section and the results were provided to the resource consultants for preliminary screening to evaluate if the resource of interest was affected by the range of water surface elevations simulated by the hydraulic model. The rating curves provided to resource consultants were based on the range of operating elevations in the current licenses for the project impoundments. The flows ranged from the approximate licensed minimum flow up to a flow of 25,000 cfs (well above each station's maximum generating capacity) as shown in Table 4-10. A limited number of rating curves were developed at flows higher than 25,000 cfs for Studies 3 and 8 (Riverbank Erosion and Channel Morphology, respectively) to provide context for evaluating flood flow effects.

Table 4-10. Rating curve summary.

Reach	Rating Curve Flow Range (cfs)	Downstream Impoundment Elevation Range (ft NAVD 88)
Gage 01138500 to Wilder dam (M_W)	700 to 25,000	379.6 to 384.6
Wilder dam to Bellows Falls dam (W_B)	700 to 25,000	288.2 to 291.2
Bellows Falls dam to Vernon dam (B_V)	1,000 to 25,000	211.6 to 219.6
Downstream of Vernon dam (V_T)	1,200 to 25,000	175.6 to 184.6

The rating curve flow range was prepared in increments of 1,000 cfs and the downstream impoundment elevation range was prepared in 1-ft increments. Rating curves were also provided to the operations modelers for refinement of the operations model (Study 5).

5.0 RESULTS

This study involved the development of a hydraulic model to simulate the routing of river flow and impoundment water surface elevations and to derive the resulting hydraulic indices and parameters (i.e., rating curves) such as water surface elevations, velocities, and flows across the study area and at locations of interest identified in other ILP studies. The results of the hydraulic model on its own, and in conjunction with the Operations Modeling Study (Study 5), inform other studies, thereby permitting the evaluation of the effects of project operations on aquatic, terrestrial, and geologic resources.

Results from the model calibration, validation, and velocity comparison confirm that the model reasonably characterizes observed river flows, water surface elevations, timing, and velocities. The hydraulic model, therefore, is suitable for its intended use.

Hydraulic model output was used to develop rating curves, which were provided to the resource consultants to inform their studies. Output in the form of lag time information from the hydraulic model was provided to Study 5 for operations model refinement.

5.1 Model Calibration and Validation

Model calibration was performed using data recorded at active USGS gages, level loggers deployed in 2014 for Study 2, and level logger data available from FirstLight. Gage and logger data for two observed flow events (operations and spill) were compared with results from the hydraulic model. The results of calibration for the observed and modeled data are presented in Table 5-1 which summarizes the results at each level logger. The table was developed by taking observed level logger data and subtracting the model results at 15-minute time intervals. The difference (observed minus model) were totaled and averaged to produce an average difference for each logger/gage location. Averages were computed separately for the operations and spill flow events and then averaged across flow events to compute an average for each reach.

Table 5-1. Calibration results – TransCanada Study 2 level loggers, USGS gages, and FirstLight level loggers.

Reach	Logger / Gage ID	2014 Operations Observed minus Modeled (ft)	2014 Spill Observed minus Modeled (ft)	Logger Average (ft)	Reach Average (ft)
M_W	02-W02	-0.2	-0.1	-0.1	0.1
	02-W03	0.1	0.2	0.1	
	02-W07	0.3	0.2	0.3	
	02-W09	0.4	0.3	0.4	
	02-W10	0.1	0.0	0.1	
W_B	02-WR01	0.3	0.1	0.2	0.1
	Gage 01144500	0.1	0.1	0.1	
	02-WR-05	0.5	-0.1	0.2	
	02-WR-08	0.2	-0.1	0.1	
	02-B01	0.1	0.0	0.0	
	02-B03	0.2	0.2	0.2	
	02-B07	-0.1	-0.3	-0.2	
	02-B09	0.1	0.0	0.0	
B_V	02-BR01	0.0	-0.2	-0.1	0.0
	Gage 01154500	0.1	0.1	0.1	
	02-BR05	0.1	0.1	0.1	
	02-V02	0.1	0.3	0.2	
	02-V03	-0.1	0.0	-0.1	
	02-V06	-0.1	-0.1	-0.1	
V_T	US Stebbins[a]	0.4	0.1	0.3	0.0
	02-VR02	-0.2	-0.3	-0.3	
	DS Stebbins	-0.1	-0.4	-0.2	
	Stateline	0.0	0.0	0.0	
	DS Pauchaug	-0.1	-0.2	-0.2	
	Rt. 10 Br	-0.1	-0.2	-0.1	

Reach	Logger/Gage ID	2014 Operations Observed minus Modeled (ft)	2014 Spill Observed minus Modeled (ft)	Logger Average (ft)	Reach Average (ft)
	NF Tailrace GSE	0.0	0.4	0.2	
	FrenchK	-0.1	0.0	-0.1	
	TF Dam	0.0	0.0	0.0	

[a] US Stebbins is the same locations as TransCanada logger 73.

Calibration results are also summarized on the graphs in Appendix B from upstream to downstream. Appendix B-1 contains the operations calibration plots. Appendix B-2 contains the spill calibration plots. Gage and level logger locations are shown on Figure 4-5. The red line on the graphs represents the observed water surface elevations from the logger data and the dashed black line represents the computed water surface elevations modeled with HEC-RAS.

The graphs in Appendix B demonstrate that the HEC-RAS model results compare very favorably with the observed data for the timing and elevation of operations and spill flow conditions. For each reach evaluated, the model results are on average within 0.1 ft of the observed results. These results indicate that the model is appropriate for its intended use in simulating the routing of river flow and to derive resulting hydraulic indices and parameters such as water surface elevations, velocities, and flows across the study area and at locations of interest identified in other ILP studies.

Differences between modeled and observed results may be related to several factors such as the level logger deployment (vertical surveys, barometers used to adjust level loggers, and logger timing), and flow data (recorded and estimated flows at dams, gages, and tributaries), as well as model inputs such as river channel geometry and Manning's n-value.

In addition to level logger data, the calibration process included a comparison of rating curves (elevation vs flow) at three USGS gages on the mainstem of the Connecticut River. The HEC-RAS results compare very favorably with the observed data at the three gage locations as depicted by the close agreement between the blue line (observed gage data) with the dashed line (model data) as shown in Figures 5-1 through 5-3 below. The location of these gages is provided in Figure 4-5.

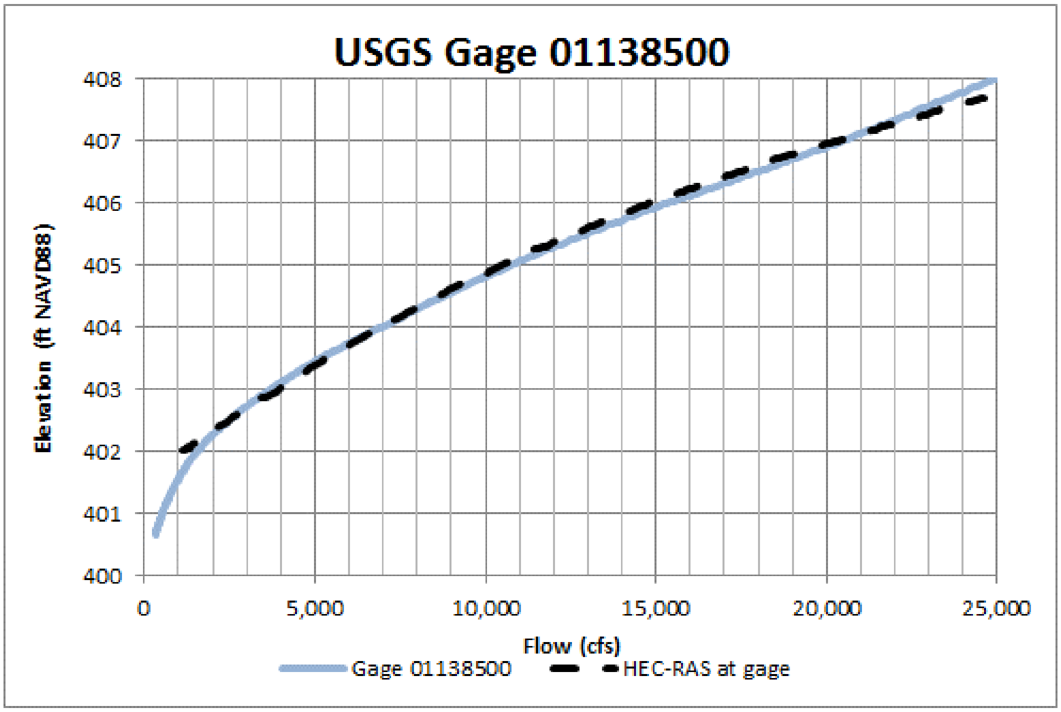

Figure 5-1. USGS 01138500 Connecticut River at Wells River, VT.

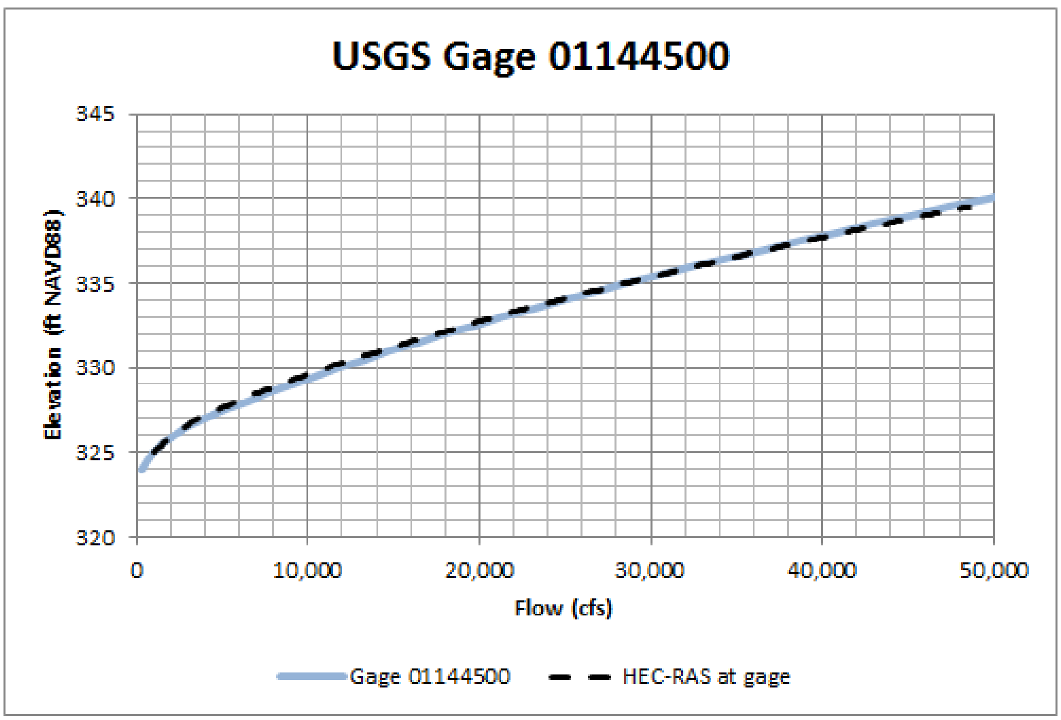

Figure 5-2. USGS 01144500 Connecticut River at West Lebanon, NH.

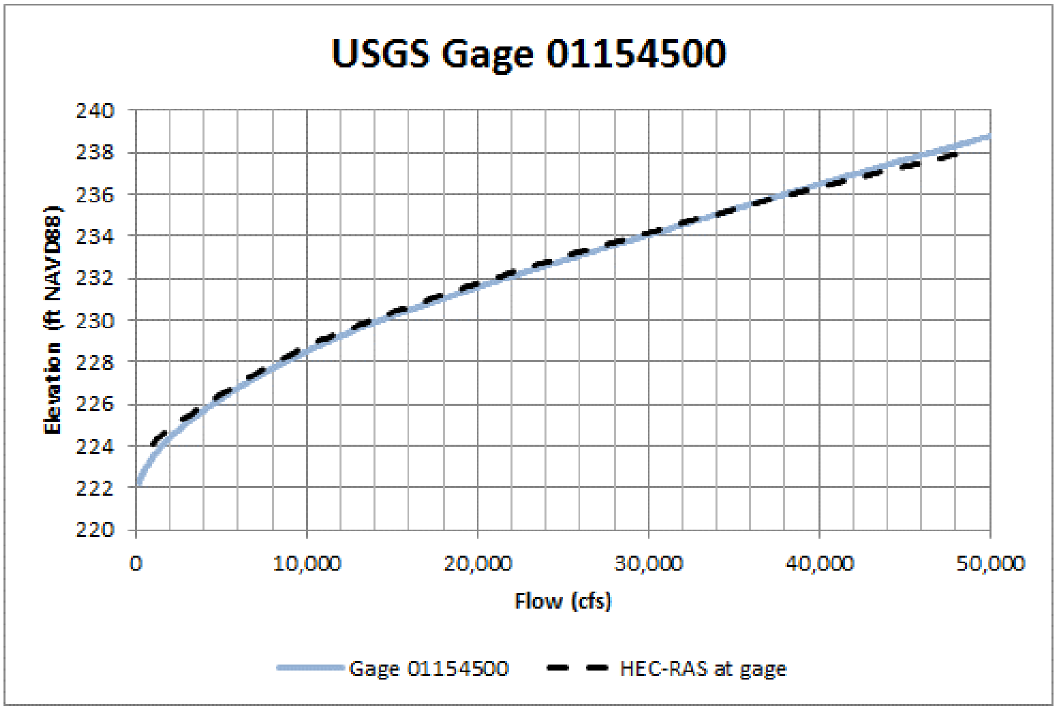

Figure 5-3. USGS 01154500 Connecticut River at North Walpole, NH.

Validation was performed following calibration to substantiate the suitability of the model for its intended use. Hydraulic model results were compared with loggers deployed as part of a separate study (Study 7) and different time period (fall 2013 and spring 2015) than the loggers used in calibration. Validation results are included in Appendix C.

The validation results confirm that the hydraulic model is appropriate for its intended use. Of particular note, the validation graphs indicate that the logger data lags the hydraulic model results by one hour suggesting the logger clocks were set an hour behind Eastern Time. Logger deployment staff confirmed the clock offsets for some loggers (e.g., loggers installed and removed during Daylight Savings Time [DST] were set to DST time rather than Eastern Standard Time).

5.2 Velocity Comparison

Velocity simulated in the hydraulic model was compared with observed average channel velocities at seven locations: one in each of three riverine reaches (Wilder, Bellows Falls, and Vernon), three in project impoundments (two in Wilder and one in Bellows Falls), and one USGS gage location (USGS 01154500 CONNECTICUT RIVER AT NORTH WALPOLE, NH). The simulated velocities compare very favorably with the observed data. Velocity data was collected as part of Study 7 and details about the methods of field data collection are included in the report for that study (Normandeau, 2015a).

River flows were documented at each velocity transect at the time of the velocity measurements and these flows were input to the hydraulic model. The downstream boundary condition was set to range of licensed impoundment elevations based on data provided by TransCanada. The velocity in the impoundments can vary depending on the downstream impoundment elevation so the hydraulic model was run for two impoundment elevations to show the potential range in simulated velocity. The results of the velocity comparison are provided in the table below.

Table 5-2. Velocity comparison.

Reach	Velocity Location ID	Flow[a] (cfs)	Observed Velocity (ft/s)	HEC-RAS Velocity[b] (ft/s)	Description
McIndoes dam to Wilder dam (M_W)	EMW3-ADCP	2,689	0.6	0.4 to 0.6	Wilder Impoundment
McIndoes dam to Wilder dam (M_W)	EMW9-ADCP	4,985	0.7	0.6 to 0.8	Wilder Impoundment
Wilder dam to Bellows Falls dam (W_B)	WR1-3	11,540	1.3	1.9	Wilder Riverine
Wilder dam to Bellows Falls dam (W_B)	EMB7	8,559	0.7	0.6 to 0.8	Bellows Falls Impoundment
Bellows Falls dam to Vernon dam (B_V)	BF3	11,969	2.1	2.1	USGS gage 01154500
Bellows Falls dam to Vernon dam (B_V)	BF17	12,044	2.7	2.5 to 2.7	Bellows Riverine
Downstream of Vernon dam (V_T)	VR8LC	8,289	2.3	1.1 to 2.3	Vernon Riverine

[a] Average river flow measured at the given location during field velocity measurements as part of Study 7. These flow values were input to the HEC-RAS model (Study 4) to develop the simulated velocities.

[b] The modeled HEC-RAS velocity is presented as a range to represent the range of operating elevations for the project impoundments under the current licenses. A single velocity value indicates the velocity is not affected by the range of downstream impoundment levels.

5.3 Rating Curves

The hydraulic model was developed to identify the hydraulic relationship between river flow and water surface elevation (in addition to other variables such as velocity) at locations of interest along the study area of the mainstem of the Connecticut River. This relationship between flow and water surface elevation is expressed in a series of rating curves at cross section locations in the hydraulic model.

Rating curves were provided to resource consultants as part of preliminary screening to evaluate for potential project effects by comparing the various resource critical water surface elevations with the hydraulic model results. The hydraulic model was run in steady state mode for a range of flows and impoundment water surface elevations to generate more than 1,200 rating curve graphs representing more than 200,000 data values (i.e., resulting water surface elevations for the range of input flows) showing the relationship between flow and water surface elevation. Some studies such as Study 8 (Channel Morphology and Benthic Habitat Study) requested additional variables to perform screening such as minimum channel elevation, channel velocity, and channel shear stress in addition to flow and water surface elevation.

For cases where screening indicated project operations have no effect on resources, no further analysis of project effects was warranted. Cases where screening indicated a potential for project operations to have an effect on resources, further examination using the Hydraulic Model and/or the Operations Model (Study 5) will be undertaken to describe the frequency and periodicity of potential project effects and to evaluate whether potential alternative operating conditions can mitigate the potential project effects. Screening and assessing potential project effects was performed by resource consultants as part of other studies.

Appendix D contains examples of rating curve data and graphs. Due to the very large number of data values and graphs produced in this study, a few examples are provided to show the type of results developed as part of this study.

5.4 Lag Time

The lag time was provided to the operations modelers to refine operations model routing. Flow pulses were routed in the hydraulic model to develop hydrographs, which were used to calculate the time interval between the hydrograph centers of mass at nodes of interest. The following figure presents an example of the hydrograph from McIndoes dam to Wilder dam as a typical flow pulse travels downstream along nodes of interest.

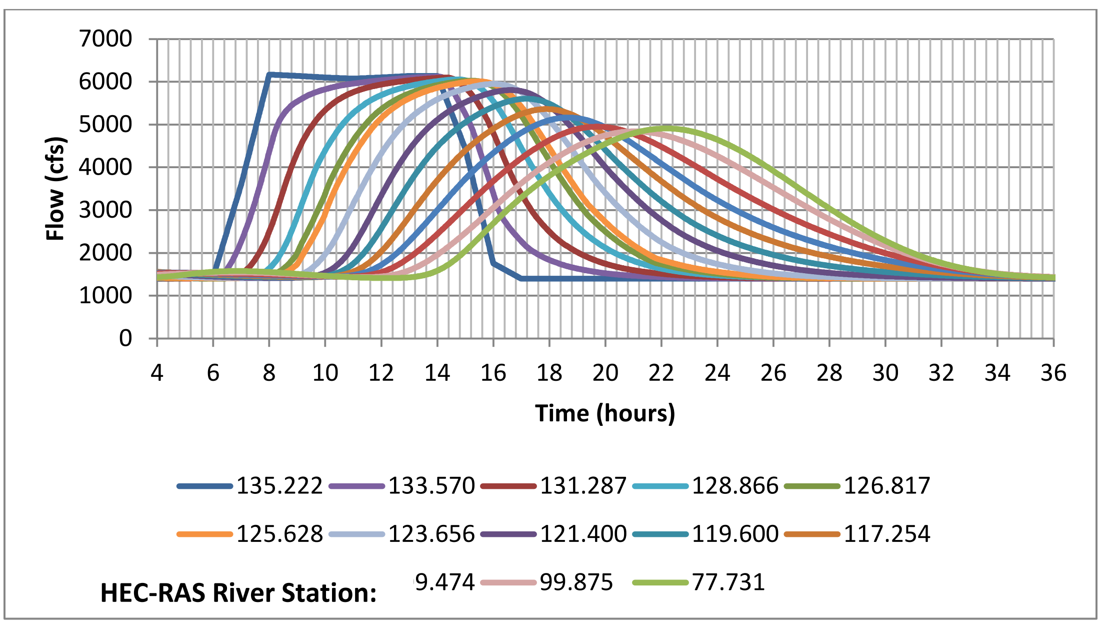

Figure 5-4. Hydrographs from typical pulse for lag time estimates, McIndoes dam to Wilder dam.

The time increments calculated from the center of mass of each hydrograph for the river station locations were provided in tabular form to the operations modelers. The table below provides an example of this output.

Table 5-3. Lag time summary – example output for operations modelers.

Reach	Description	Cumulative Lag Time (hr)	HEC-RAS River Station	HEC-RAS Node
McIndoes dam to Wilder dam	Downstream of McIndoes dam	0.0	135.222	1335
	1 hour	1.0	133.570	1315
	Dodge Falls dam (2 hours)	2.0	131.287	1294
	3 hours	3.0	128.866	1279
	Woodsville Junction	3.7	126.817	1255
	4 hours	4.0	125.628	1240
	5 hours	5.0	123.656	1222
	6 hours	6.0	121.400	1203
	7 hours	7.0	119.600	1197
	8 hours	8.0	117.254	1190
	9 hours	9.0	114.037	1172
	10 hours	10.0	109.474	1137
	11 hours	11.0	99.875	1057
	Upstream of Wilder dam	11.6	77.731	870

6.0 ASSESSMENT OF PROJECT EFFECTS

This study was performed to simulate hydraulic routing of river flow through riverine sections and project impoundments (Wilder, Bellows Falls, and Vernon). The primary output from this study was the development of a set of rating curves to identify the relationship between variables such as flow and water surface elevation across the study area and at locations of interest identified in other ILP studies. The results of the hydraulic model on its own and in conjunction with the Operations Modeling Study (Study 5) inform resource consultants regarding the effects of project operations on various aquatic, terrestrial, and geologic resources.

The rating curves allowed for an initial screening of project effects on resources by comparing the various resource-critical flows and water surface elevations noted in the field with modeled flows and water surface elevations. For cases where potential effects were unlikely, no further analysis of the resource would be warranted since project operations were identified as having little or no effect. For situations where the screening analysis indicated potential effects were possible, further examination using the Hydraulic Model and/or the Operations Model (Study 5) will be considered.

Both the screening evaluation of potential project effects and the need for further analysis or examination of operating alternatives to mitigate potential effects will be provided in the individual study reports prepared by the resource consultants.

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APPENDIX A

Manning's N-Value

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FEMA Flood Insurance Studies - Summary of Manning's n-values evaluated in Study 4.

Table 8: Manning's "n" Values

Flooding Source	Channel "n" Values	Overbank "n" Values
Androscoggin River	0.031 to 0.10	0.030 to 0.10
Bog Brook	0.03 to 0.04	0.07 to 0.20
Burnside Brook	0.060 to 0.082	0.08 to 0.18
Caleb Brook	0.030 to 0.063	0.06 to 0.17
Clear Stream	0.038 to 0.039	0.039 to 0.10
Clement Brook	0.04 to 0.041	0.04 to 0.10
Connecticut River	0.020 to 0.030	0.05 to 0.17
Dead River	0.02 to 0.045	0.04 to 0.10
Greenough Brook	0.038 to 0.039	0.038 to 0.10
Indian Brook	0.027 to 0.057	0.05 to 0.17
Israel River	0.022 to 0.060	0.04 to 0.17
Jericho Brook	0.02 to 0.045	0.04 to 0.095
Moose Brook	0.04 to 0.05	0.03 to 0.10
Moose Brook Split	0.04 to 0.05	0.03 to 0.10
Moose River	0.038 to 0.04	0.04 to 0.10
Otter Brook	0.030 to 0.063	0.06 to 0.17
Peabody River	0.035 to 0.050	0.040 to 0.20
Redman Brook	0.030 to 0.063	0.07 to 0.17
Tinker Brook	0.035	0.04 to 0.10
Whipple Brook	0.050 to 0.078	0.06 to 0.15

Source: FEMA FIS for Coos County, NH, (2/20/2013)

Stream	Channel "n"	Overbank "n"
Connecticut River	0.030-0.100	0.035-0.110
Passumpsic River	0.013-0.045	0.020-0.080
Stevens River	0.013-0.090	0.013-0.090

Source: FEMA FIS for Barnet, Caldonia County, VT (5/17/1988)

Channel roughness factors (Manning's "n") used in the hydraulic computations were chosen by engineering judgement and were based on field observations of the streams and floodplain areas. Channel "n" values for the Wells River, Quarry Road Brook, and Scott Brook ranged from 0.025 to 0.073 and the overbank "n" values ranged from 0.035 to 0.120.

Source: FEMA FIS for Ryegate, Caldonia County, VT (7/17/1991)

Channel roughness factors (Manning's "n") used in the hydraulic computations were estimated by field inspection at each cross section for the Waits River. Channel roughness factors for the Waits River ranged from 0.040 to 0.050, and overbank "n" values ranged from 0.040 to 0.100.

Source: FEMA FIS for Bradford, Orange County, VT (6/3/1991)

TABLE 7 - MANNING'S "n" VALUES

Stream	Channel "n"	Overbank "n"
Ammonoosuc River	0.045	0.060
Baker Brook	0.025-0.030	0.060
Baker River	0.030-0.050	0.050-0.250
Beede Brook	0.043-0.050	0.050-0.120
Canaan Street Lake outlet	0.035-0.14	0.035-0.14
Clay Brook	0.020	0.070
Cockermouth River	0.035-0.070	0.055-0.250
Connecticut River	0.025-0.050	0.040-0.100
Dells Brook	0.030-0.035	0.060-0.065
East Branch Pemigewasset River	0.035	0.060-0.120
Farr Brook	0.030-0.035	0.060-0.065
Goose Pond Brook	0.035-0.070	0.060-0.250
Grant Brook	0.040	0.070
Ham Branch	0.043-0.052	0.060-0.150
Hewes Brook	0.040	0.065
Indian River	0.030-0.065	0.060-0.150
Knox River	0.030-0.070	0.060-0.120
Lovejoy Brook	0.040-0.100	0.060-0.120
Mascoma River	0.030-0.065	0.040-0.150
Mink Brook	0.025-0.050	0.040-0.100
Monahan Brook	0.025-0.050	0.040-0.100
Newfound River	0.040-0.055	0.020-0.150

36

TABLE 7 - MANNING'S "n" VALUES - continued

Stream	Channel "n"	Overbank "n"
Orange Brook	0.045-0.050	0.070-0.120
Ore Hill Brook	0.025-0.060	0.100-0.250
Owl Brook	0.043-0.050	0.050-0.120
Palmer Brook	0.045	0.060
Pemigewasset River	0.030-0.055	0.040-0.160
Punch Brook	0.040	0.080-0.200
Sanborn Mill Brook	0.045-0.080	0.030-0.120
Slade Brook	0.025-0.050	0.040-0.100
South Branch Baker River	0.040	0.047-0.150
Stinson Brook	0.040-0.045	0.080-0.150
Trout Brook	0.020	0.070

Source: FEMA FIS for Grafton County, NH (02/20/2008)

Manning's 'n' values were assigned using GIS-based automated modeling techniques based on a land cover datalayer developed from project planimetric and orthophoto maps. Each land cover type was assigned a representative Manning's 'n' value. Channel Manning's 'n' values ranged from 0.03 to 0.08, and overbank Manning's 'n' values ranged from 0.01-0.13.

Source: FEMA FIS for Windsor County, VT (9/28/2007)

TABLE 5 – MANNING'S "n" VALUES

Stream	Channel "n"	Overbank "n"
Beaver Brook #1	0.040-0.050	0.080-0.120
Blow-Me-Down Brook	0.035-0.045	0.06-0.25
Butternut Brook	0.025-0.0075	0.035-0.110
Connecticut River	0.03-0.080	0.01-0.13
Grandy Brook	0.043-0.054	0.05-0.12
Little Sugar River	0.030-0.060	0.070-0.120
North Branch Sugar River	0.025-0.050	0.025-0.150
Ox Brook	0.030-0.070	0.090-0.120
Redwater Brook	0.043-0.054	0.05-0.12
Skinner Brook	0.030-0.070	0.025-0.120

20

TABLE 5 – MANNING'S "n" VALUES – continued

Stream	Channel "n"	Overbank "n"
South Branch Sugar River	0.035-0.040	0.100-0.150
Spring Farm Brook	0.043-0.054	0.05-0.12
Stocker Brook	0.025-0.065	0.025-0.120
Stocker Brook Outlet Channel	0.025-0.065	0.025-0.120
Sugar River	0.028-0.500	0.050-0.150
Trask Brook	0.060	0.080-0.140
Tyler Brook	0.043-0.054	0.05-0.12
Unnamed Tributary	0.060	0.080-0.140

Source: FEMA FIS for Sullivan County, VT (9/28/2007)

APPENDIX B-1

Hydraulic Model Calibration Graphs – Operations

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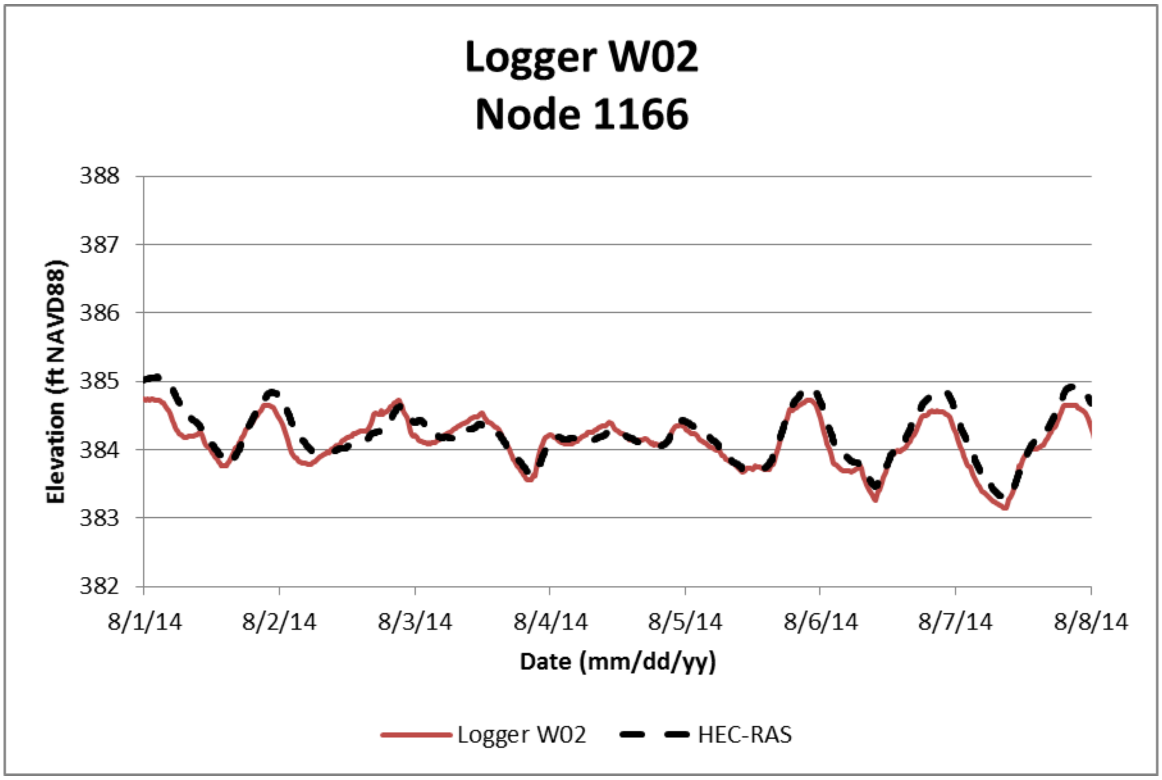
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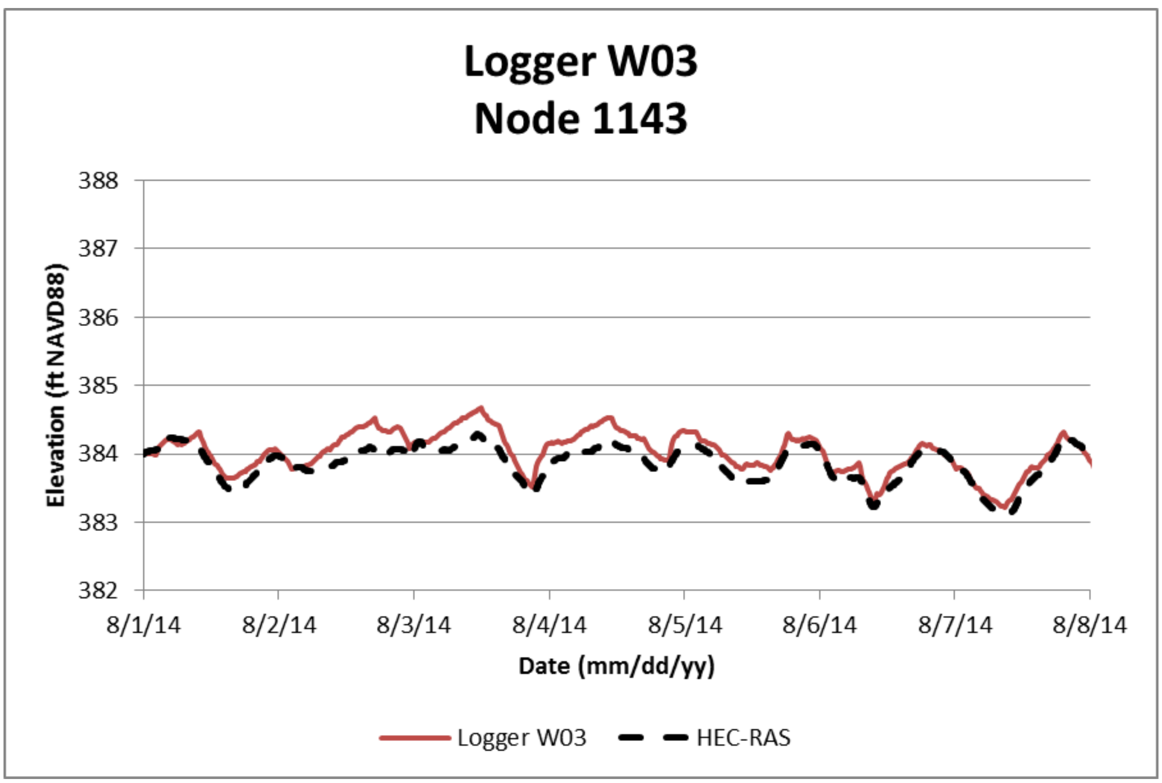
8/6/14
8/7/14
8/8/14
Date (mm/dd/yy)
Logger W02
HEC-RAS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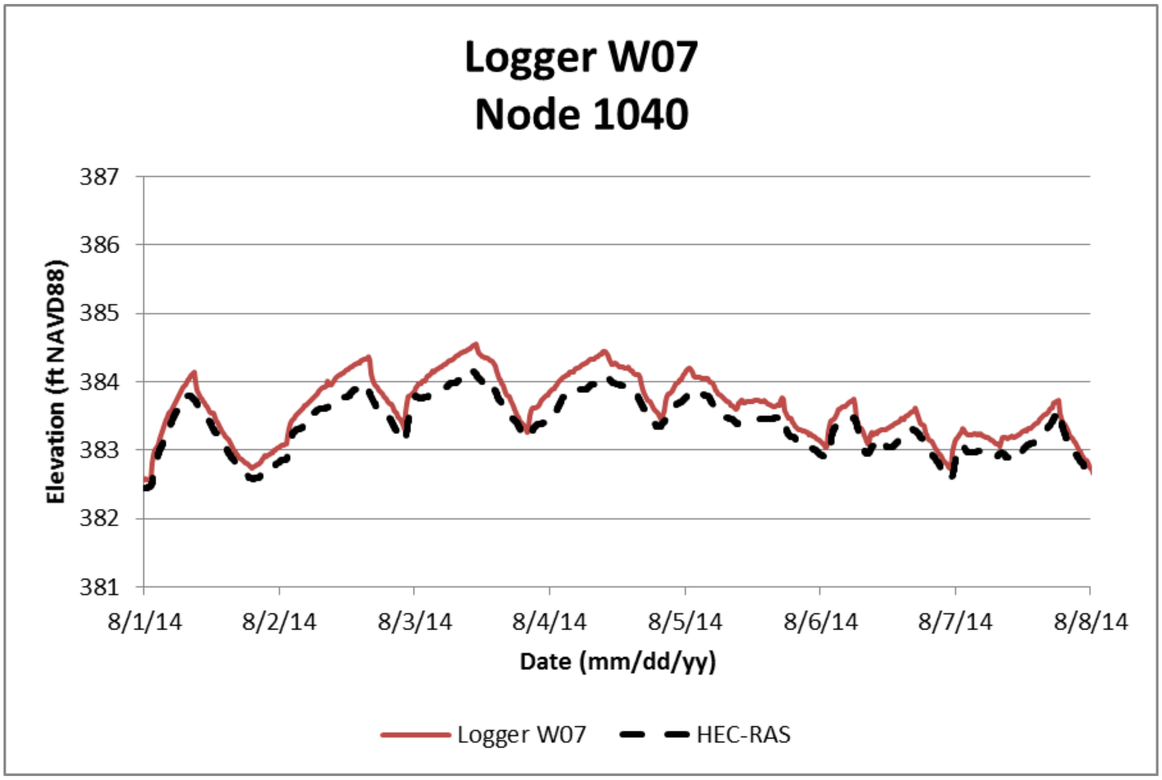
8/8/14
Date (mm/dd/yy)
Logger W03
HEC-RAS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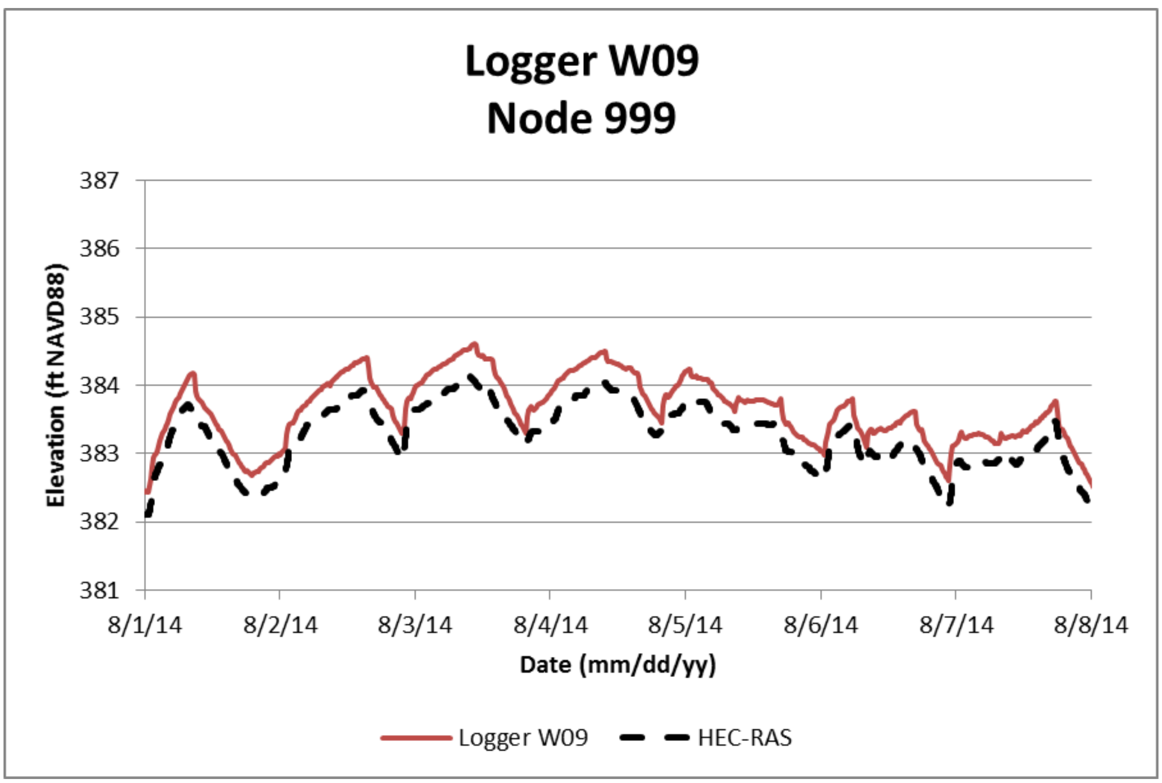
8/8/14
Date (mm/dd/yy)
Logger W07
HEC-RAS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Logger W09
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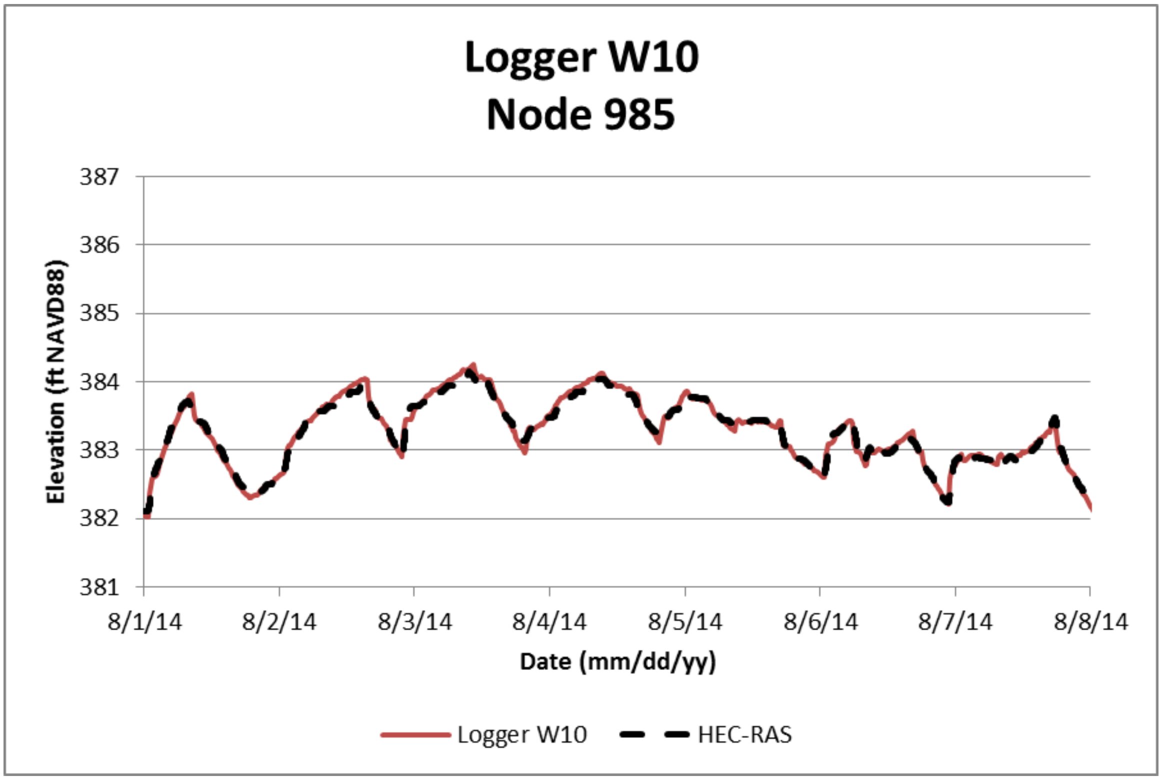
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Logger W10
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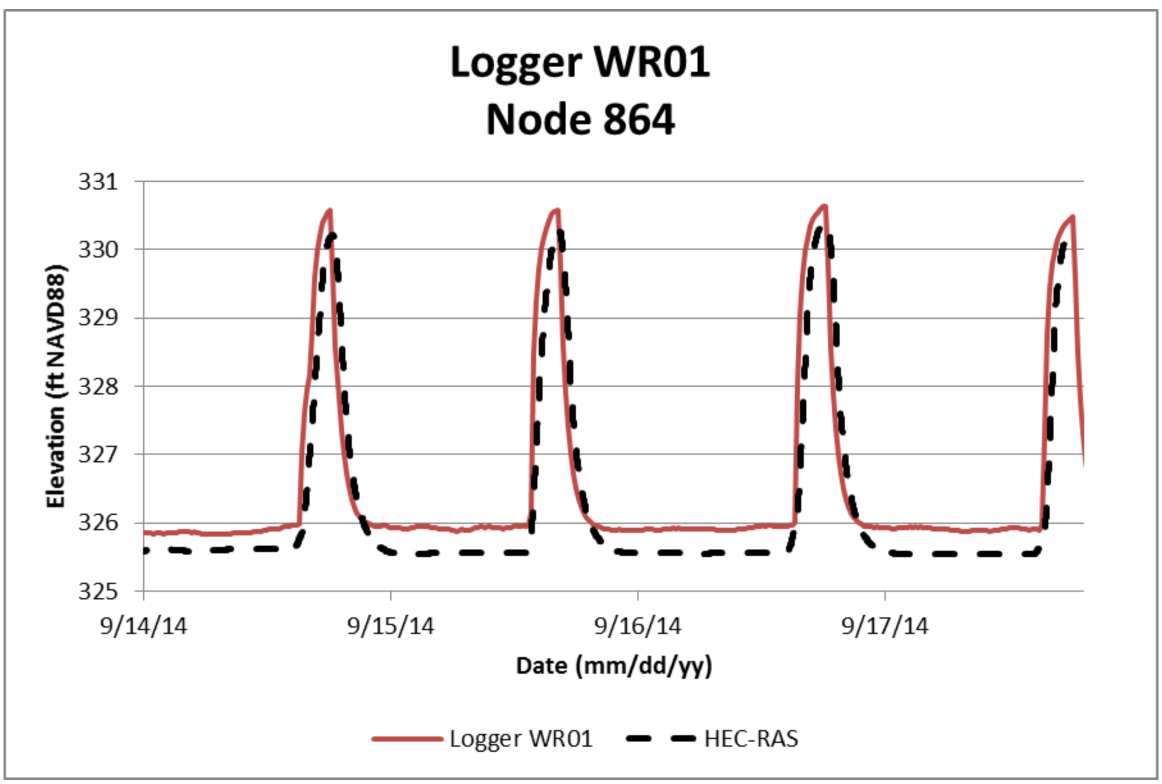
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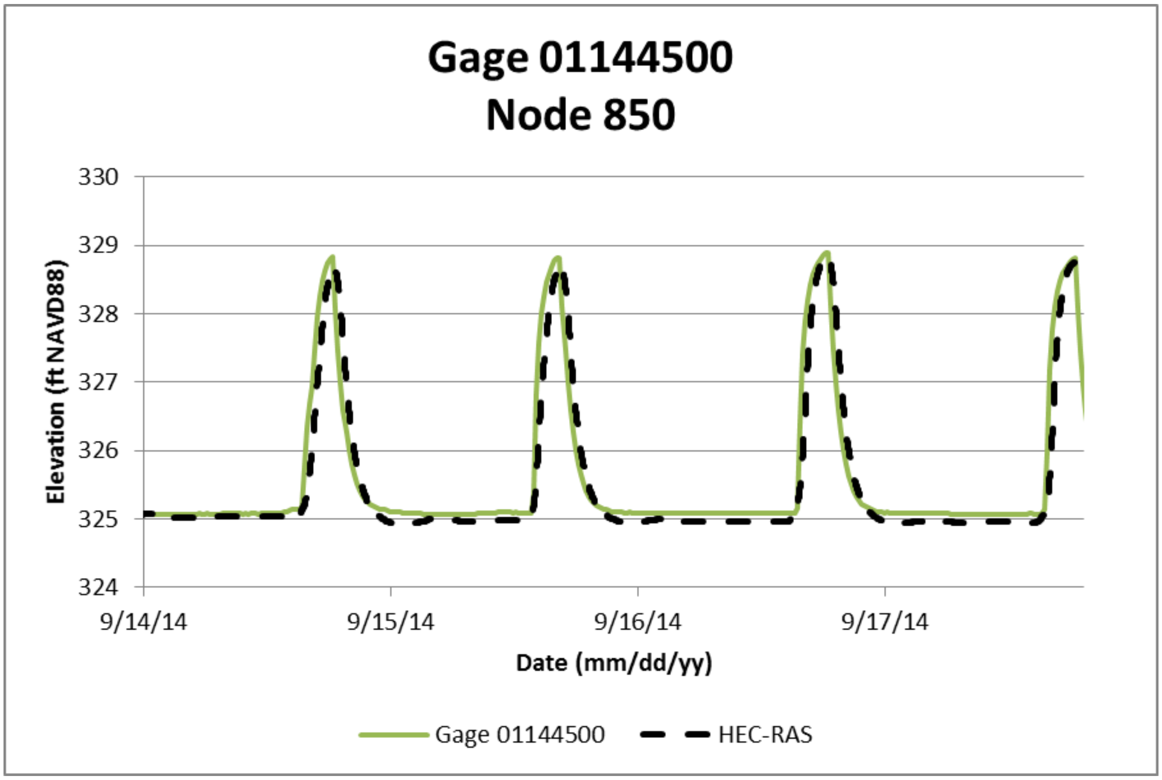
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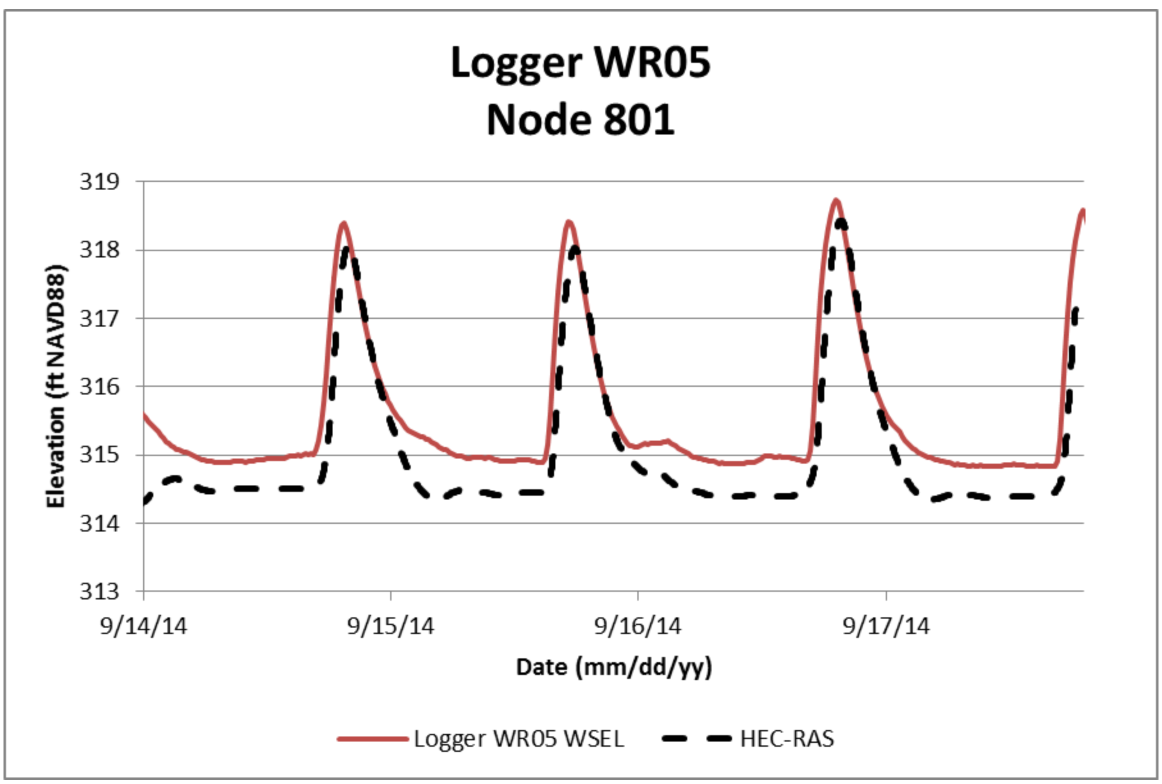
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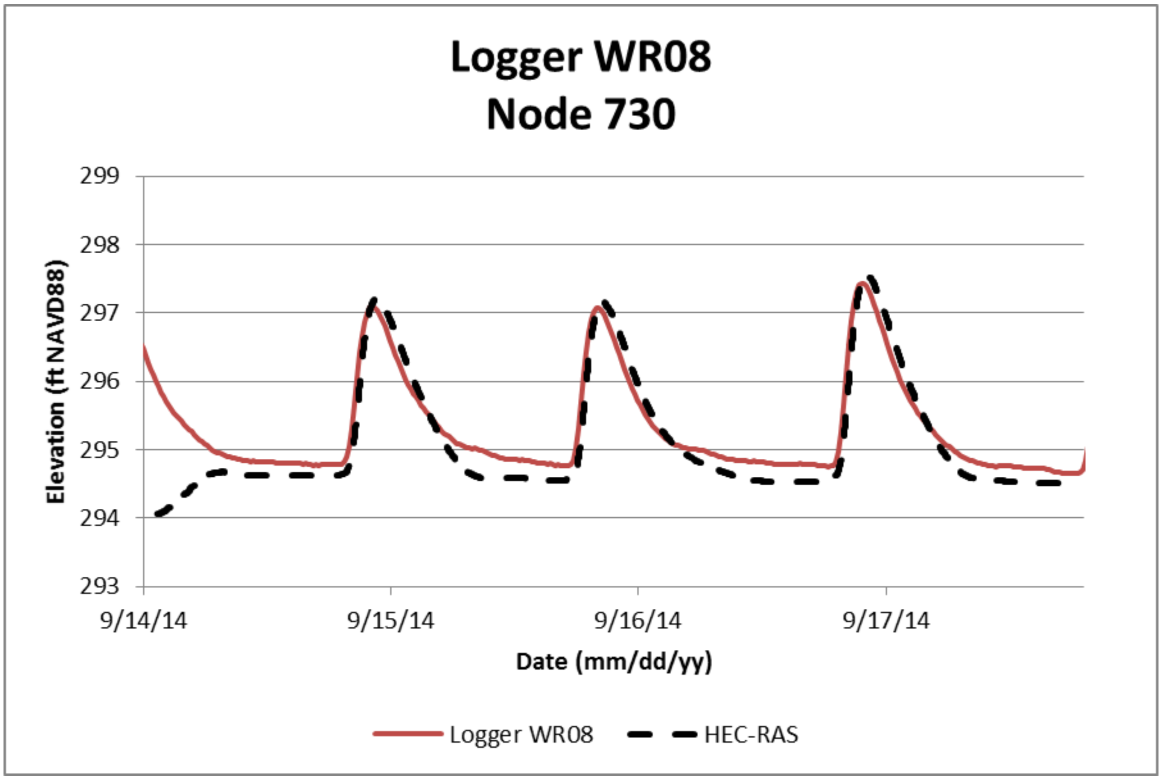
HEC-RAS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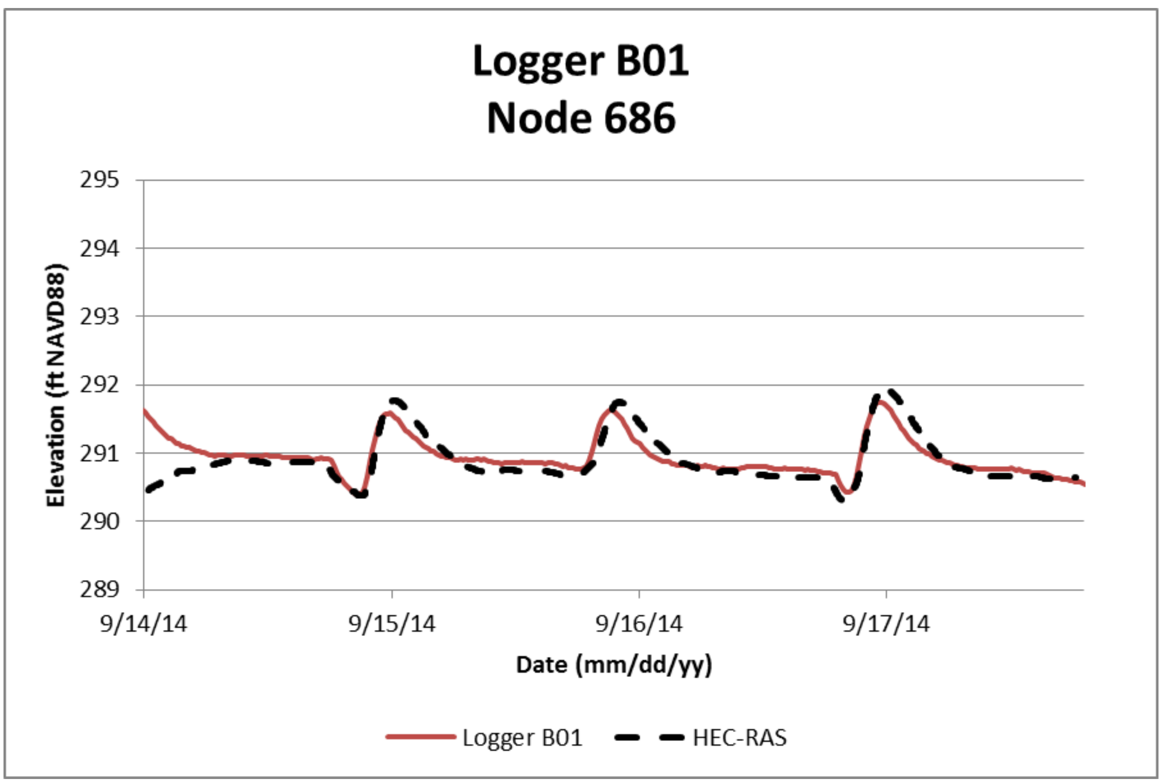
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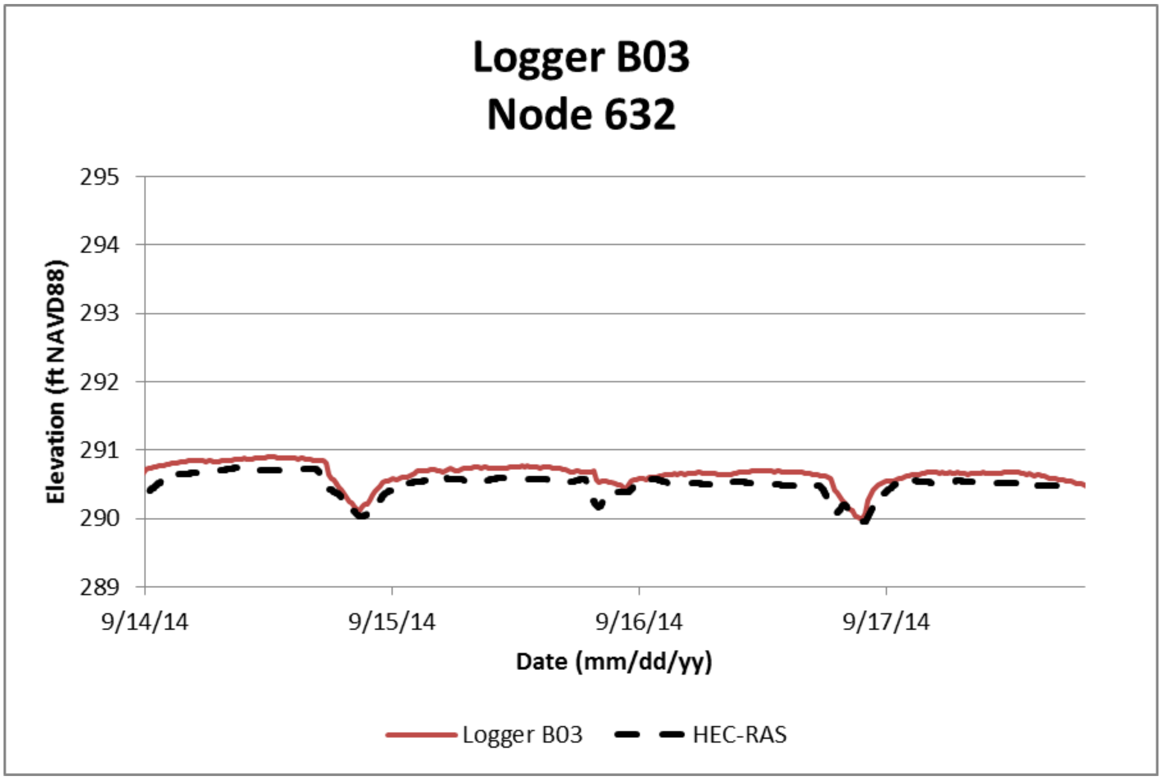
Logger B01
HEC-RAS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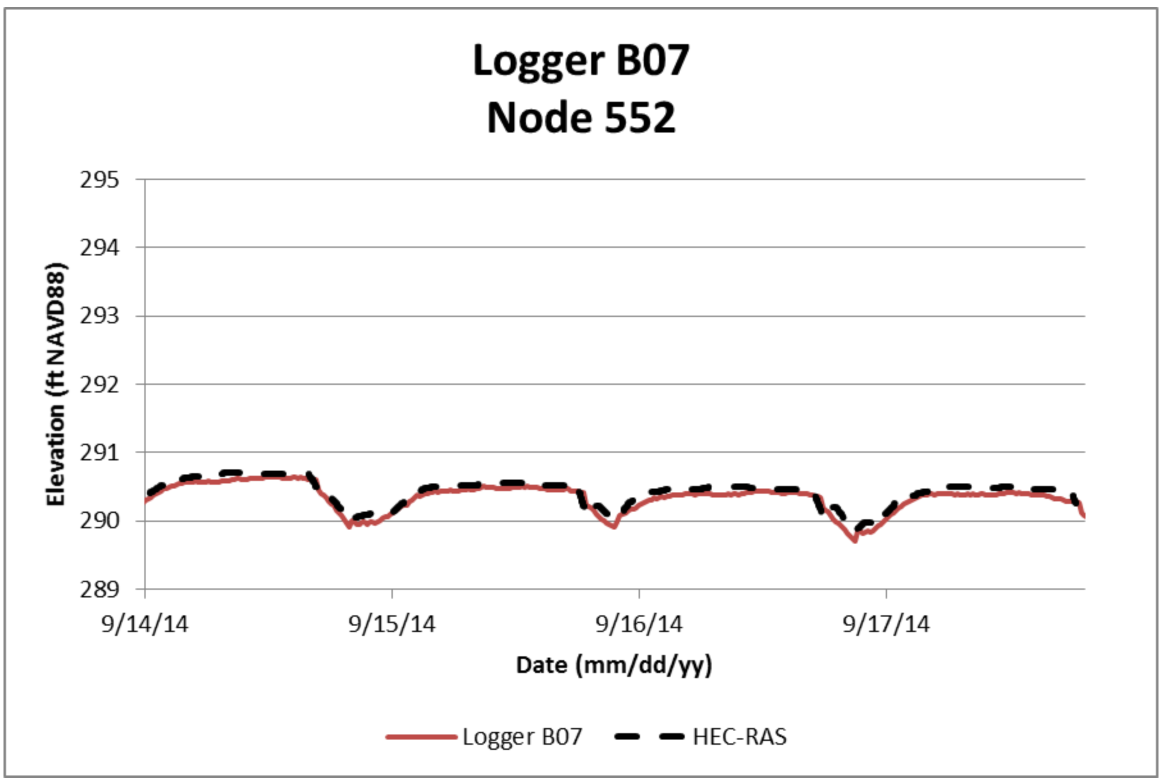
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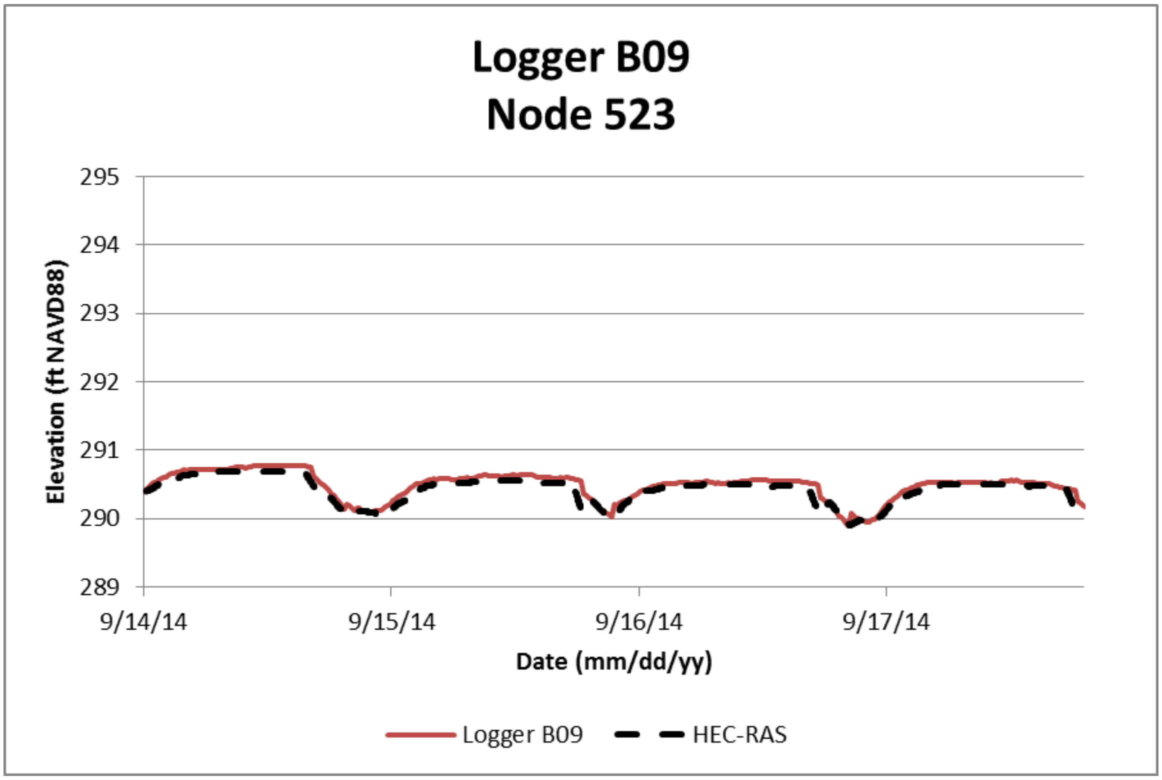
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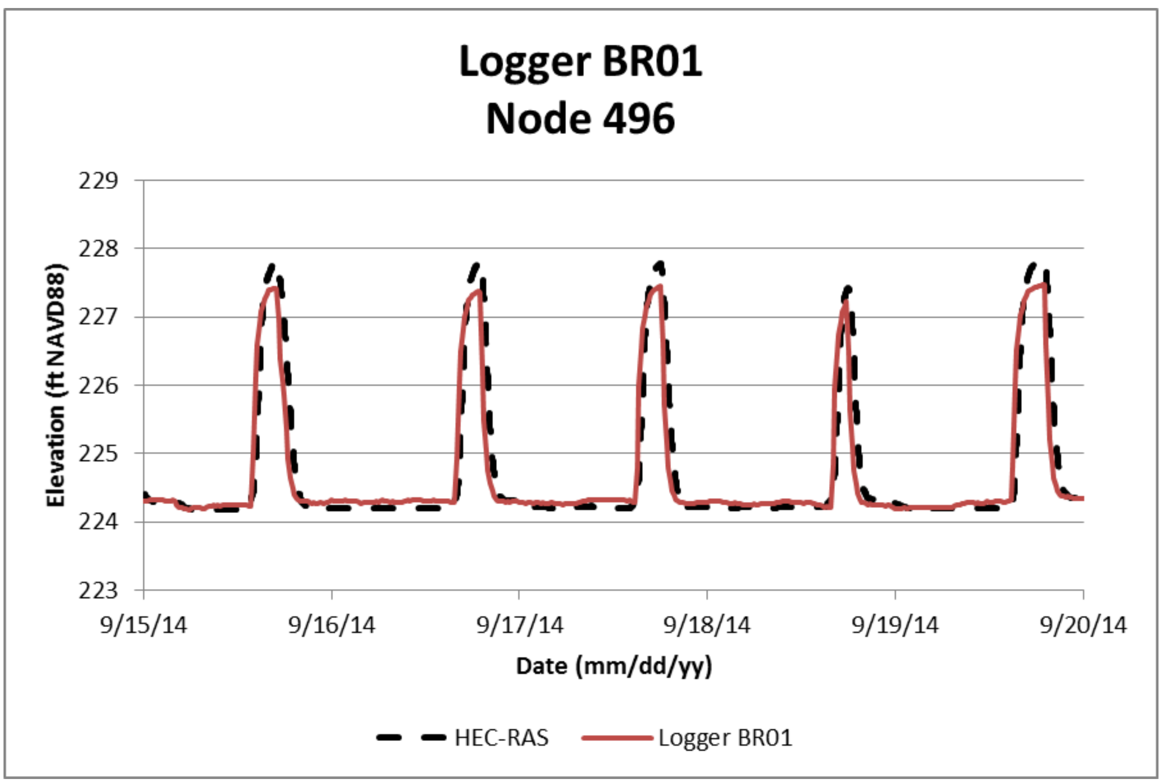
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Date (mm/dd/yy)
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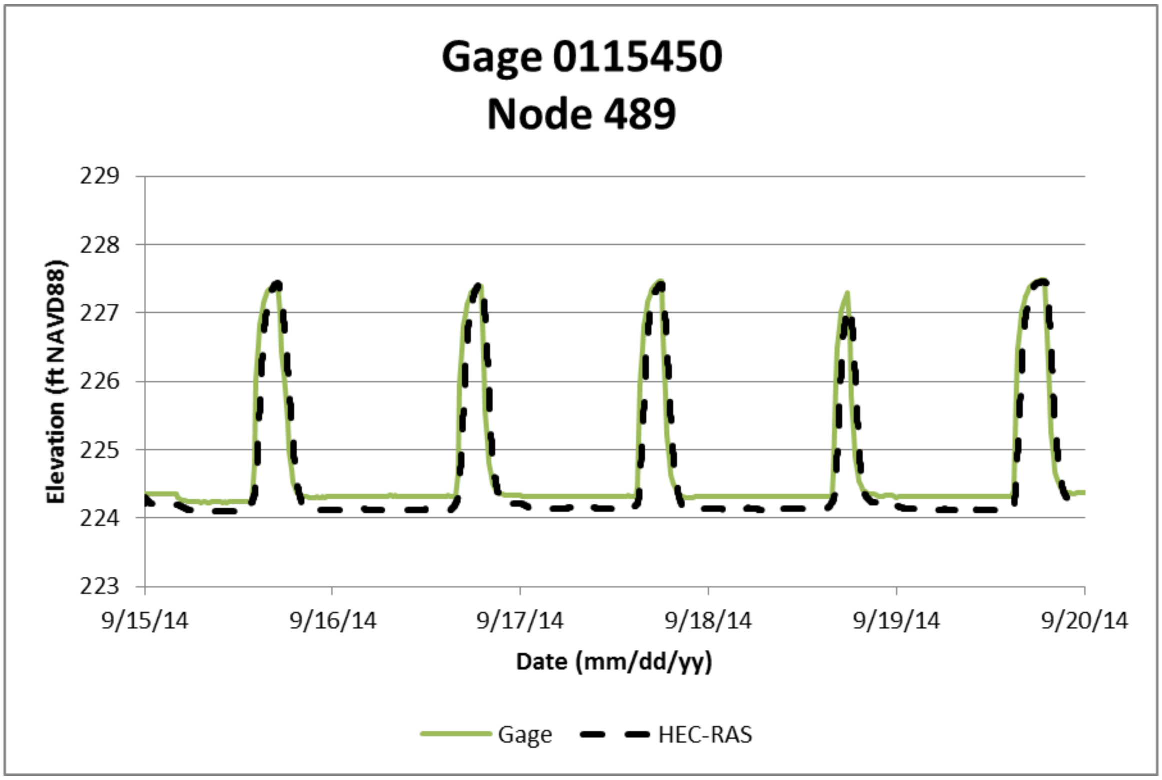
Logger BR01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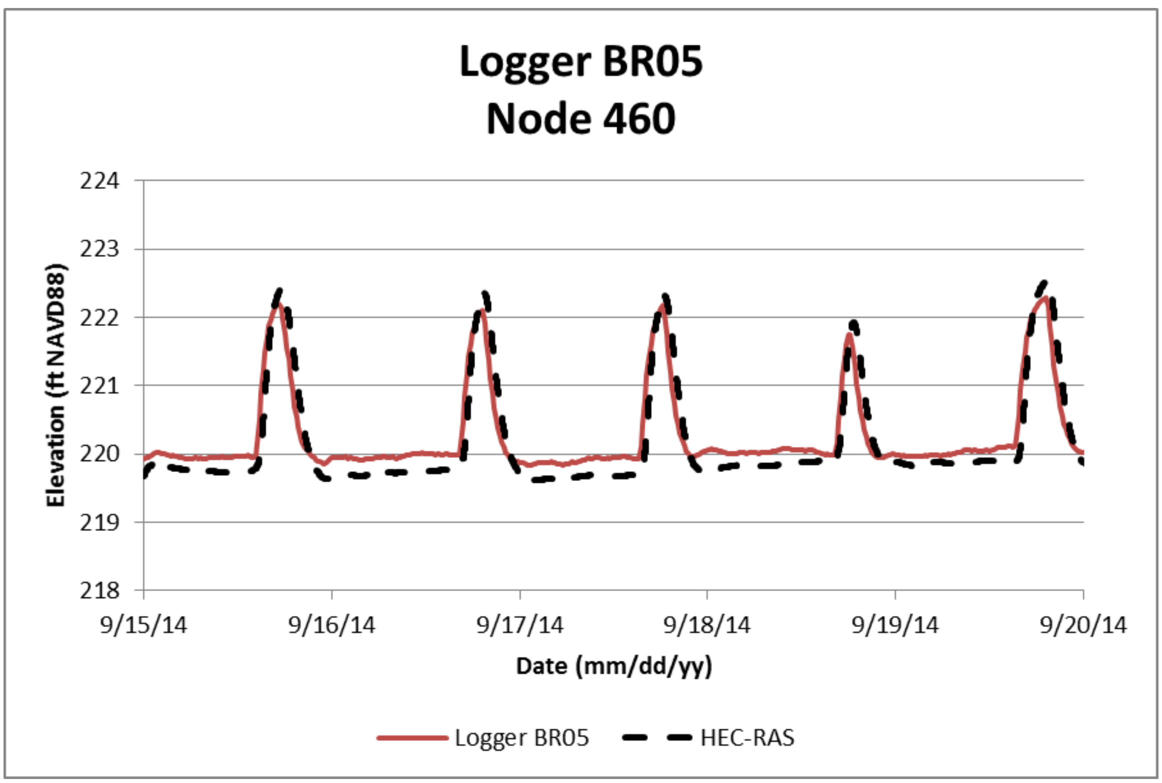
Gage
HEC-RAS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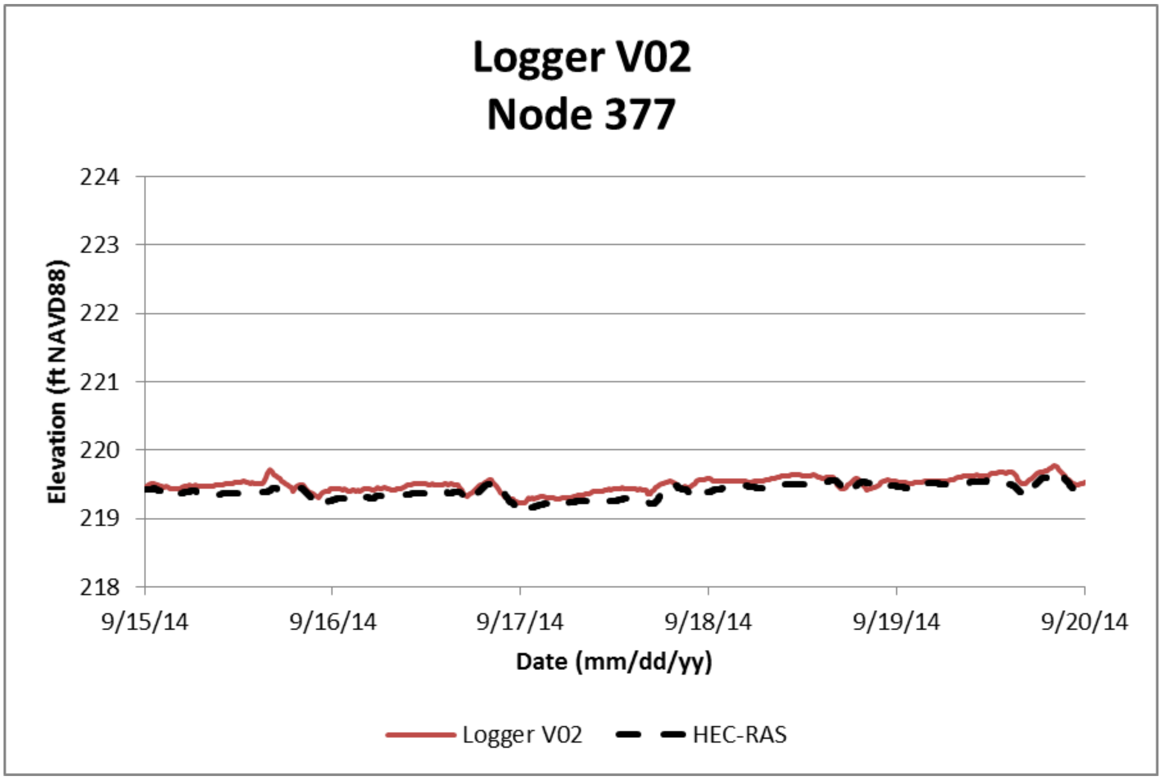
9/20/14
Date (mm/dd/yy)
Logger BR05
HEC-RAS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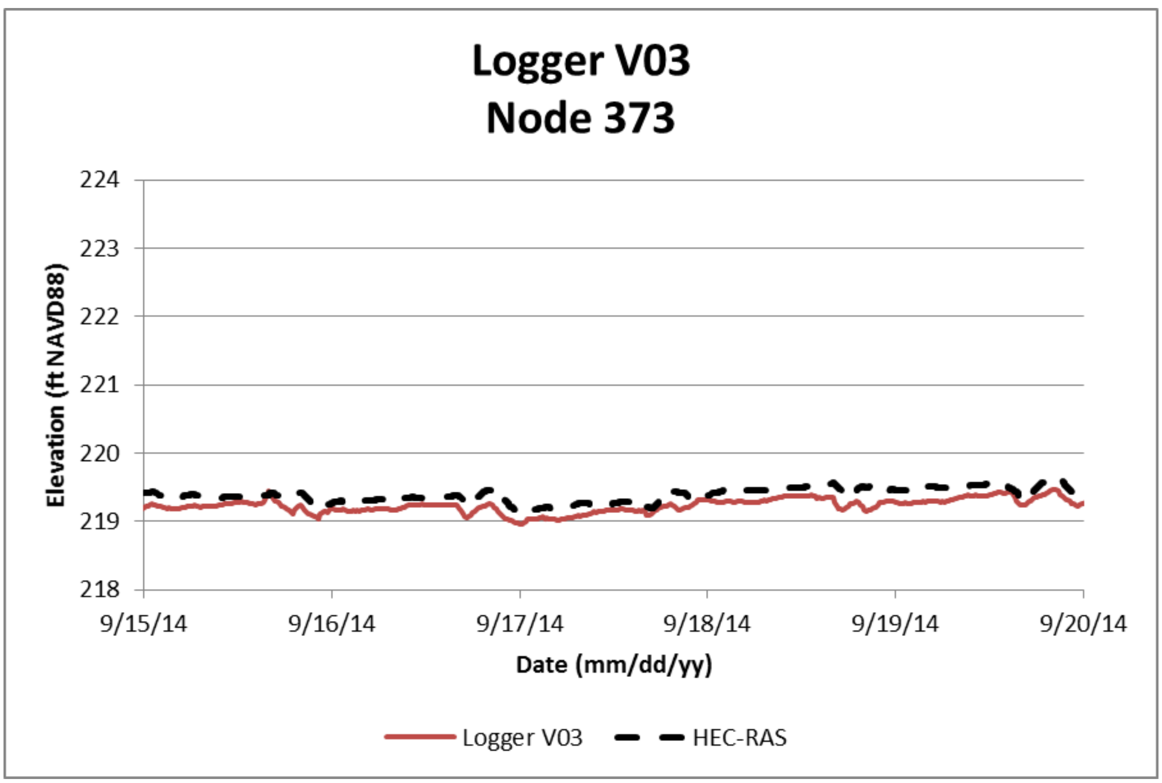
9/19/14
9/20/14
Date (mm/dd/yy)
Logger V02
HEC-RAS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Logger V03
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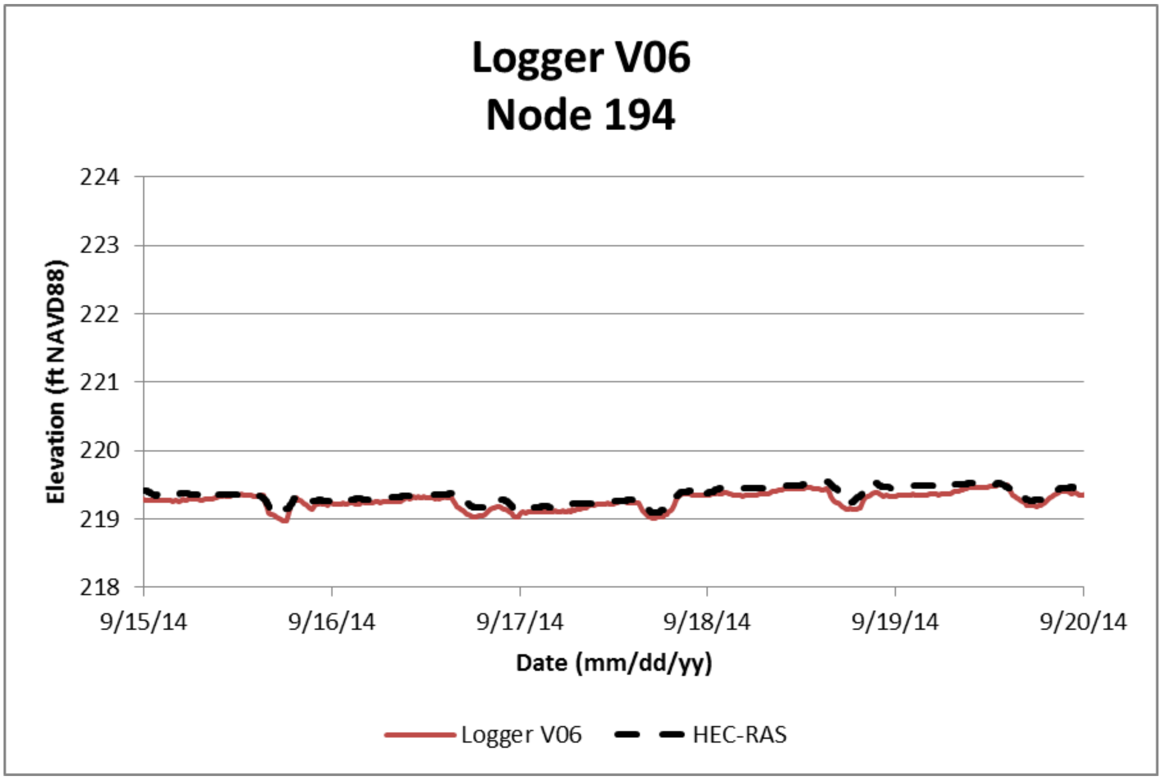
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Date (mm/dd/yy)
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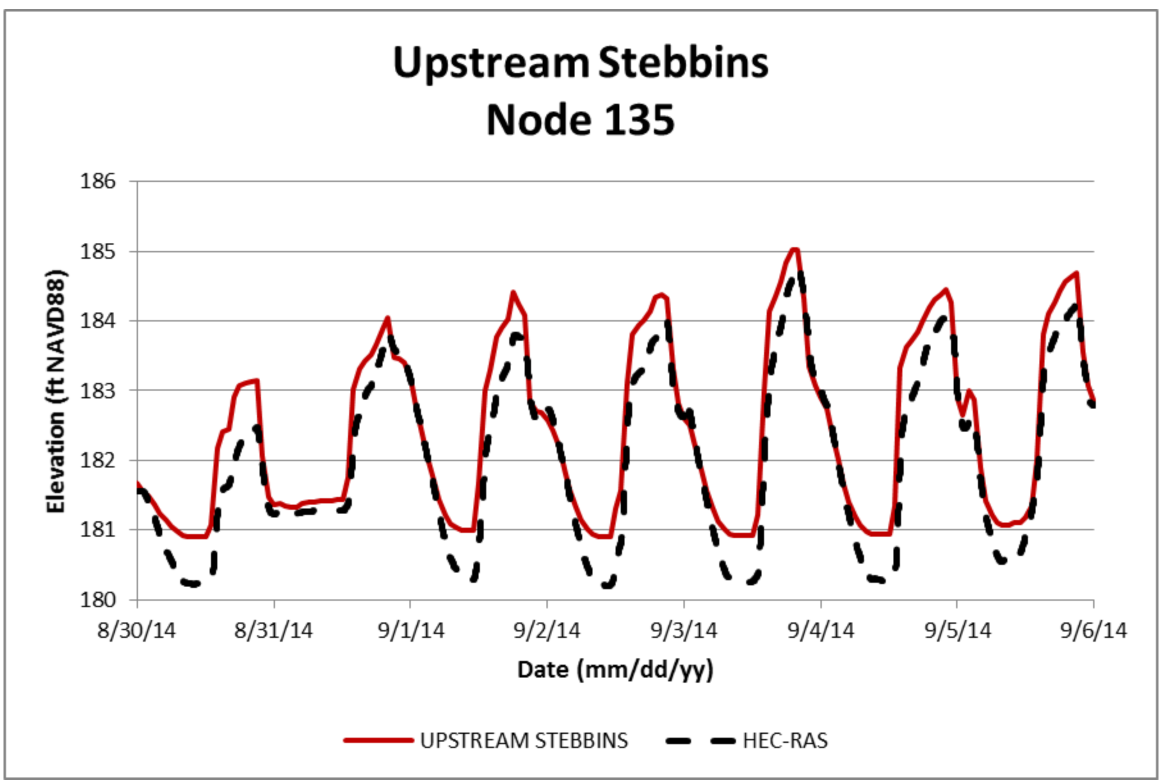
Upstream Stebbins
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Elevation (ft NAVD88)
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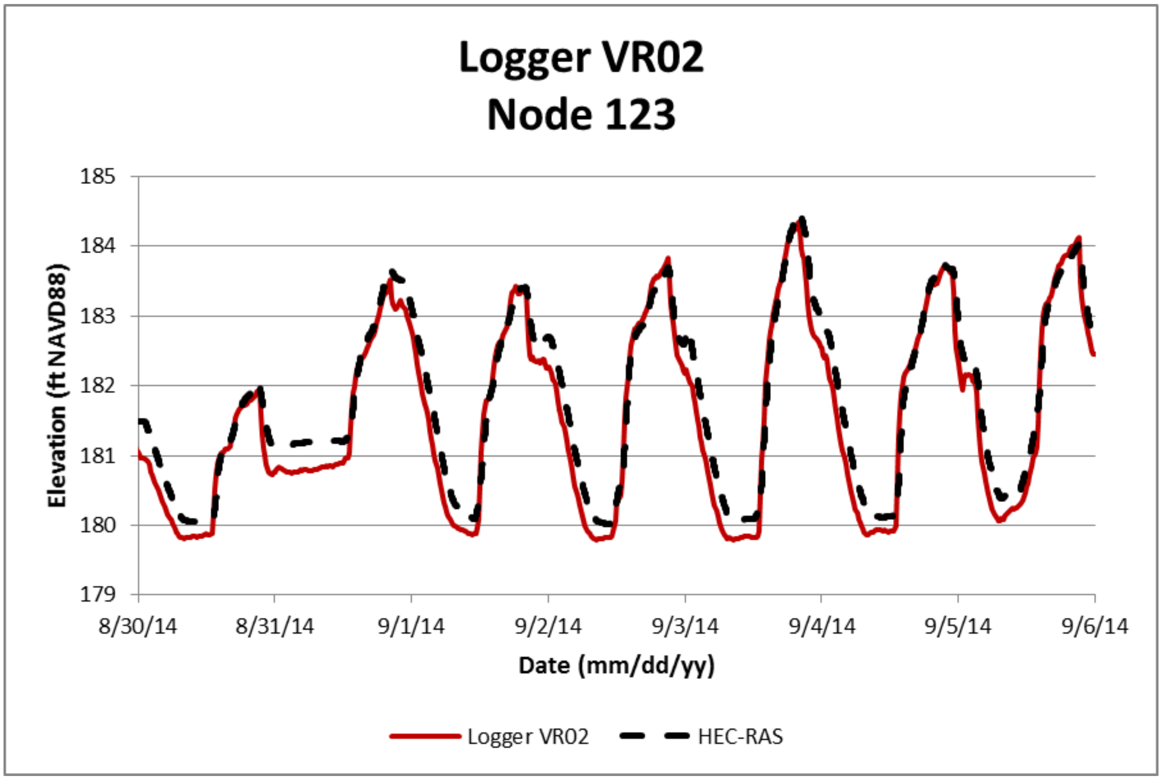
Date (mm/dd/yy)
UPSTREAM STEBBINS
HEC-RAS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Elevation (ft NAVD88)
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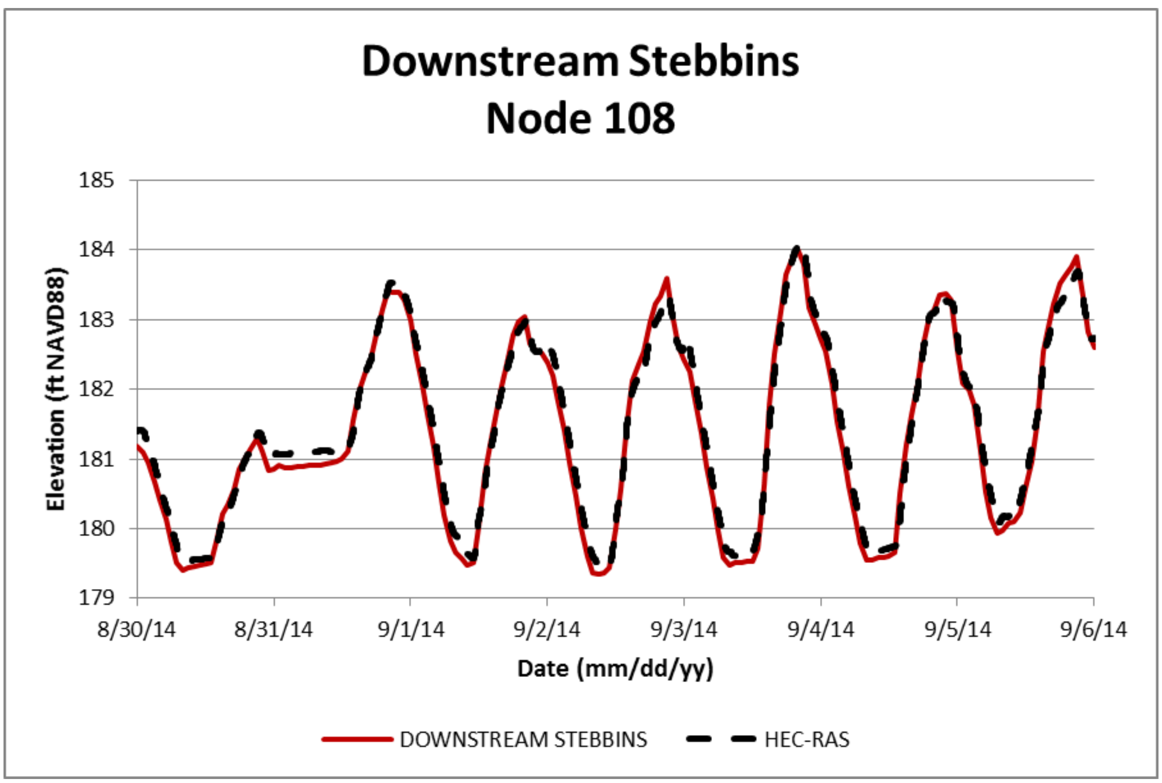
Logger VR02
HEC-RAS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Date (mm/dd/yy)
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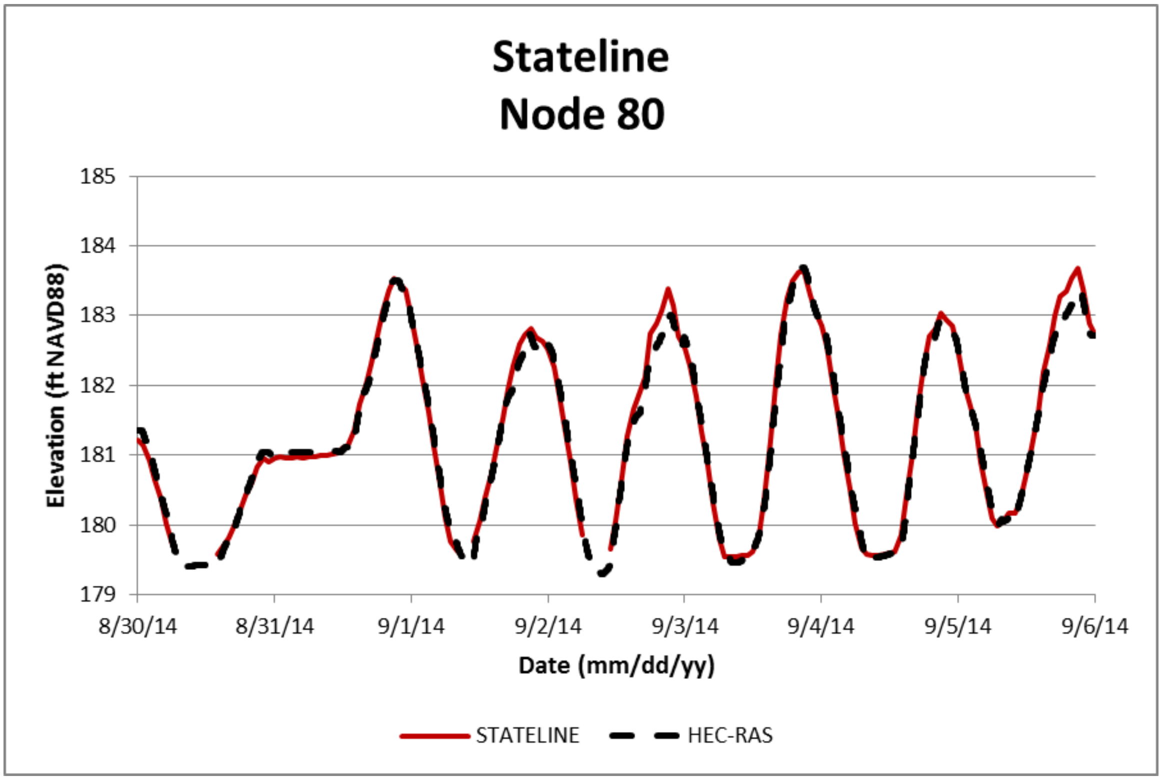
Stateline
Node 80
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9/5/14
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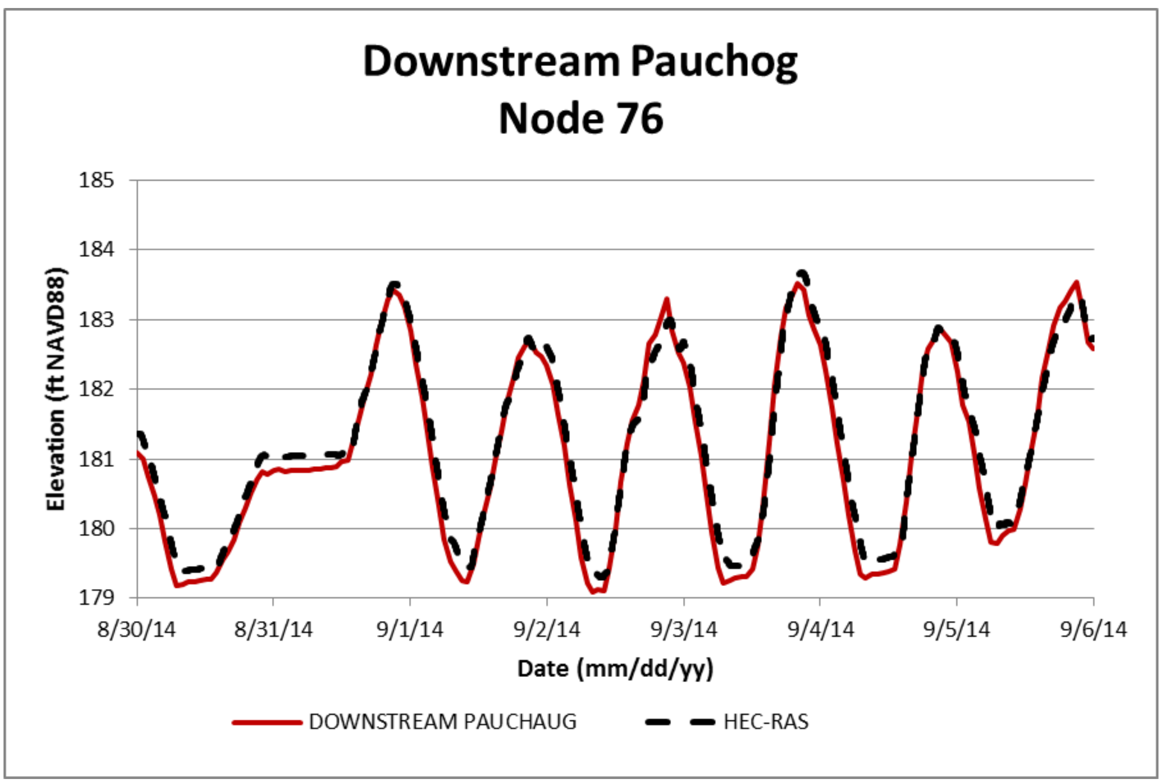
Date (mm/dd/yy)
STATELINE
HEC-RAS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Date (mm/dd/yy)
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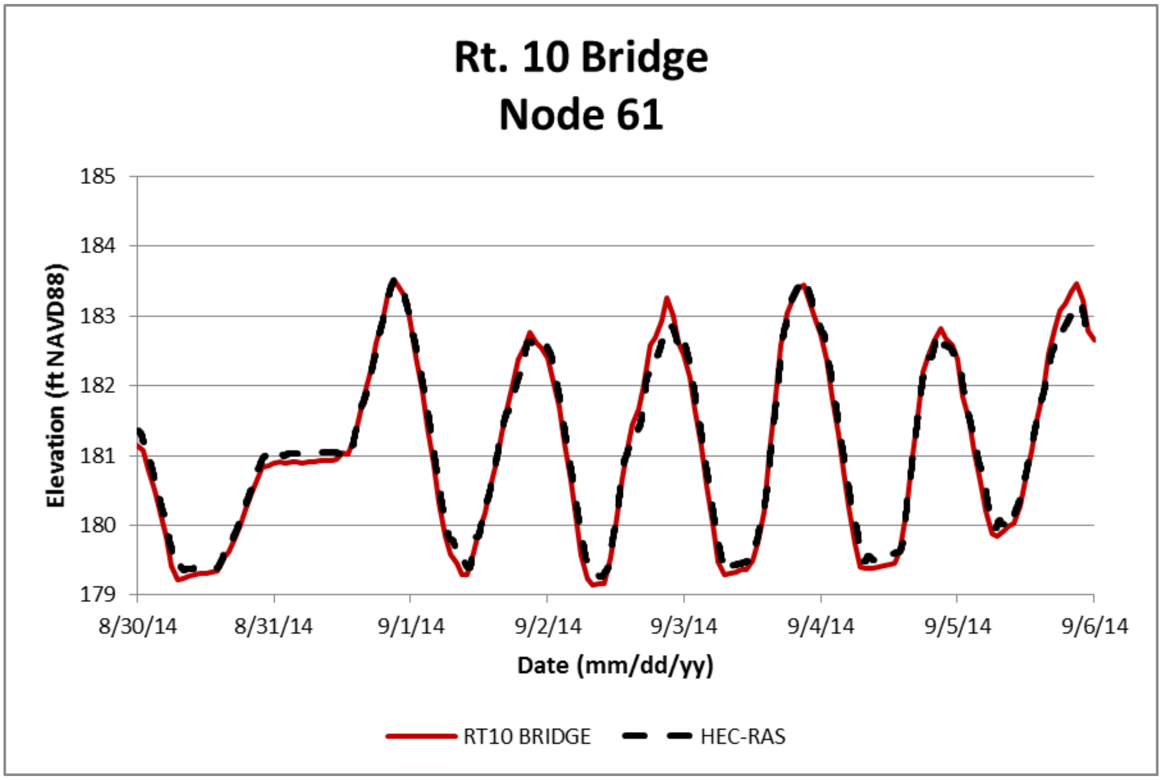
HEC-RAS


Rt. 10 Bridge
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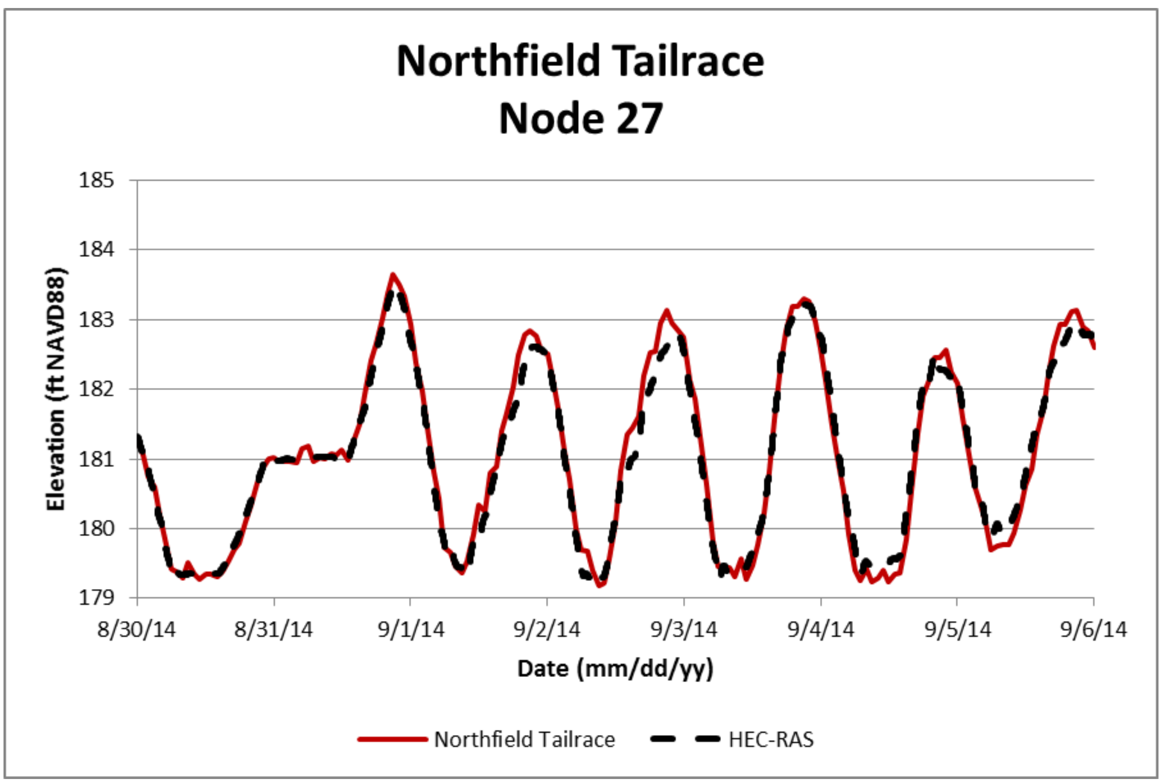
RT10 BRIDGE
HEC-RAS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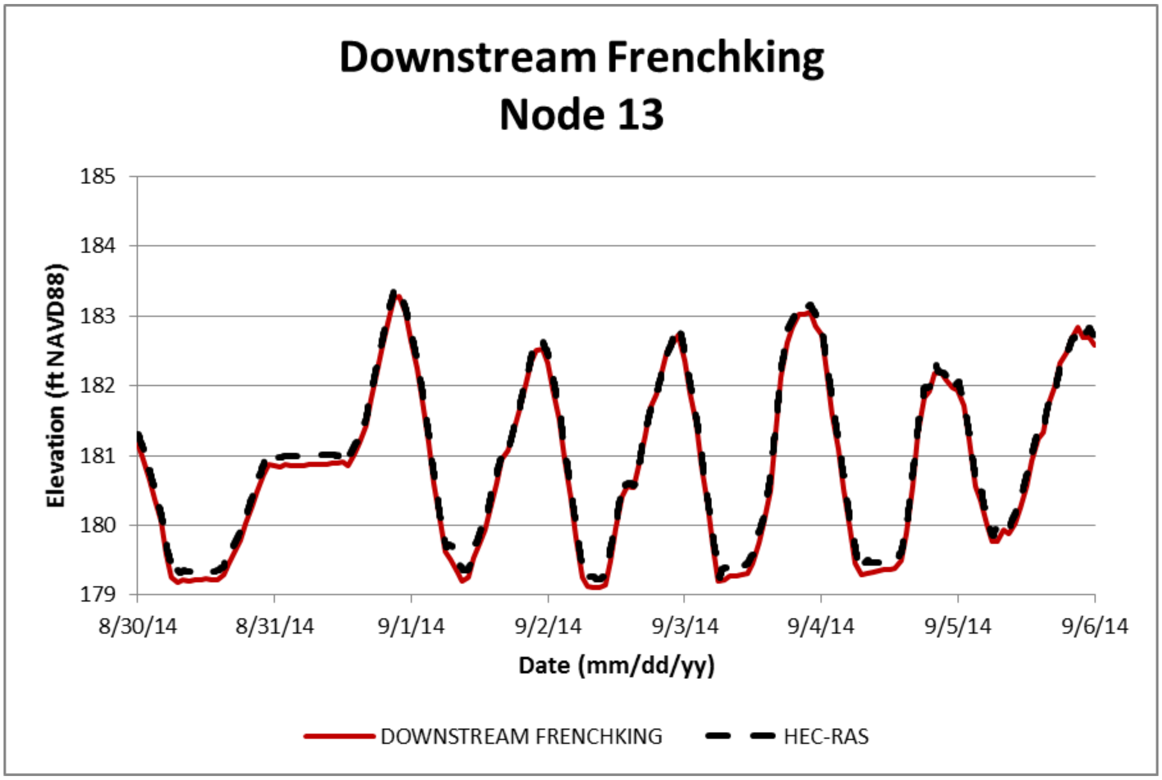
Date (mm/dd/yy)
Northfield Tailrace
HEC-RAS


Downstream Frenchking
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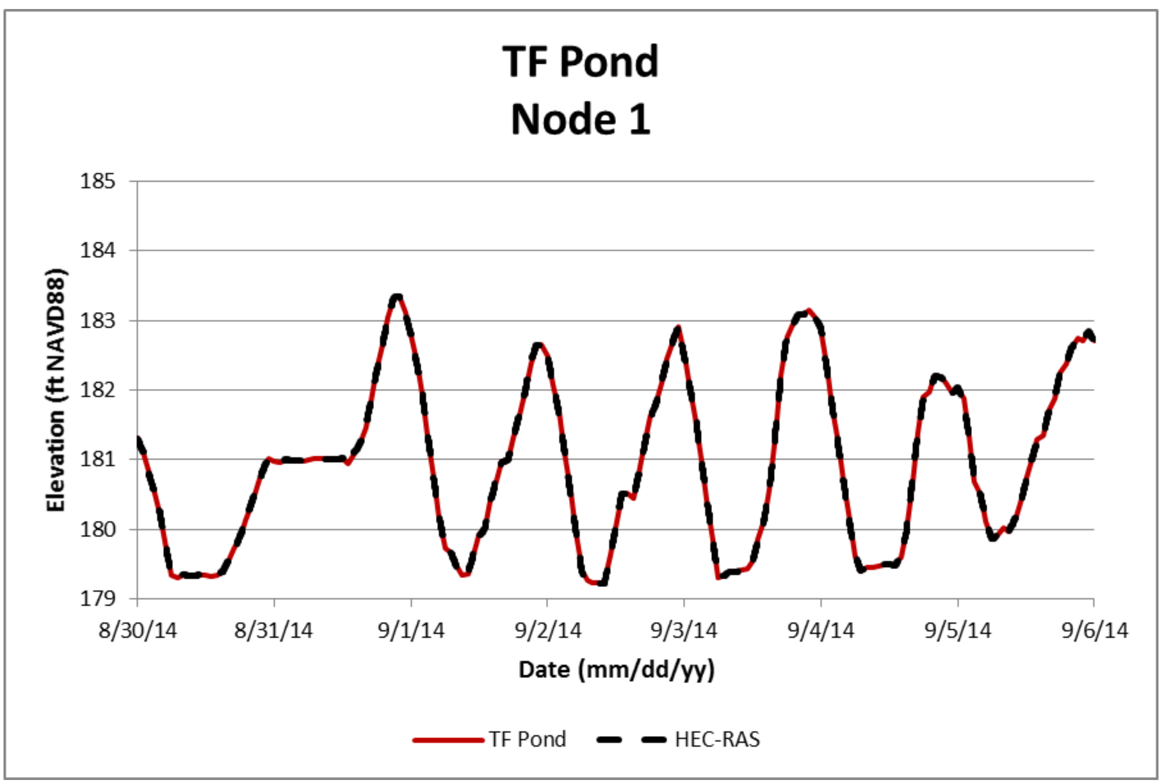
Date (mm/dd/yy)
DOWNSTREAM FRENCHKING
HEC-RAS


TF Pond
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Elevation (ft NAVD88)
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9/4/14
9/5/14
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Date (mm/dd/yy)
TF Pond
HEC-RAS

APPENDIX B-2

Hydraulic Model Calibration Graphs – Spill

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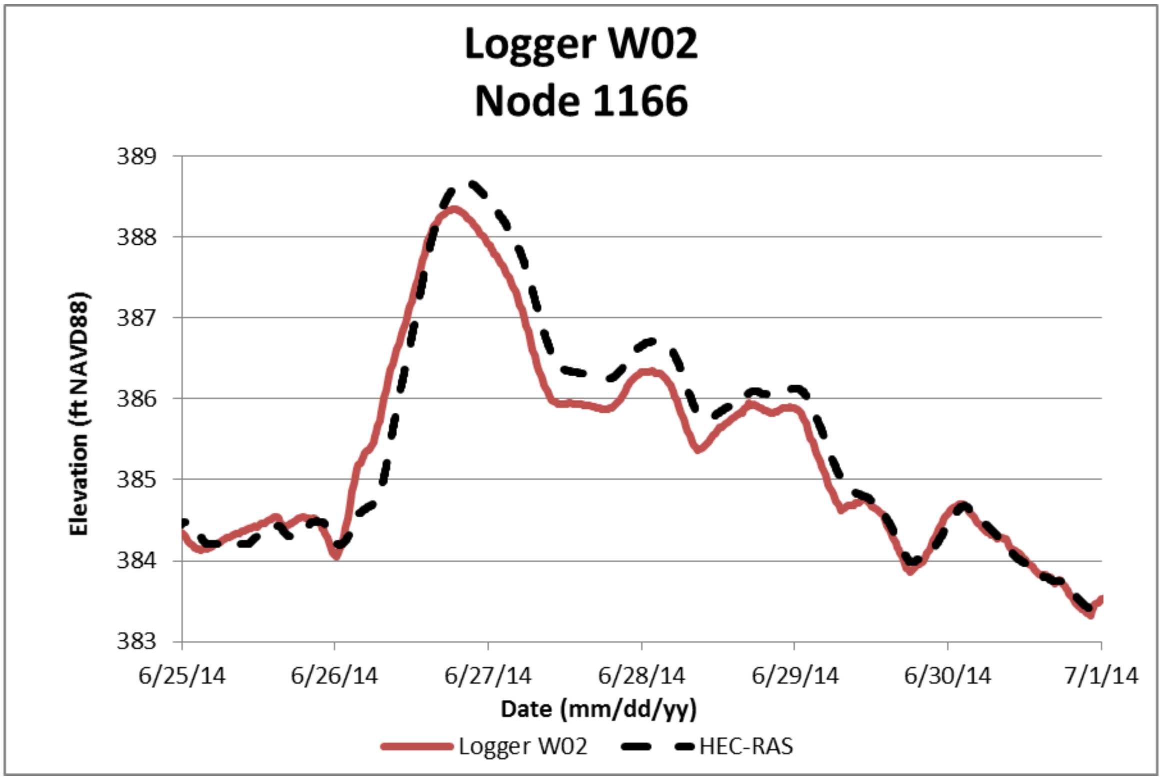
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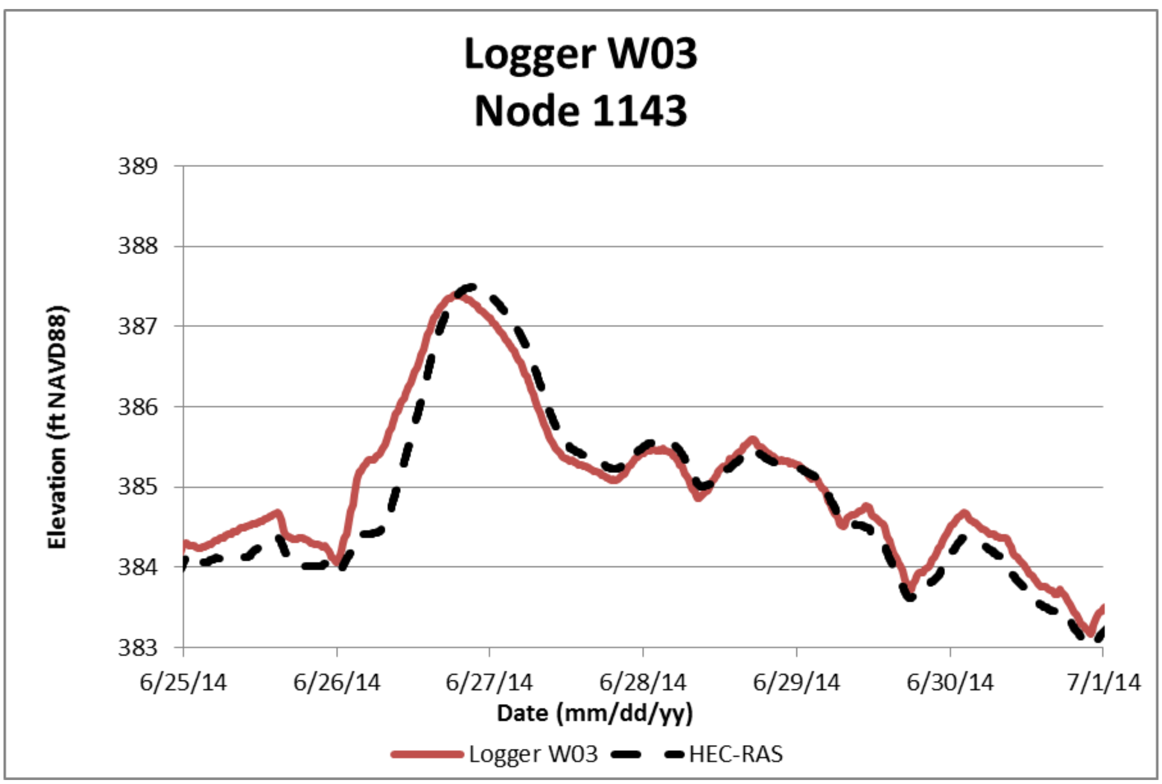
7/1/14
Date (mm/dd/yy)
Logger W02
HEC-RAS


Logger W03
Node 1143
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Elevation (ft NAVD88)
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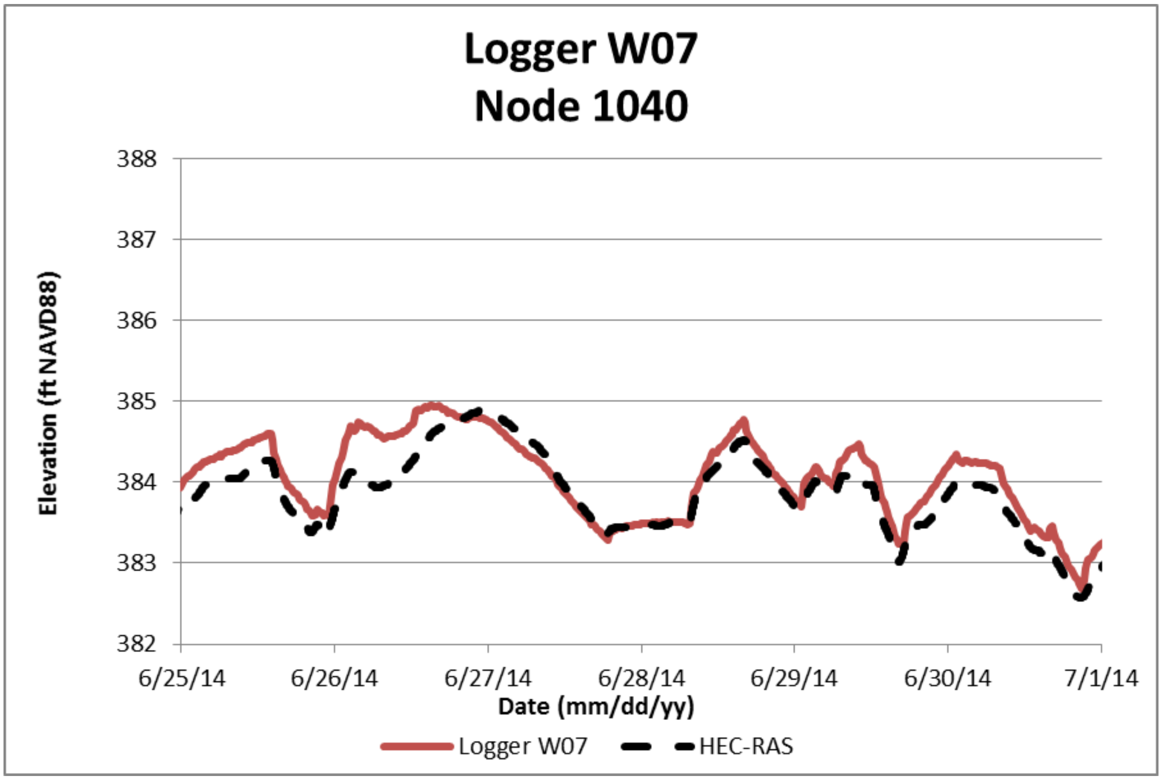
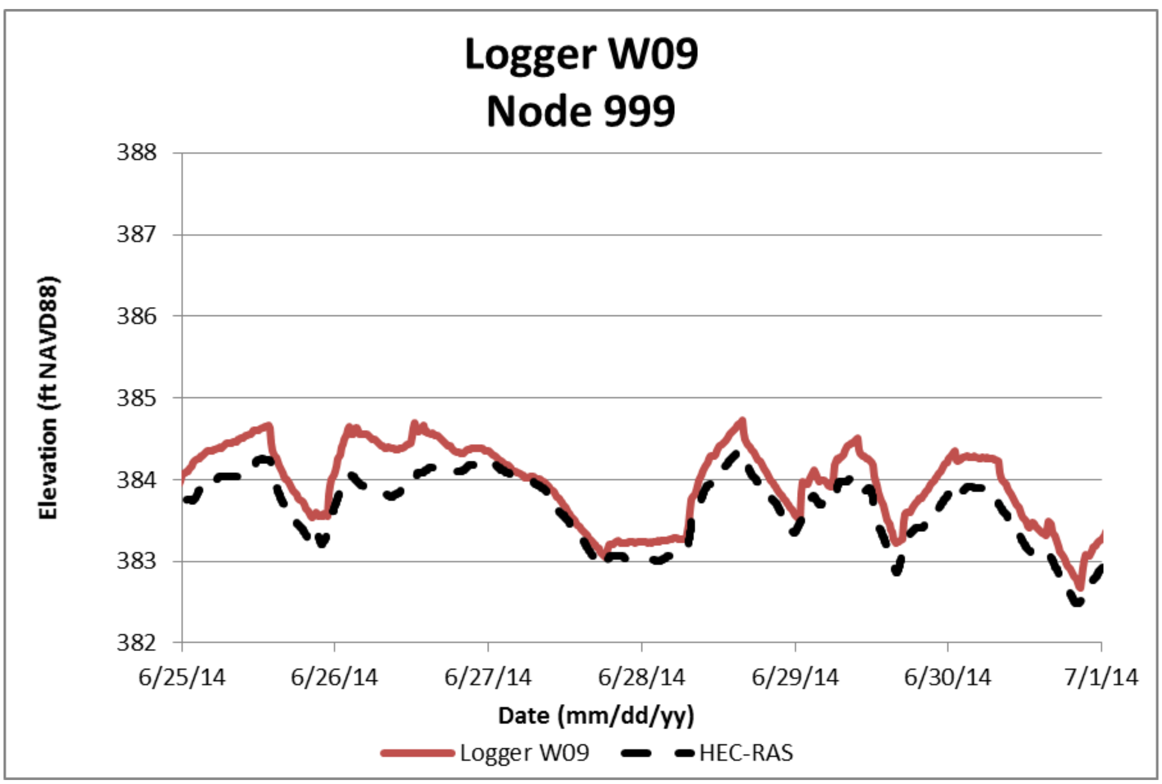
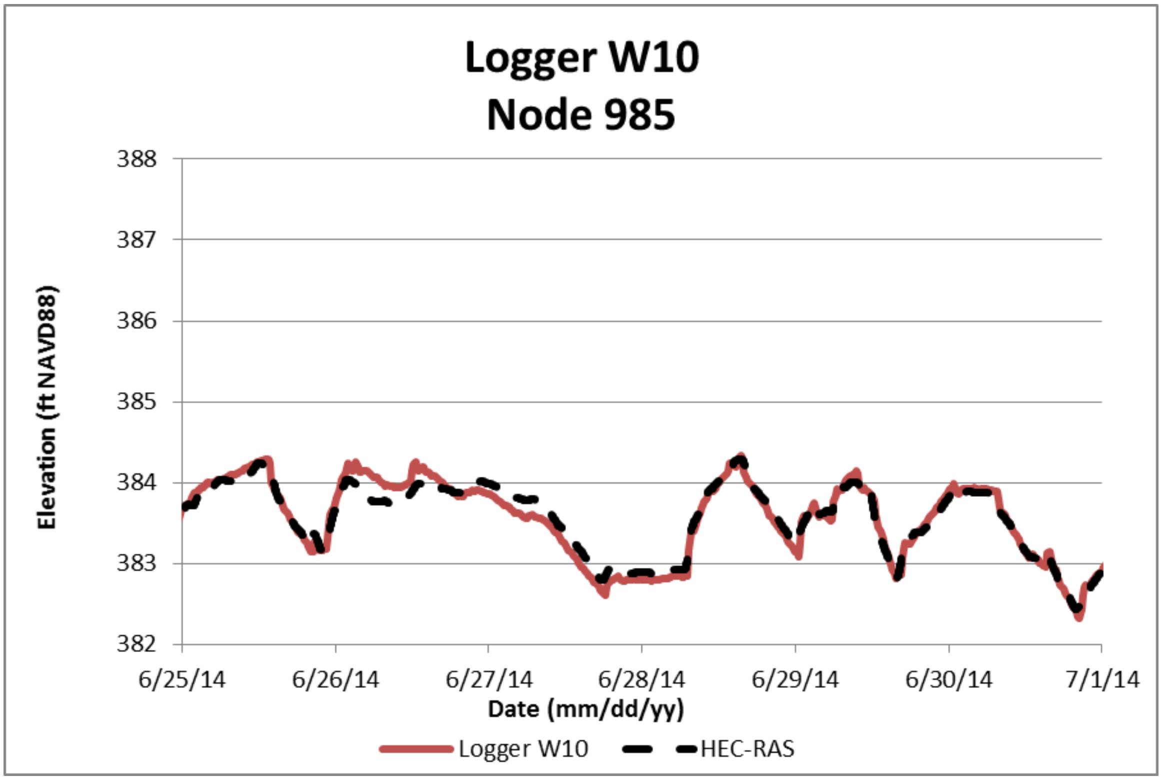
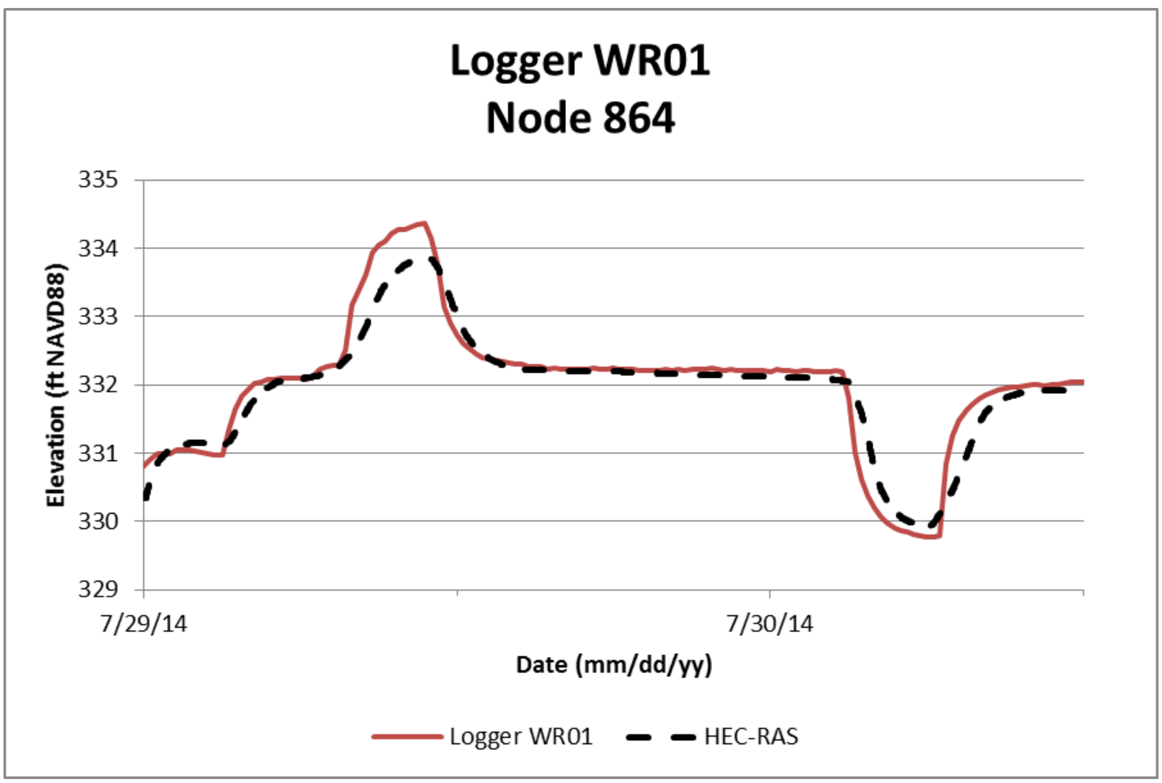
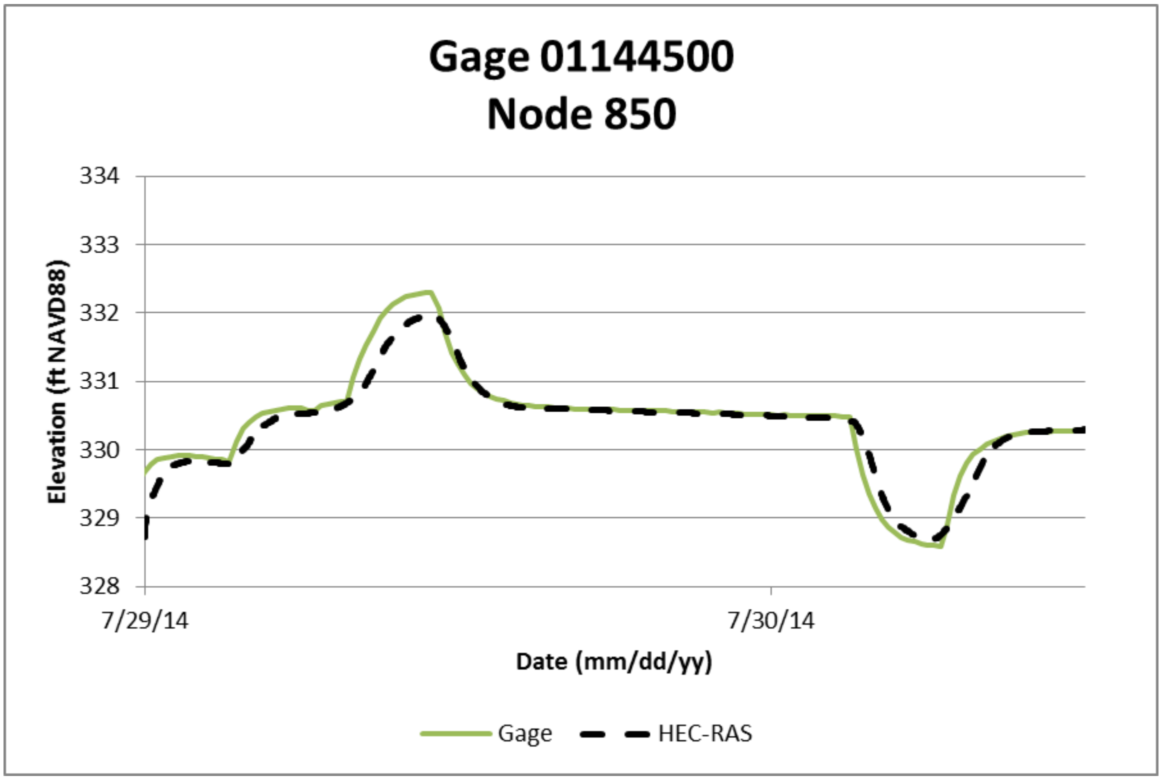
6/29/14
6/30/14
7/1/14
Date (mm/dd/yy)
Logger W03
HEC-RAS

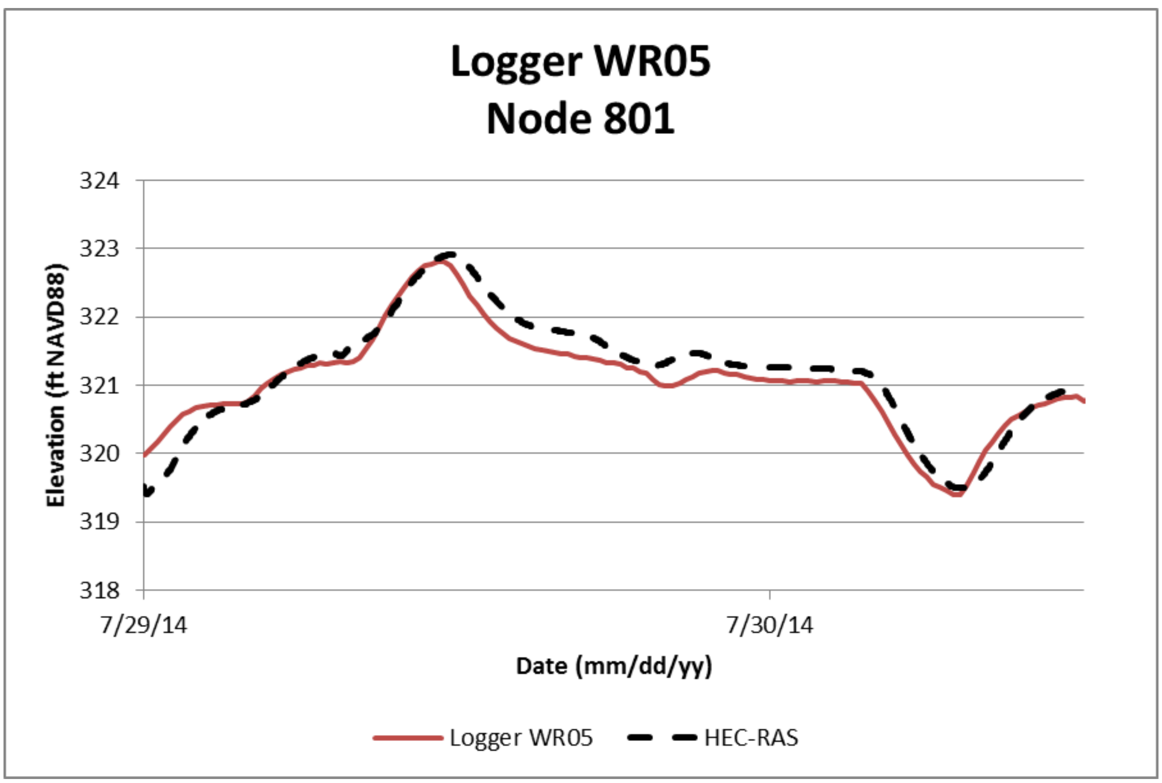

Logger W07
Node 1040
388
387
386
385
384
383
382
Elevation (ft NAVD88)
6/25/14
6/26/14
6/27/14
6/28/14
6/29/14
6/30/14
7/1/14
Date (mm/dd/yy)
Logger W07
HEC-RAS

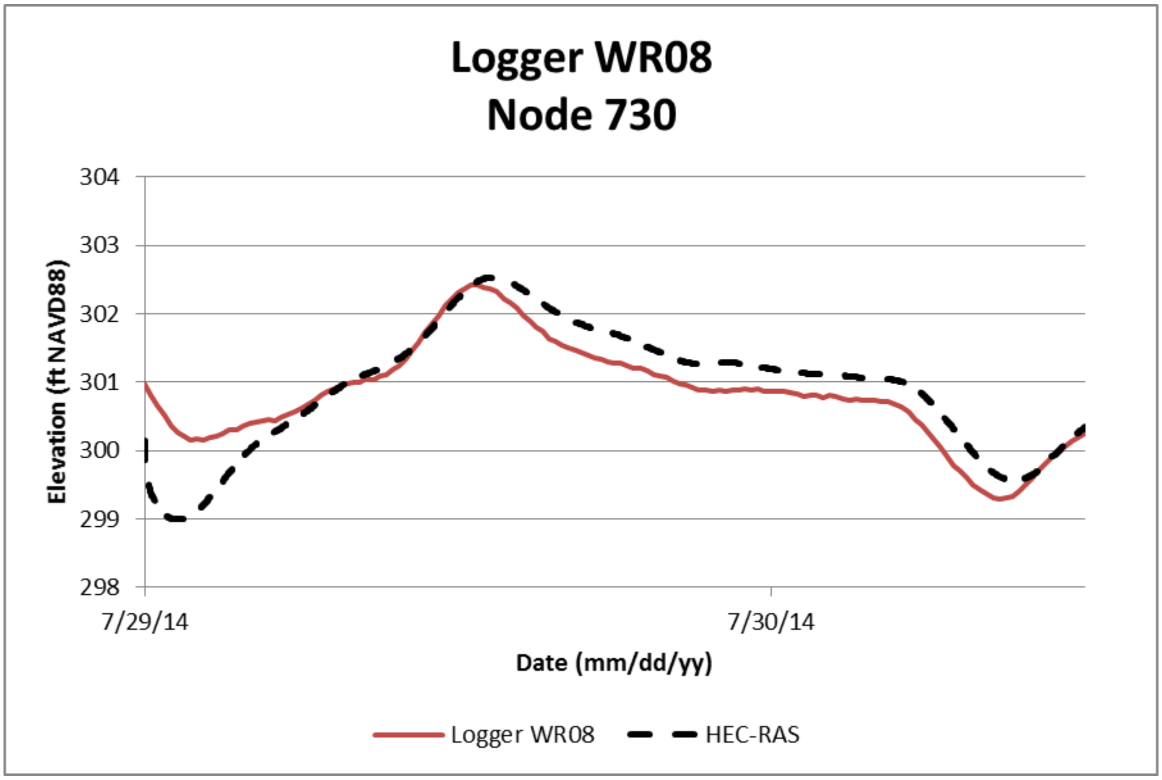

Logger W09
Node 999
388
387
386
385
384
383
382
Elevation (ft NAVD88)
6/25/14
6/26/14
6/27/14
6/28/14
6/29/14
6/30/14
7/1/14
Date (mm/dd/yy)
Logger W09
HEC-RAS

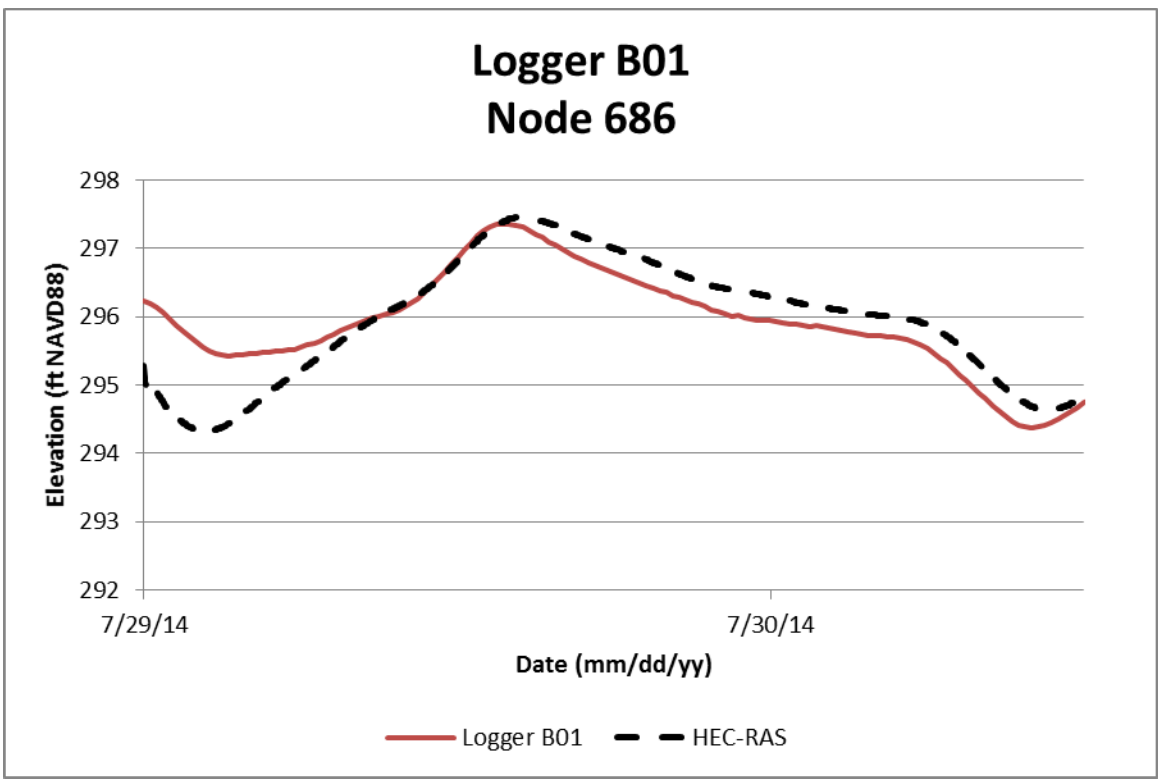

Logger W10
Node 985
388
387
386
385
384
383
382
Elevation (ft NAVD88)
6/25/14
6/26/14
6/27/14
6/28/14
6/29/14
6/30/14
7/1/14
Date (mm/dd/yy)
Logger W10
HEC-RAS

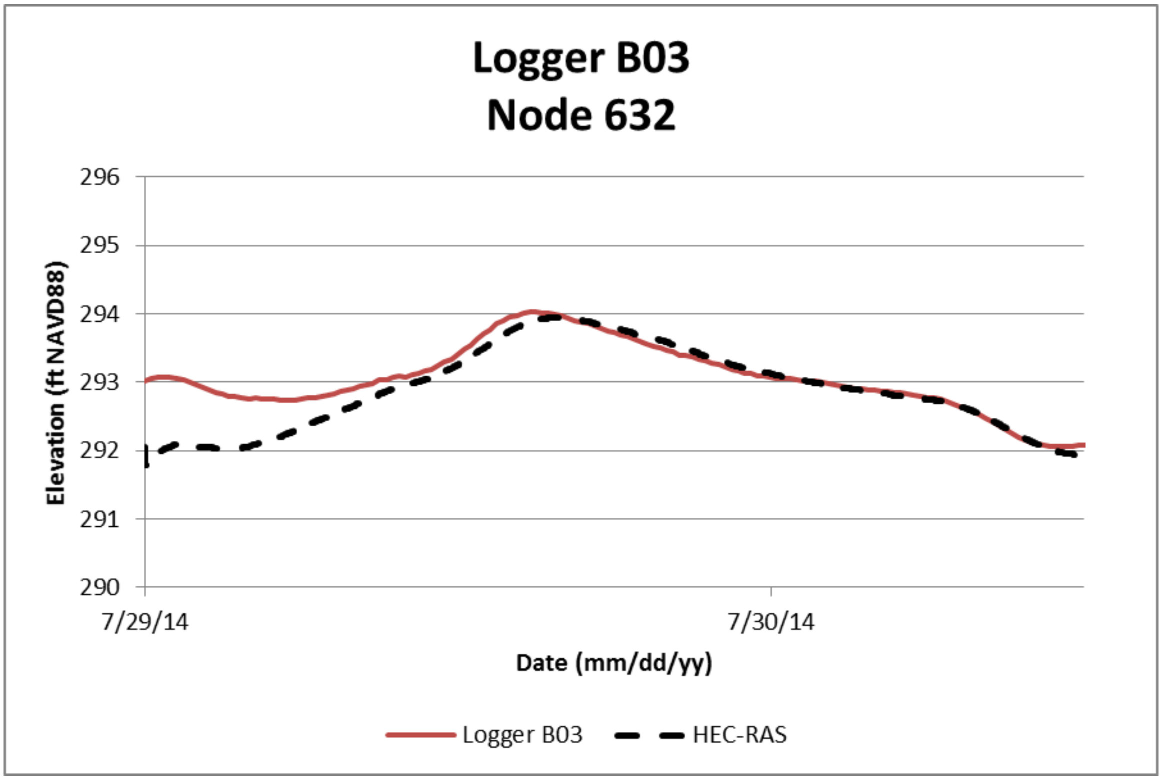

Logger WR01
Node 864
335
334
333
332
331
330
329
Elevation (ft NAVD88)
7/29/14
7/30/14
Date (mm/dd/yy)
Logger WR01
HEC-RAS

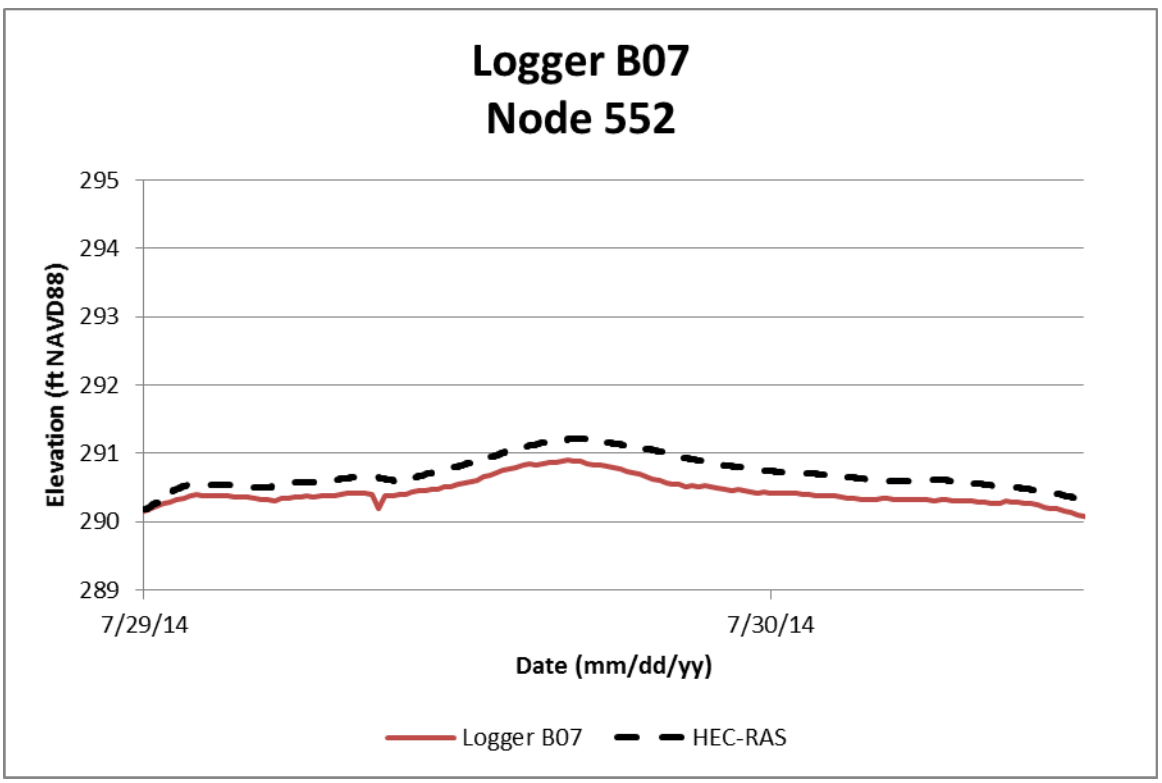

Gage 01144500
Node 850
334
333
332
331
330
329
328
Elevation (ft NAVD88)
7/29/14
7/30/14
Date (mm/dd/yy)
Gage
HEC-RAS

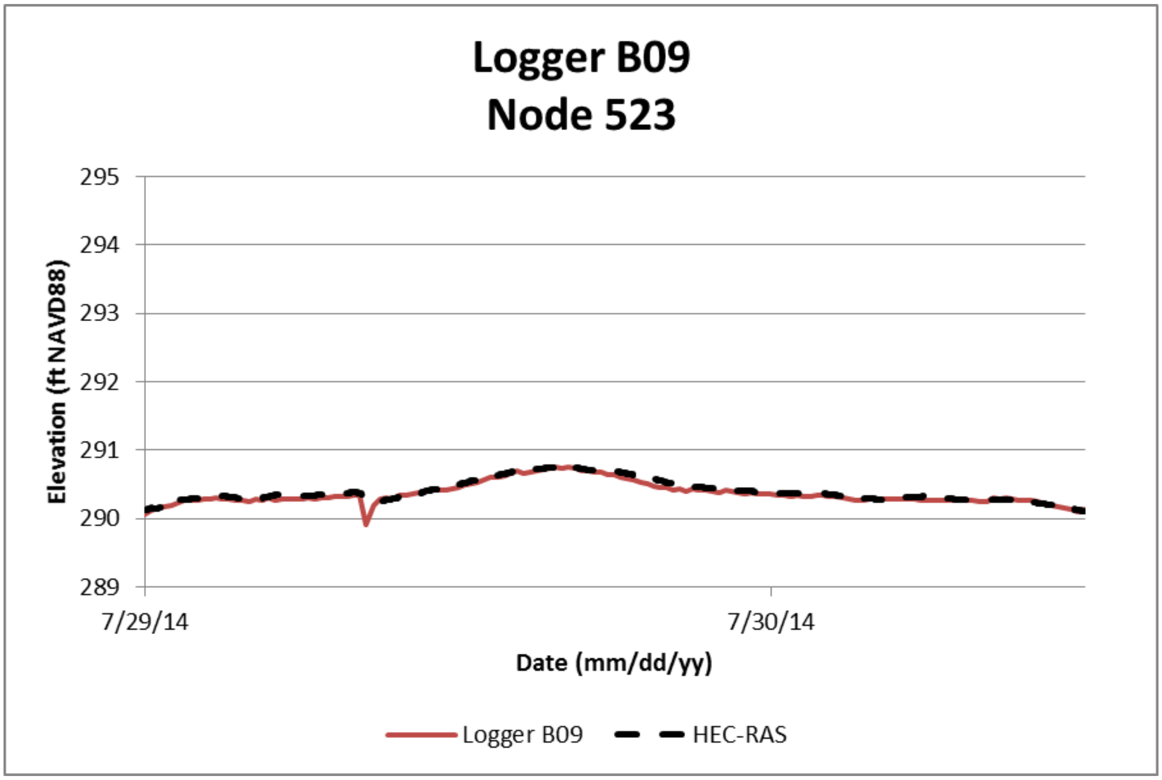

Logger WR05
Node 801
324
323
322
321
320
319
318
Elevation (ft NAVD88)
7/29/14
7/30/14
Date (mm/dd/yy)
Logger WR05
HEC-RAS

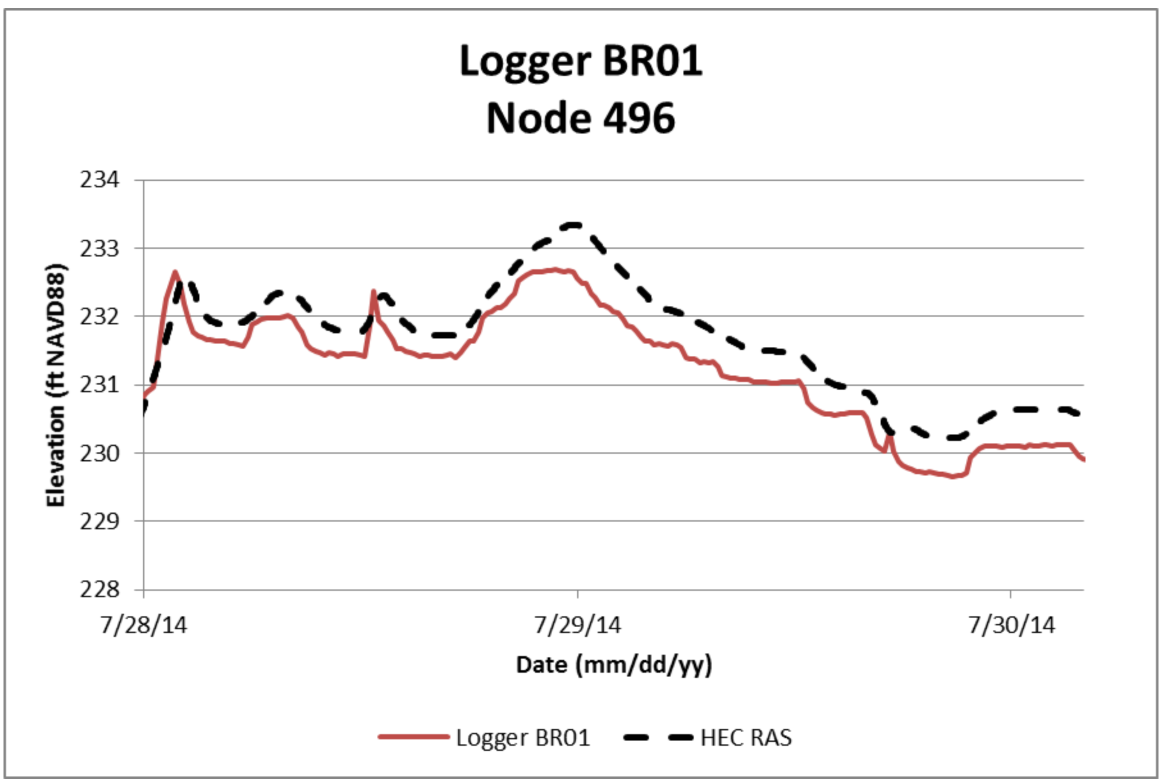

Logger WR08
Node 730
304
303
302
301
300
299
298
Elevation (ft NAVD88)
7/29/14
7/30/14
Date (mm/dd/yy)
Logger WR08
HEC-RAS

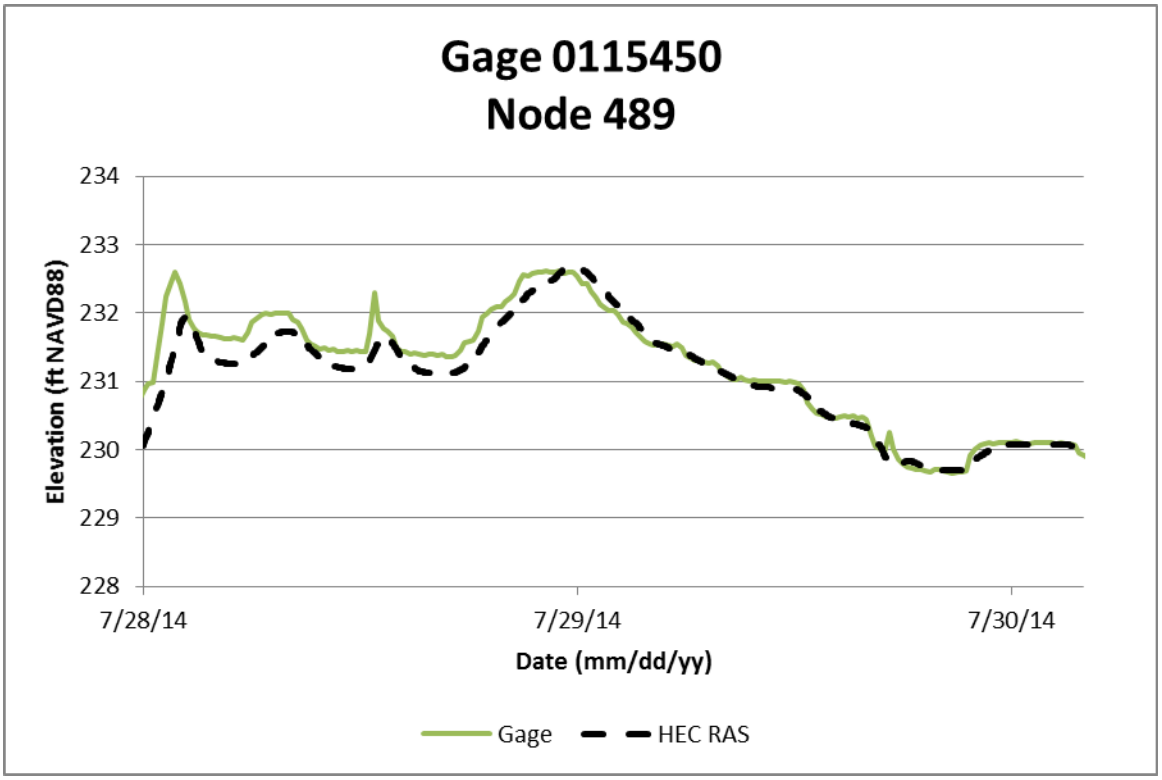

Logger B01
Node 686
298
297
296
295
294
293
292
Elevation (ft NAVD88)
7/29/14
7/30/14
Date (mm/dd/yy)
Logger B01
HEC-RAS

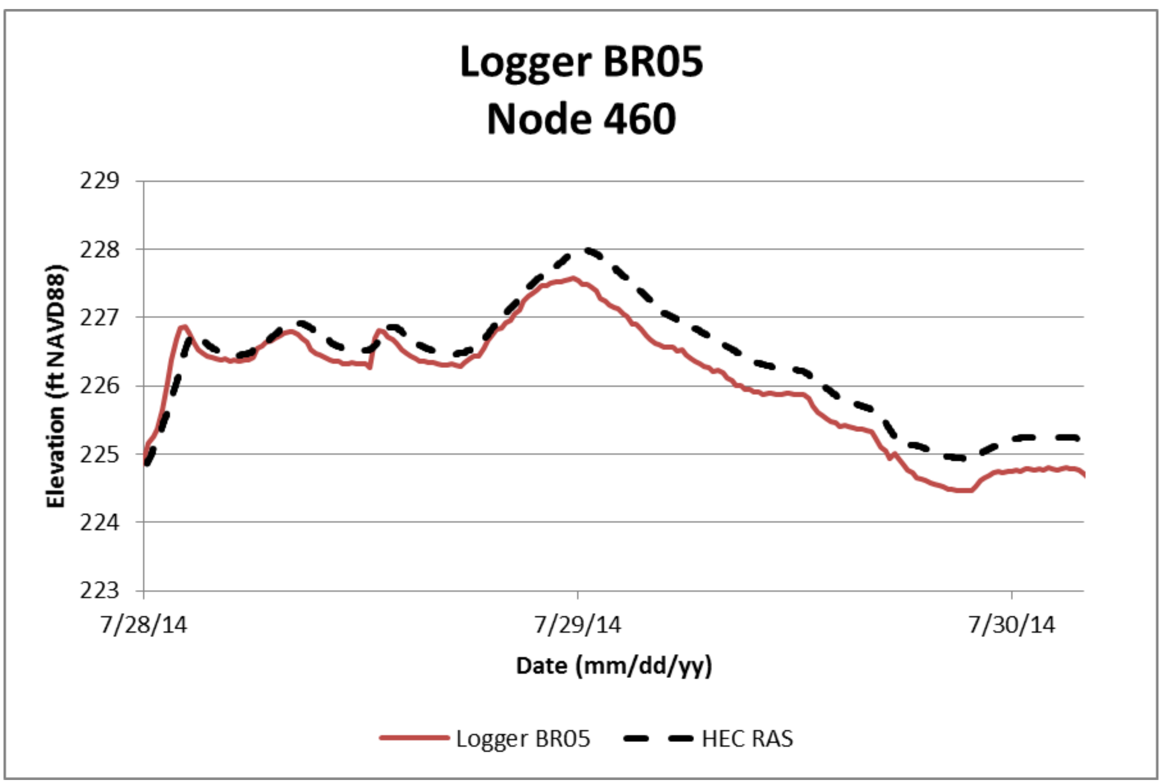

Logger B03
Node 632
296
295
294
293
292
291
290
Elevation (ft NAVD88)
7/29/14
7/30/14
Date (mm/dd/yy)
Logger B03
HEC-RAS

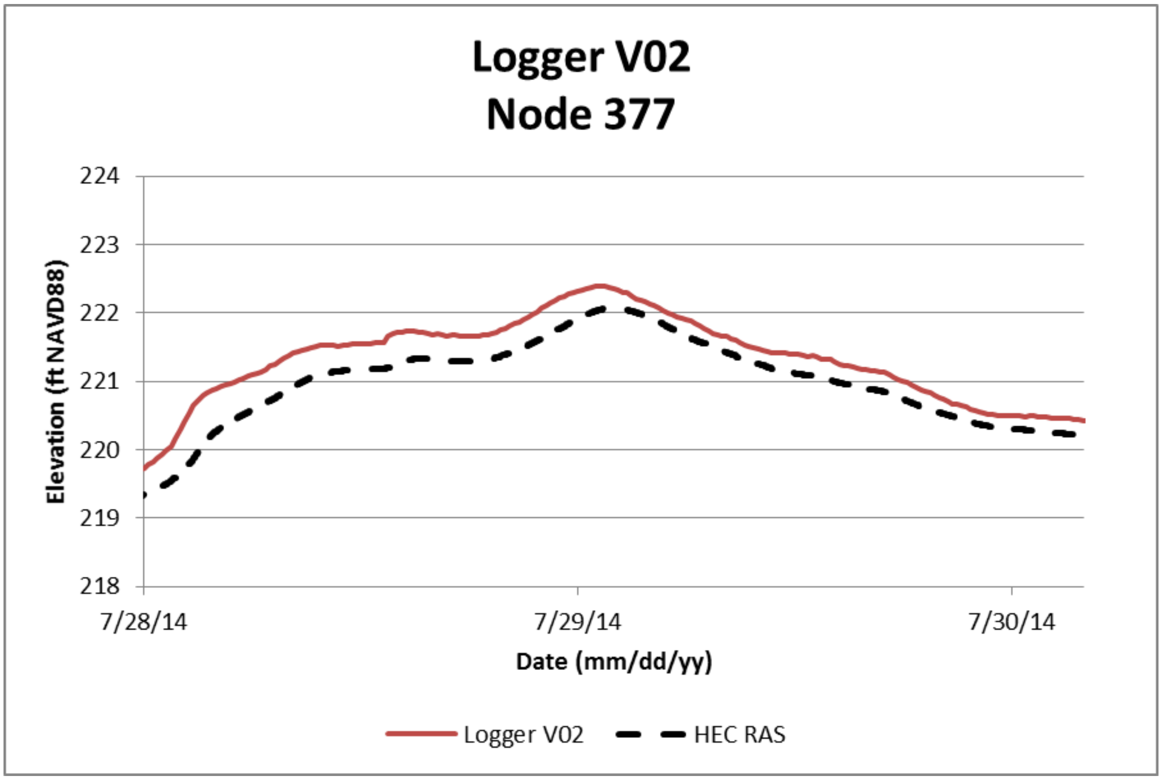

Logger B07
Node 552
295
294
293
292
291
290
289
Elevation (ft NAVD88)
7/29/14
7/30/14
Date (mm/dd/yy)
Logger B07
HEC-RAS

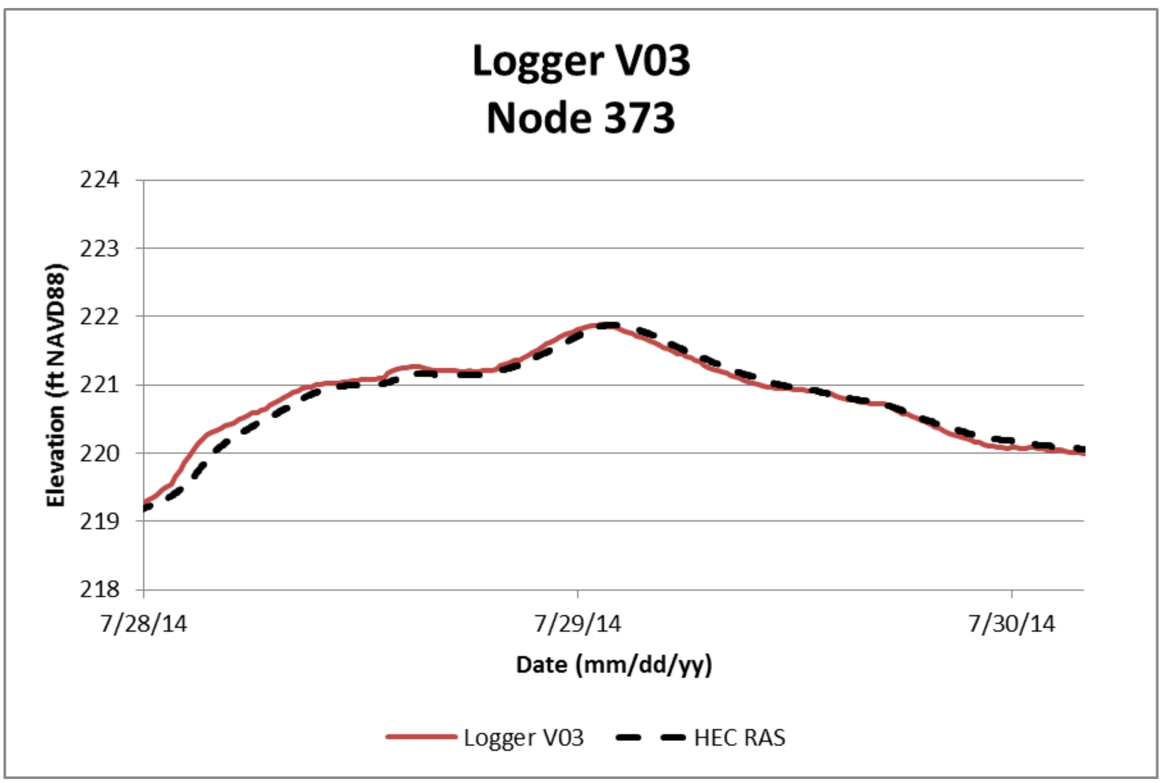

Logger B09
Node 523
295
294
293
292
291
290
289
Elevation (ft NAVD88)
7/29/14
7/30/14
Date (mm/dd/yy)
Logger B09
HEC-RAS

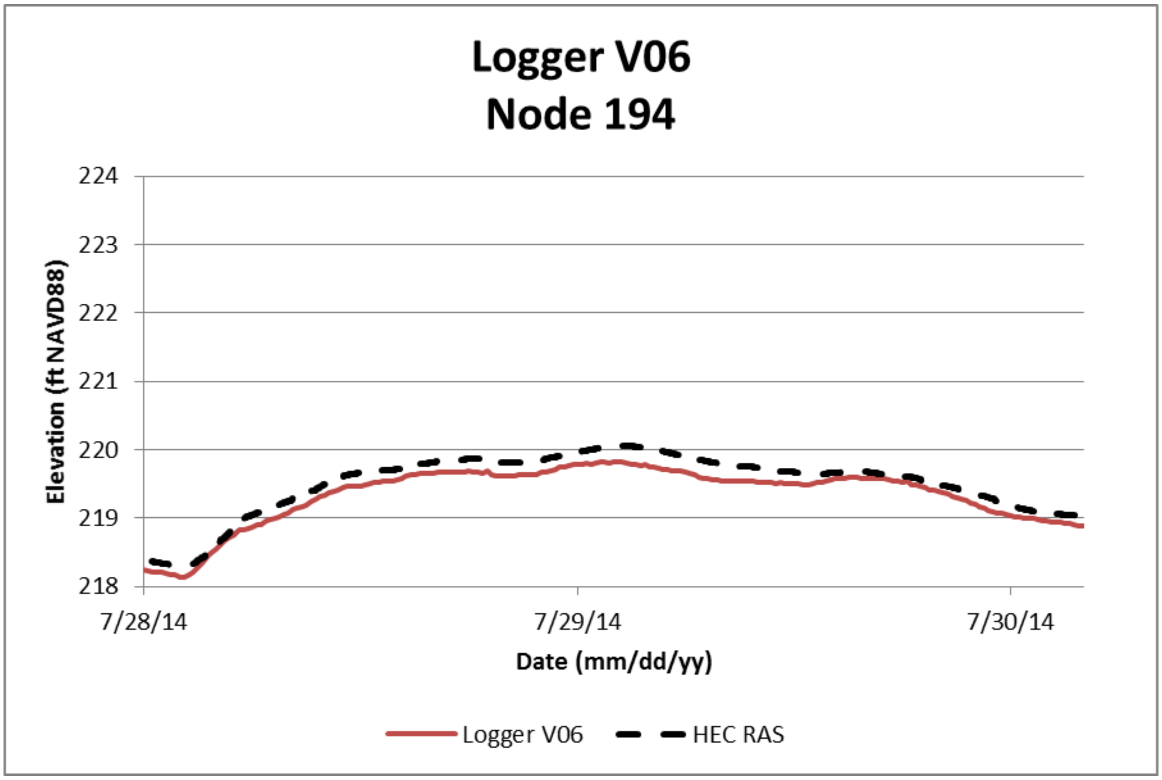

Logger BR01
Node 496
234
233
232
231
230
229
228
Elevation (ft NAVD88)
7/28/14
7/29/14
7/30/14
Date (mm/dd/yy)
Logger BR01
HEC RAS

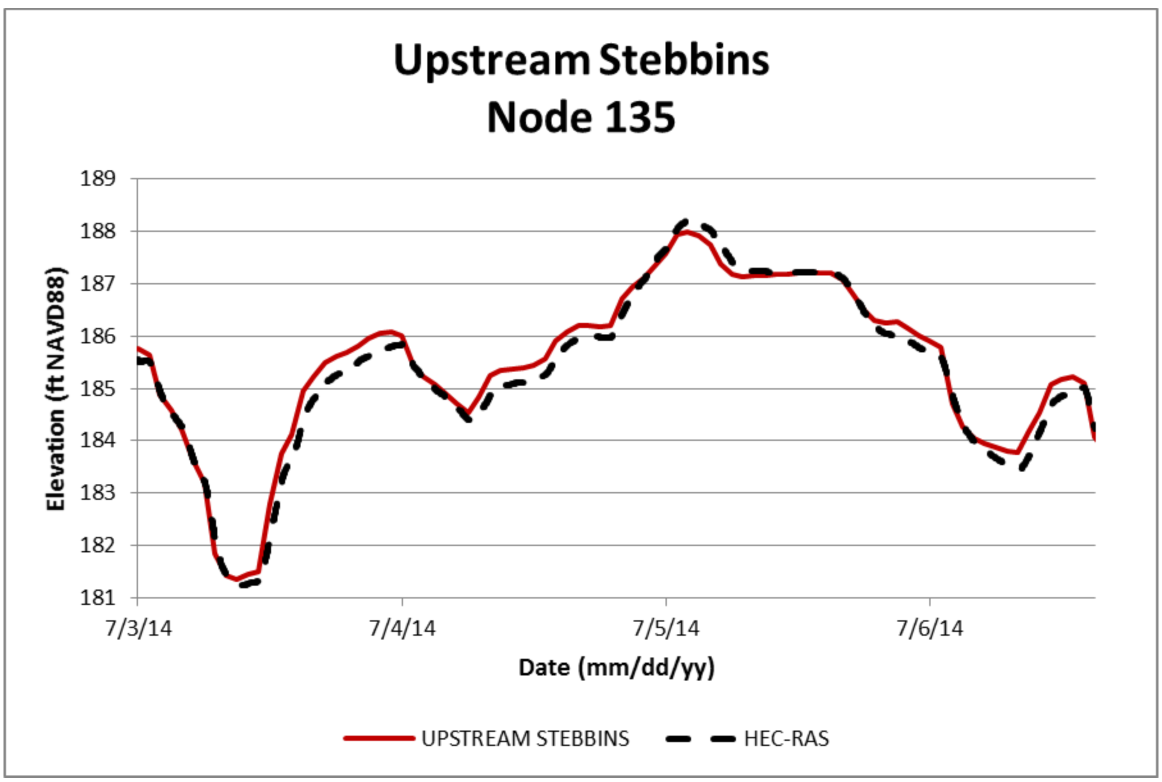

Gage 0115450
Node 489
234
233
232
231
230
229
228
Elevation (ft NAVD88)
7/28/14
7/29/14
7/30/14
Date (mm/dd/yy)
Gage
HEC RAS

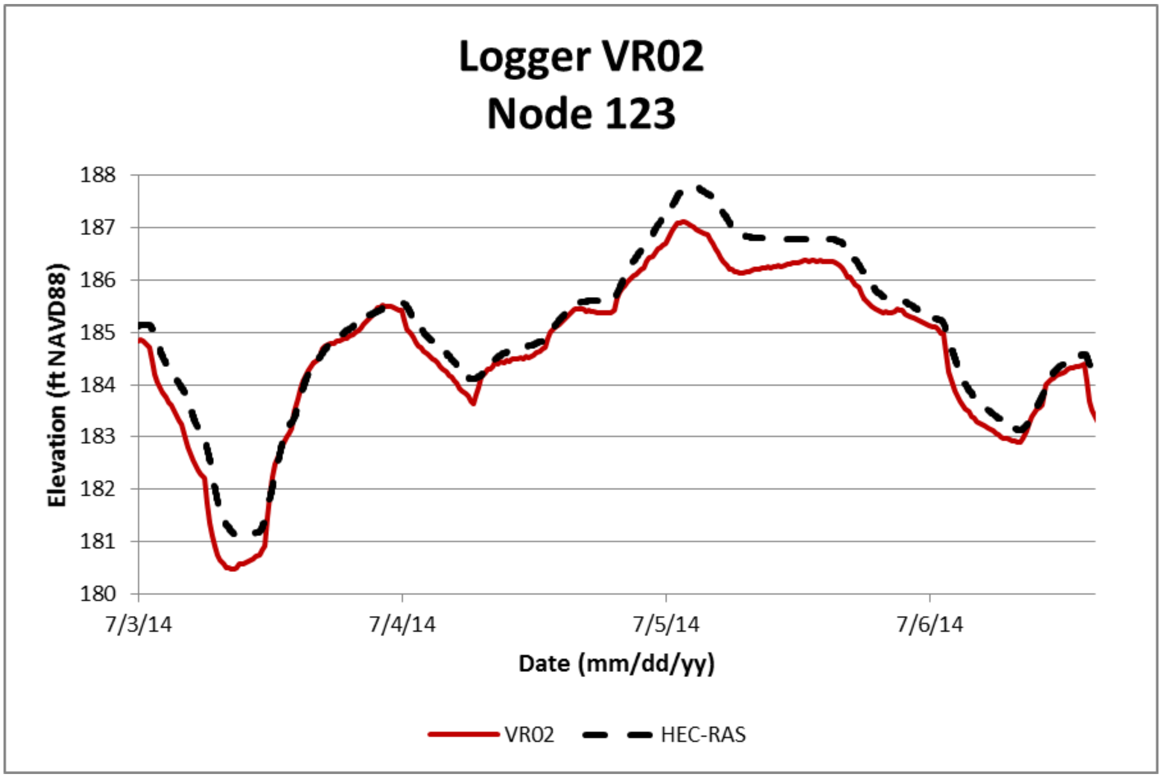

Logger BR05
Node 460
229
228
227
226
225
224
223
Elevation (ft NAVD88)
7/28/14
7/29/14
7/30/14
Date (mm/dd/yy)
Logger BR05
HEC RAS

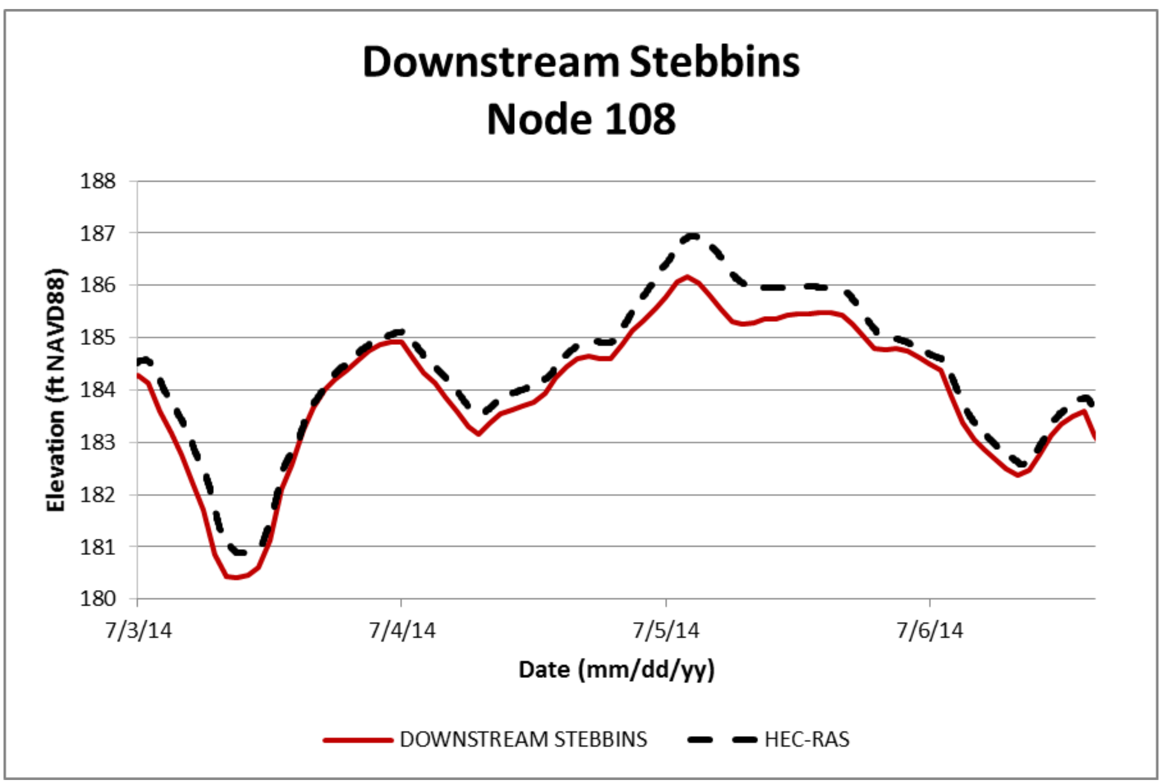

Logger V02
Node 377
224
223
222
221
220
219
218
Elevation (ft NAVD88)
7/28/14
7/29/14
7/30/14
Date (mm/dd/yy)
Logger V02
HEC RAS

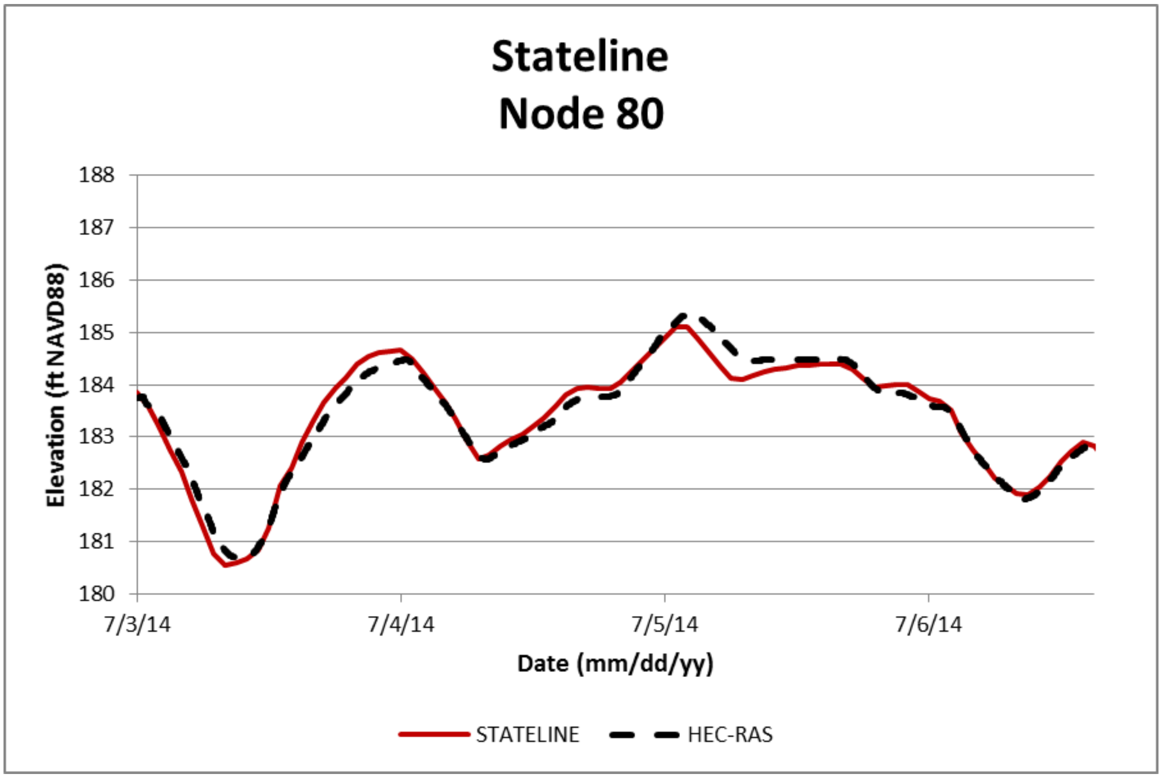

Logger V03
Node 373
224
223
222
221
220
219
218
Elevation (ft NAVD88)
7/28/14
7/29/14
7/30/14
Date (mm/dd/yy)
Logger V03
HEC RAS

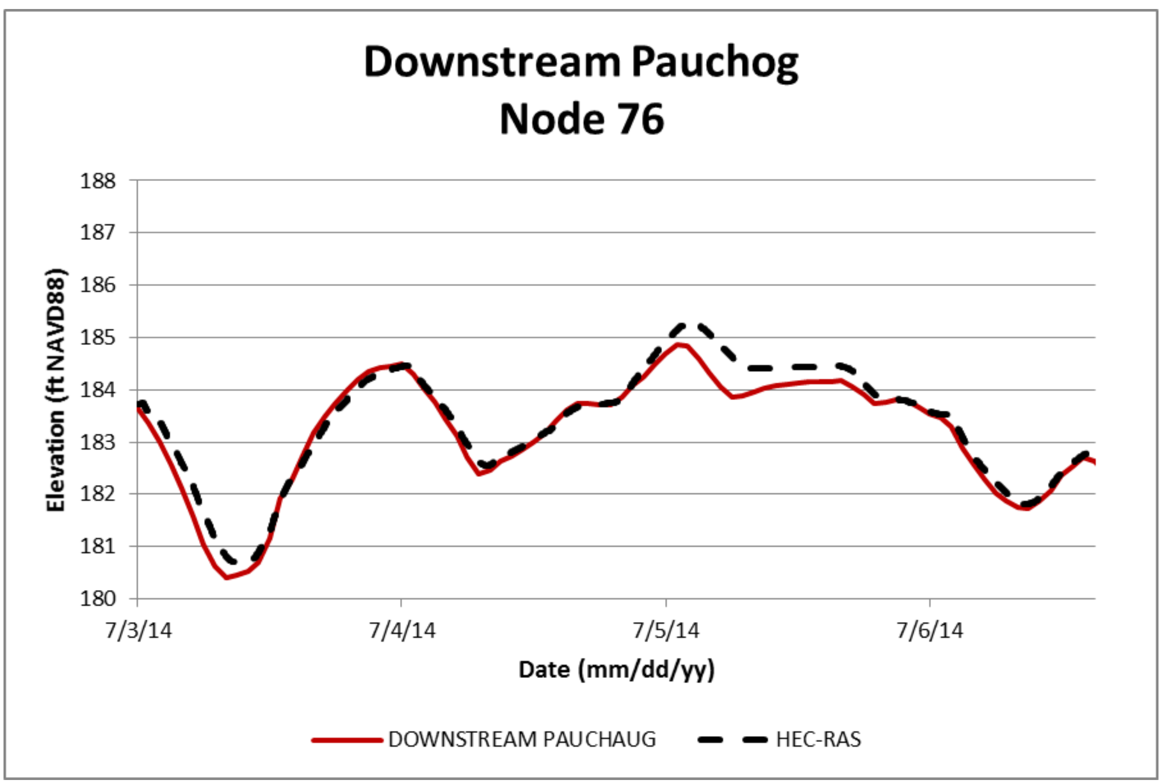

Logger V06
Node 194
Elevation (ft NAVD88)
224
223
222
221
220
219
218
7/28/14
7/29/14
7/30/14
Date (mm/dd/yy)
Logger V06
HEC RAS

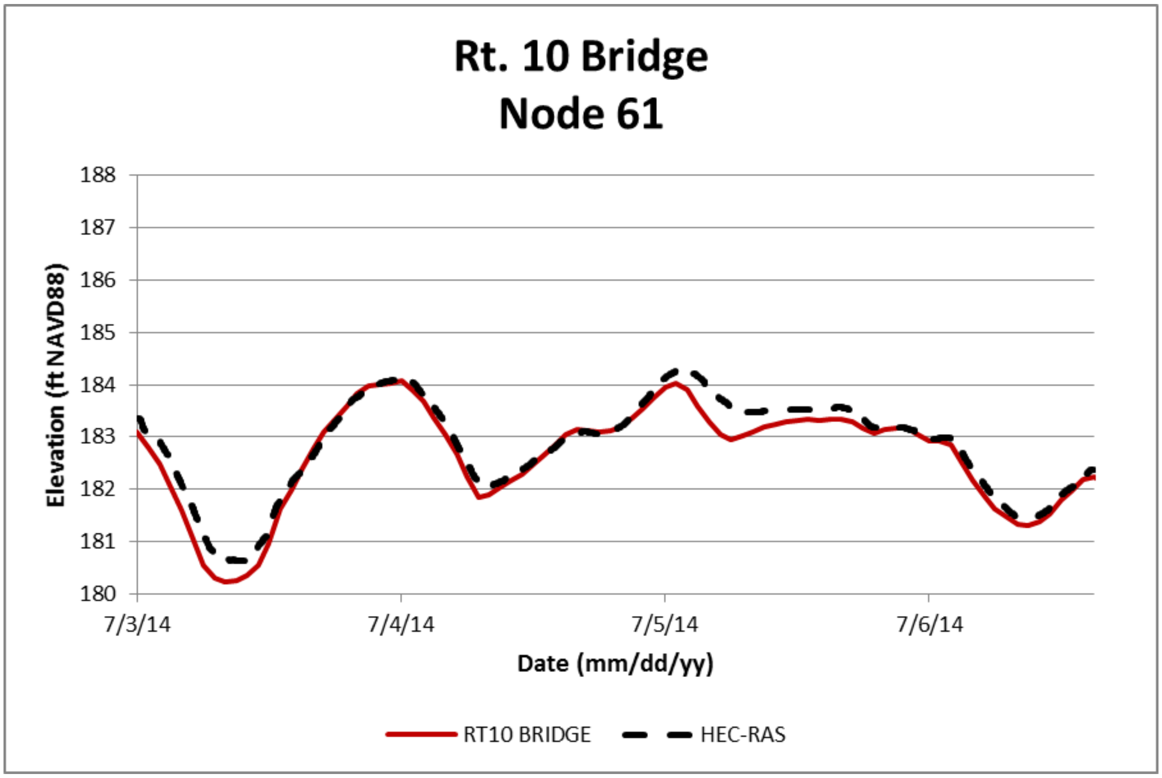

Upstream Stebbins
Node 135
Elevation (ft NAVD88)
189
188
187
186
185
184
183
182
181
7/3/14
7/4/14
7/5/14
7/6/14
Date (mm/dd/yy)
UPSTREAM STEBBINS
HEC-RAS

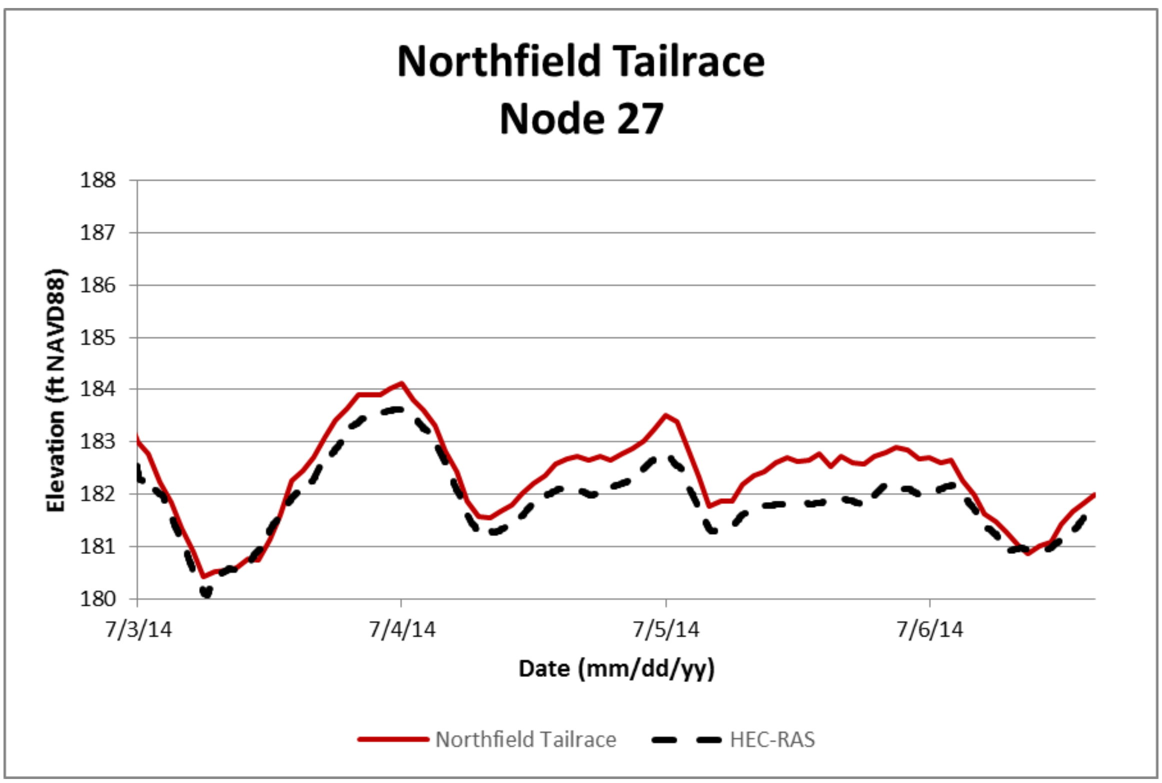

Logger VR02
Node 123
188
187
186
185
184
183
182
181
180
Elevation (ft NAVD88)
7/3/14
7/4/14
7/5/14
7/6/14
Date (mm/dd/yy)
VR02
HEC-RAS

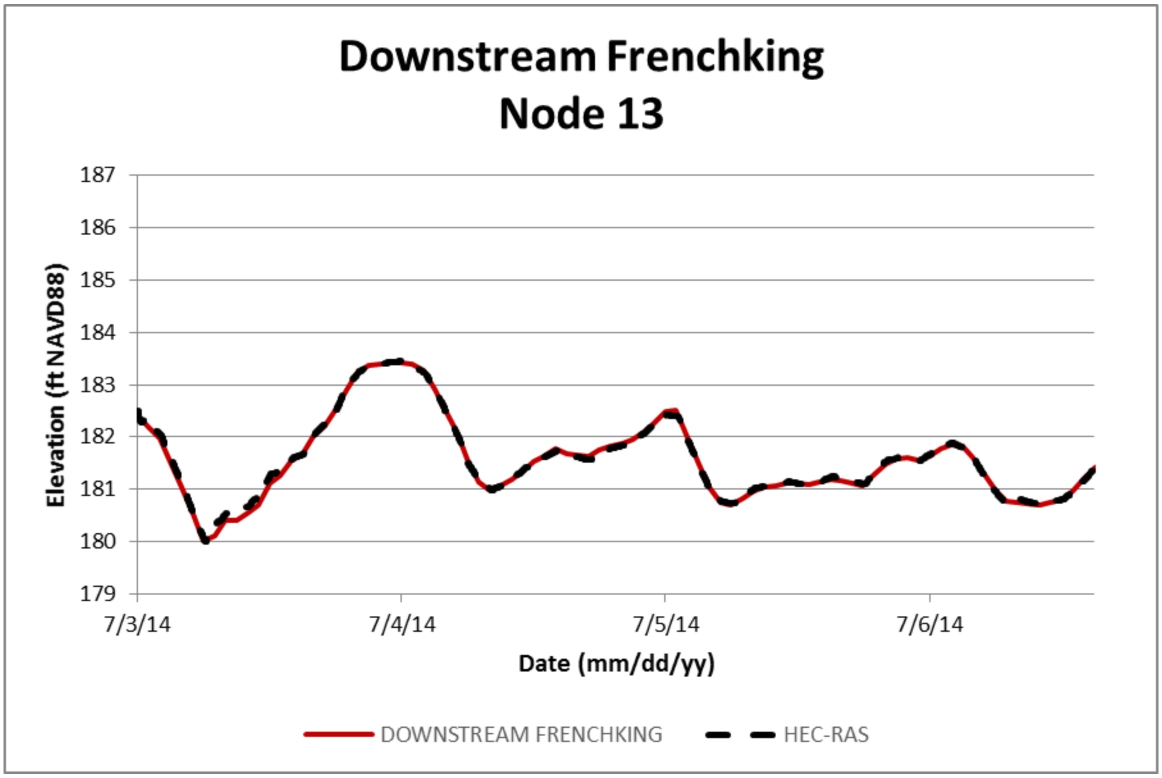

Downstream Stebbins
Node 108
188
187
186
185
184
183
182
181
180
Elevation (ft NAVD88)
7/3/14
7/4/14
7/5/14
7/6/14
Date (mm/dd/yy)
DOWNSTREAM STEBBINS
HEC-RAS

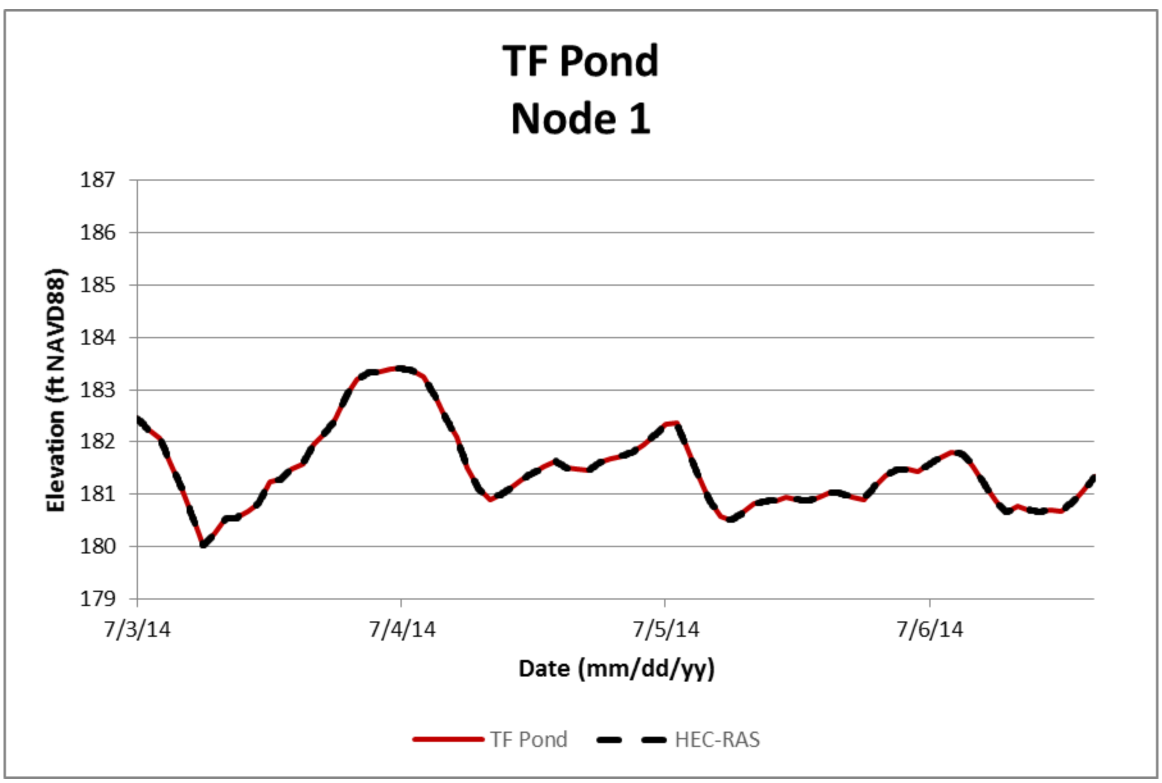

Stateline
Node 80
188
187
186
185
184
183
182
181
180
Elevation (ft NAVD88)
7/3/14
7/4/14
7/5/14
7/6/14
Date (mm/dd/yy)
STATELINE
HEC-RAS


Downstream Pauchog
Node 76
188
187
186
185
184
183
182
181
180
Elevation (ft NAVD88)
7/3/14
7/4/14
7/5/14
7/6/14
Date (mm/dd/yy)
DOWNSTREAM PAUCHAUG
HEC-RAS


Rt. 10 Bridge
Node 61
188
187
186
185
184
183
182
181
180
Elevation (ft NAVD88)
7/3/14
7/4/14
7/5/14
7/6/14
Date (mm/dd/yy)
RT10 BRIDGE
HEC-RAS


Northfield Tailrace
Node 27
188
187
186
185
184
183
182
181
180
Elevation (ft NAVD88)
7/3/14
7/4/14
7/5/14
7/6/14
Date (mm/dd/yy)
Northfield Tailrace
HEC-RAS


Downstream Frenchking
Node 13
187
186
185
184
183
182
181
180
179
Elevation (ft NAVD88)
7/3/14
7/4/14
7/5/14
7/6/14
Date (mm/dd/yy)
DOWNSTREAM FRENCHKING
HEC-RAS


TF Pond
Node 1
187
186
185
184
183
182
181
180
179
Elevation (ft NAVD88)
7/3/14
7/4/14
7/5/14
7/6/14
Date (mm/dd/yy)
TF Pond
HEC-RAS

APPENDIX C

Hydraulic Model Validation Graphs

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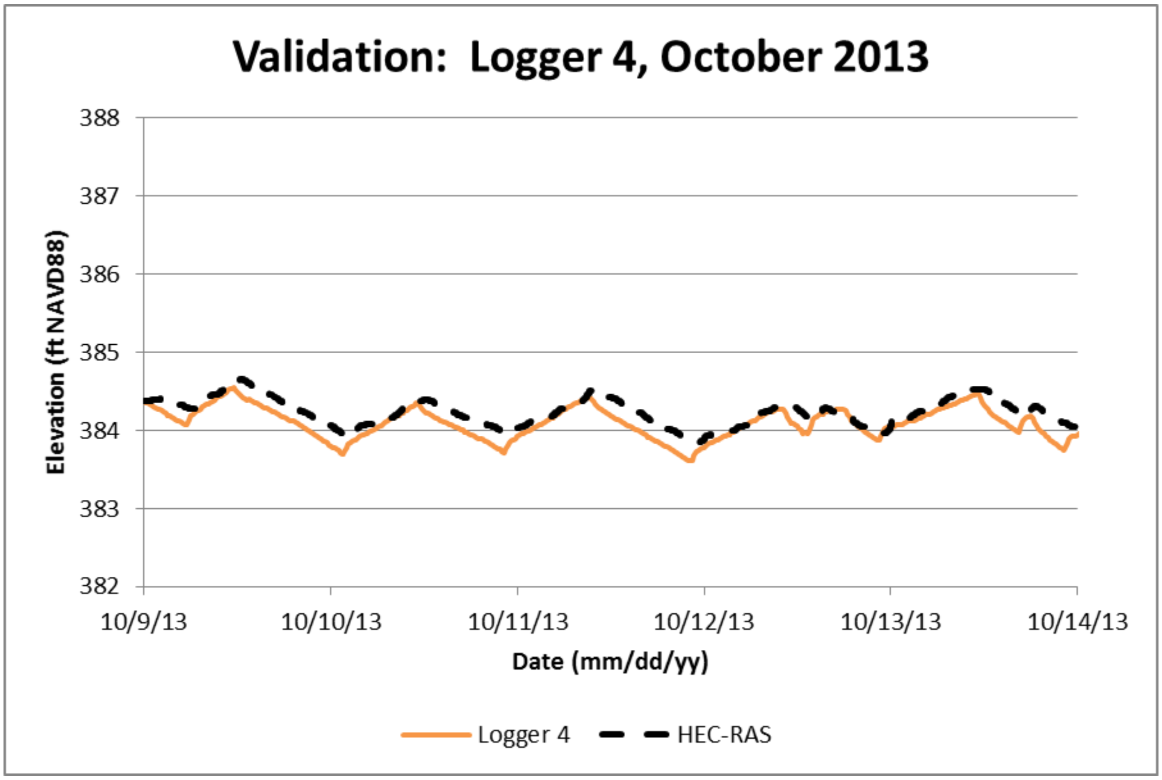
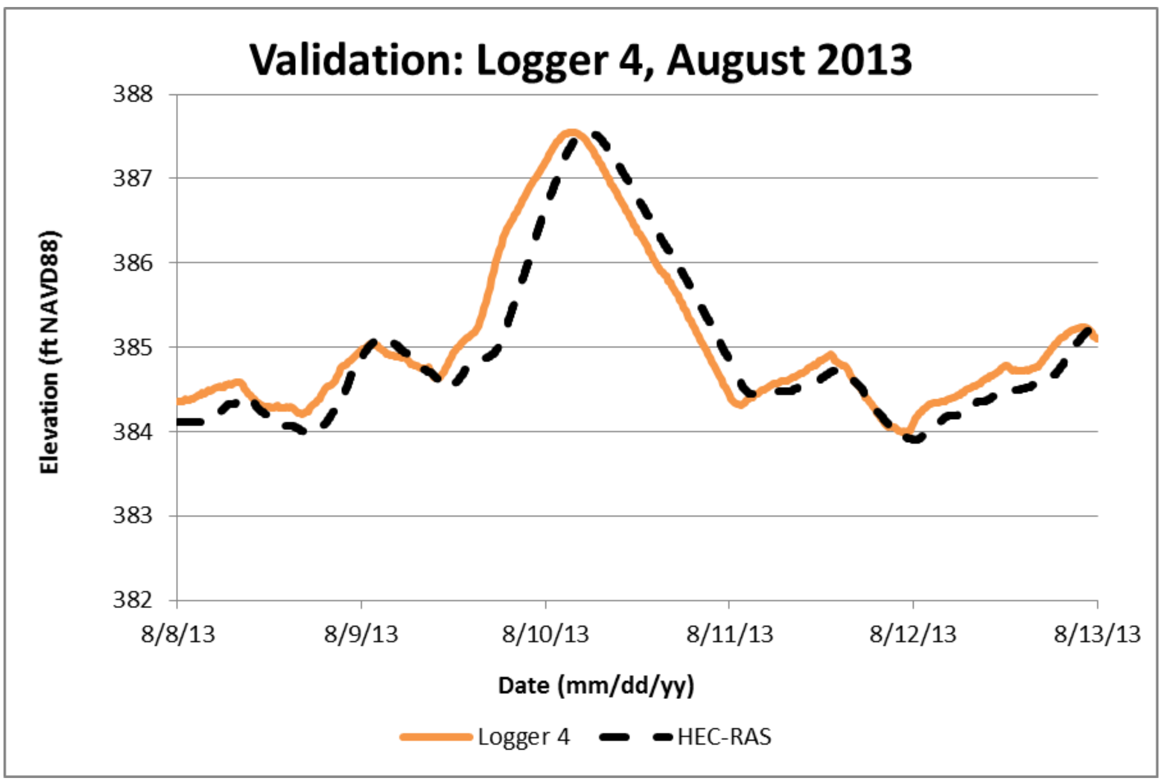
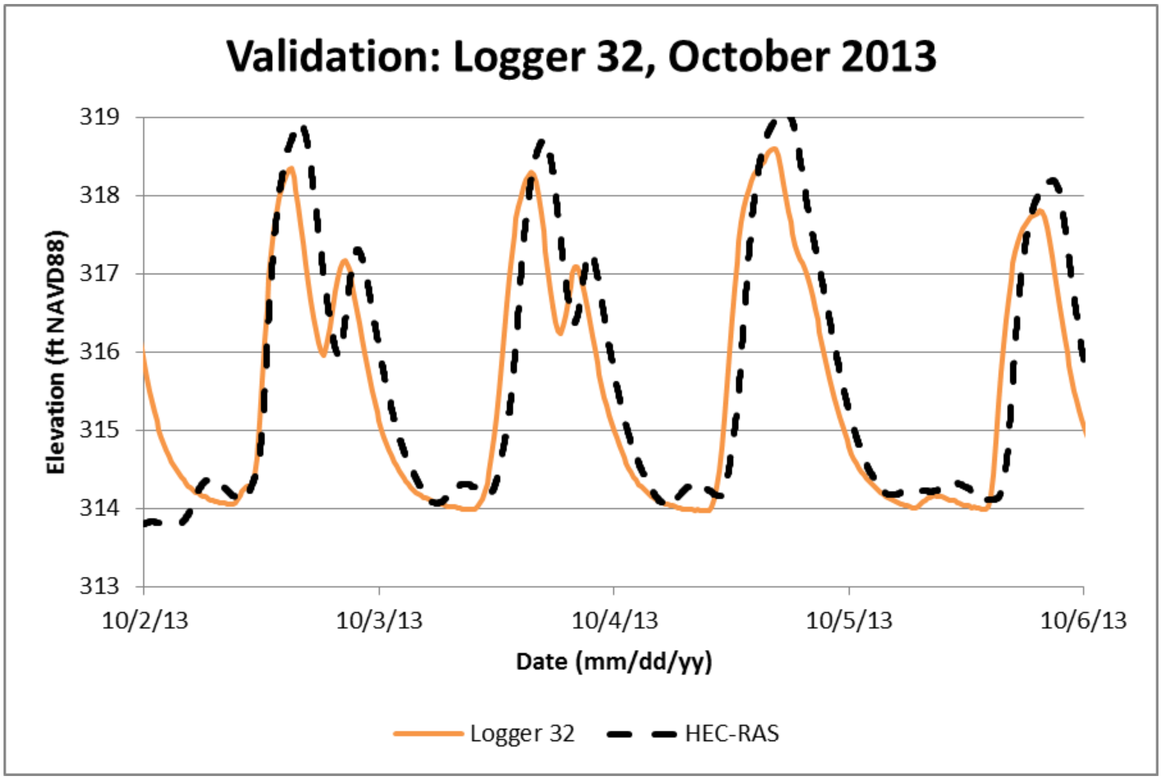
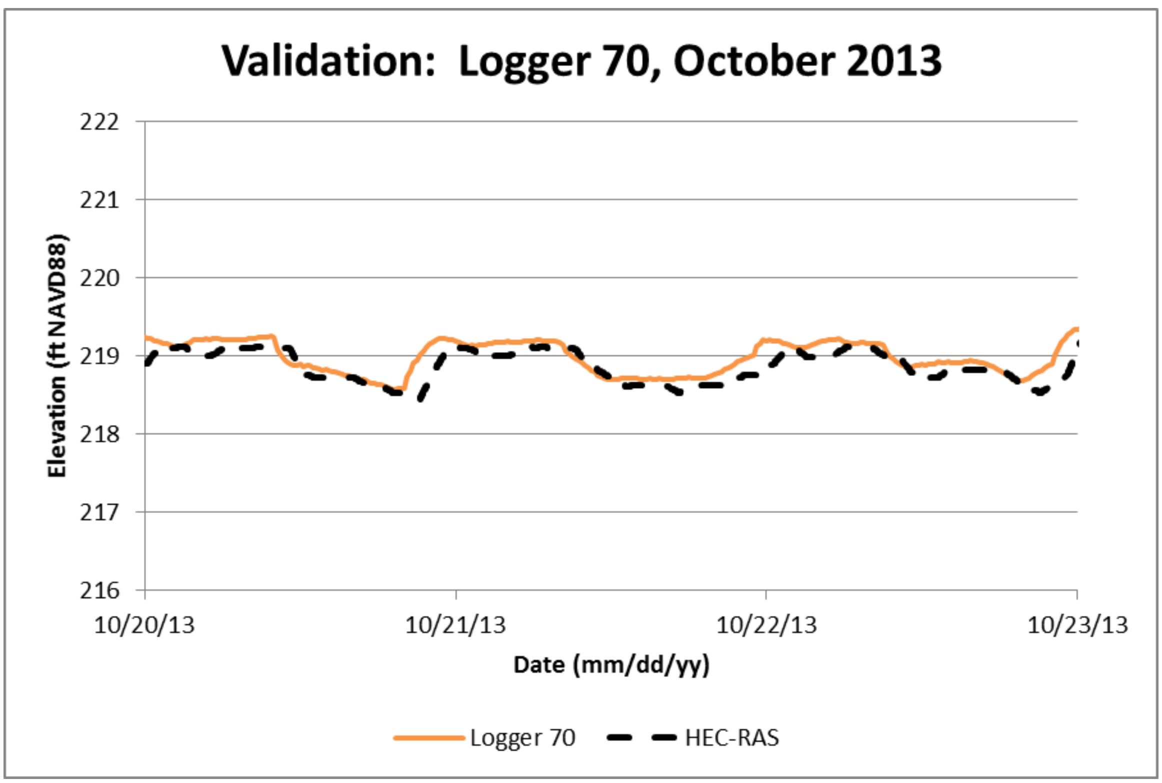


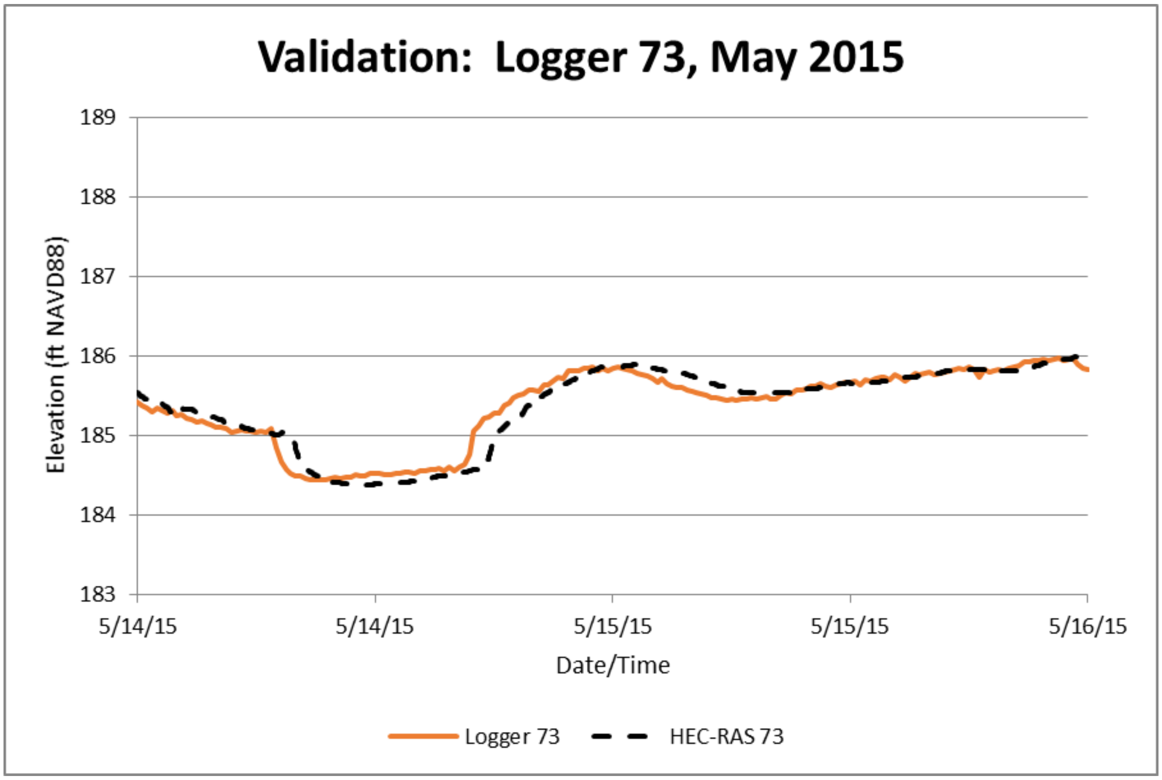


NOTE: Logger clock appears to lag model time by one hour. Field staff confirmed clock offset.





NOTE: Logger clock appears to lag model time by one hour. Field staff confirmed clock offset.



NOTE: Logger clock appears to lag model time by one hour. Field staff confirmed clock offset.

APPENDIX D

Examples of Rating Curve Data and Graphs

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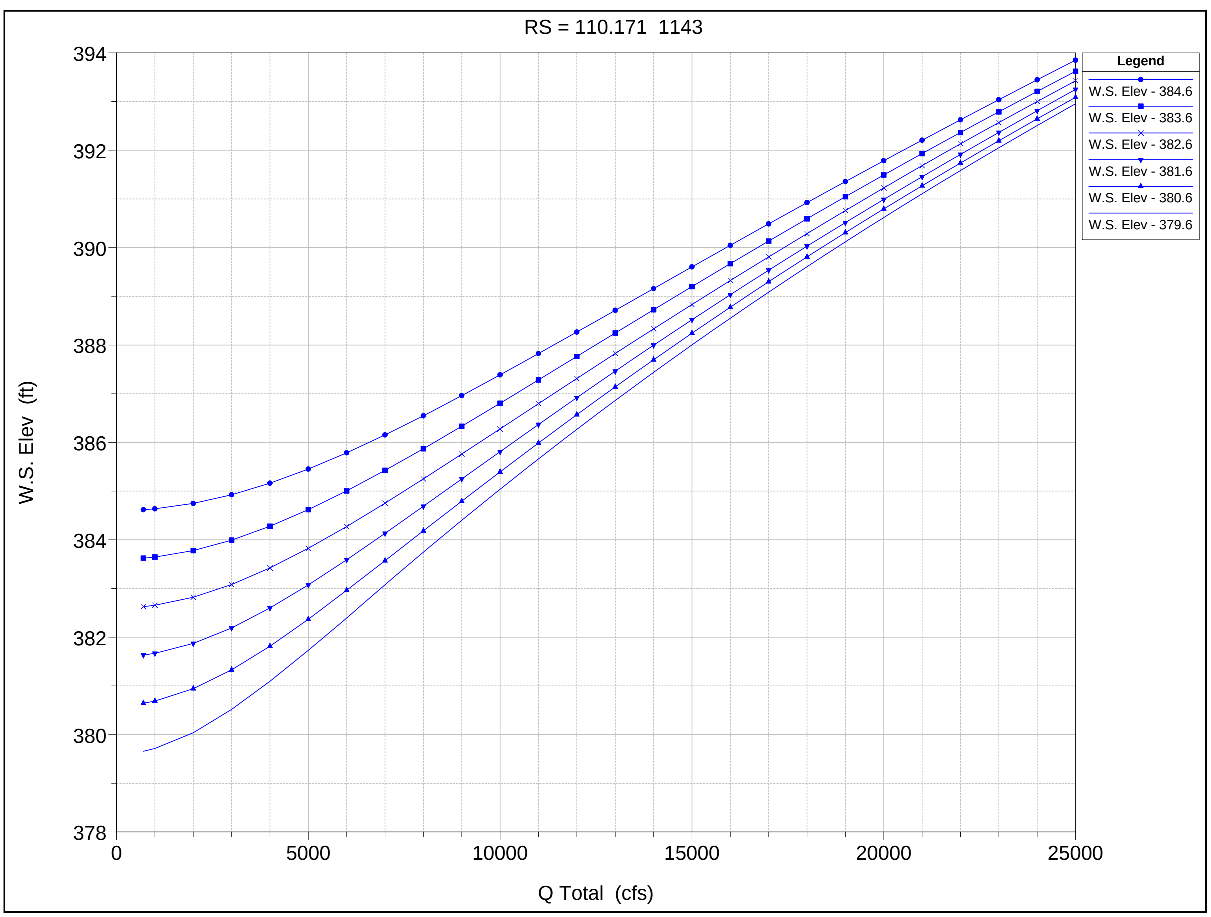
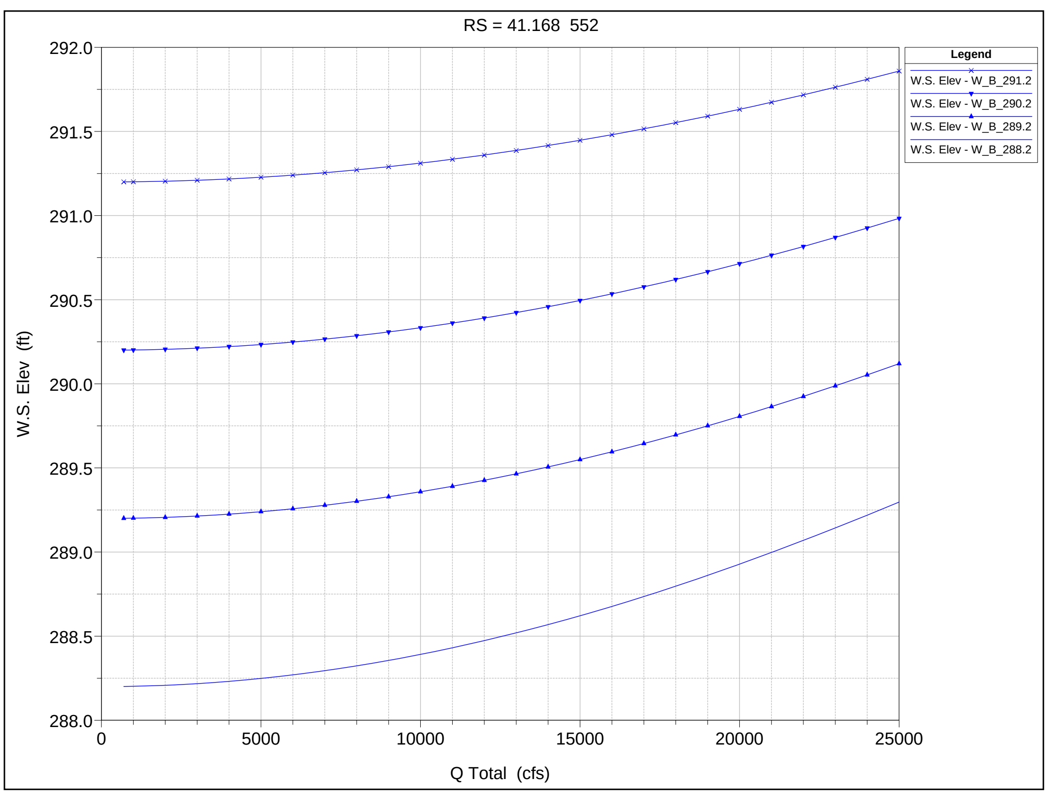
Wilder Reservoir: 379.6 380.6 381.6 382.6 383.6 384.6 elevation (ft NAVD88)

River Station	Node	Flow (cfs)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)
110.171	1143	700	379.7	380.6	381.6	382.6	383.6	384.6
110.171	1143	1000	379.7	380.7	381.7	382.7	383.6	384.6
110.171	1143	2000	380.0	380.9	381.9	382.8	383.8	384.7
110.171	1143	3000	380.5	381.3	382.2	383.1	384.0	384.9
110.171	1143	4000	381.1	381.8	382.6	383.4	384.3	385.2
110.171	1143	5000	381.7	382.4	383.1	383.8	384.6	385.5
110.171	1143	6000	382.4	383.0	383.6	384.3	385.0	385.8
110.171	1143	7000	383.1	383.6	384.1	384.8	385.4	386.2
110.171	1143	8000	383.7	384.2	384.7	385.3	385.9	386.5
110.171	1143	9000	384.4	384.8	385.2	385.8	386.3	387.0
110.171	1143	10000	385.0	385.4	385.8	386.3	386.8	387.4
110.171	1143	11000	385.7	386.0	386.4	386.8	387.3	387.8
110.171	1143	12000	386.3	386.6	386.9	387.3	387.8	388.3
110.171	1143	13000	386.9	387.1	387.5	387.8	388.2	388.7
110.171	1143	14000	387.4	387.7	388.0	388.3	388.7	389.2
110.171	1143	15000	388.0	388.2	388.5	388.8	389.2	389.6
110.171	1143	16000	388.6	388.8	389.0	389.3	389.7	390.0
110.171	1143	17000	389.1	389.3	389.5	389.8	390.1	390.5
110.171	1143	18000	389.6	389.8	390.0	390.3	390.6	390.9
110.171	1143	19000	390.1	390.3	390.5	390.8	391.0	391.4
110.171	1143	20000	390.6	390.8	391.0	391.2	391.5	391.8
110.171	1143	21000	391.1	391.3	391.5	391.7	391.9	392.2
110.171	1143	22000	391.6	391.7	391.9	392.1	392.4	392.6
110.171	1143	23000	392.1	392.2	392.4	392.6	392.8	393.0
110.171	1143	24000	392.5	392.6	392.8	393.0	393.2	393.4
110.171	1143	25000	393.0	393.1	393.3	393.4	393.6	393.8

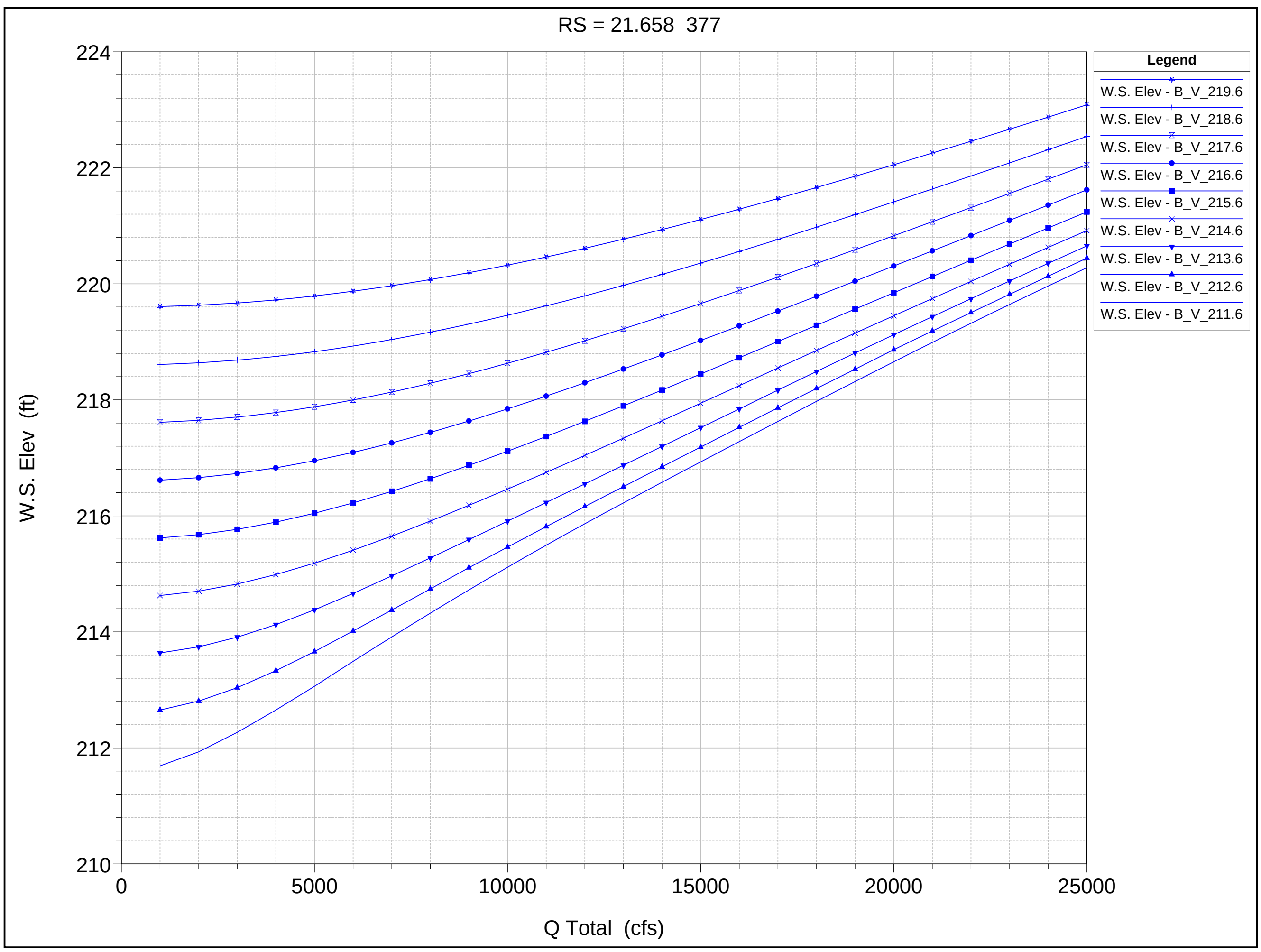


Bellows Falls Reservoir: 288.2 289.2 290.2 291.2 elevation (ft NAVD88)

River Station	Node	Flow (cfs)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)
41.168	552	700	288.2	289.2	290.2	291.2
41.168	552	1000	288.2	289.2	290.2	291.2
41.168	552	2000	288.2	289.2	290.2	291.2
41.168	552	3000	288.2	289.2	290.2	291.2
41.168	552	4000	288.2	289.2	290.2	291.2
41.168	552	5000	288.2	289.2	290.2	291.2
41.168	552	6000	288.3	289.3	290.2	291.2
41.168	552	7000	288.3	289.3	290.3	291.3
41.168	552	8000	288.3	289.3	290.3	291.3
41.168	552	9000	288.4	289.3	290.3	291.3
41.168	552	10000	288.4	289.4	290.3	291.3
41.168	552	11000	288.4	289.4	290.4	291.3
41.168	552	12000	288.5	289.4	290.4	291.4
41.168	552	13000	288.5	289.5	290.4	291.4
41.168	552	14000	288.6	289.5	290.5	291.4
41.168	552	15000	288.6	289.5	290.5	291.4
41.168	552	16000	288.7	289.6	290.5	291.5
41.168	552	17000	288.7	289.6	290.6	291.5
41.168	552	18000	288.8	289.7	290.6	291.6
41.168	552	19000	288.9	289.8	290.7	291.6
41.168	552	20000	288.9	289.8	290.7	291.6
41.168	552	21000	289.0	289.9	290.8	291.7
41.168	552	22000	289.1	289.9	290.8	291.7
41.168	552	23000	289.1	290.0	290.9	291.8
41.168	552	24000	289.2	290.1	290.9	291.8
41.168	552	25000	289.3	290.1	291.0	291.9



Vernon Reservoir:			211.6	212.6	213.6	214.6	215.6	216.6	217.6	218.6	219.6 elevation (ft NAVD88)
River Station	Node	Flow (cfs)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)
21.658	377	1000	211.7	212.7	213.6	214.6	215.6	216.6	217.6	218.6	219.6
21.658	377	2000	211.9	212.8	213.7	214.7	215.7	216.7	217.6	218.6	219.6
21.658	377	3000	212.3	213.0	213.9	214.8	215.8	216.7	217.7	218.7	219.7
21.658	377	4000	212.7	213.3	214.1	215.0	215.9	216.8	217.8	218.7	219.7
21.658	377	5000	213.1	213.7	214.4	215.2	216.0	216.9	217.9	218.8	219.8
21.658	377	6000	213.5	214.0	214.7	215.4	216.2	217.1	218.0	218.9	219.9
21.658	377	7000	213.9	214.4	215.0	215.7	216.4	217.3	218.1	219.0	220.0
21.658	377	8000	214.3	214.7	215.3	215.9	216.6	217.4	218.3	219.2	220.1
21.658	377	9000	214.7	215.1	215.6	216.2	216.9	217.6	218.5	219.3	220.2
21.658	377	10000	215.1	215.5	215.9	216.5	217.1	217.8	218.6	219.5	220.3
21.658	377	11000	215.5	215.8	216.2	216.7	217.4	218.1	218.8	219.6	220.5
21.658	377	12000	215.9	216.2	216.6	217.0	217.6	218.3	219.0	219.8	220.6
21.658	377	13000	216.2	216.5	216.9	217.3	217.9	218.5	219.2	220.0	220.8
21.658	377	14000	216.6	216.8	217.2	217.6	218.2	218.8	219.4	220.2	220.9
21.658	377	15000	216.9	217.2	217.5	217.9	218.4	219.0	219.7	220.4	221.1
21.658	377	16000	217.3	217.5	217.8	218.2	218.7	219.3	219.9	220.6	221.3
21.658	377	17000	217.6	217.9	218.2	218.5	219.0	219.5	220.1	220.8	221.5
21.658	377	18000	218.0	218.2	218.5	218.9	219.3	219.8	220.4	221.0	221.7
21.658	377	19000	218.3	218.5	218.8	219.1	219.6	220.0	220.6	221.2	221.9
21.658	377	20000	218.7	218.9	219.1	219.4	219.8	220.3	220.8	221.4	222.1
21.658	377	21000	219.0	219.2	219.4	219.7	220.1	220.6	221.1	221.6	222.3
21.658	377	22000	219.3	219.5	219.7	220.0	220.4	220.8	221.3	221.9	222.5
21.658	377	23000	219.6	219.8	220.0	220.3	220.7	221.1	221.6	222.1	222.7
21.658	377	24000	220.0	220.1	220.4	220.6	221.0	221.4	221.8	222.3	222.9
21.658	377	25000	220.3	220.4	220.7	220.9	221.2	221.6	222.1	222.5	223.1



Turners Falls Reservoir:			175.6	176.6	177.6	178.6	179.6	180.6	181.6	182.6	183.6	184.6 elevation (ft NAVD88)
River Station	Node	Flow (cfs)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)	WSEL (ft)
18.914	123	1200	178.7	178.7	178.7	179.0	179.8	180.7	181.7	182.6	183.6	184.6
18.914	123	2000	179.2	179.2	179.3	179.6	180.1	180.8	181.7	182.7	183.7	184.6
18.914	123	3000	179.9	179.9	180.0	180.1	180.5	181.1	181.9	182.8	183.7	184.7
18.914	123	4000	180.4	180.4	180.5	180.6	180.9	181.4	182.1	182.9	183.9	184.8
18.914	123	5000	180.8	180.8	180.9	181.0	181.3	181.7	182.3	183.1	184.0	184.9
18.914	123	6000	181.2	181.2	181.3	181.4	181.6	182.0	182.6	183.3	184.1	185.0
18.914	123	7000	181.5	181.5	181.6	181.7	182.0	182.3	182.9	183.5	184.3	185.2
18.914	123	8000	181.8	181.9	181.9	182.1	182.3	182.6	183.1	183.8	184.5	185.3
18.914	123	9000	182.2	182.2	182.3	182.4	182.6	183.0	183.4	184.0	184.7	185.5
18.914	123	10000	182.5	182.5	182.6	182.7	183.0	183.3	183.7	184.3	184.9	185.6
18.914	123	11000	182.8	182.9	182.9	183.1	183.3	183.6	184.0	184.5	185.1	185.8
18.914	123	12000	183.1	183.2	183.3	183.4	183.6	183.9	184.3	184.8	185.4	186.0
18.914	123	13000	183.5	183.5	183.6	183.7	183.9	184.2	184.6	185.0	185.6	186.2
18.914	123	14000	183.8	183.8	183.9	184.1	184.2	184.5	184.8	185.3	185.8	186.4
18.914	123	15000	184.1	184.2	184.2	184.4	184.6	184.8	185.1	185.5	186.1	186.6
18.914	123	16000	184.4	184.5	184.6	184.7	184.9	185.1	185.4	185.8	186.3	186.9
18.914	123	17000	184.7	184.8	184.9	185.0	185.2	185.4	185.7	186.1	186.5	187.1
18.914	123	18000	185.0	185.1	185.2	185.3	185.5	185.7	186.0	186.3	186.8	187.3
18.914	123	19000	185.3	185.4	185.5	185.6	185.8	186.0	186.2	186.6	187.0	187.5
18.914	123	20000	185.6	185.7	185.8	185.9	186.1	186.3	186.5	186.9	187.3	187.7
18.914	123	21000	185.9	186.0	186.1	186.2	186.3	186.5	186.8	187.1	187.5	188.0
18.914	123	22000	186.2	186.3	186.4	186.5	186.6	186.8	187.1	187.4	187.7	188.2
18.914	123	23000	186.5	186.6	186.7	186.8	186.9	187.1	187.3	187.6	188.0	188.4
18.914	123	24000	186.8	186.9	186.9	187.0	187.2	187.4	187.6	187.9	188.2	188.6
18.914	123	25000	187.1	187.1	187.2	187.3	187.5	187.6	187.8	188.1	188.5	188.9