RELICENSING STUDY 3.2.2

HYDRAULIC STUDY OF TURNERS FALLS IMPOUNDMENT, BYPASS REACH AND BELOW CABOT

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)

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EXECUTIVE SUMMARY

FirstLight Hydro Generating Company (FirstLight), a subsidiary of GDF SUEZ North America, Inc., is the current licensee of the Northfield Mountain Pumped Storage Project (Northfield Mountain Project, FERC No. 2485) and the Turners Falls Hydroelectric Project (Turners Falls Project, FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the Northfield Mountain and Turners Falls Projects using the FERC's Integrated Licensing Process (ILP). The current licenses for the Northfield Mountain and Turners Falls Projects were issued on May 14, 1968 and May 5, 1980, respectively, and both licenses expire on April 30, 2018. On September 13, 2013, FERC issued a study plan determination for the Projects which, among other studies, requires FirstLight to conduct Study No. 3.2.2 Hydraulic Study of Turners Falls Impoundment, Bypass Reach and below Cabot Station. Per the Revised Study Plan (RSP), (filed on August 14, 2013) hydraulic modeling was to be conducted in two reaches of the Connecticut (CT) River as follows:

- The Turners Falls Impoundment (hereinafter Impoundment) reach from Vernon Dam to the Turners Falls Dam, and;
- The Turners Falls Dam to Holyoke Dam reach[1].

The methodology and scope for the hydraulic study outlined in the RSP was approved with modification by the Commission in its September 13, 2013 SPDL (FERC, 2013). FERC's only modification to the RSP was to install two additional water level loggers in the Impoundment to measure water surface elevations (WSELs) and to have all water level loggers record data, at a minimum, during the months of April through November 2014.

As defined in the RSP, the goals of the hydraulic study were as follows:

- Provide WSEL and mean channel velocity information at transects to help inform other environmental, geologic and recreation studies. As noted in the RSP, there are seven other studies associated with the relicensing that will utilize this model in assessing impacts. For example, a study will be conducted to locate spawning habitat in the Impoundment. As part of that study, data will be collected on the depth of the spawning habitat. The hydraulic model results will be used as part of that study to assess whether Impoundment fluctuations impact spawning habitat.

- A hydraulic model of the Impoundment reach will be used to determine the impact on WSEL fluctuations due to a) the Vernon Hydroelectric Project, b) the Northfield Mountain Project, c) the Turners Falls Project d) naturally occurring high flows, and e) combinations of the above.

- A hydraulic model of the Turners Falls to Holyoke Dam reach will be used to determine the impact on WSEL fluctuations due to a) the Turners Falls Project, b) the Deerfield River Project[2], c) naturally occurring high flows, d) operations at Holyoke Dam, and e) combinations of the above.

The physical limits of the Impoundment reach hydraulic model extended from just upstream of the Turners Falls Dam and to just below Vernon Dam. The physical limits of the downstream reach hydraulic

[1] As explained in the main report, FirstLight had a variance on the geographic extent of the study. Rather than terminating the upstream extent of the hydraulic model at the Turners Falls Dam, it was terminated at the United States Geological Survey gage located on the CT River in Montague.

[2] The Deerfield River enters the CT River just below Cabot Station. The Deerfield River has several peaking hydroelectric projects and two seasonally operated storage reservoirs.

model extended from just upstream of the Holyoke Dam to the Montague United States Geological Survey (USGS) Gage[3].

Per the RSP, FirstLight used the one-dimensional HEC-RAS (Hydrologic Engineering Center River Analysis System) hydraulic model developed by the United States Army Corps of Engineers (USACE). The HEC-RAS hydraulic model predicts WSEL's, mean channel velocities, and a wide range of other parameters at the modeled transects under a range of flows and operating conditions. For this study, the HEC-RAS models were operated in both a steady-state and unsteady-state conditions. Steady-state means that the flow throughout the reach is constant and unsteady conditions represent variable flow conditions over time as a result of Vernon peaking, tributary inflow, Northfield pumping/generating, Cabot Station peaking, and other variables.

To assist in calibrating the Impoundment hydraulic model to observed flows and water surface elevations throughout the study reach, the following data were obtained:

- Water surface elevation (WSEL) data were collected over a range of flows and operating conditions. Water level loggers were installed throughout the length of the Impoundment at various locations during parts of 2013 and 2014.
- Transect data for the hydraulic model were obtained from bathymetric mapping of the Impoundment. The bathymetric mapping was based on a combination of updated data collected in 2014 to supplement bathymetric data collected in 2006. In 2014, bathymetric data were collected from Vernon Dam to just downstream of the NH/VT/MA border and 5 km upstream and downstream of the Northfield Mountain tailrace.
- Flow data were obtained- specifically Vernon Hydroelectric Project discharges plus flow contributions from the major tributaries. In addition, pumped flows and generation flows were obtained for the period the water level loggers were installed.

To assist in calibrating the Downstream reach hydraulic model to observed flows and water surface elevations throughout the study reach, the following data were obtained:

- WSEL data were collected over a range of flows and operating conditions at three locations in the study reach.
- Transect data for the hydraulic model included a combination of: transects from Federal Emergency Management Agency (FEMA) flood insurance studies, transects of the CT River in the town of Hatfield, and another hydraulic model developed by the Corps of Engineers of the Northampton area. Flow data were obtained- specifically flow from the Montague USGS gage plus flow contributions from tributaries.

The HEC-RAS models for the Impoundment and Downstream reaches were first calibrated and validated to the WSEL's measured at the water level loggers under steady-state conditions. To calibrate to steady state conditions, the goal was to identify periods where WSEL fluctuations (largely due to the peaking operations of projects on the river) were as minor as possible. After initial calibration to steady state conditions, the Impoundment model was also calibrated to unsteady conditions. In general, the calibration procedure consisted of adjusting the Manning's n value (roughness) and adjusting contraction and expansion coefficients within reasonable measures such that the observed and modeled WSELs at the water level loggers were reasonably close[4]. The Impoundment model has a tighter calibration and validation results than the Downstream model, likely due in part to the more detailed bathymetry in the

[3] The Montague USGS Gage at the railroad bridge crossing located approximately 4,000 feet below the Cabot Powerhouse and immediately downstream of the Deerfield River confluence.
[4] Generally less than 0.5 ft.

Impoundment. Numerous figures and tables describing the calibration and validation processes are shown in Section 4.

Tasks 4 and 7 of the RSP required simulation of various steady-state scenarios for the hydraulic models of the Impoundment and Downstream reaches. For the Impoundment model, the 15 scenarios included Vernon operating under maximum generation or minimum flow conditions, Northfield Mountain operating under maximum generation or pumping, and the WSEL at the Turners Falls Dam at the maximum (185 ft) and minimum (176 ft) licensed levels as well as the median (181.3 ft) WSEL. For the Downstream model, 8 scenarios were modeled including the Turners Falls Project operating under maximum generation or minimum flow conditions, the Deerfield River Project at maximum generation or minimum flows, and the licensed minimum and maximum WSEL at the Holyoke Dam. The analysis of the WSELs at key locations from these scenarios allowed FirstLight to determine the relative impacts of operating conditions that are within and outside of the control of FirstLight.

In addition to the scenarios required in the RSP, FirstLight also developed 11 unsteady-state scenarios for the Impoundment model and 20 unsteady-state scenarios for the Downstream model. These unsteady-state scenarios modeled daily peaking operations at Vernon, Northfield Mountain, Turners Falls, and the Deerfield River Hydroelectric Projects under varying downstream boundary conditions of their respective models. Section 5 contains numerous figures and tables providing and analyzing the results of both the steady and unsteady-state modeling scenarios.

The hydraulic models developed for this study provide the ability to accurately model a variation of flows and downstream boundary conditions. The analysis of the WSELs at key locations, as summarized and shown in figures and tables in Section 5 of the steady-state and unsteady-state scenarios, allows FirstLight to determine the relative impacts of operating conditions that are within and outside of the control of FirstLight. This model is expected to be extensively used in the relicensing process, especially for the following 7 studies:

- Study No. 3.1.2 *Northfield Mountain/Turners Falls Operations Impact on Existing Erosion and Potential Bank Instability.*
- Study No. 3.3.6 *Impact of Project Operations on Shad Spawning, Spawning Habitat and Egg Deposition in the area of the Northfield Mountain and Turners Falls Projects*.
- Study No. 3.3.10 *Assess Operational Impacts on Emergence of State Listed Odonates in the Connecticut River*.
- Study No. 3.3.13 *Impacts of the Turners Falls Project and Northfield Mountain Project Operations on Littoral Zone Fish Habitat and Spawning*.
- Study No. 3.3.17 *Assess the Impacts of Project Operations of the Turners Falls Project and Northfield Mountain Project on Tributary and Backwater Area Access and Habitats*.
- Study No. 3.5.1 *Baseline Inventory of Wetland, Riparian and Littoral Habitat in the Turners Falls Impoundment, and Assessment of Operational Impacts on Special-Status Species* (includes rare plants and tiger beetles).
- Study No. 3.6.6 *Assessment of Effects of Project Operation on Recreation and Land Use*.

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cfs	cubic feet per second
CT	Connecticut
ft	feet
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Hydro Generating Company
FIS	flood insurance study
GIS	Geographic Information Systems
GPS	Global Positioning System
HEC-RAS	Hydrologic Engineering Center River Analysis System
ILP	Integrated Licensing Process
MA	Massachusetts
MassDOT	Massachusetts Department of Transportation
mi^2	Square mile
NH	New Hampshire
NOI	Notice of Intent
Northfield Mountain	Northfield Mountain Pumped Storage Project
PAD	Pre-Application Document
PSP	Proposed Study Plan
RSP	Revised Study Plan
RTK	Real-Time Kinematic
RTK-GPS	Real-Time Kinematic- Global Positioning System
SD1	Scoping Document 1
SD2	Scoping Document 2
SPDL	Study Plan Determination Letter
the Commission	Federal Energy Regulatory Commission
the Impoundment	Turners Falls Impoundment
the Project	Northfield Mountain Pumped Storage and Turners Falls Hydroelectric Projects
TNC	The Nature Conservancy
USGS	United States Geological Survey
USACE	United States Army Corps of Engineers
Vernon	Vernon Hydroelectric Project
VT	Vermont
WSEL	water surface elevation
WSP	water surface profile

1 INTRODUCTION

1.1 Background

FirstLight Hydro Generating Company (FirstLight), a subsidiary of GDF SUEZ North America, Inc., is the current licensee of the Northfield Mountain Pumped Storage Project (Northfield Mountain Project, FERC No. 2485) and the Turners Falls Hydroelectric Project (Turners Falls Project, FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the Northfield Mountain and Turners Falls Projects using the FERC's Integrated Licensing Process (ILP). The current licenses for the Northfield Mountain and Turners Falls Projects were issued on May 14, 1968 and May 5, 1980, respectively, with both set to expire on April 30, 2018. This report documents the results of Study No. 3.2.2 Hydraulic Study of Turners Falls Impoundment, Bypass Reach and below Cabot Station. Per the Revised Study Plan (RSP), hydraulic modeling was to be conducted in two reaches[5] of the Connecticut (CT) River as follows:

- the Turners Falls Impoundment (hereinafter Impoundment) reach from Vernon Dam to the Turners Falls Dam, and;

- the Turners Falls Dam to Holyoke Dam reach[6].

As part of the ILP, FERC conducted a public scoping process during which various resource issues were identified. On October 31, 2012, FirstLight filed its Pre-Application Document (PAD) and Notice of Intent (NOI) with FERC. The PAD included FirstLight's preliminary list of proposed studies. On December 21, 2012, FERC issued Scoping Document 1 (SD1) and preliminarily identified resource issues and concerns. On January 30 and 31, 2013, FERC held scoping meetings for the Northfield Mountain and Turners Falls Projects. FERC issued Scoping Document 2 (SD2) on April 15, 2013.

FirstLight filed its Proposed Study Plan (PSP) on April 15, 2013 and, per the Commission regulations, held a PSP meeting at the Northfield Visitors Center on May 14, 2013. Thereafter, FirstLight held ten resource-specific study plan meetings to allow for more detailed discussions on each PSP and on studies not being proposed.[7] On June 28, 2013, FirstLight filed with the Commission an Updated PSP to reflect further changes to the PSP based on comments received at the meetings. On or before July 15, 2013, stakeholders filed written comments on the Updated PSP. FirstLight filed a Revised Study Plan (RSP) on August 14, 2013 with FERC and addressed stakeholder comments. Included in the RSP was Study No. 3.2.2 Hydraulic Study of Turners Falls Impoundment, Bypass Reach and below Cabot (hereinafter referred to as the hydraulic study). The methodology and scope for the hydraulic study outlined in the RSP was approved with modification by the Commission in its September 13, 2013 SPDL (FERC, 2013). FERC's only modification to the RSP was to install two additional water level loggers in the Impoundment to measure water surface elevations (WSELs) and to have all water level loggers record data, at a minimum, during the months of April through November 2014.

As noted in the RSP, the goals of the hydraulic study were as follows:

[5] Reach is meant to describe the CT River from Vernon Dam to Turners Falls Dam (Impoundment) or the CT River from the Montague United States Geological Survey (USGS) Gage to Holyoke Dam.
[6] As described later, FirstLight had a variance on the geographic extent of the study. Rather than terminating the upstream extent of the hydraulic model at the Turners Falls Dam, it was terminated at the United States Geological Survey Gage located on the CT River in Montague. The rationale is explained later in this document.
[7] The ten meetings were held on May 14, 15, 21, and 22, and June 4, 5, 11, 12, and 14 and August 8.

- Provide WSEL and mean channel velocity information at transects to help inform other environmental, geologic and recreation studies. As noted in the RSP, there are seven other studies associated with the relicensing that will utilize this model in assessing impacts.[8] For example, a study will be conducted to locate spawning habitat in the Impoundment. As part of that study, data will be collected on the depth of the spawning habitat. The hydraulic model results will be used as part of that study to assess whether Impoundment fluctuations impact spawning habitat.

- A hydraulic model of the Impoundment reach will be used to determine the impact on WSEL fluctuations due to a) the Vernon Hydroelectric Project[9], b) the Northfield Mountain Project, c) the Turners Falls Project d) naturally occurring high flows, and e) combinations of the above.

- A hydraulic model of the Turners Falls Dam to Holyoke Dam reach will be used to determine the impact on WSEL fluctuations due to a) the Turners Falls Project, b) the Deerfield River Project, c) naturally occurring high flows, d) operations at Holyoke Dam and e) combinations of the above.

1.2 Hydraulic Model Physical Limits

The physical limits of the Impoundment reach hydraulic model are shown in Figure 1.2-1. As shown on the figure, the Impoundment model starts at the boat barrier line, approximately 1,250 feet upstream of the Turners Falls Dam. Due to safety concerns bathymetric data in the Impoundment from the boat barrier line to the Turners Falls Dam were not collected, hence the model starts at the boat barrier line. Similarly, the upstream extent of the Impoundment reach hydraulic model terminates approximately 350 feet below Vernon Dam.

As noted above, per the RSP the upstream extent of the downstream model was the Turners Falls Dam. FirstLight has a variance in the upstream extent of the model, terminating at the Montague United States Geological Survey (USGS) Gage as shown in Figure 1.2-2—in short the bypass reach was not included in the hydraulic model for this study. The reason for the variance is that FirstLight is developing three separate hydraulic models of the bypass reach as part of Study No. 3.3.1 Instream Flow Study in Bypass Channel and below Cabot Station. Starting at the Montague USGS Gage and moving upstream to the Turners Falls Dam the following hydraulic models are in the process of being developed as part of Study No. 3.3.1:

- Montague USGS Gage to just above Rock Dam[10]: a 2-dimensional hydraulic model is being developed.

- From just above Rock Dam to the Station No. 1 discharge: a 1-dimensional hydraulic model is being developed.

[8] The other seven studies include: 3.1.2 Causation Study, 3.3.6 Shad Spawning, 3.3.10 Odonates, 3.3.13 Littoral Zone and Spawning, 3.3.17 Tributary backwaters, 3.5.1 Baseline Inventory of Wetlands, and Special-Status Species and 3.6.6 Recreation and Land Use.

[9] The Vernon Hydroelectric Project is owned and operated by TransCanada. TransCanada is also in the process of relicensing three hydroelectric projects in series upstream of the Turners Falls Dam including from south to north the Vernon Hydroelectric Project (FERC No. 1904), Bellows Falls Hydroelectric Project (FERC No. 1855) and Wilder Hydroelectric Project (FERC No. 1892). All three TransCanada projects have the same license expiration date as the Northfield Mountain and Turners Falls Projects- April 30, 2018.

[10] Rock Dam is a natural ledge formation where the water drops vertically.

- From the Station No. 1 discharge to the Turners Falls Dam: bathymetry of the plunge pool is being collected and water level recorders installed at various locations. Due to the very complex hydraulics in this reach, a detailed hydraulic model is not being developed.

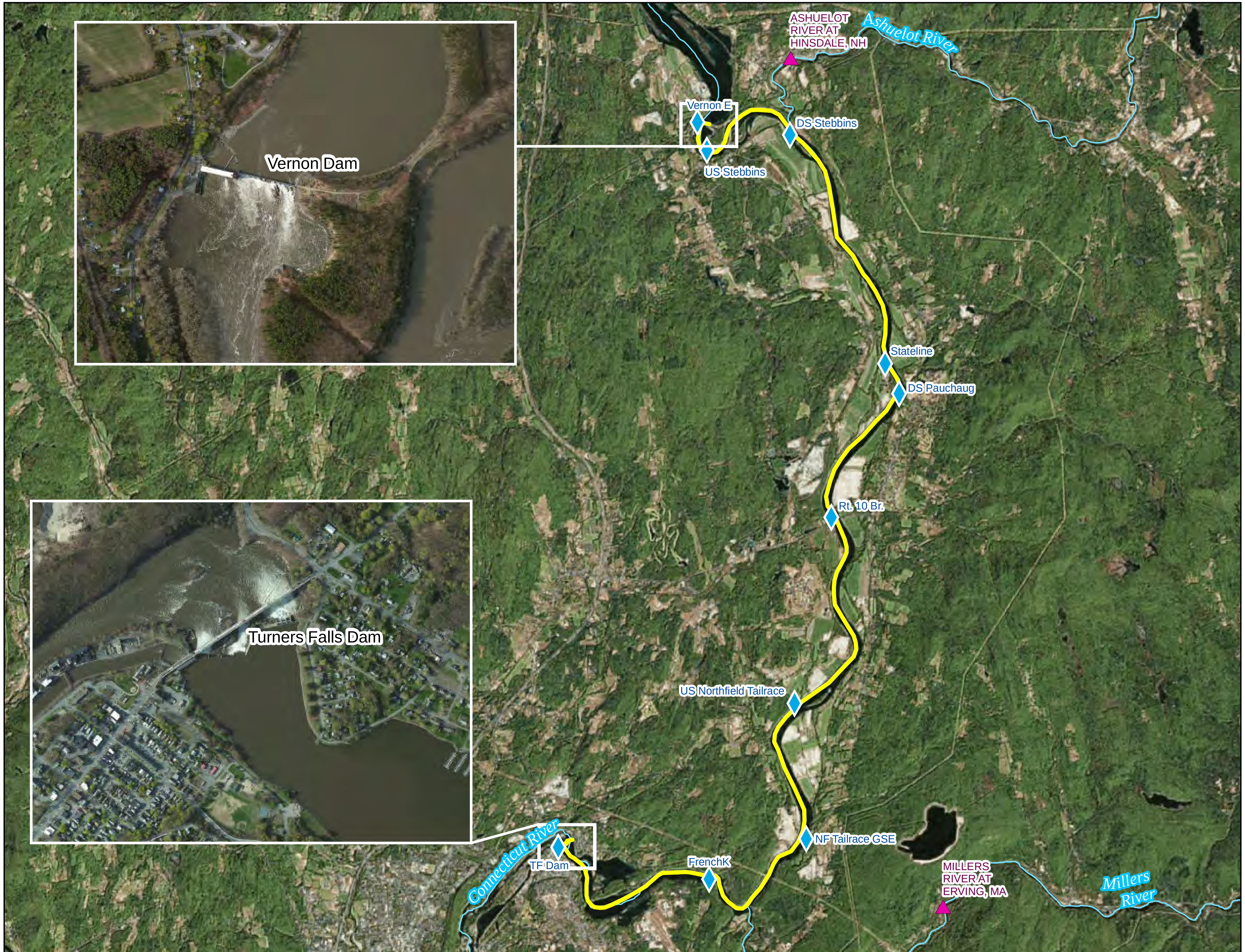
Thus, for the reach between the Montague USGS Gage and the Station No. 1 tailrace, detailed hydraulic models are already being developed as part of Study No. 3.3.1. In addition, the hydraulics in the reach between the Montague USGS Gage and Rock Dam, which includes multiple islands, are better suited for a 2D model as opposed to a 1D model like HEC-RAS which was used for this study. Given this, FirstLight believes that the hydraulic models developed for the bypass reach as part of Study No. 3.3.1 are more detailed and can address study objectives where hydraulic data is needed in the bypass reach.

1.3 Vertical Datum

Note that the datum used in this study is the National Geodetic Vertical Datum of 1929 (NGVD29). Although a more up-to-date datum is available[11], FirstLight has used the NGVD29 datum in reporting dam elevation data, water level data, etc. over numerous years. Thus, all water level logger data, and hydraulic modeling was based on the same NGVD29 datum.

Note: All figures and larger tables appear at the end of each Section.

[11] NAVD88- North American Vertical Datum of 1988 (NAVD88).



FIRSTLIGHT POWER RESOURCES

Hydraulic Study of Turners Falls Impoundment, Bypass Reach and below Cabot Station

Figure 1.2-1

Legend

- USGS Stream Gage
- Water Level Logger
- HEC-RAS Hydraulic Model Extent

N

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0 0.75 1.5 3 Miles

1 inch = 1.5 miles

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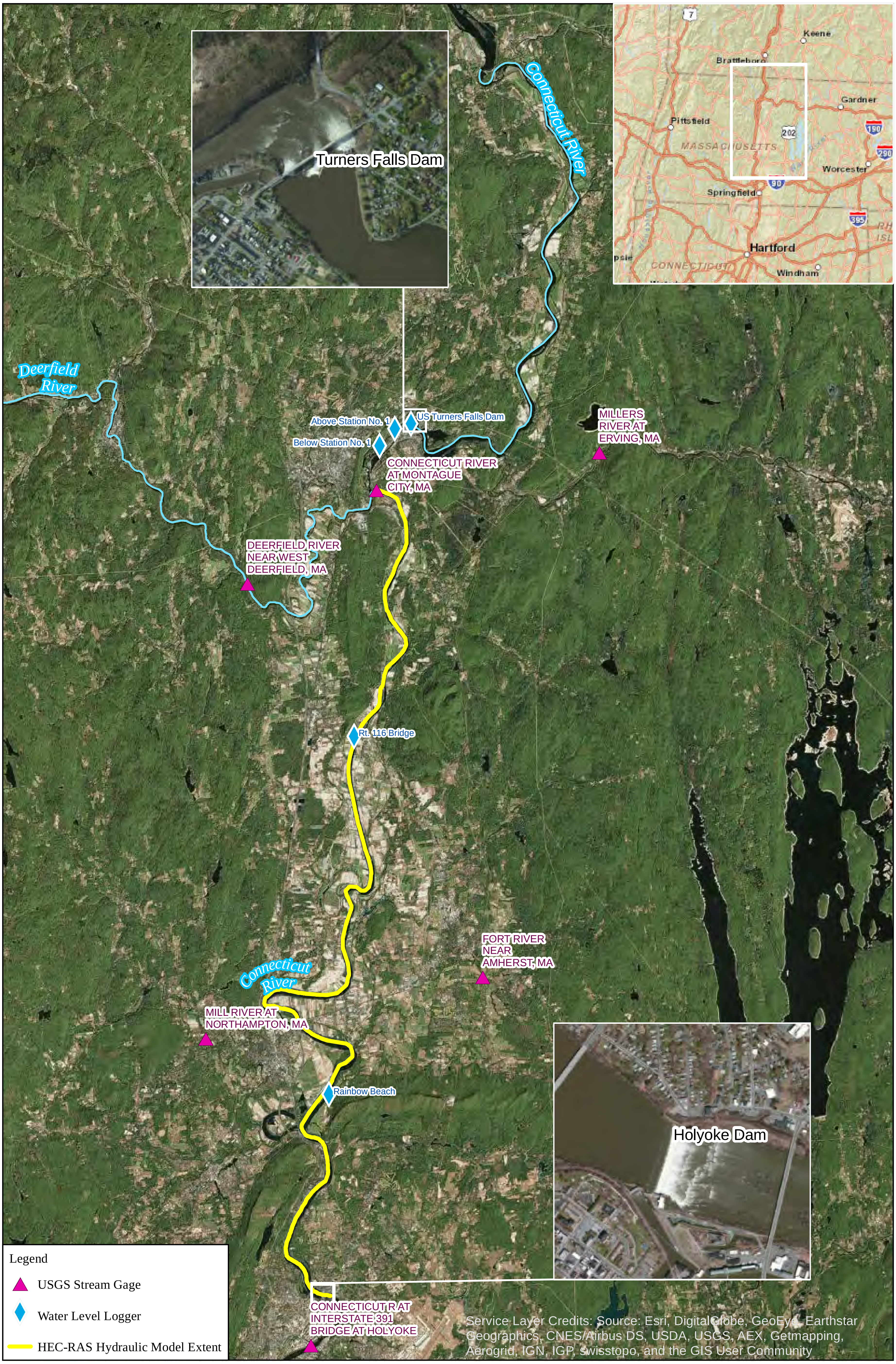

FirstLight GDF SUEZ

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)

Hydraulic Study of Turners Falls Impoundment, Bypass Reach and below Cabot Station

Figure 1.2-2

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2 SUMMARY OF FIELD DATA COLLECTION

Considerable field data were collected to develop calibrated hydraulic models of each reach. The following data were collected:

- Measured WSELs at transects along each reach.
- Measured or computed flows (in cubic feet per second, cfs) along each reach.
- Bathymetry or transects of the CT River along each reach.

The following sections describe the data collected for WSELs, flows and bathymetry in the two reaches. The subsections are organized by reach- Impoundment reach first, followed by the Montague USGS Gage to Holyoke Dam reach.

2.1 Water Level Loggers

2.1.1 Vernon Dam to Turners Falls Dam: Turners Falls Impoundment

Sample Water Level Logger

In the Impoundment, either In-Situ Level TROLL Model 500 or Onset HOBO Water Level Logger Model U20 water level loggers were installed. An example of a TROLL logger is shown in the inset. Both loggers record pressure, which is proportional to the height of the water above the instrument. The In-Situ loggers are vented, thus they require no adjustment of the difference between the recorded pressure and atmospheric pressure. The HOBO loggers are non-vented and thus must be barometrically compensated using an atmospheric pressure logger—or a logger that records atmospheric pressure.

When installed, the loggers were surveyed to the NGVD29 datum using a Real-Time Kinematic- Global Positioning System or RTK-GPS unit. The loggers were serviced approximately monthly whereby the data was downloaded and the logger re-installed.

Listed in Table 2.1.1-1 and shown in Figure 1.2-1 are the locations of water level loggers placed in the Impoundment. Table 2.1.1-1 lists the approximate river mile, the HEC-RAS transect location number[12], and the dates the logger was installed/retrieved. An abbreviated name is shown in parenthesis at each water level logger location. This abbreviated name was used in the labeling of water level loggers on numerous plots as described later. Note that the raw water level logger data underwent a rigorous QA/QC procedure before the data was considered "good". The QA/QC procedure resulted, in some cases, questionable data being eliminated. In general, the QA/QC process involved plotting the WSELs of each water level logger in synchrony with WSELs from other loggers for viewing and identification of any broad-scale elevation issues (i.e. a WSEL much higher or lower than expected based on the WSEL at other water level loggers). These issues were often resolved by re-checking survey data for data entry errors or by re-calibrating to a different RTK GPS survey at the same location. If the

[12] The HEC-RAS model for the Impoundment starts at the boat barrier line at Transect No. 474.94

issue could not be resolved, as was the case if the logger shifted or moved, these data were flagged to avoid use. Finer-scale data issues were also flagged using a combination of visualization and inspection of the raw data parameters such as depth, pressure, and temperature. Extreme depths/pressures were only observed in one logger, which indicated loss of calibration. Extreme temperatures or temperature patterns differing from other water level loggers would identify approximately when the logger was out of the water. Questionable values were examined via plotting and, if deemed incorrect, were flagged to avoid use. All values, flagged and normal data, were uploaded into the database. Export of values from the database is automatically set to include only "Normal" values, and does not export values that were flagged during QA unless specifically requested.

Table 2.1.1-1: Location of Water Level Loggers in Turners Falls Impoundment

Description	River Mile	HEC-RAS Transect Location No.	Date Installed	Date Retrieved
*Turners Falls Dam (TF Dam)	122.3	474.94		
2013			Continuous	Continuous
2014			Continuous	Continuous
Below French King Gorge (FrenchK)	125.47	14877.95		
2014			4/29/14	11/7/14
**Northfield Tailrace (NF Tailrace GSE)	127.72	26689.96		
2013			8/1/13	11/19/13
2014			4/6/14	7/12/14
Upstream of Northfield Tailrace (US Northfield Tailrace)	130.00	38849.68		
2013			8/1/13	11/19/13
2014			4/14/14	7/31/14
Route 10 Bridge (Rt. 10 Br.)	133.51	57319.76		
2013			8/1/13	11/19/13
2014			3/24/14	11/7/14
Just below confluence of Pauchaug Brook (DS Pauchaug)	135.83	69314.55		
2014			3/25/14	11/7/14
MA and VT/NH Stateline (Stateline)	136.34	71976.27		
2013			8/1/13	11/19/13
2014			5/9/14	11/7/14
Below Stebbins Island (DS Stebbins)	140.34	93245.75		
2013			8/1/13	11/19/13
2014			3/24/14	11/7/14
Just above Stebbins Island (US Stebbins)	142.19	102987.4		
2013			8/1/13	11/19/13

Description	River Mile	HEC-RAS Transect Location No.	Date Installed	Date Retrieved
2014			3/24/14	11/7/14
***Downstream of Vernon Dam (DS Vernon TC)	142.31	103486		
2014			3/24/14	7/1/14
*Vernon Dam tailrace (Vernon E)	142.6	104998.8		
2013			Continuous	Continuous
2014			Continuous	Continuous

* Signifies long-term water level logger.

** FirstLight has a long-term operating logger in the Northfield tailrace; however, because of some QA/QC issues with the logger, a second logger was installed.

*** This is TransCanada's logger. TransCanada likely installed the logger earlier than shown and the date retrieved signifies the period of data for which data were obtained by FirstLight.

In 2013, the loggers were installed on August 1 and retrieved on November 19. The loggers were set to record data on a 15-minute time increment to capture changes in flow over relatively short time increments.

In 2014, the majority of loggers were installed on March 24-25 and were retrieved on November 7. The logger just below the French King Gorge was not installed at the same time as the others due to high flows and safety concerns; it was installed on April 29. During high flow conditions, the velocity is too high through the French King Gorge area, creating safety concerns. The loggers were set to record data on a 15-minute time increment.

2.1.2 Montague USGS Gage to Holyoke Dam

Listed in Table 2.1.2-1 and shown in Figure 1.2-2 are the location of water level loggers placed in the Montague USGS Gage to Holyoke Dam reach during a portion of 2012. Table 2.1.2-1 lists the approximate river mile, the HEC-RAS transect location number, and the dates the logger was installed/retrieved. Again, the water level logger raw data underwent a rigorous QA/QC procedure as summarized in Section 2.1.1, before the data was considered "good".

The loggers were surveyed to the NGVD29 datum using an RTK-GPS unit. The loggers were serviced approximately monthly whereby the data were downloaded and the logger re-installed.

Table 2.1.2-1: Location of Water Level Loggers in Montague USGS Gage to Holyoke Dam Reach (2012)

Description	River Mile	HEC-RAS Transect Location No.	Date Installed	Date Retrieved
Montague USGS Gage	118.5	118.5	Continuous	Continuous
Route 116 Bridge	109.5	109.5	5/1/2012	10/24/2012
Across from Rainbow Beach	92.7	92.7	5/1/2012	10/24/2012

In 2012 the majority of loggers were installed on May 1 and retrieved on October 24. The loggers were set to record data on a 15-minute time increment.

2.2 Flow Data

2.2.1 Vernon Dam to Turners Falls Dam: Turners Falls Impoundment

Historically, there was a USGS gage located immediately below the Vernon Dam – USGS Gage No. 011565000 Connecticut River at Vernon, VT. The gage was active from 1936 to 1973, but was retired in 1973 due to the raising of Turners Falls Dam and hence upstream water levels. With the gage inactive, TransCanada, owners of the Vernon Hydroelectric Project (FERC No. 1806), estimates the Vernon discharge. The Vernon discharge estimate includes both generation flow and spill; spill is computed using rating curves.

In addition to estimated Vernon discharge, there are two larger tributaries draining into the Turners Falls Impoundment as summarized in Table 2.2.1-1 and shown in Figure 1.2-1. The drainage areas at the Vernon Dam and Turners Falls Dam are 6,266 mi2 and 7,163 mi2, respectively, a difference of 897 mi2. The combined gaged drainage area of the Ashuelot and Millers Rivers is 792 mi2 or 88% of the drainage area between the Vernon Dam and Turners Falls Dam.

Table 2.2.1-1: Rivers with USGS Gages draining into the Turners Falls Impoundment

Gage No.	Gage Name	Period of Record	Drainage Area	Regulation
01161000	Ashuelot River at Hinsdale, NH	1907-current	420 mi^2	Regulated by Corps Storage Reservoir- Surry Dam since 1941.
01166500	Millers River at Erving, MA	1915-current	372 mi^2	Regulated by Corps Storage Reservoirs- Tully Dam and Birch Hill Dams since 1949 and 1941, respectively.

The Ashuelot River drains into the Impoundment just below the Vernon Dam and the Millers River drains into the Impoundment approximately 7,000 feet below the Northfield Project Tailrace; immediately below the French King Highway Bridge (Route 2).

The goal of installing the water level loggers was to record WSEL's over a range of flows, and operating conditions. FirstLight commonly refers to the flow through the Impoundment as "naturally routed flow", which is the sum of the computed Vernon discharge plus the observed flows measured at the Ashuelot and Millers Rivers USGS Gages. The flow data in 2013 and 2014 (when the loggers were installed) were reviewed to determine how representative it was of the range of flows commonly observed in this section as measured by the Montague USGS Gage. Details of this gage are shown in Table 2.2.1-2. The Montague USGS is located just below the confluence with the Deerfield River.

Table 2.2.1-2: USGS Gage on CT River at Montague City, MA

Gage No.	Gage Name	Period of Record	Drainage Area	Regulation
01170500	Connecticut River at Montague City, MA	1904-current	7,860 mi^2	Regulated seasonally by dams on the CT River: First and Second CT Lakes, Moore Reservoir and Comerford Reservoir. Seasonally regulated by dams on the Deerfield River: Somerset and Harriman Reservoirs. Regulated by hydropower peaking operations on the CT River and Deerfield River.

Shown in Figure 2.2.1-1 is the following:

- the 2013 and 2014 daily hydrographs of the naturally routed flow, and;
- the period of record mean daily average hydrograph at the Montague USGS Gage for the period 1975-2014. Although the Montague USGS Gage has been active for a longer period, more recent flow data were selected to reflect current flow regulation and since the Vermont Yankee Nuclear Facility came on-line in 1972.

Note that some of the flow data measured at the CT River at Montague, Ashuelot River and Millers River Gages for the period October 1, 2013 through December 31, 2014 are considered provisional[13], at this time, by the USGS. The purpose for plotting the period of record is to compare 2013 and 2014 flow conditions—when the water level loggers were installed--- relative to long term (1975-2014) flow conditions. As Figure 2.2.1-1 shows, during the period when loggers were operating, the magnitude of the naturally routed flow varied considerably.

To further evaluate if the flows were representative of long-term conditions, shown in Figure 2.2.1-2 are four flow duration curves representing flows at the Montague USGS Gage for the following periods:

- full period of record, January 1, 1975 to December 31, 2014,
- May 1-October 24, 2012 (represents the period loggers were installed in the Montague USGS Gage to Holyoke Dam reach),
- August 1-November 19, 2013 (represents the period loggers were installed in the Turners Falls Impoundment reach), and;
- March 24-November 7, 2014 represents the period loggers were installed in the Turners Falls Impoundment reach).

The 2012 data are discussed in the following section as it pertains to water level loggers in the Montague USGS Gage to Holyoke Dam reach. As Figure 2.2.1-2 shows, flow conditions during the period the water level loggers were installed in the Impoundment reach during 2014 are representative of the range of flows observed in the CT River. The peak flow at the Montague USGS Gage was 79,200 cfs as measured on April 17, 2014. Relative to the period of record, this flow is equaled or exceeded approximately 1% of the time. In addition, flows were consistently low in September 2014 (generally below 5,000 cfs). The lowest flow at the Montague USGS Gage was 2,090 cfs as measured on September 27, 2014. Relative to the period of record, this flow is equaled or exceeded approximately 98% of the time. Thus, during the period the water level loggers were installed in 2014 flows ranged from 2,090 to 79,200 cfs, covering the range of flows observed at the Montague USGS from 1975-2014.

2.2.2 Montague USGS Gage to Holyoke Dam

There is one USGS gage on the CT River located just downstream of the Deerfield River- the Montague USGS Gage, which measures the total flow from Turners Falls Dam spill (if any), Fall River (tributary to the upper end of the bypass channel), Station No. 1 (if operating), Cabot (if operating) and the Deerfield River.

[13] As of March 2015, the data for these gages after October 2014 are classified as provisional.

The Deerfield River USGS Gage is located downstream of the Deerfield River Hydroelectric Project (FERC No. 2323). Flow on the Deerfield River is regulated from peaking hydroelectric facilities and by two seasonal storage reservoirs located in Vermont.

The drainage areas at the Montague USGS Gage and Holyoke Dam are 7,860 mi2 and 8,309 mi2, a difference of 449 mi2. Only one tributary is gaged in this reach—the Mill River at Northampton as summarized in Table 2.2.2-1.

Table 2.2.2-1: Rivers with USGS Gages draining into the Reach between the Montague USGS Gage to Holyoke Dam

Gage No.	Gage Name	Period of Record	Drainage Area	Regulation
01171500	Mill River at Northampton, MA	November 1938-current	52.6 mi^2	Regulation (probably minor) prior to October 1, 2002 by an upstream mill.

The flow data in 2012 (when the loggers were installed) were reviewed to determine how representative it was of the range of flows commonly observed in this section of the CT River.

Shown in Figure 2.2.2-1 is the following:

- the mean daily hydrographs at the Montague USGS Gage flow for the year 2012, and;
- the mean daily average hydrograph at the Montague USGS Gage for the period January 1, 1975-December 31, 2014.

As Figure 2.2.2-1 shows, during the period when loggers were operating in 2012 the magnitude of the flow at the Montague USGS Gage ranged from 1,500 cfs to 38,000 cfs. To further evaluate if the flows were representative of long-term conditions, shown in Figure 2.2.1-2 are flow duration curves representing flows at the Montague USGS Gage for the following periods:

- January 1, 1975 to December 31, 2014, and;
- May 1-October 24, 2012 (the period the loggers operated in the Montague USGS Gage to Holyoke Dam reach).

The magnitude of the peak flow at the Montague USGS Gage was close to 38,000 cfs on May 10, 2014; a flow of 38,000 cfs is equaled or exceeded approximately 7% of the time based on the full period of record (1904-2014). In addition, a low flow of 1,500 cfs, which occurred on September 3, 2012, is equaled or exceeded approximately 97% of the time based on the same full period of record. Based on this information, the range of flow conditions during which the loggers were operating reasonably represents the range of flows observed at the Montague USGS Gage.

2.3 Water Level Loggers, Flow Data and Project Operations

2.3.1 Vernon Dam to Turners Falls Dam: Turners Falls Impoundment

As noted above, Impoundment fluctuations are a function of Vernon Hydroelectric Project operations, Northfield Mountain Project operations and the Turners Falls Project operations. Numerous plots were developed comparing WSEL data recorded at the various water level loggers against the Vernon discharge and the Northfield Mountain generation/pumping discharges.

Shown in Appendix A and Appendix B are plots showing the following for 2013 and 2014, respectively:

- The x-axis represents time in 5-day increments. All of the water level data and flow data are shown in 15-minute increments.
- The WSELs at the water level loggers in the Impoundment are shown on the primary y-axis. Note that some logger data were eliminated after completing the QA/QC process.
- The Vernon flow and Northfield flow (pump or gen) is shown on the secondary y-axis. Note some flow data were eliminated after completing the QA/QC process.

When reviewing the plots in Appendix A and B, note that the Vernon Hydroelectric Project has a minimum flow requirement of 1,250 cfs; however, TransCanada generally maintains a higher minimum flow of 1,600 via one of its units. The Vernon Project has a total of 10 units, with a total hydraulic capacity of approximately 17,130 cfs. The Vernon discharge shown on the plots includes both generation flow and computed spill flow (if spilling).

The Northfield Mountain Project has a total of four pump-turbine units for a total pumping hydraulic capacity of approximately 15,200 cfs, and a total generation hydraulic capacity of approximately 20,000 cfs. FirstLight measures the pump and generation discharge via Accusonic equipment. Based on the equipment standards, it measures flows to within 3% of the actual flow.

2.3.2 Montague USGS Gage to Holyoke Dam

As noted above, the CT River below Cabot Station is a function of Cabot peaking operations and to a lesser extent the Deerfield River Hydroelectric Project operations. Similar to the Impoundment reach, numerous plots were developed comparing WSEL data recorded at the various water level loggers against the estimated Cabot discharge and discharges measured at the Deerfield River USGS Gage located downstream of all of the Deerfield hydroelectric developments.

Shown in Appendix C are plots showing the following for 2012:

- The x-axis represents time in 5-day increments. All of the water level data and flow data are shown in 15-minute increments.
- The WSELs at the water level loggers are shown on the primary y-axis. Note that some logger data were eliminated after completing the QA/QC process.
- The Montague USGS gaged flow is shown on the secondary y-axis.

When reviewing the plots in Appendix C, note that Cabot Station includes six equally sized turbines for a total station hydraulic capacity of approximately 13,728 cfs or 2,288 cfs/unit.

The lowermost hydroelectric project on the Deerfield River is Station No. 2, which has a continuous year-round minimum flow requirement of 200 cfs (guaranteed from storage) and a full generation hydraulic capacity of 1,450 cfs.

2.4 Bathymetric Data

2.4.1 Vernon Dam to Turners Falls Dam: Turners Falls Impoundment

Bathymetric data were originally collected in the Impoundment in 2006 by Hydroterra, Inc. The bathymetry covered the area from the boat barrier line just above the Turners Falls Dam upstream to just below Vernon Dam. After installing water level loggers during a portion of 2013 and the majority of 2014, FirstLight identified an error in the bathymetric data. More specifically, there was a vertical datum error in the bathymetric data between Vernon Dam and approximately one-half mile downstream of the NH/VT/MA Stateline. After making unsuccessful efforts to resolve the vertical datum discrepancy, FirstLight opted to re-collect bathymetric data in 2014 between the Vernon Dam and approximately one-half mile downstream of the Stateline. In addition, as part of Study No. 3.3.9 Two-Dimensional Modeling of the Northfield Mountain Project Intake/Tailrace and Connecticut River Upstream and Downstream of the Intake/Tailrace FirstLight collected bathymetric data in 2014 from 0.5 km (1,640 ft) below to 0.5 km (1,640 ft) above the Northfield Mountain Project intake/tailrace. In addition, more detailed information was obtained for all bridges traversing the Impoundment.

Finally, TransCanada provided FirstLight with Light Detection and Ranging (LiDAR) data of the Impoundment riverbanks. The LiDAR[14] was flown from April 26-28, 2013 (leaf off) during normal river flows (flow at the Montague USGS Gage on these days ranged from 15,600 to 21,000 cfs).

One seamless bathymetric/topographic map was developed of the Impoundment using the 2006 bathymetry data, 2014 bathymetry data described above, LiDAR data and bridge information. As described later the seamless data were entered into a Geographic Information System (GIS) for use with HEC-GeoRAS. Shown in Figure 2.4.1-1 (a-d) is a series of maps showing the following: aerial image background, HEC-RAS transects, location of water level loggers, major tributaries (Ashuelot and Millers River) and the bathymetric/topographic data.

2.4.2 Montague USGS Gage to Holyoke Dam

In the Montague USGS Gage to Holyoke Dam reach, the RSP calls for developing a hydraulic model using existing Federal Emergency Management Agency (FEMA) flood insurance studies (FIS). FIS's of the CT River in this reach were developed in the 1980's to map inundation area associated with the 100-year flood. The FIS's are typically categorized by town. The towns covering this reach include from upstream to downstream order: Montague, Deerfield, Sunderland, Whately, Hadley, Hatfield, Northampton, Easthampton, South Hadley, and Holyoke.

FirstLight contacted FEMA to secure the FIS written reports and HEC-2[15] hydraulic model data (input and output files) for the towns listed above and located between the Montague USGS Gage and Holyoke Dam. FEMA provided FirstLight with the FIS's and paper copies of the HEC-2 hydraulic model input and output files for the various towns, with the exception of Hatfield, MA. FirstLight made numerous inquiries with federal, state and local officials to track down the Hatfield HEC-2 input and output files with no success. Given this, in 2014 FirstLight collected eight transects of the CT River in the Hatfield reach such that a complete model could be developed.

In addition to the FEMA FIS transect data and the 2014 transect data collected in Hatfield, The Nature Conservancy (TNC) noted that a HEC-RAS model of the Northampton area had been developed by the United States Army Corps of Engineers (USACE) and TNC in 2012-13. TNC conducted a study of floodplain forests in the CT River Basin and one of the study sites was in the Northampton, MA area of the CT River (Marks, 2014). Bathymetry data were collected by the USACE in the fall of 2011. The original HEC-RAS model was developed by the USACE, but was later modified by TNC. The modified HEC-RAS model was provided to FirstLight.

[14] The data were collected by US Imaging using an Optech M-300 Orion LiDAR Sensor and Integrated CS-10000 Digital CameraAircraft– Cessna T210N – N6258YQA. The LiDAR data were checked against the independently obtained QA/QC points throughout the project area and was found to have a Root Mean Square Error (RMSE) for the sample (RMSEz) of 6.1cm (vertical). The digital imagery was checked against more than 60 photo targets and Photo ID points along the project corridor and was found to have better than 12 cm horizontal standard deviation.

[15] The predecessor hydraulic model to HEC-RAS was HEC-2, also developed by the United States Army Corps of Engineers.

Shown in Figure 2.4.2-1(a-h) is a series of maps showing the following for the reach between the Montague USGS Gage and Holyoke Dam: aerial image background, FEMA transects, USACE Northampton transects, FirstLight Hatfield transects, location of water level loggers, and the major tributary to the reach—the Deerfield River

Figure 2.2.1-1: Annual Daily Hydrograph of Naturally Routed Flow (2013, 2014) and Long-Term (1975-2014) Hydrograph of USGS Gage Connecticut River at Montague, MA

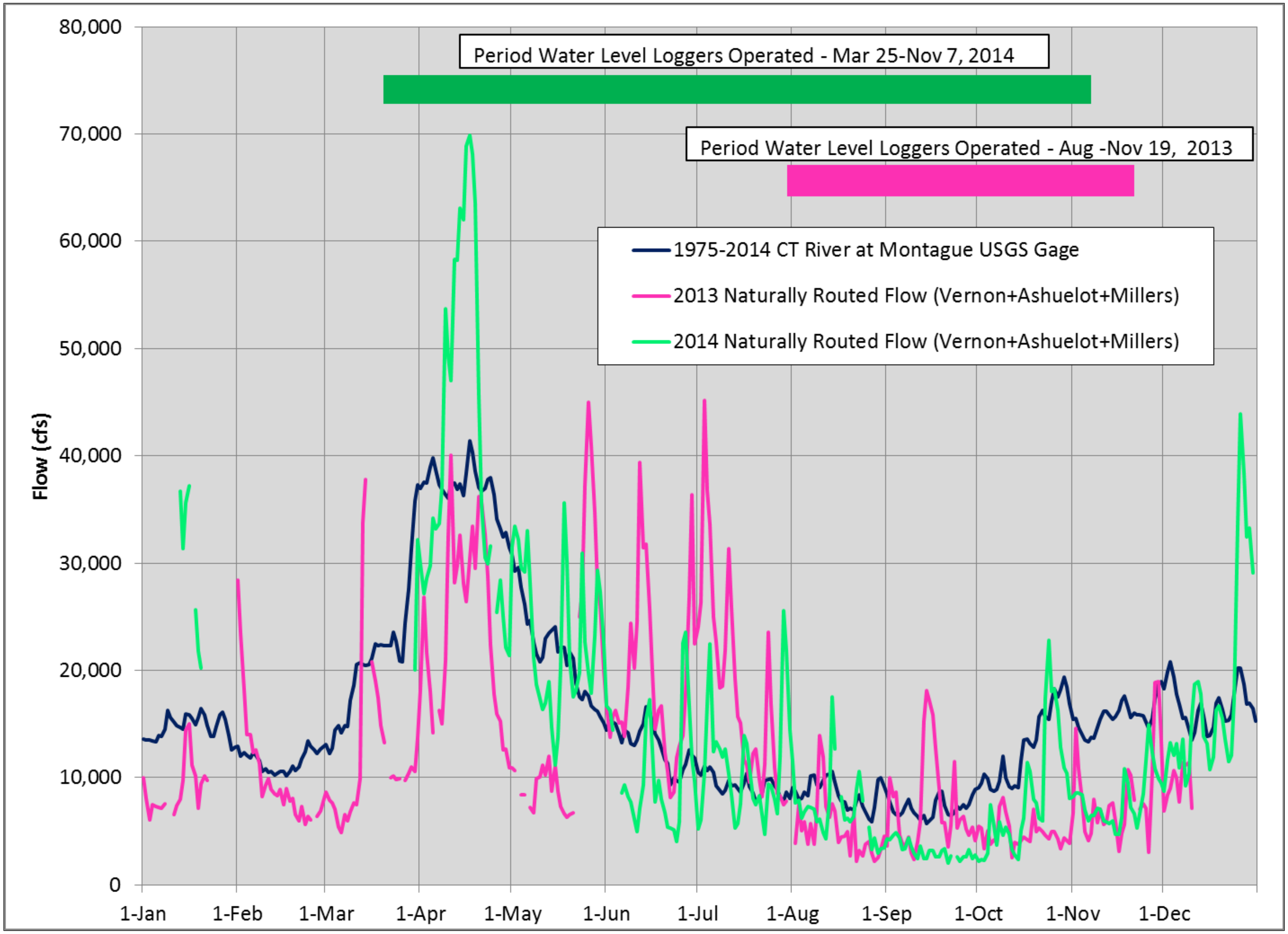


Figure 2.2.1-2: Flow Duration Curves at the CT River USGS Gage at Montague, MA for the Period of Record and Portions of 2012, 2013 and 2014

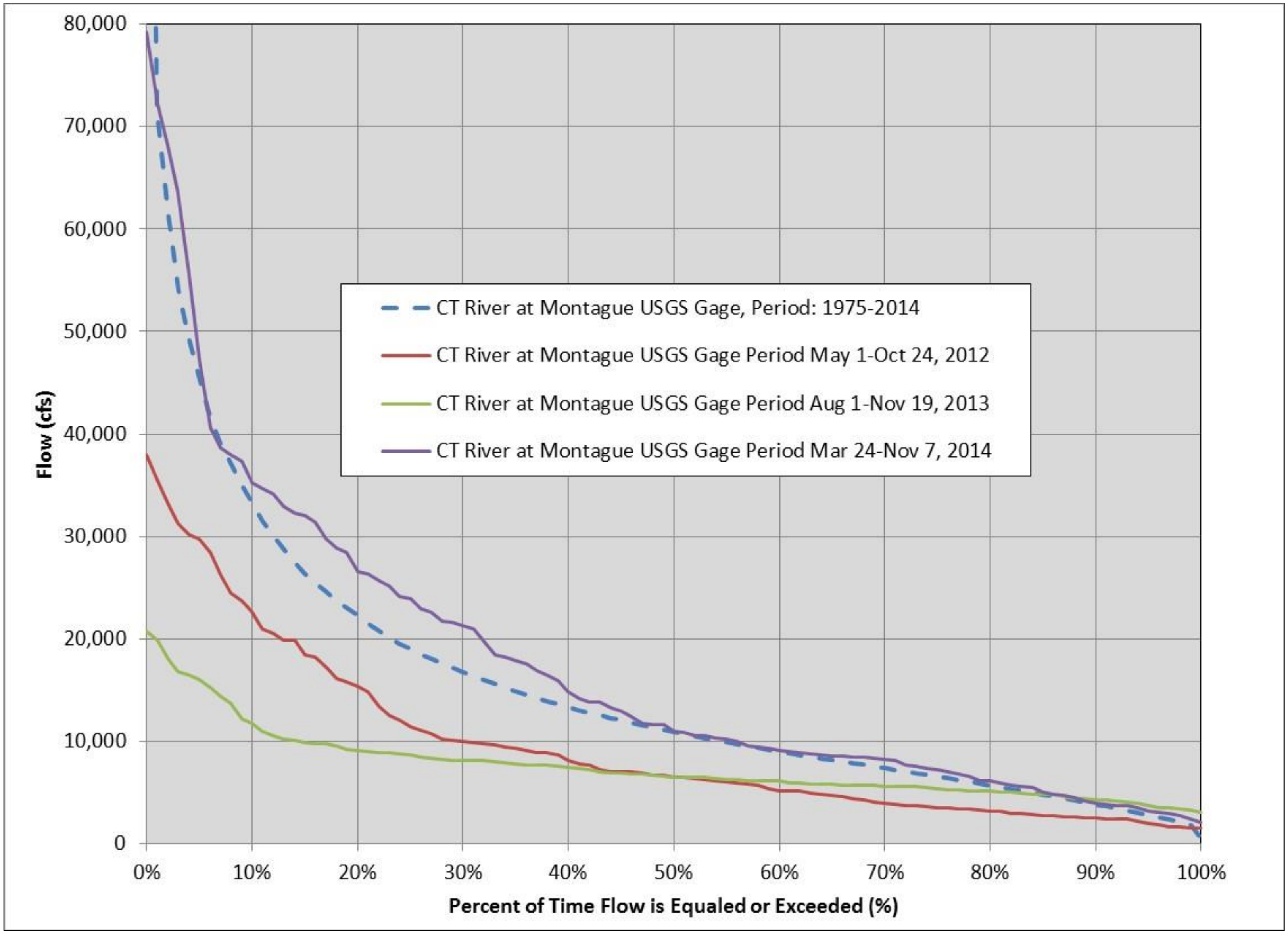
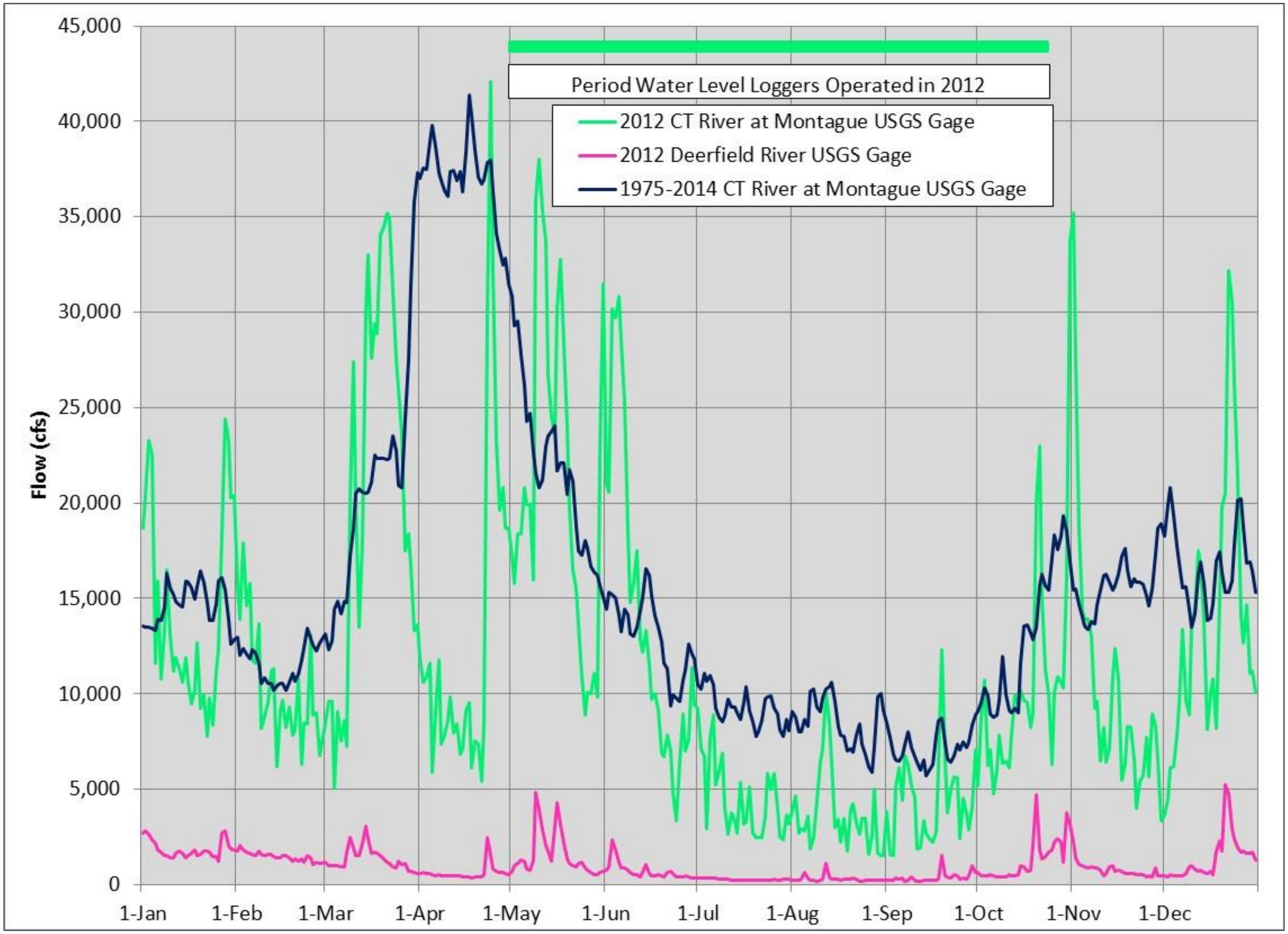
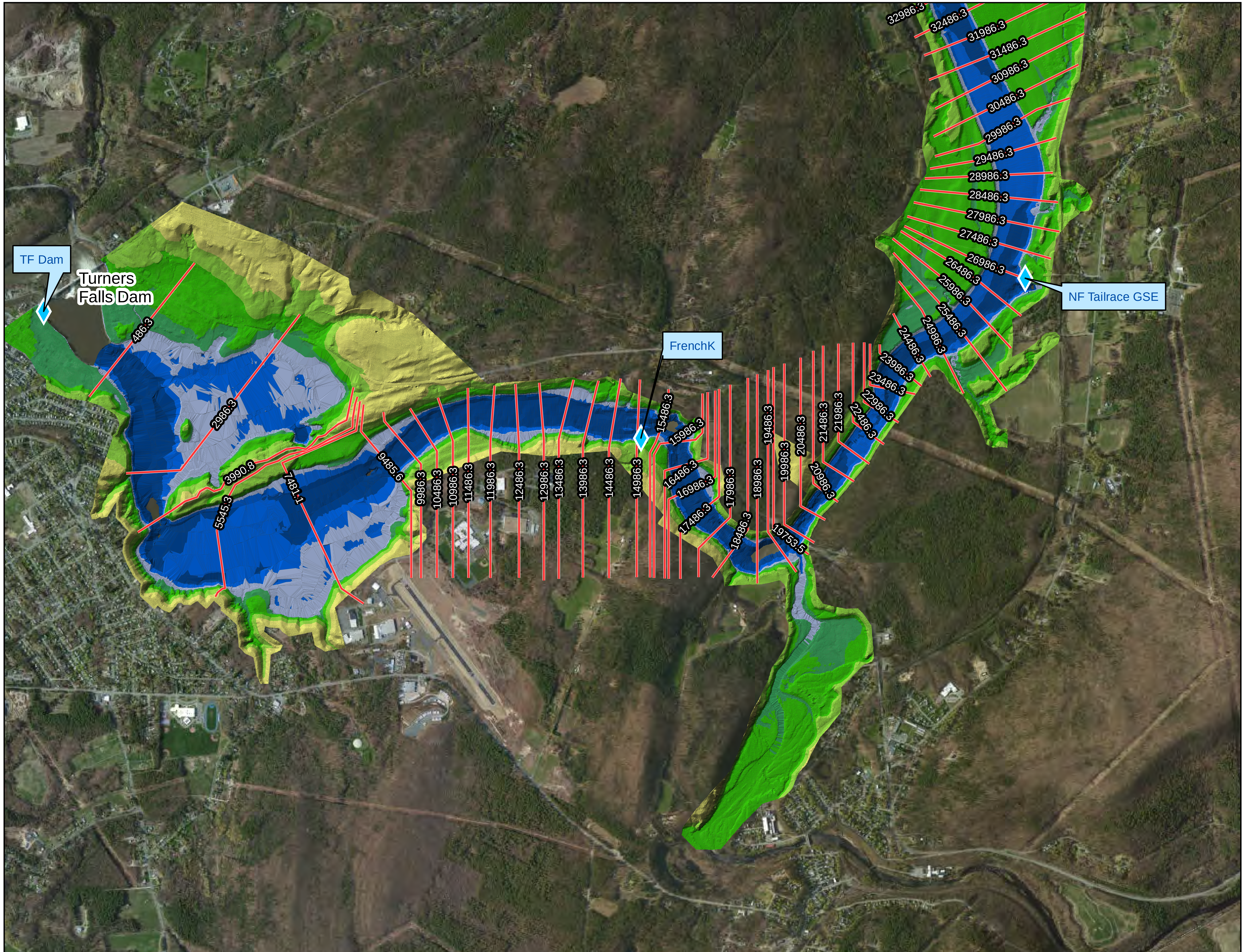
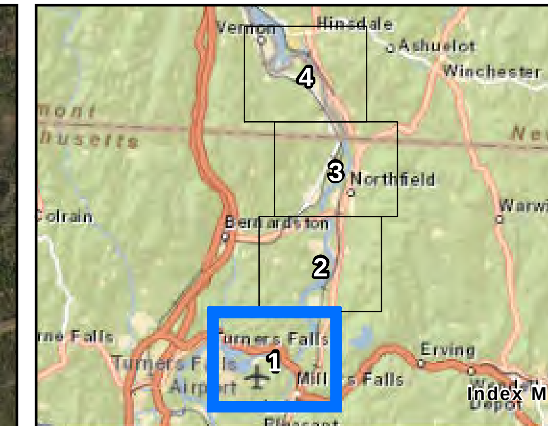


Figure 2.2.2-1: 2012 Mean Daily Hydrograph of USGS Gages on Deerfield River at West Deerfield, MA and Connecticut River at Montague, MA Long-Term Hydrograph of Connecticut River at Montague, MA







FIRSTLIGHT POWER RESOURCES
Hydraulic Study of Turners Falls Impoundment

Figure 2.4.1-1a
Plan Map of Turners Falls Impoundment
HEC-RAS Transect Numbers

Legend

N

- USGS Stream Gage
- Water Level Logger
- Transects

Impoundment Terrain (NGVD29)

- >275'
- 225' - 275'
- 195' - 225'
- 185' - 195'
- 176' - 185'
- 165' - 176'
- 128' - 165'

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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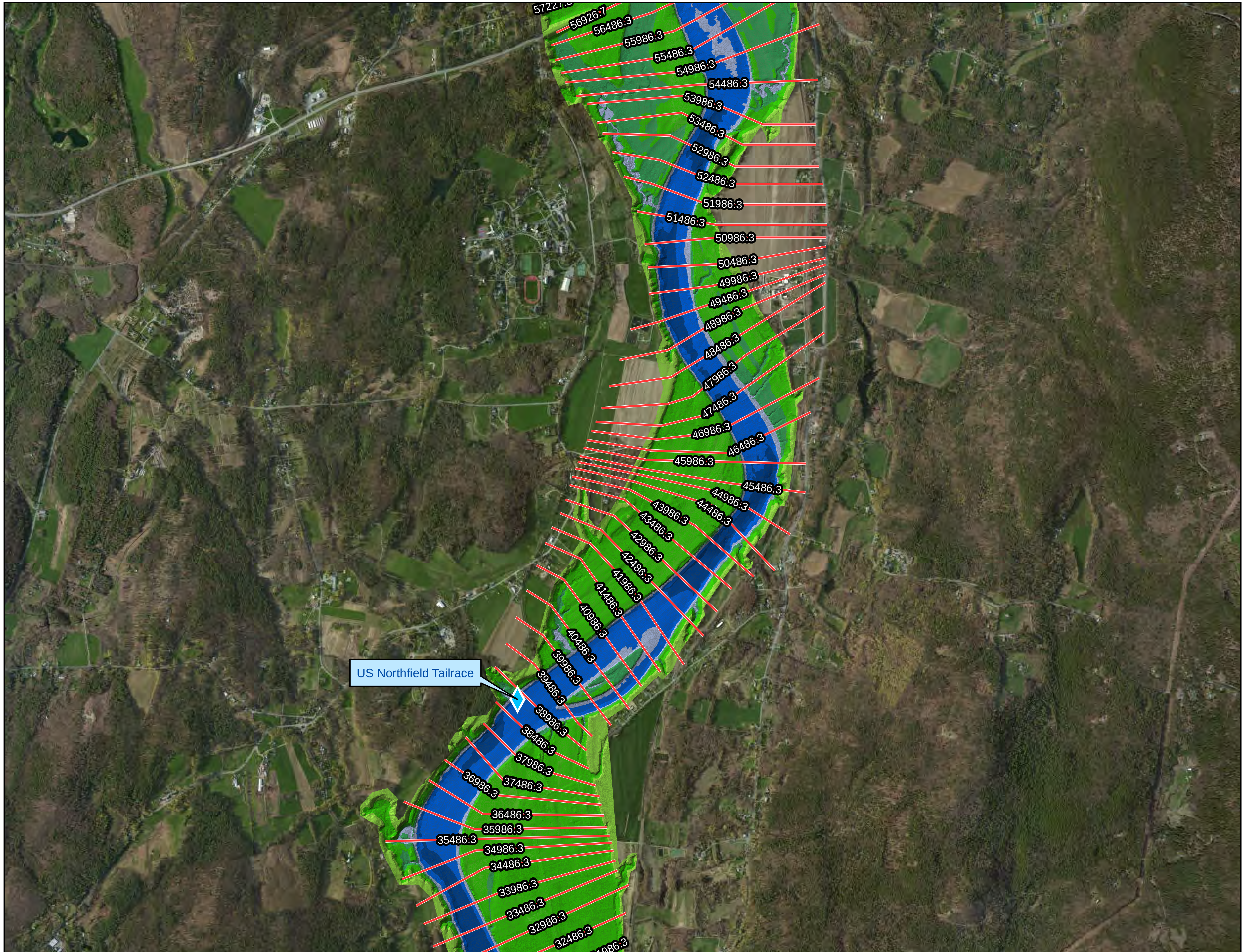

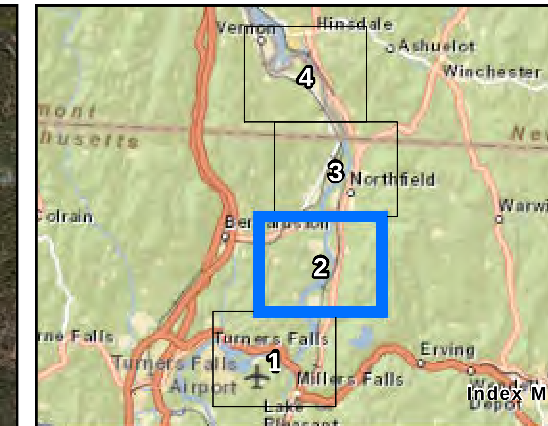

FIRSTLIGHT POWER RESOURCES

Hydraulic Study of Turners Falls Impoundment

Figure 2.4.1-1b
Plan Map of Turners Falls Impoundment
HEC-RAS Transect Numbers

Legend

- USGS Stream Gage
- Water Level Logger
- Transects

Impoundment Terrain (NGVD29)

- >275'
- 225' - 275'
- 195' - 225'
- 185' - 195'
- 176' - 185'
- 165' - 176'
- 128' - 165'

N

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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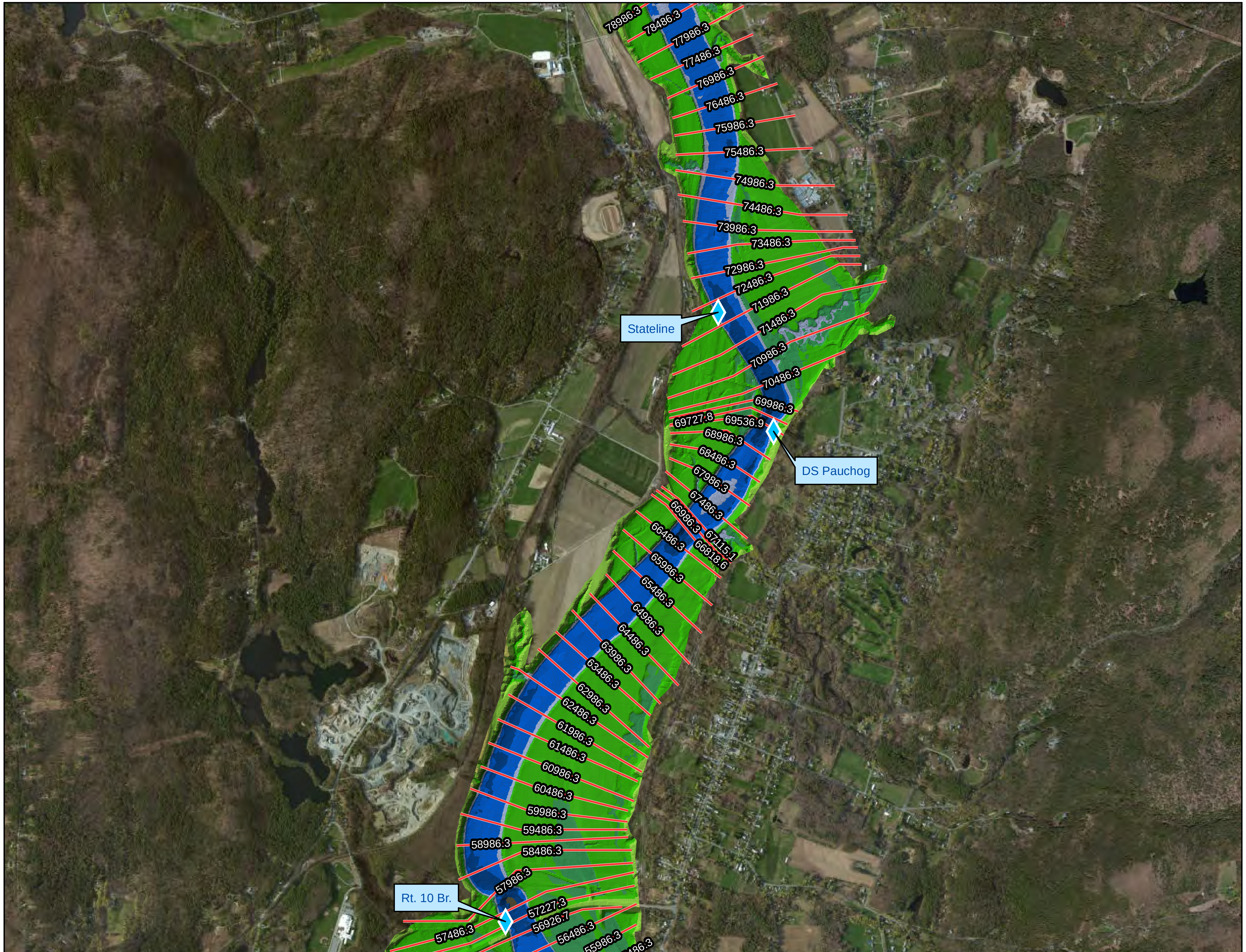

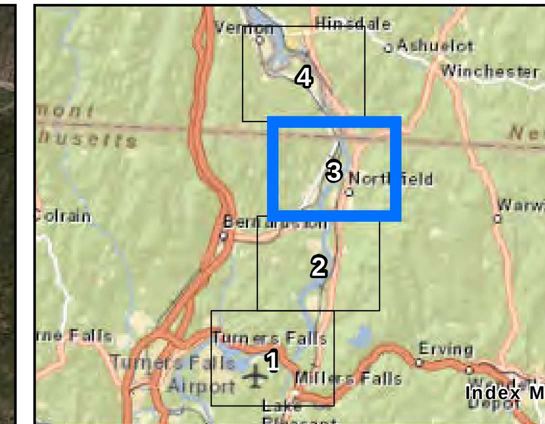

FIRSTLIGHT POWER RESOURCES

Hydraulic Study of Turners Falls Impoundment

Figure 2.4.1-1c

Plan Map of Turners Falls Impoundment

HEC-RAS Transect Numbers

Legend

- USGS Stream Gage
- Water Level Logger
- Transects

Impoundment Terrain (NGVD29)

- >275'
- 225' - 275'
- 195' - 225'
- 185' - 195'
- 176' - 185'
- 165' - 176'
- 128' - 165'

N

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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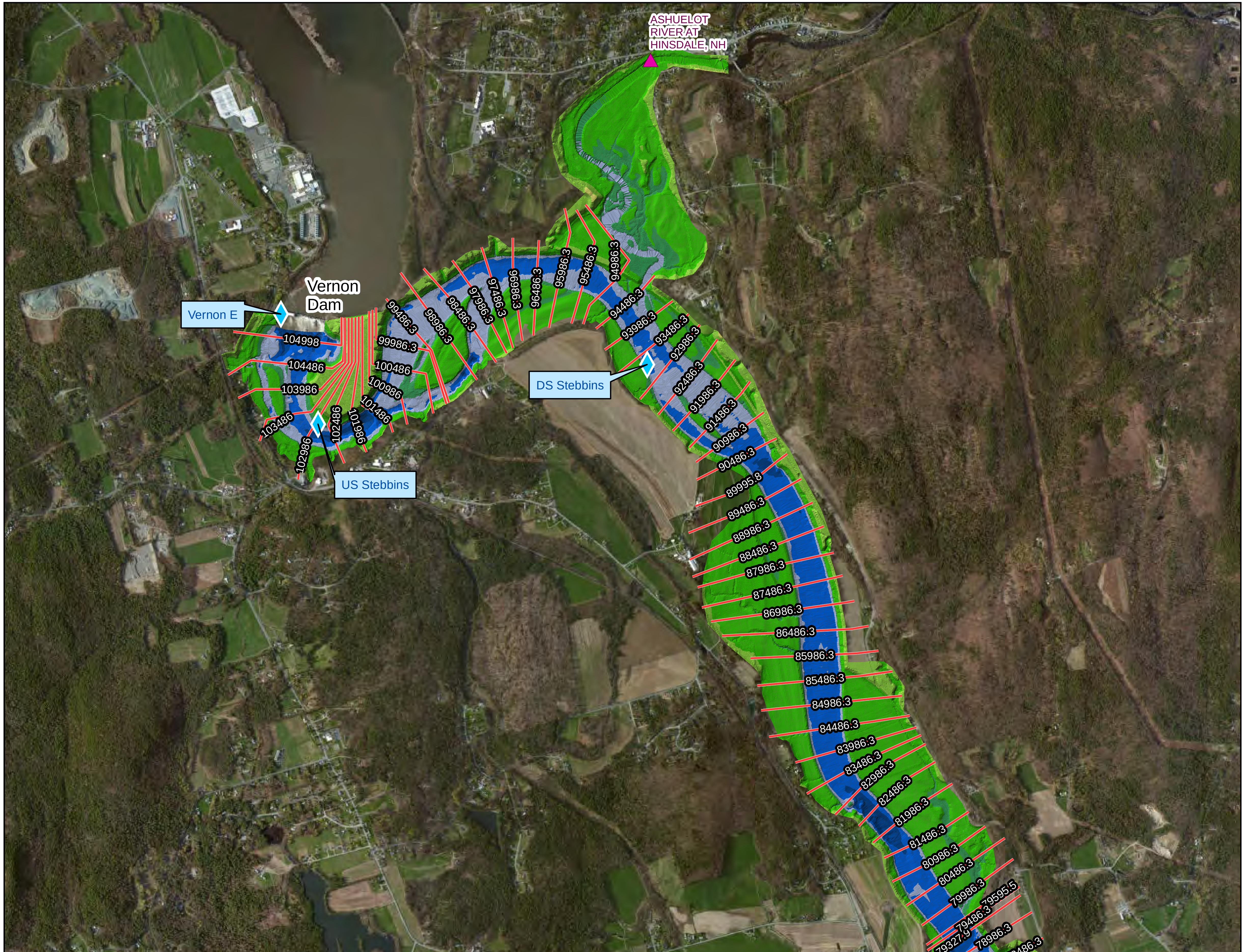

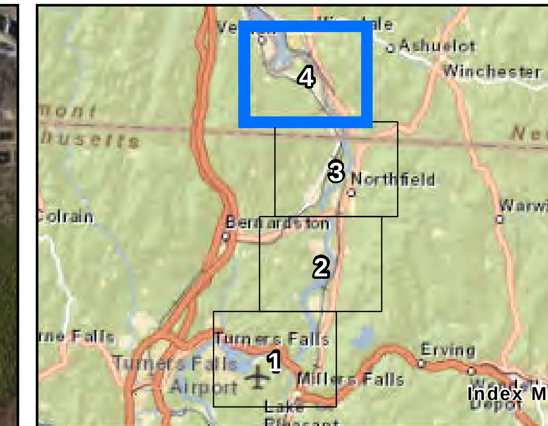

FIRSTLIGHT POWER RESOURCES

Hydraulic Study of Turners Falls Impoundment

Figure 2.4.1-1d
Plan Map of Turners Falls Impoundment
HEC-RAS Transect Numbers

Legend

- USGS Stream Gage
- Water Level Logger
- Transects

Impoundment Terrain (NGVD29)

- >275'
- 225' - 275'
- 195' - 225'
- 185' - 195'
- 176' - 185'
- 165' - 176'
- 128' - 165'

N

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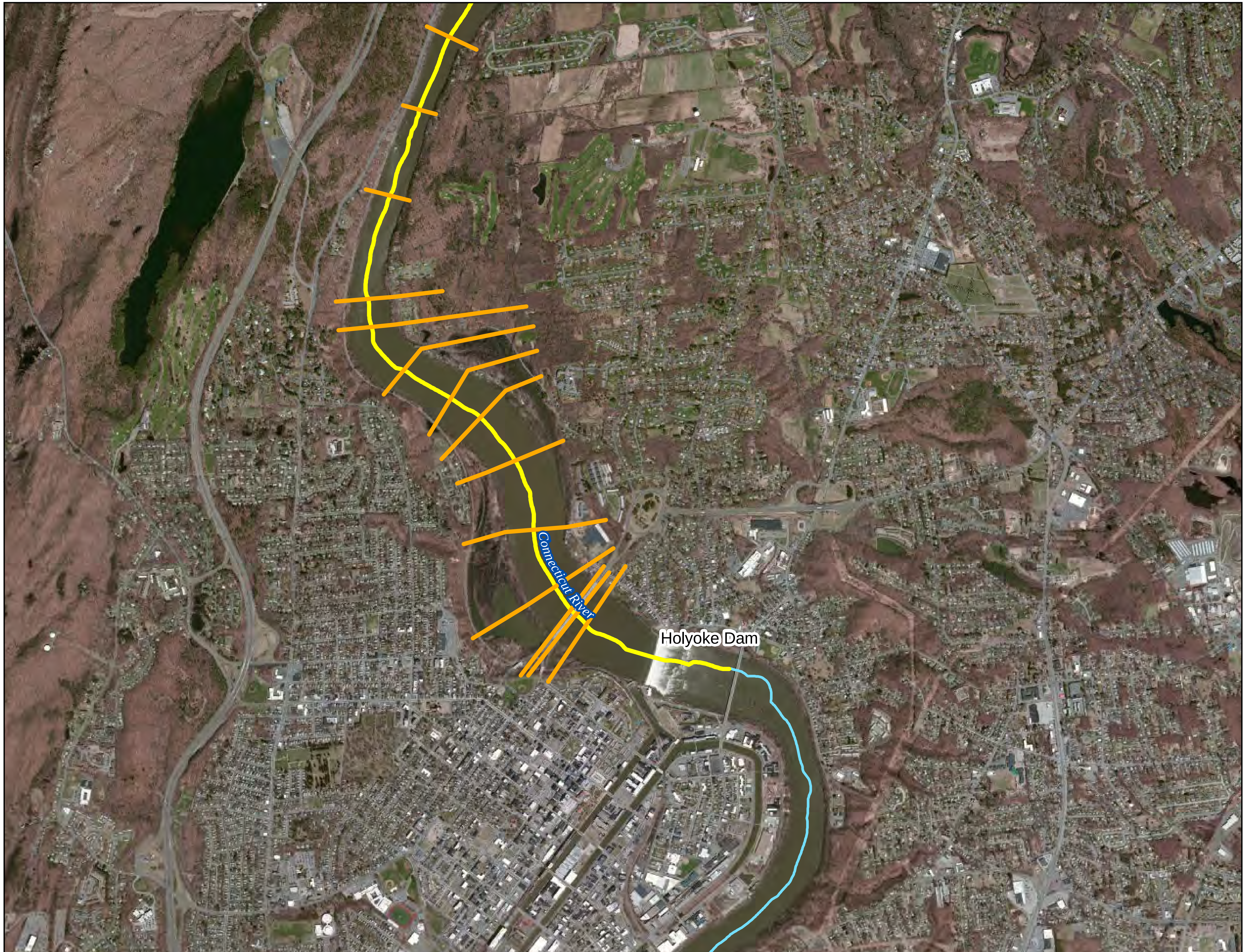

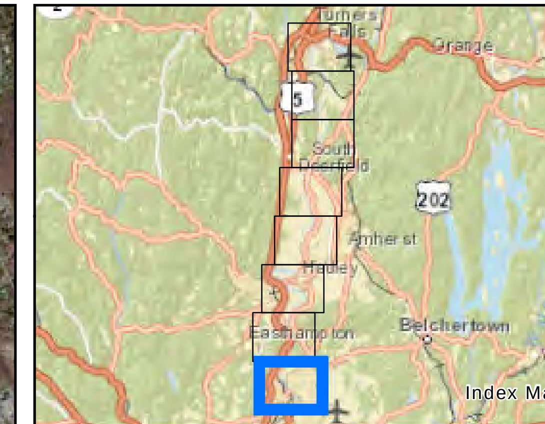

FIRSTLIGHT POWER RESOURCES
Hydraulic Study of Connecticut River
from Montague USGS Gage to Holyoke Dam

Figure 2.4.2-1a
Plan Map of HEC-RAS Transects
from Montague USGS Gage to Holyoke Dam

Legend

- USGS Stream Gage
- Water Level Logger
- FEMA transects
- FirstLight Hatfield transects
- USACE Northampton transects
- HEC-RAS Hydraulic Model Extent

N

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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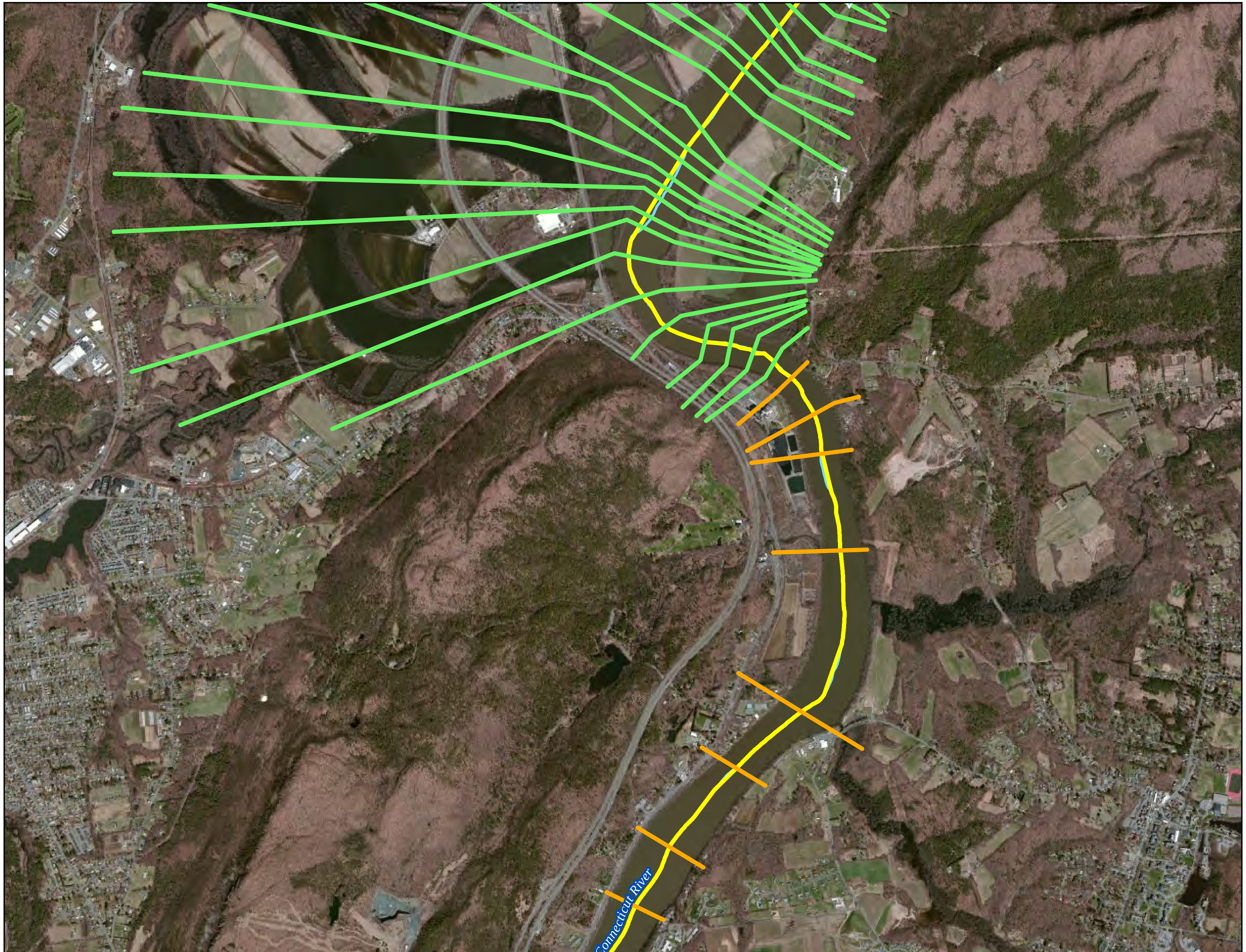

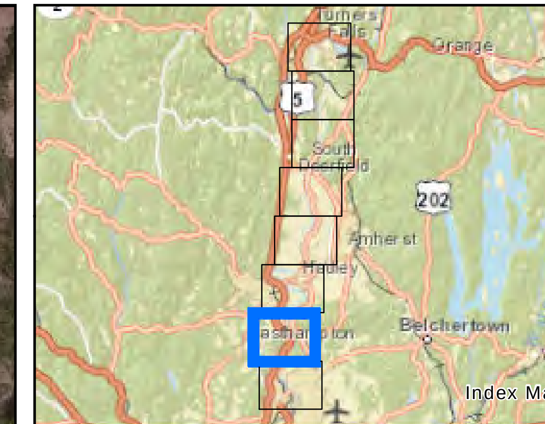

FIRSTLIGHT POWER RESOURCES
Hydraulic Study of Connecticut River
from Montague USGS Gage to Holyoke Dam

Figure 2.4.2-1b
Plan Map of HEC-RAS Transects
from Montague USGS Gage to Holyoke Dam

Legend

N

- USGS Stream Gage
- Water Level Logger
- FEMA transects
- FirstLight Hatfield transects
- USACE Northampton transects
- HEC-RAS Hydraulic Model Extent

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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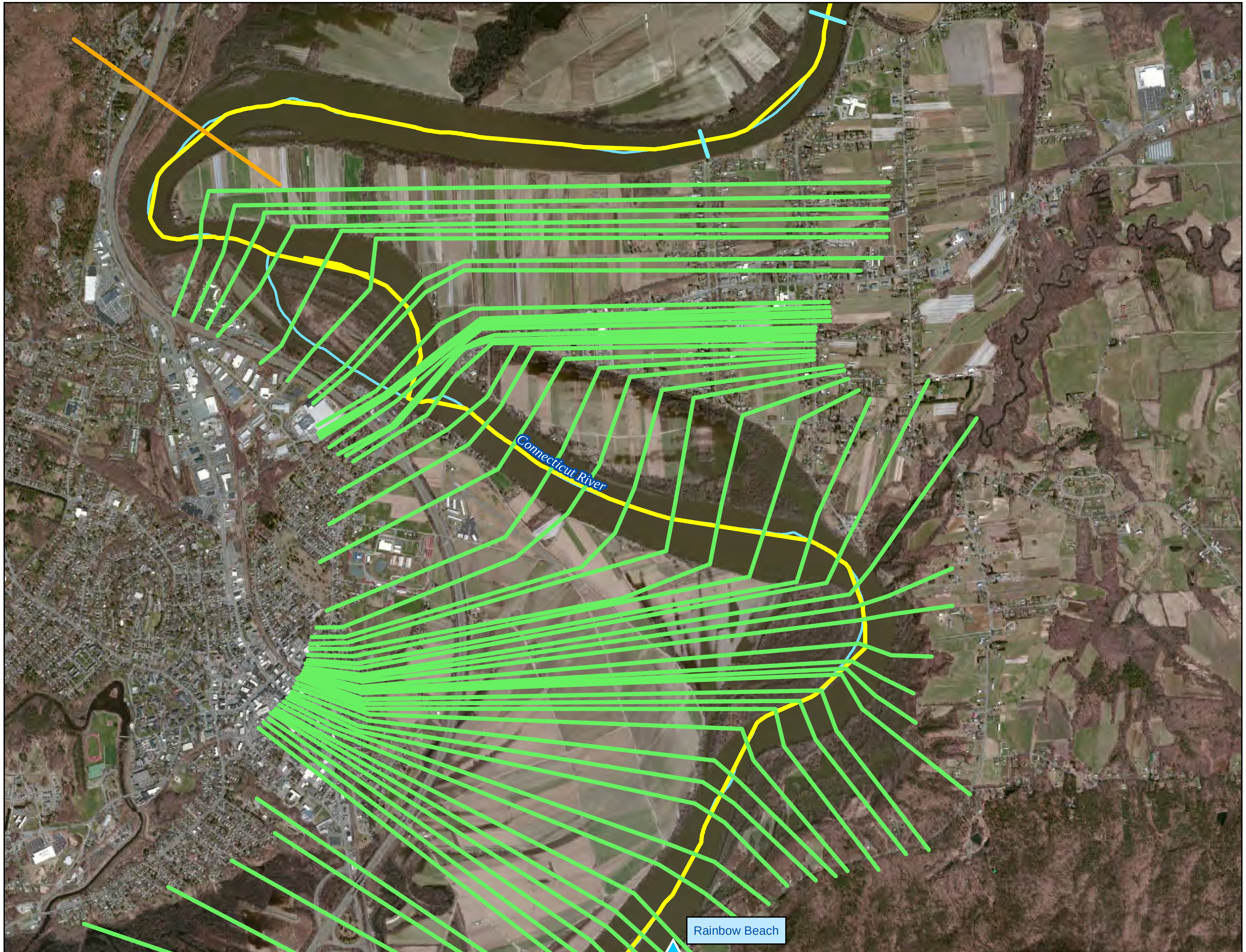

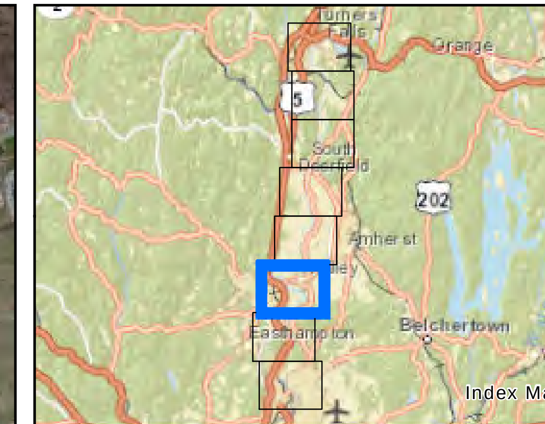

FIRSTLIGHT POWER RESOURCES
Hydraulic Study of Connecticut River
from Montague USGS Gage to Holyoke Dam

Figure 2.4.2-1c
Plan Map of HEC-RAS Transects
from Montague USGS Gage to Holyoke Dam

Legend

- USGS Stream Gage
- Water Level Logger
- FEMA transects
- FirstLight Hatfield transects
- USACE Northampton transects
- HEC-RAS Hydraulic Model Extent

N

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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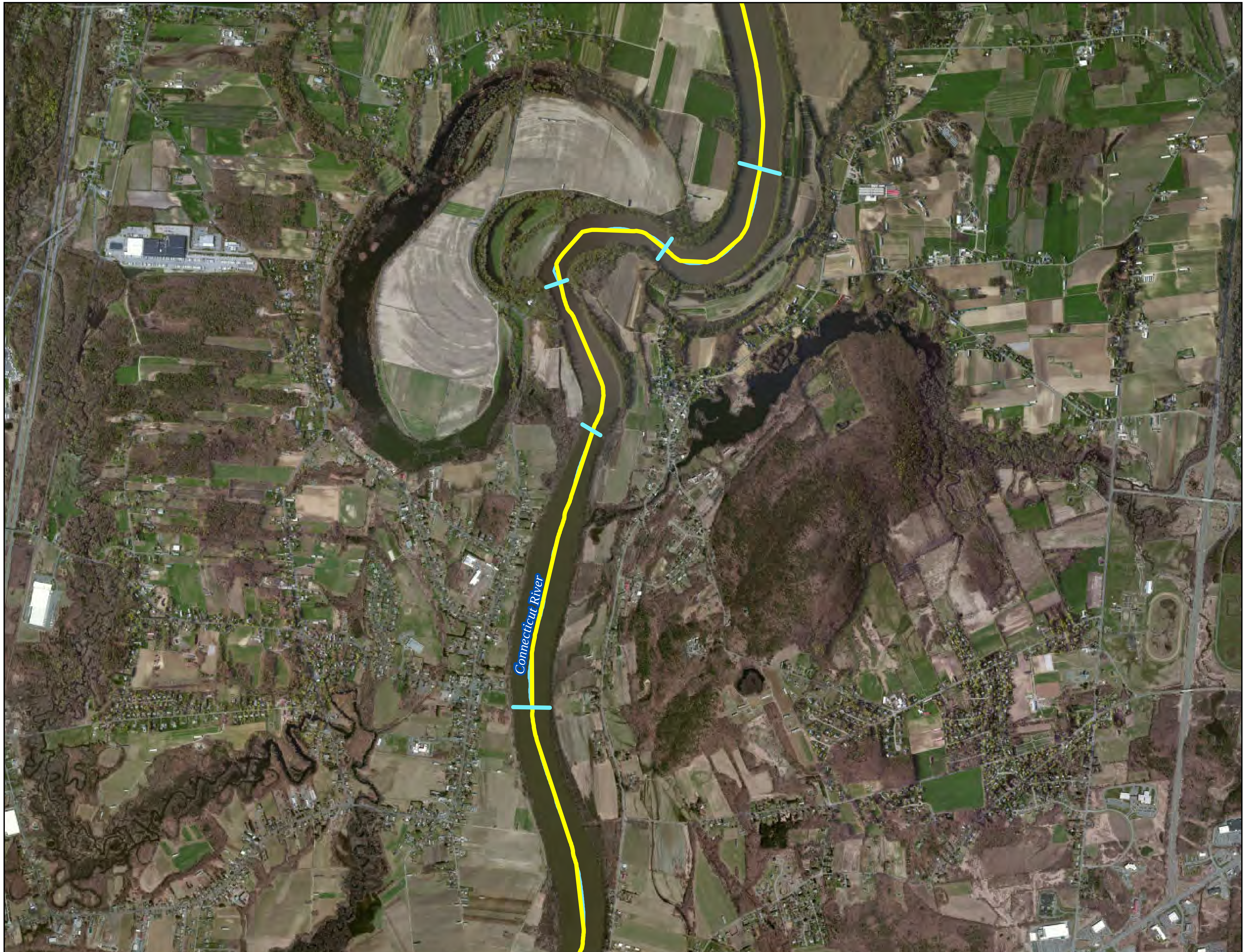

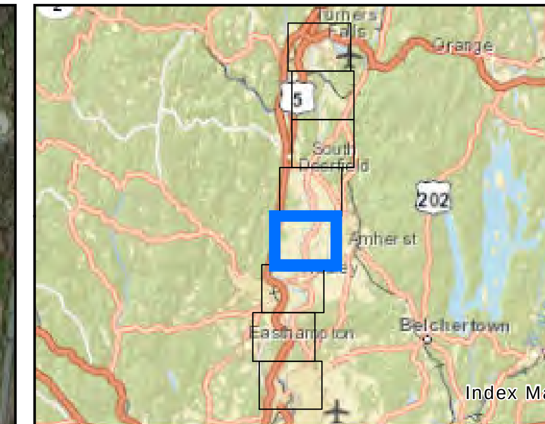

FIRSTLIGHT POWER RESOURCES
Hydraulic Study of Connecticut River
from Montague USGS Gage to Holyoke Dam

Figure 2.4.2-1d
Plan Map of HEC-RAS Transects
from Montague USGS Gage to Holyoke Dam

Legend

- USGS Stream Gage
- Water Level Logger
- FEMA transects
- FirstLight Hatfield transects
- USACE Northampton transects
- HEC-RAS Hydraulic Model Extent

N

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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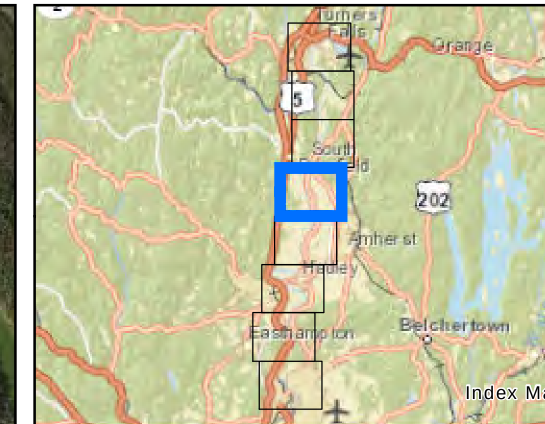

FIRSTLIGHT POWER RESOURCES
Hydraulic Study of Connecticut River
from Montague USGS Gage to Holyoke Dam

Figure 2.4.2-1e
Plan Map of HEC-RAS Transects
from Montague USGS Gage to Holyoke Dam

Legend

- USGS Stream Gage
- Water Level Logger
- FEMA transects
- FirstLight Hatfield transects
- USACE Northampton transects
- HEC-RAS Hydraulic Model Extent

N

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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FirstLight
GDF SUEZ

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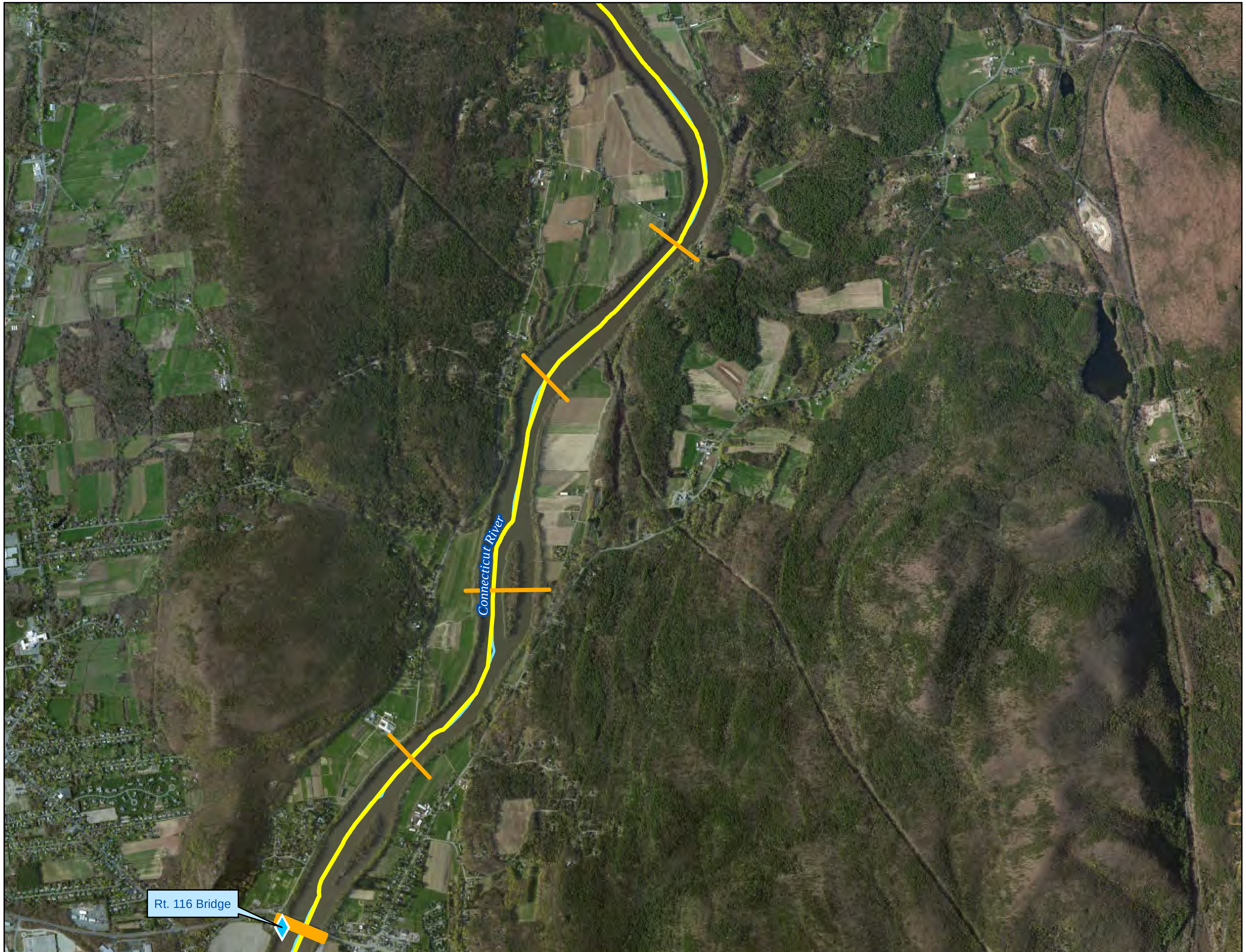

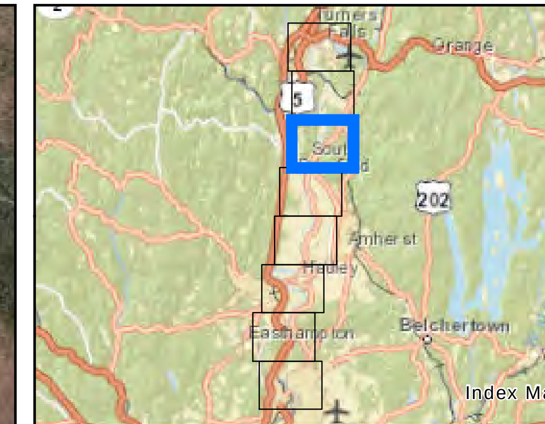

FIRSTLIGHT POWER RESOURCES
Hydraulic Study of Connecticut River
from Montague USGS Gage to Holyoke Dam

Figure 2.4.2-1f
Plan Map of HEC-RAS Transects
from Montague USGS Gage to Holyoke Dam

Legend

- USGS Stream Gage
- Water Level Logger
- FEMA transects
- FirstLight Hatfield transects
- USACE Northampton transects
- HEC-RAS Hydraulic Model Extent

N

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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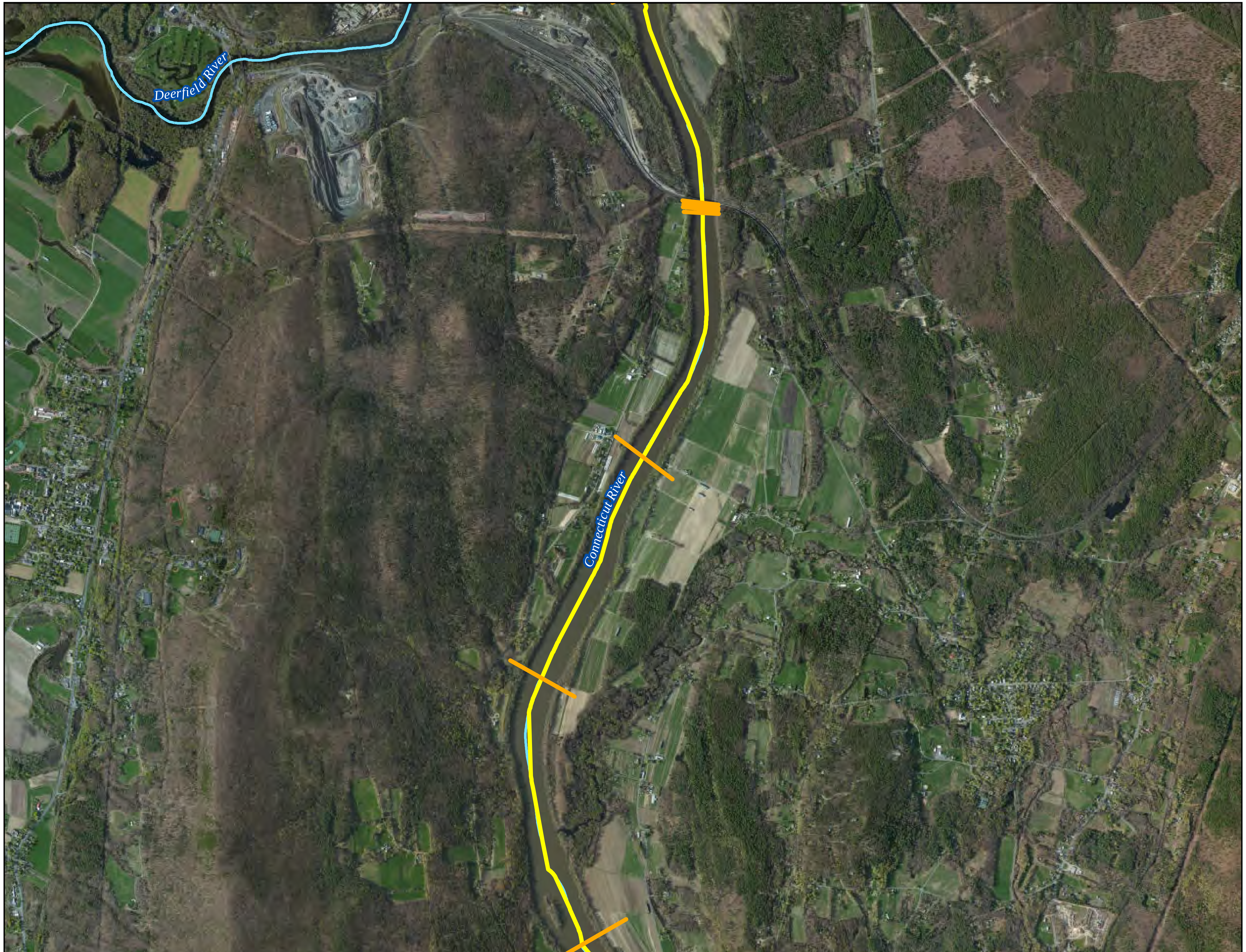

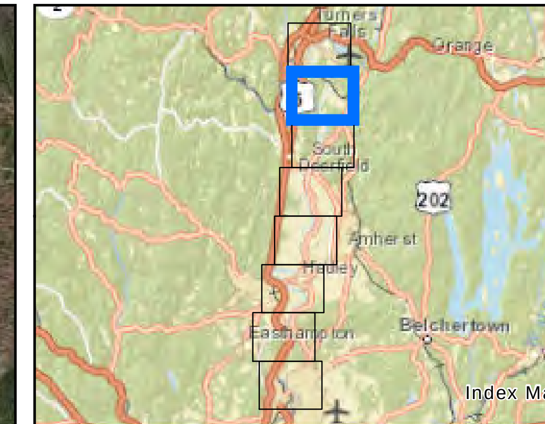

FIRSTLIGHT POWER RESOURCES
Hydraulic Study of Connecticut River
from Montague USGS Gage to Holyoke Dam

Figure 2.4.2-1g
Plan Map of HEC-RAS Transects
from Montague USGS Gage to Holyoke Dam

Legend

- USGS Stream Gage
- Water Level Logger
- FEMA transects
- FirstLight Hatfield transects
- USACE Northampton transects
- HEC-RAS Hydraulic Model Extent

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Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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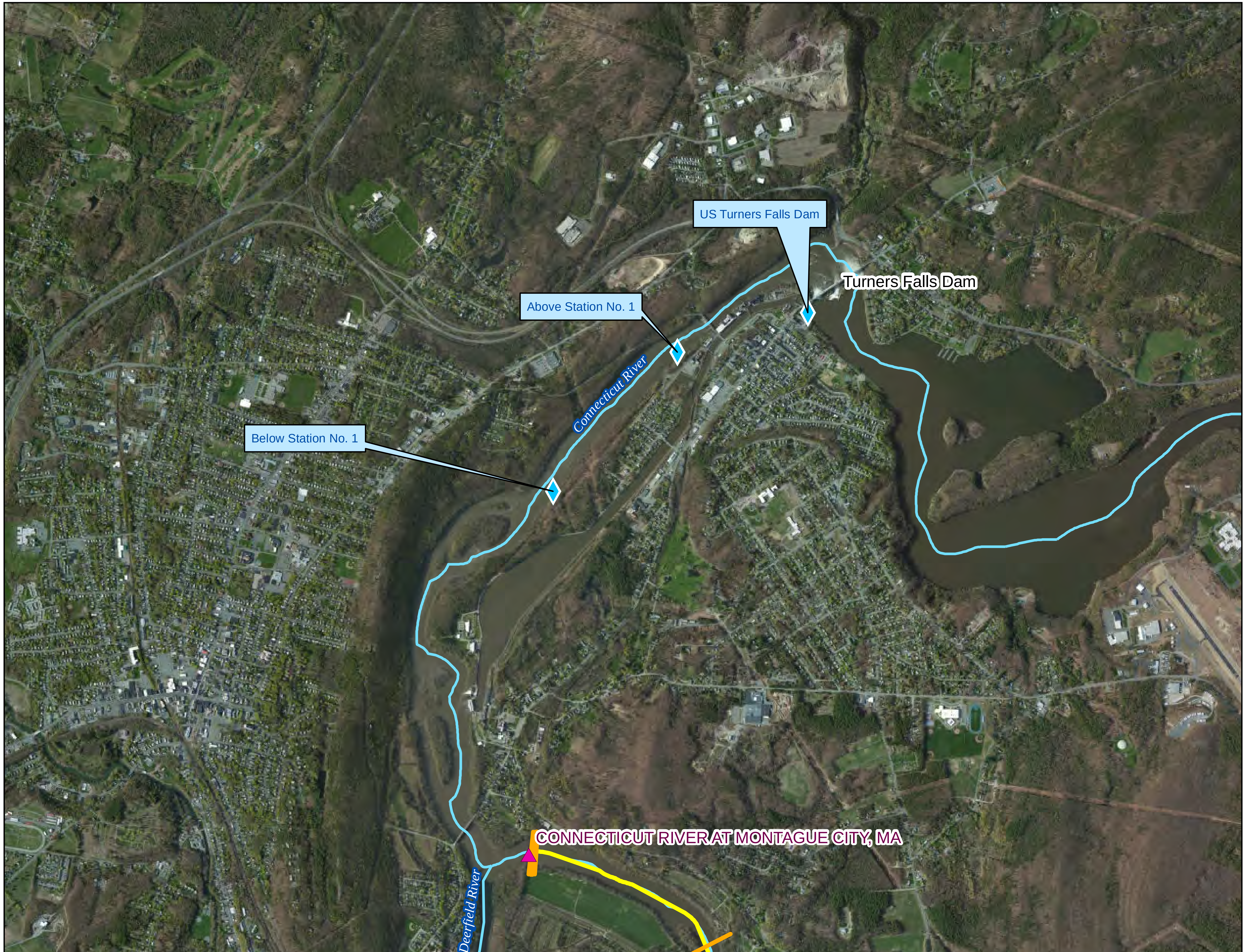

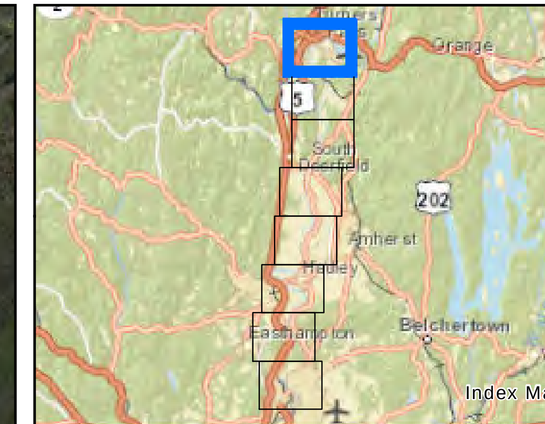

FIRSTLIGHT POWER RESOURCES
Hydraulic Study of Connecticut River
from Montague USGS Gage to Holyoke Dam

Figure 2.4.2-1h
Plan Map of HEC-RAS Transects
from Montague USGS Gage to Holyoke Dam

Legend

N

- USGS Stream Gage
- Water Level Logger
- FEMA transects
- FirstLight Hatfield transects
- USACE Northampton transects
- HEC-RAS Hydraulic Model Extent

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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3 HEC-RAS MODEL SETUP

3.1 HEC-RAS Model Background

Per the RSP, FirstLight used the one-dimensional HEC-RAS[16] hydraulic model developed by the USACE. The modeling software is publically available free-of-charge on the USACE's website. The HEC-RAS hydraulic model predicts WSEL's, river depths, and mean channel velocities at various transects under a range of flows and operating conditions (Vernon peaking, Northfield pumping/generating).

This section provides brief technical background on how HEC-RAS predicts water depths, WSELs, velocities, and water surface profiles (WSP) along the two studied reaches of the CT River. This section contains technical terms relating to hydraulics and hydrology. Whenever possible effort has been made to simplify hydraulic concepts presented; however, if further clarification or explanation is desired, the reader is referred to the HEC-RAS Hydraulic Reference Manual (Brunner, 2010) http://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_4.1_Reference_Manual.pdf or any standard open channel flow text.

HEC-RAS is designed to perform one-dimensional, steady (flow does not change over time), gradually-varied flow calculations in natural and manmade channels, as well as to perform unsteady (flow changes over a time) flow routing. The model can simulate depths, WSELs and velocities for a single reach, a branched system, or a full network of channels. HEC-RAS can simulate subcritical, supercritical, and mixed flow regimes.

Hydraulic analyses performed by HEC-RAS are based upon a step-wise solution of the one-dimensional energy equation. In instances of rapid change in the WSEL causing turbulence and energy loss, HEC-RAS uses the momentum equation. In HEC-RAS, rapid changes in the WSEL may occur under the following conditions: bridge constrictions, inline structures (dams and weirs), confluence of two or more flows, rapid changes in the channel bed elevation, and hydraulic jumps. Energy losses in the channel are associated with friction (solved with Manning's equation) or with contraction and expansion (solved by multiplying a loss coefficient by the change in velocity head between transects). Flows over weirs and other inline structures (dams) are determined with the standard weir equation. HEC-RAS also permits the modeler to include gate structures that accompany inline structures such as dams.

Steady and Unsteady-State Conditions

As noted above, the HEC-RAS model can be operated in either steady-state or unsteady-state conditions. Steady-state means that the flow throughout the reach is constant. For example, the 2013 and 2014 water level, flow and operations data were reviewed to find periods where the release from the Vernon Hydroelectric Project was relatively constant and the Northfield Mountain Project had limited operation. Similarly, periods where the Cabot discharge was relatively constant were identified. As described later, given the dynamics of the river system, it was not possible to find a truly "stable" flow condition; however, periods of limited WSEL fluctuations were identified for calibration. These data were used to further calibrate the hydraulic models to observed WSEL's at the water level logger locations.

Unsteady-state means the flow throughout the reach can vary over time—similar to a hydrograph whereby flow changes over time. In this case, peaking releases from the Vernon Hydroelectric Project, and pumping/generating at the Northfield Project that vary over time can be simulated in the HEC-RAS model. In the case of the Impoundment reach, the 2013 and 2014 water level, flow and operations data were used to help calibrate the model to unsteady-state conditions. In the case of the Montague USGS Gage to Holyoke Dam reach, the 2012 water level, flow and operations data were used to help calibrate

[16] HEC-RAS: Hydrologic Engineering Center River Analysis System

the model to unsteady-state conditions. The time step used in the unsteady-state calibration was every 15 minutes.

3.2 Model Inputs

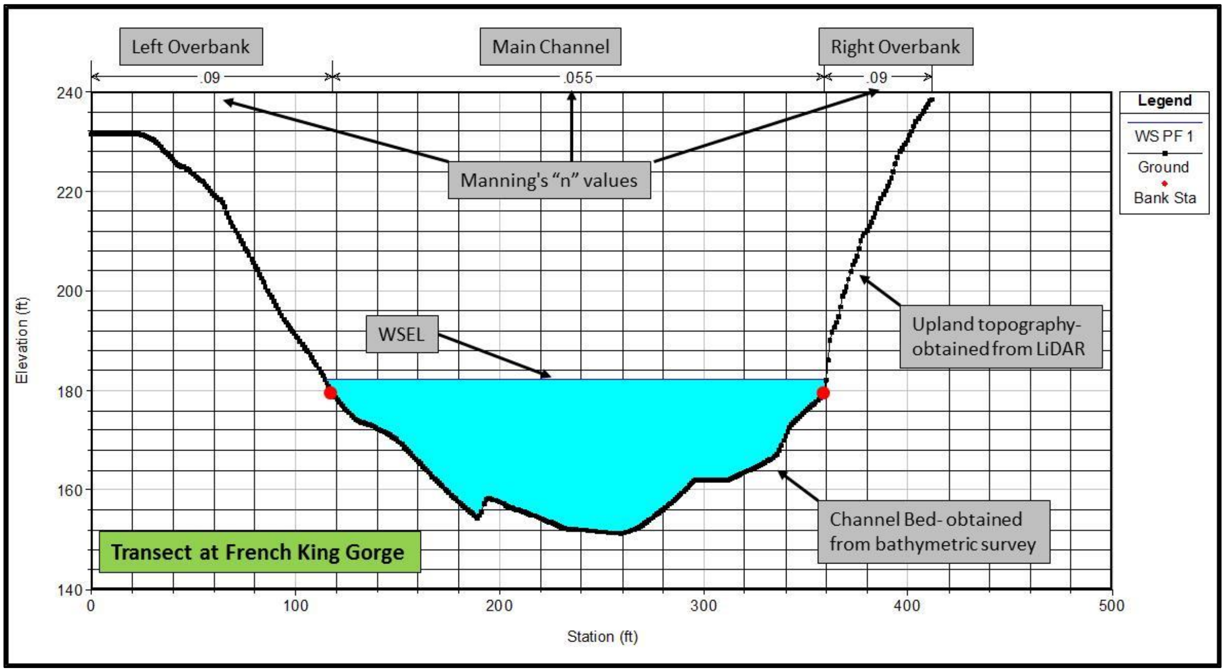
There are four major inputs to the HEC-RAS model including:

- Channel morphology or transects perpendicular to flow showing the channel bed.
- Manning's n value.
- Channel expansion and contraction coefficients.
- Downstream boundary conditions.
- Flow data—steady-state is a constant flow through the reach, unsteady-state is a time varying flow through the reach.

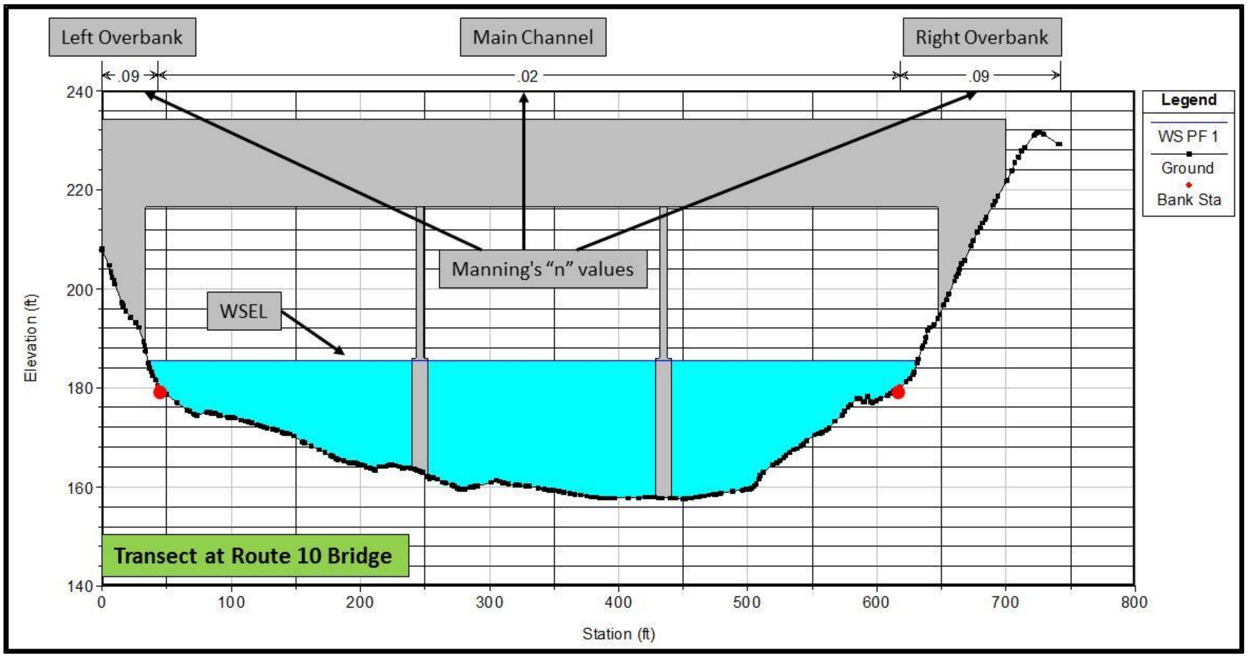
The major inputs above are described in more detail below.

3.2.1 Channel Morphology

In the case of the Impoundment model, transects were "cut" from the seamless bathymetric/topographic data using HEC-GeoRAS every 200 feet from the Turners Falls Dam boat barrier line to just below Vernon Dam. The transect data consists of station (x-axis) and channel bed or ground elevation points (y-axis) across the transect—an example of a transect "cut" through the French King Gorge is shown in the inset below. Note that HEC-RAS plots transect data assumes one is looking in a downstream direction. The main channel section reflects the bathymetric data and the overbank areas reflects the LiDAR data. The transect includes a red dot denoting the right and left overbanks of the channel- labeled below. In this case, the left and right overbanks Manning's n values are 0.09 and the main channel is 0.055.



The channel morphology also includes bridges- an example of the Route 10 Bridge traversing the Turners Falls Impoundment is shown in the inset below. Of importance here are the inclusion of piers occupying space in the channel bed, and the low and high chord on the bridge deck. The low chord is important in case water levels were to rise high enough to inundate the low chord and thus create pressure on the bridge. Note that for all of the CT River Bridges traversing the Impoundment reach and the Montague USGS Gage to Holyoke Dam reach, the low chords of the bridge decks are well above any flows that were evaluated as part of this study; pressure flow was not an issue.



In the case of the Montague USGS Gage to Holyoke Dam reach, the transect data are generally spaced much further apart which is consistent with FEMA FIS studies.

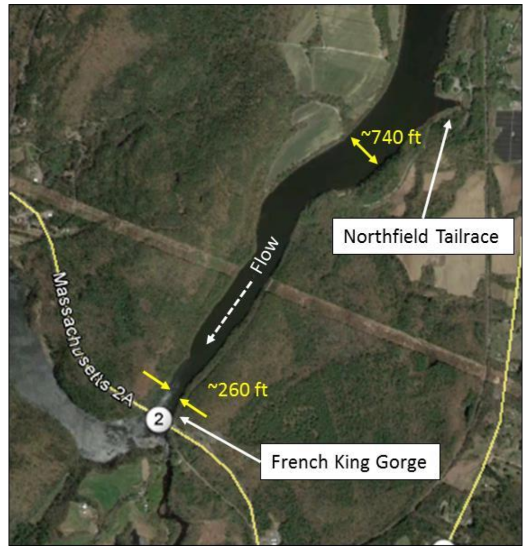
3.2.2 Manning's n Values

HEC-RAS requires the user to define Manning's n-values at each transect. Manning's n-values are used to describe the roughness of a channel; the higher the n-value, the rougher the channel. For example, a Manning's n-value of 0.03 is representative of channel substrates such as sand, whereas a Manning's n-value of 0.05 is representative of cobbles[17]. The HEC-RAS program requires the user to enter the Manning's n-values for at least the right overbank, main channel, and left overbank at each transect (additional delineations can be, and often are, made). When flow moves beyond the right/left overbanks, which is typically defined as the top of bank, it may be conveyed through trees and upland vegetation. In these instances, the Manning's n-values in these overbanks are higher to reflect the greater flow resistance.

3.2.3 Expansion and Contraction Coefficients

HEC-RAS requires the user to define expansion and contraction coefficients at each transect. When a river constricts—meaning the width decreases—it creates a 'bottleneck' and the water level upstream will rise. A classic example of this is the French King Gorge—when the magnitude of flow is high, the gorge creates a bottleneck resulting in rising WSELs above the gorge. As shown on the inset below, based on a GoogleEarth image, the width changes from approximately 740 feet to 260 feet at the gorge.

[17] These are text book values that are typical of high flow situations.



In addition, when the channel bed slope becomes negative (meaning the channel bed elevation increases when moving in a downstream direction) it too can cause a contraction. The opposite of contraction is expansion whereby the channel width changes from narrow to wider.

The default coefficients for gradual transitions of contraction and expansion used in the HEC-RAS model are 0.1 and 0.3, respectively. In cases of river constrictions, the values may rise to 0.3 and 0.5, respectively. In most instances expansion and contraction coefficients of 0.1 and 0.3 were applied to the transects. However, where constrictions occur, such as the French King Gorge, the contraction and expansion coefficients were increased.

3.2.4 Downstream Boundary Conditions

The HEC-RAS program requires a downstream boundary condition so the model knows at what WSEL to start the model. In the case of the Impoundment reach, the most downstream transect – at the boat barrier line—is representative of the WSEL at the Turners Falls Dam. The current FERC license permits the WSEL at the dam to vary between 176 feet and 185 feet, a 9 foot fluctuation. As described later, several HEC-RAS model runs were simulated with different downstream starting WSEL's including 176 feet, 185 feet, and the average (over the period 2000-2010) of 181.3 feet.

In the case of the Montague USGS Gage to Holyoke Dam reach, the most downstream transect is just upstream of the Holyoke Dam. The current FERC license for the Holyoke Project permits the WSEL at the dam to vary between 99.47 feet and 100.67 feet, a 1.2 foot fluctuation. The HEC-RAS model runs were simulated with two different downstream WSEL's of 99.47 feet and 100.67 feet.

3.2.5 Flow Data

In the case of the Impoundment Reach, as noted above, there are two gaged tributaries discharging into the CT River—the Ashuelot River and Millers River. The two tributaries were added into the model at their respective locations for both the steady and unsteady-state calibration modeling. Shown in Figures 3.2.5-1 and 3.2.5-2 is the naturally routed flow (Vernon discharge + Ashuelot River gaged flows + Millers River gaged flow), and the flow measured at the USGS gages on the Ashuelot River and Millers River for the years 2013 and 2014, respectively. As the figures show, the contribution of the Ashuelot (420 mi^2) and Millers River (372 mi^2) is small compared to the Vernon discharge. The bulk of the naturally routed flow is controlled by the Vernon Hydroelectric Project release, which represents 6,266 mi^2 of the Connecticut River. The computed (Vernon discharge) plus measured discharges at the Ashuelot and Millers Rivers account for the following drainage area:

Drainage area at Vernon Dam:	6,266 mi^2
Drainage area at Ashuelot River USGS Gage:	420 mi^2
Drainage area at Millers River USGS Gage:	372 mi^2
Total Drainage Area:	7,058 mi^2
Drainage Area at Turners Falls Dam:	7,163 mi^2
Unaccounted for Drainage Area Flow:	105 mi^2 (7,163-7,058)

The Ashuelot River USGS Gage is located just upstream of the confluence with the CT River, thus its drainage area is representative of the entire river. The Millers River USGS Gage is located upstream of the confluence with the CT River; the drainage area at the confluence is 390 mi^2, an increase of 18 mi^2 below the gaging location. The remaining balance of the unaccounted for drainage area is 105-18 or 87 mi^2. There are numerous ungaged small tributaries draining into the Impoundment Reach. To account for the additional 87 mi^2 of drainage, the Ashuelot and Millers River gaged flows were prorated by half (43.5 mi^2) of the unaccounted for drainage area of 87 mi^2.

Thus, the tributary inflow between the Vernon and Turners Falls Dam used in the HEC-RAS model were computed as follows:

Ashuelot River flow = Q_{gage} x [(420+43.5)/420] or $Q_{Ashuelot\ gage}$ x 1.104

Millers River flow= Q_{gage} x [(372+18+43.5)/372] or $Q_{Millers\ gage}$ x 1.165

In the end, the full intervening flow regime between the Vernon and Turners Falls Dams was accounted for.

In the case of the Montague USGS Gage to Holyoke Dam reach, the drainage areas at the Montague USGS Gage and Holyoke Dam are as follows:

Drainage Area at Montague USGS Gage	7,860 mi^2
Drainage Area at Holyoke Dam	8,309 mi^2
Unaccounted for Drainage Area	449 mi^2

There is only one active USGS gage (USGS Gage No. 01171500 Mill River at Northampton, MA) on tributaries entering the CT River between the Montague USGS Gage and Holyoke Dam. From June 1966 to September 1996, there was also a USGS gage on the Fort River (USGS Gage No. 01171300 Fort River near Amherst, MA). There is a USGS Gage on the CT River at the I-391 Bridge in Holyoke, MA (Gage No. 01172010, Drainage Area= 8,332 mi^2) located about 2.5 miles downstream of the Holyoke Dam ("Holyoke Gage"). This gage measures all of the flow on the Connecticut River, including flow through the Holyoke canal system.

Due to the limited regulation of flow under normal hydrologic conditions in the Holyoke Impoundment, from the licensed range of WSEL variation of 1.2 ft at the Holyoke Dam, the use of the Holyoke Gage to estimate flows in the CT River above Holyoke Dam was investigated- consideration was given to subtracting the daily flows of the two gages to estimate the incremental inflow between the Montague and Holyoke Gages. However, it was quickly apparent that the expected correlation between the Montague and Holyoke Gages was very poor especially in low flow periods as summarized below in Table 3.2.5-1. As the table shows, mean daily flows recorded at the Montague gage are actually greater than that recorded at the Holyoke Gage.

Table 3.2.5-1: Comparison of the Average Daily Flows at the Montague and Holyoke Gages under Low Flow Conditions.

Low flow date range	Average Daily Flow (cfs)		Percent (Montague /Holyoke)
	Montague	Holyoke	
Jun 26 to Aug 1, 2003	4,922	4,742	104%
Jul 21 to Oct 7, 2005	4,915	4,016	122%
Aug 9 to Sep 30, 2006	6,614	6,008	110%
Jul 27 to Oct 19, 2007	4,489	3,505	128%
Jul 1 to Sep 30, 2010	4,971	4,458	111%
Jul 1 to Sep 15, 2012	4,089	3,192	128%
Aug 1 to Sep 12, 2013	6,821	6,255	109%

According to communications with the USGS[18], this difference is caused by the lower end of the rating curve being much more stable at the Montague Gage than at the Holyoke Gage. Therefore, according to the USGS, the Montague Gage has a higher level of accuracy at low flows than the Holyoke Gage.

Given this, an alternative method of estimating incremental inflow between the Montague Gage and Holyoke Dam was developed. FirstLight used the USGS StreamStats program (http://streamstatsags.cr.usgs.gov/ma_ss/) to estimate the drainage areas and key watershed parameters of the main tributaries entering the Connecticut River between the Montague Gage and the Holyoke Dam. This investigation indicated that the drainage area characteristics of these main tributaries are relatively similar as summarized in Table 3.2.5-2.

Table 3.2.5-2: Comparison of the Average Daily Flows at the Montague and Holyoke Gages under Low Flow Conditions.

Tributary	Approx. RM of the Confluence with the CT River	Drainage Area (mi^2)	Average Area Slope (%)	Area of Forest (%)	Area of Urban Land (%)
Sawmill River Montague	114.5	32	6.7	76.1	6.0
Mill River (Hadley)	102.5	31.7	4.3	57.2	16.5
Mill River (Hatfield)	99.0	49	6.0	64.4	11.3
Fort River Hadley	94.5	54.8	4.8	59.7	13.0
Fort River at old USGS site	NA	36.3	5.4	68.9	10.4
Mill River at current USGS site	NA	52.6	7.0	68.9	7.8
*Mill River (Northampton Oxbow)	91.3	57.1	6.6	71.4	10.6
Manhan River (Oxbow)	91.3	84.1	5.3	63.3	11.4
Bachelor Brook	89.6	31.5	4.1	70.0	9.0
Stoney Brook	89.2	22.7	1.3	28.7	28.0

*Mill River (Northampton Oxbow) is the same river as the Mill River at current USGS site, except the drainage area is at the confluence with the CT River.
Note: Three of the tributaries are named “Mill River.”

The total drainage area of the above tributaries is about 363 mi^2 or about 81% (363/449) of the unaccounted for drainage area between the Montague Gage and Holyoke Dam. The mean daily flow of the Fort River and Mill River Gages was computed for two periods of record: 1966-1996 and 1990-1996. For these two periods the computed mean daily flow of the Fort River was divided by the mean daily flow for the Mill River. As shown below, the ratio of mean daily flows was nearly the same as the ratio of the drainage areas.

Proration for the drainage areas between the Fort River and Mill River Gages (36.3/52.6)	0.69
Daily average flow comparison for 1966 to 1996	0.66
Daily average flow comparison for 1990 to 1996	0.70

Based on this, flows from the Mill River Gage (01171500) was used to estimate the tributary inflow below Montague by multiplying the drainage areas of the tributaries (combined tributary drainage areas= 363, mi^2, 363 x 1.237= 449 mi^2) by 1.237 to account for the remaining unaccounted drainage area. Then hourly flows from the Mill River Gage were prorated to estimate inflow at the tributaries listed in Table 3.2.5-2.

[18] Personnel communication- phone call with Richard Verdi of the USGS Northboro office on March, 14 2014.

While this method is an approximation it was determined to be much more suitable than any attempts to use the data from the Holyoke Gage. In addition, this is a reasonable approximation especially since the drainage area at the Montague Gage represents about 95% of the drainage area at the Holyoke Dam. In addition, inflows from the tributaries between the Montague Gage and Holyoke Dam are especially minor during low flow periods in the summer when flows in the CT River and Deerfield River are often below the maximum hydraulic capacity of the Turners Falls and Deerfield River Projects.

Figure 3.2.5-1: 2013 Daily Hydrograph of Naturally Routed Flow, Ashuelot River and Millers River

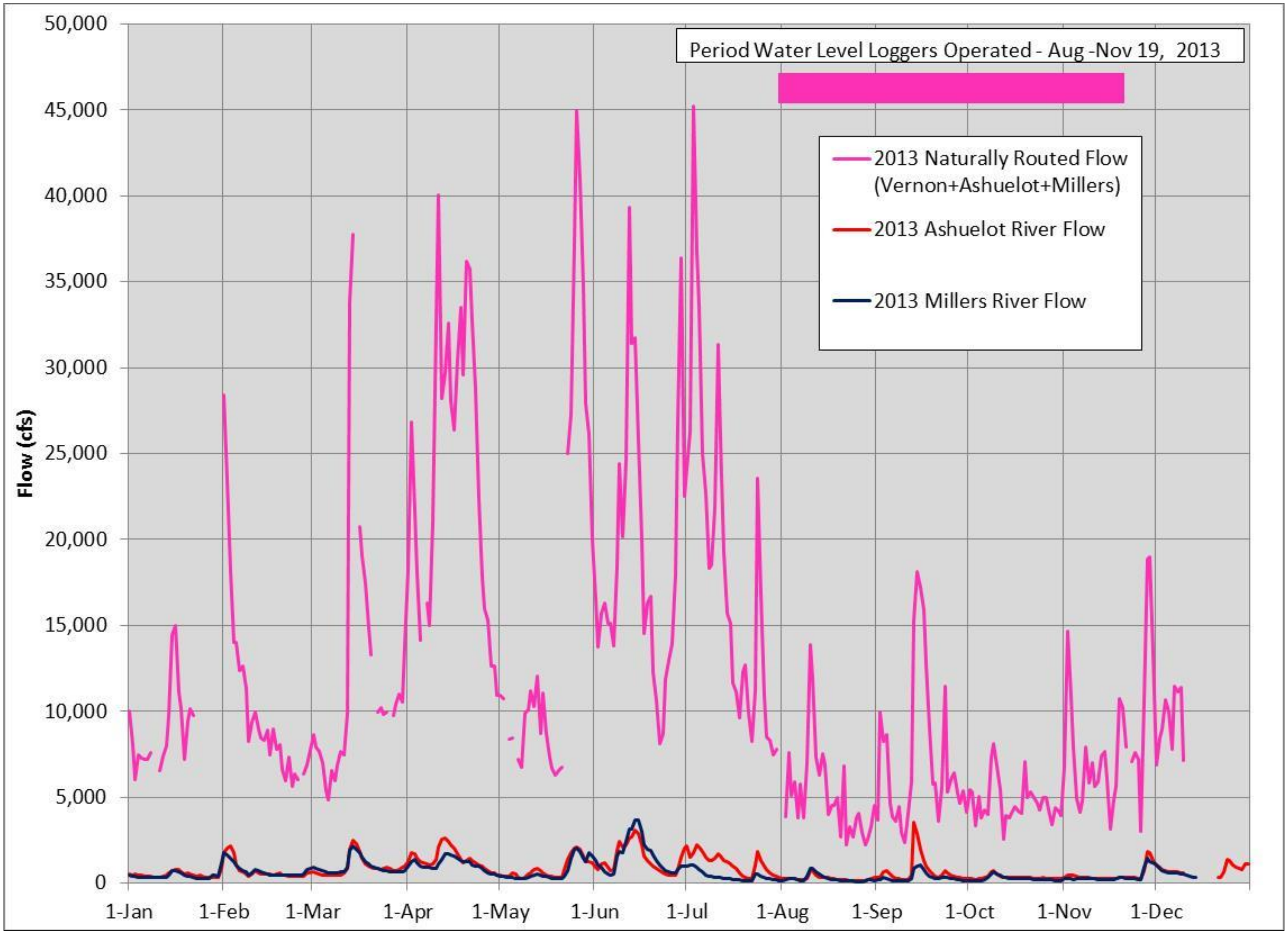
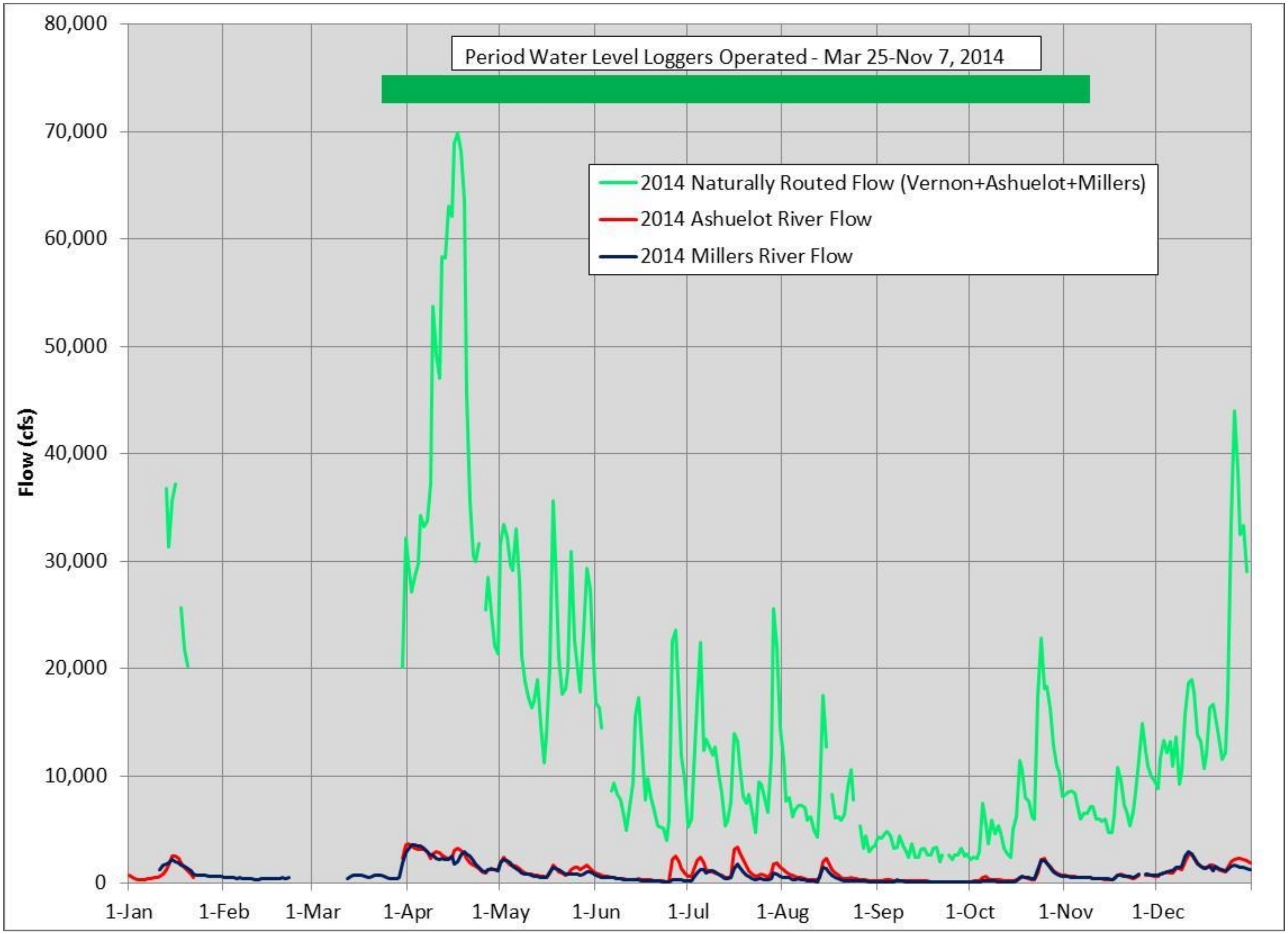


Figure 3.2.5-2: 2014 Daily Hydrograph of Naturally Routed Flow, Ashuelot River and Millers River



4 HEC-RAS MODEL CALIBRATION

4.1 Vernon Dam to Turners Falls Dam: Turners Falls Impoundment

4.1.1 Turners Falls Impoundment: Steady-State Modeling Periods

The HEC-RAS model was first calibrated to the WSEL's measured at the water level loggers under steady-state conditions. To calibrate to steady state conditions, the goal was to identify periods where WSEL fluctuations were minor. In reality, it is not possible to find a truly steady-state condition given the peaking nature of the river system. However, based on reviewing the flow and water level logger data, two periods were selected for calibration. Graphs of each period showing the WSELs at the water level loggers, Northfield Mountain Project pumping/generating flows and Vernon discharges, on a 15-minute time increment, are noted below.

- May 4-5, 2014 (see Figure 4.1.1-1).
    - Vernon average flow= 25,785 cfs (high flow event)
- May 8, 2014 (see Figure 4.1.1-2).
    - Vernon average flow= 17,141 cfs (near Vernon's hydraulic capacity of 17,130 cfs)

As can be seen from these figures, while these periods are being characterized as "steady-state", varying flow conditions and Impoundment WSEL fluctuations existed, but not to the extent of most other time periods. Again, it is not possible to obtain a truly steady-state flow condition; however, these periods were reasonably close.

4.1.2 Turners Falls Impoundment: Steady-State Calibration Process

Prior to the detailed calibration process, an evaluation was conducted on how best to model the numerous islands within the Impoundment reach. The following islands are in the Impoundment, listed in upstream to downstream order (the HEC-RAS transect number is shown in parenthesis – see Figure 2.4.1-1 (a-d):

- A small island just downstream of Vernon Dam, about 1,400 feet long (HEC-RAS Transect No. 103986);
- Stebbins Island, about 3,000 feet long (HEC-RAS Transect No. 98986.3);
- A small island downstream of the Ashuelot River confluence, about 1,500 feet long (HEC-RAS Transect No. 91486.3);
- Kidds Island, about 2.25 miles upstream of the Northfield Mountain Tailrace, and about 2,200 feet long (HEC-RAS Transect No. 40486.3);
- Barton Island, located in the lower Impoundment about 3,800 feet upstream of the Turners Falls Dam (HEC-RAS Transect No. 3990.8).

The initial analysis of the effects these islands may have on the flow within the Impoundment included a detailed investigation of the bathymetry in the side channels as compared to the main channel areas. In addition, under preliminary runs (using the two steady-state scenarios described above), the WSELs upstream and downstream of the islands were investigated. The lower three islands are located in areas with a relatively low hydraulic gradient with a difference in the WSEL at the upstream and lower ends of the islands of 0.20 feet or less. Thus, it was determined that these three islands did not need to be modeled in HEC-RAS's split flow option. Initially, the small island downstream of Vernon Dam was modeled using the split flow option with junctions upstream and downstream of the island. However, this analysis showed that only a very low percentage of the flow in the CT River used the Vermont (west) side of this island even in high flow conditions and that the split flow option had a very limited effect on the WSEL in the nearby areas. However, analysis of Stebbins Island indicated that it needed to be modeled as an island with the split flow option, and matched WSELs at the upstream and downstream junctions.

Using these two periods of record and the split flow option at Stebbins Island, the calibration procedure consisted of adjusting the Manning's n value (roughness) and adjusting contraction and expansion coefficients within reasonable measures such that the observed and modeled WSELs at the water level loggers were reasonably close. Initial Manning's n values were generally:

- Channel: 0.03
- Overbank forested and brush: 0.09
- Overbank agricultural and fields: 0.04
- Overbank residential areas: 0.15

HEC-RAS includes an extension called HEC-GeoRAS, which allows the user to integrate GIS. For example, the GIS of the Impoundment includes detailed bathymetry and upland topography. Also shown on the GIS are recent aerial images. These images were used to draw polygons in the channel and along the riverbanks and Manning's n values were assigned to these polygons. Using HEC-GeoRAS, transects can be "cut" and the corresponding transects (station, elevation coordinates) and the Manning's n values were directly uploaded to HEC-RAS (rather than having to keypunch these data into HEC-RAS; in short it is a more automated process).

During the calibration process, the Manning's n values for the overbank areas were generally not adjusted due to the limited amount of water flowing in these areas. The channel Manning's n values were adjusted to values as low as 0.02 in a few areas, but mostly in the 0.025 to 0.035 range. One exception was the French King Gorge area where the channel Manning's n value was increased to 0.055 and higher contraction and expansion coefficients (0.03 and 0.05, respectively) were applied, to model this constricted area.

After calibrating the WSELs at the water level loggers to the May 4-5, 2014 and May 8-9, 2014 flow conditions, the hydraulic model showed an average difference --- defined as the observed average[19] WSEL minus the modeled elevation --- of -0.09 feet for the May 4-5 period and -0.03 feet for the May 8-9 period at the water level logger locations shown in Table 4.1.2-1.

Table 4.1.2-1: Summary of WSEL Calibration Process for May 4-5 and May 8-9, 2014

Location Name and HEC-RAS station number in parenthesis below	May 4- 5, 2014			May 8-9, 2014		
	Observed Average WSEL (ft)	Modeled WSEL (ft)	Difference (ft)	Observed Average WSEL (ft)	Modeled WSEL (ft)	Difference (ft)
Vernon Tailrace (104,998.8)	189.64	189.69	-0.05	187.08	186.88	0.20

[19] Technically, this is a steady state calibration run so it is difficult to compare observed WSELs, which are changing over time with a modeled WSEL, which is one value. Thus, observed WSELs measured at the water level loggers, where data are obtained every 15 minutes were averaged for the two day calibration periods to yield one "observed average WSEL" at each logger.

Location Name and HEC-RAS station number in parenthesis below	May 4- 5, 2014			May 8-9, 2014		
	Observed Average WSEL (ft)	Modeled WSEL (ft)	Difference (ft)	Observed Average WSEL (ft)	Modeled WSEL (ft)	Difference (ft)
Downstream Vernon (102,987.4)	189.09	189.18	-0.09	186.53	186.44	0.09
Downstream Stebbins (93,245.75)	187.40	187.45	-0.05	184.74	184.83	-0.09
Stateline (73,328.77)	no data	185.85		183.15	183.35	-0.20
Downstream Pauchaug (69,314.55)	185.68	185.68	0.00	183.21	183.25	-0.04
Rt. 10 Bridge (57,319.76)	184.67	185.13	-0.46	182.41	182.81	-0.40
Northfield Tailrace (26,689.96)	183.51	183.59	-0.08	181.64	181.71	-0.07
Downstream French King (15,148.62)	181.15	181.03	0.12	180.64	180.36	0.28
Average Difference (ft)			**-0.09**			**-0.03**

Figure 4.1.2-1 shows the WSP from the Turners Falls Dam to just below Vernon Dam at the nine water level loggers listed in the Table 4.1.2-1 for the following conditions:

- The May 4-5, 2014 and May 8-9, 2014 observed average WSEL at the same nine water level loggers listed in Table 4.1.2-1.
- The May 4-5, 2014 and May 8-9, 2014 observed average WSEL plus +1 standard deviation and minus -1 standard deviation.
- The May 4-5, 2014 and May 8-9, 2014 modeled WSEL.

Figure 4.1.2-1 shows that the difference between observed and modeled WSELs are generally less than 0.20 feet, near the accuracy of the water level loggers.

4.1.3 Turners Falls Impoundment: Unsteady-State Modeling Periods

The majority of time the Turners Falls Impoundment is operating under unsteady flow conditions due to Vernon peaking operations, the pumping/generation cycles at Northfield Mountain, variations in the WSEL at the Turners Falls Dam and to a much lesser extent the variation of inflow from the Ashuelot River, Millers River, and smaller tributaries. The flow and WSEL data for the period the water level loggers operated were reviewed to identify periods where maximum peaking operations at Vernon and Northfield Mountain cycling occurred. Typically, these conditions occur during low flow, high energy demand periods in the mid-to-late summer. The period selected for further model calibration was August 24 to September 3, 2014. Shown in Figure 4.1.3-1 is the Vernon discharge, Northfield generating/pumping flows, and the WSELs recorded at the water level loggers. As can be seen, this period exemplified peak electrical demand and low flow during non-generation periods.

Further fine-tuning of the Manning's n values occurred during this modeling period since unsteady-state conditions within the range of accurate flow measurement (turbine operations instead of spillage operations at Vernon) were determined to be more realistic than the quasi steady-state conditions described earlier. However, the only major change in the Manning's n value was increasing it in the upper reaches of the Impoundment near Vernon to 0.035 and 0.04.

After calibrating the WSELs at the water level loggers to the August 24-September 3 flow conditions, the observed and modeled average WSELs at the water level loggers were compared for the August 24-September 3 period as shown in Table 4.1.3-1.

Table 4.1.3-1: Average Difference (ft) between Modeled and Observed WSELs for August 24-September 3, 2014

Vernon Tailrace	Upstream of Stebbins Island	Downstream of Stebbins Island	Stateline	Downstream of Pauchaug	Rte. 10 Bridge	Northfield Tailrace	Downstream of French King Gorge
0.03	0.15	-0.06	0.64	0.04	-0.11	-0.07	-0.11

Note: a negative number means the modeled average WSEL was higher than the observed average WSEL.

Shown in Figures 4.1.3-2, -3, -4, -5, -6, -7, -8, and -9 is a comparison of the observed (pink line) and modeled (yellow dots) WSELs at each of the water level loggers listed in Table 4.1.2-1 during the period August 24-September 3, 2014. As the figures show, there is an excellent match relative to the magnitude and timing of the observed versus modeled WSELs at the various water level loggers. Given the closeness of fit between observed and modeled conditions, the hydraulic model was deemed fully calibrated.

Because the hydraulic model is well-calibrated to observed conditions, it can be used to predict WSEL's at different locations in the Impoundment as long as the following data are available: Vernon discharge, USGS gage flows on the Ashuelot and Millers Rivers, Northfield Mountain operational data (pumping or generating flows), and elevation data at the Turners Falls Dam.

4.2 Montague USGS Gage to Holyoke Dam Reach

4.2.1 Montague USGS Gage to Holyoke Dam Reach: Steady-State Modeling Periods

As noted earlier, paper copies of the original HEC-2 hydraulic model, developed in the 1980s was obtained from FEMA and then entered into HEC-RAS. Also, as noted earlier, no transect data were available for the town of Hatfield and thus eight (8) transects were obtained in 2014 to supplement the model. FirstLight contacted the Massachusetts Department of Transportation (MassDOT) to obtain bridge information (pier shape, low chord, etc.) to update the model to reflect current bridge geometry. Initial validation of the constructed HEC-RAS models was done to compare results shown in the HEC-2 printouts to the HEC-RAS output.

A comparison of the initial HEC-RAS model to the HEC-2 output WSEL's of the CT River from the Montague USGS Gage to above Hatfield is shown in Table 4.2.1-1.

Table 4.2.1-1: HEC-RAS and FEMA (HEC-2) WSELs at selected cross sections, between Montague Gage and Hatfield

Cross Section (RM)	Return Interval	Flow (cfs)	HEC-RAS WSEL (feet)	FEMA HEC-2 WSEL (feet)	Delta (FEMA WSEL minus HEC-RAS) (feet)
118.5	10-yr	105,000	132.89	133.61	0.28
	50-yr	147,000	138.51	139.17	0.34
	100-yr	168,000	140.94	141.59	0.65
117.75	10-yr	105,000	131.92	132.69	0.77

Cross Section (RM)	Return Interval	Flow (cfs)	HEC-RAS WSEL (feet)	FEMA HEC-2 WSEL (feet)	Delta (FEMA WSEL minus HEC-RAS) (feet)
	50-yr	147,000	137.61	138.29	0.68
	100-yr	168,000	140.08	140.75	0.67
116.86	10-yr	105,000	130.44	131.24	0.80
	50-yr	147,000	135.77	136.47	0.70
	100-yr	168,000	138.07	138.75	0.68
113.83	10-yr	112,000	128.79	129.97	1.18
	50-yr	158,000	133.97	135.11	1.14
	100-yr	180,000	136.21	137.36	1.15
111.92	10-yr	112,000	127.59	128.92	1.33
	50-yr	158,000	132.49	133.79	1.30
	100-yr	180,000	134.63	135.94	1.31
109.50[20]	10-yr	112,000	125.87	126.03	0.16
	50-yr	158,000	130.39	130.62	-0.23
	100-yr	180,000	132.36	132.32	-0.04
108.74	10-yr	112,000	125.59	125.58	-0.01
	50-yr	158,000	130.04	130.01	-0.03
	100-yr	180,000	131.99	131.95	-0.04

Similarly a comparison of the results between the constructed HEC-RAS model and the HEC-2 model was conducted from the southern boundary of Hatfield to near Holyoke Dam as shown in Table 4.2.1-2.

Table 4.2.1-2: HEC-RAS and FEMA (HEC-2) WSELs at selected cross sections, between Hatfield and Holyoke Dam

Cross Section (RM)	Return Interval	Flow (cfs)	HEC-RAS WSEL (feet)	FEMA HEC-2 WSEL (feet)	Delta (FEMA WSEL minus HEC-RAS) (feet)
96.07	10-yr	112,000	118.96	NA	-
	50-yr	158,000	123.26	NA	-
	100-yr	180,000	125.13	124.67	-0.46
92.92	10-yr	112,000	116.89	NA	-
	50-yr	158,000	121.59	NA	-
	100-yr	180,000	123.65	123.24	-0.41
90.96	10-yr	112,000	115.69	115.59	-0.10
	50-yr	158,000	120.40	120.34	-0.06
	100-yr	180,000	122.45	122.40	-0.05

[20] Cross section 109.50 is located at the Route 116 Bridge. Problematic modeling results were identified in the HEC-2 output indicating that the Route 116 Bridge acted more like a a hydraulic control than was deemed appropriate. The HEC-2 output indicated velocities above 12 feet/sec (considerably higher than transects just upstream and downstram of the bridge) during the 10-year event and a flow cross section area of about half of what it should be. These factors create an increase in the water level of about 2 feet immediately upstream of the bridge. The differences noted in this table between the HEC-RAS and HEC-2 results were largely the result of the modeling of this bridge.

Cross Section (RM)	Return Interval	Flow (cfs)	HEC-RAS WSEL (feet)	FEMA HEC-2 WSEL (feet)	Delta (FEMA WSEL minus HEC-RAS) (feet)
89.31	10-yr	112,000	114.11	114.49	0.38
	50-yr	158,000	118.47	118.97	0.50
	100-yr	180,000	120.37	120.94	0.57
87.57	10-yr	112,000	111.36	111.36	0.00
	50-yr	158,000	114.92	114.98	0.06
	100-yr	180,000	116.48	116.57	0.09
86.06	10-yr	112,000	108.28	108.31	0.03
	50-yr	158,000	111.35	111.38	0.03
	100-yr	180,000	112.76	112.78	0.02

Following this, transects in the Hatfield reach were added to the models to create one continuous model from near Holyoke Dam to the Montague Gage.

The HEC-RAS model was then calibrated to the WSEL's measured at the water level loggers under relatively steady-state conditions as measured at the Route 116 Bridge, Mitch's Marina area, and at the Montague USGS Gage in 2012. To calibrate to steady state conditions, the goal was to identify periods where WSEL and flow fluctuations were minor. Based on reviewing the flow and water level logger data, two periods were selected for calibration.

- June 3-5, 2012 (see Figure 4.2.1-1).
  - Montague average flow= 30,472 cfs (a high flow event)
- July 20-23, 2012 (see Figure 4.2.1-1).
  - Montague average flow = 2,473 cfs (a low flow period)

Graphs of each period showing the WSELs at the water level loggers and the flow at the Montague Gage on a 15-minute time increment, are provided below in Figures 4.2.1-1 and 4.2.1-2. As can be seen from these figures, while these periods are characterized as "steady-state", varying flow conditions and WSEL fluctuations still existed, but not to the extent as some other time periods.

4.2.2 Montague USGS Gage to Holyoke Dam Reach: Steady-State Calibration Process

Using these two periods of record, the calibration procedure consisted of adjusting the Manning's n value (roughness) and adjusting contraction and expansion coefficients within reasonable measures such that the observed and modeled WSELs at the water level loggers were reasonably close. Initial Manning's n values were generally:

- Channel: 0.03
- Overbank forested and brush: 0.07
- Overbank agricultural and fields: 0.05

During the calibration process, the Manning's n values for the overbank areas were generally not adjusted due to the limited amount of water flowing in these areas. The channel Manning's n values were adjusted to values as low as 0.02 in a few areas, but mostly around 0.025.

After calibrating the WSELs at the water level loggers to the June 3-5, 2012 and July 20-23, 2012 flow conditions, the hydraulic model showed an average WSEL difference - defined as the observed average[21] WSEL minus the modeled average elevation --- of -0.11 feet for the June 3-5 period and -0.13 feet for the July 20-23 period at the water level logger locations shown in Table 4.2.2-1.

After this calibration, the HEC-RAS model was updated to include the more accurate Corps/TNC hydraulic model transects, replacing the FIS transects in this area. Utilizing the Corps/TNC transects, most of which had a channel Manning's n value of 0.04, produced values substantially higher WSELs in the upper part of the model area than were observed by the water level loggers. When the channel Manning's n values were decreased to similar values used in the FIS transects, about 0.022, the model produced the results noted in Table 4.2.2-2. Additional accuracy was noted in the Mitch's Marina area; accuracy at Route 116 Bridge and the Montague Gage remained similar. The modeled accuracy increased near Mitch's Marina and Rainbow Beach was likely due to more accurate modeling parameters of the Coolidge (Route 9) and the upstream Norwattuck Rail Trail bridge near RM 96 associated with the Corps/TNC transects.

Table 4.2.2-1: Summary of WSEL Calibration Process for June 3-5, 2012 and July 20-23, 2012 (excluding Northampton transect updates)

Location Name and HEC-RAS station number in parenthesis below	June 3-5, 2012			July 20-23, 2012		
	Observed Average WSEL (ft)	Modeled WSEL (ft)	Difference (ft)	Observed Average WSEL (ft)	Modeled WSEL (ft)	Difference (ft)
Montague Gage (118.5) High	116.44	116.97	0.53	106.41	106.04	-0.37
Montague Gage (118.5) Low	116.44	116.97	0.53	106.41	106.04	-0.37
Route 116 Bridge (109.5) High	110.02	109.92	-0.1	102.05	102.25	0.20
Route 116 Bridge (109.5) Low	110.02	109.86	-0.16	102.05	102.19	0.14
Mitch's Marina (92.7) High	105.28	104.67	-0.61	100.97	100.71	-0.26
Mitch's Marina (92.7) Low	105.28	104.43	-0.85	100.97	106.04	
Average Difference (ft)			-0.11			-0.13

[21] Technically, this is a steady state calibration run so it is difficult to compare observed WSELs, which are changing over time with a modeled WSEL, which is one value. Thus, observed WSELs measured at the water level loggers, where data were obtained every 15 minutes were averaged for the three day calibration periods to yield one "observed average WSEL" at each logger.

Table 4.2.2-2: Summary of WSEL Calibration Process for June 3-5, 2012 and July 20-23, 2012 (including Northampton transect updates)

Location Name and HEC-RAS station number in parenthesis below	June 3-5, 2012			July 20-23, 2012		
	Observed Average WSEL (ft)	Modeled WSEL (ft)	Difference (ft)	Observed Average WSEL (ft)	Modeled WSEL (ft)	Difference (ft)
Montague Gage (118.5) High	116.44	116.90	0.46	106.41	106.03	-0.38
Montague Gage (118.5) Low	116.44	116.89	0.45	106.41	106.03	-0.38
Route 116 Bridge (109.5) High	110.02	110.60	0.58	102.05	102.28	0.23
Route 116 Bridge (109.5) Low	110.02	110.56	0.54	102.05	102.2	0.15
Mitch's Marina (92.7) High	105.28	105.36	0.08	100.97	100.74	-0.23
Mitch's Marina (92.7) Low	105.28	105.19	-0.08	100.97	99.61	
Average Difference (ft)			0.34			-0.12

4.2.3 Montague USGS Gage to Holyoke Dam Reach: Unsteady-State Modeling Periods

The majority of time the CT River from the Montague USGS Gage to Holyoke Dam is operating under unsteady flow conditions due to Cabot peaking operations, Deerfield Project peaking operations, Station No. 1 operations, variations in discharges from the Turners Falls Dam, and to a much lesser extent the variation of inflow from the tributaries entering the CT River. The flow and WSEL data for the period the water level loggers operated was reviewed to identify periods where variation in flows within the 10,000 to 30,000 cfs range occurred and where maximum peaking operations at Cabot occurred. Typically, these conditions occur during late spring period for the 10,000 to 30,000 range, and low flow, high energy demand periods in the mid-to-late summer. Two periods were selected for further model calibration including May 22 to June 1, 2002 and July 1 to 11, 2012. Shown in Figure 4.2.3-1 is the observed WSEL at the water level loggers and the observed flow at the Montague USGS Gage. Shown in Figures 4.2.3-2, 4.2.3-3 and 4.2.3-4 are the modeled and observed WSELs (May 22-June 1) at the three water level locations- Montague USGS Gage, Route 116 Bridge and Mitch's Marina, respectively. Also note that two modeled WSELs are shown in these plots to reflect that the WSEL at the Holyoke Dam could have been anywhere between the FERC-licensed water levels of 99.47 and 100.67 ft. Similarly shown in Figures 4.2.3-5, 4.2.3-6 and 4.2.3-7 are the modeled and observed WSELs (July 1-11) at the three water level locations- Montague USGS Gage, Route 116 Bridge and Mitch's Marina, respectively.

Unlike the upstream model, further fine-tuning of the Manning's n values did not occur during these modeling periods. This is due to a combination of more steady state conditions as compared to the upstream model, most of the channel Manning's n values were near the lower range of values for a large river such as the CT River, limited calibration points, and over most of the model, less accurate cross sectional data.

Figure 4.1.1-1: Vernon Discharge, Northfield Mountain Pump/Gen Flows and Water Surface Elevations at the Water Level Loggers for the Period May 4-5, 2014

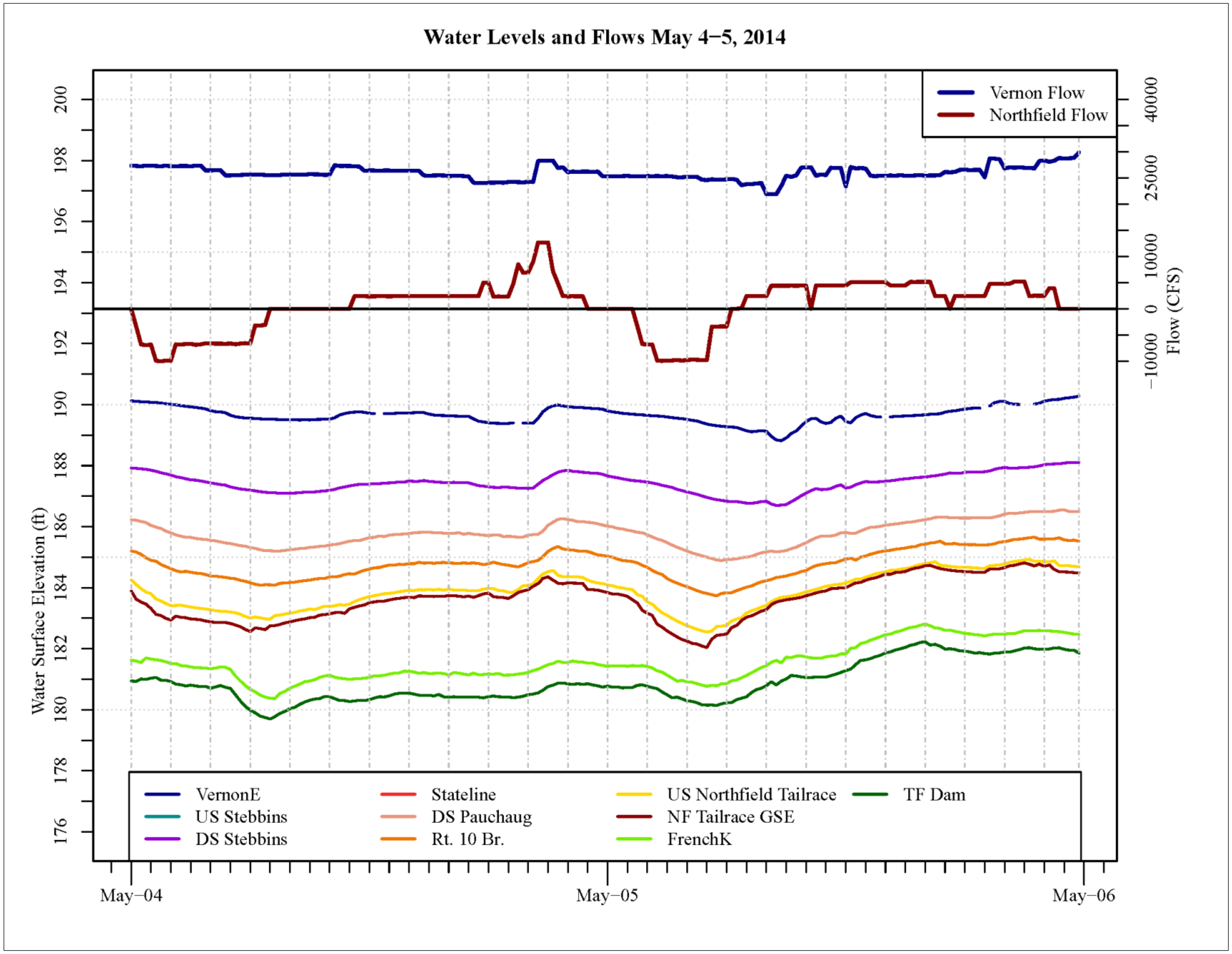


Figure 4.1.1-2: Vernon Discharge, Northfield Mountain Pump/Gen Flows and Water Surface Elevations at the Water Level Loggers for the Period May 8-9, 2014

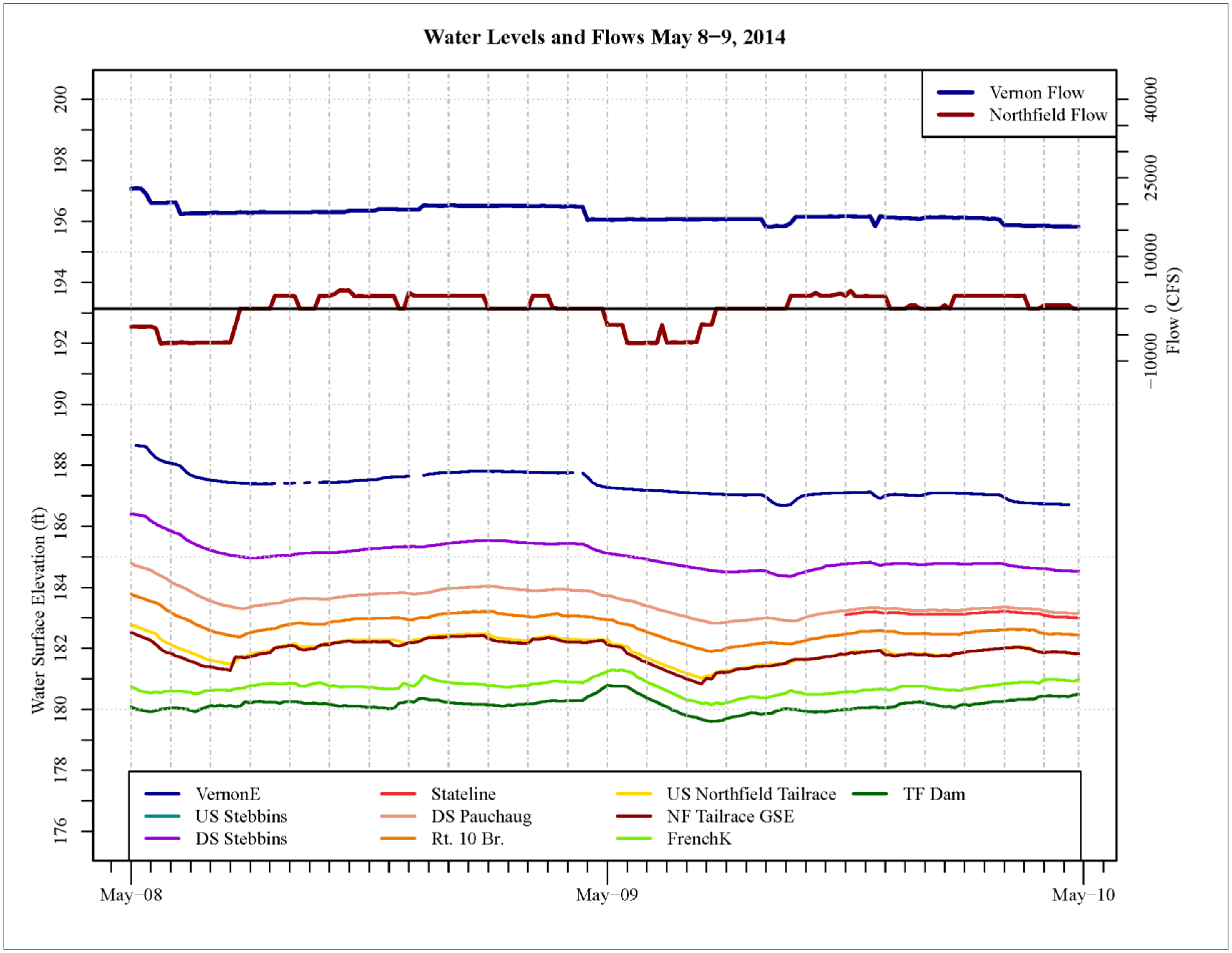


Figure 4.1.2-1: Observed and Modeled Water Surface Profile of Turners Falls Impoundment for May 4-5 and May 8-9, 2014

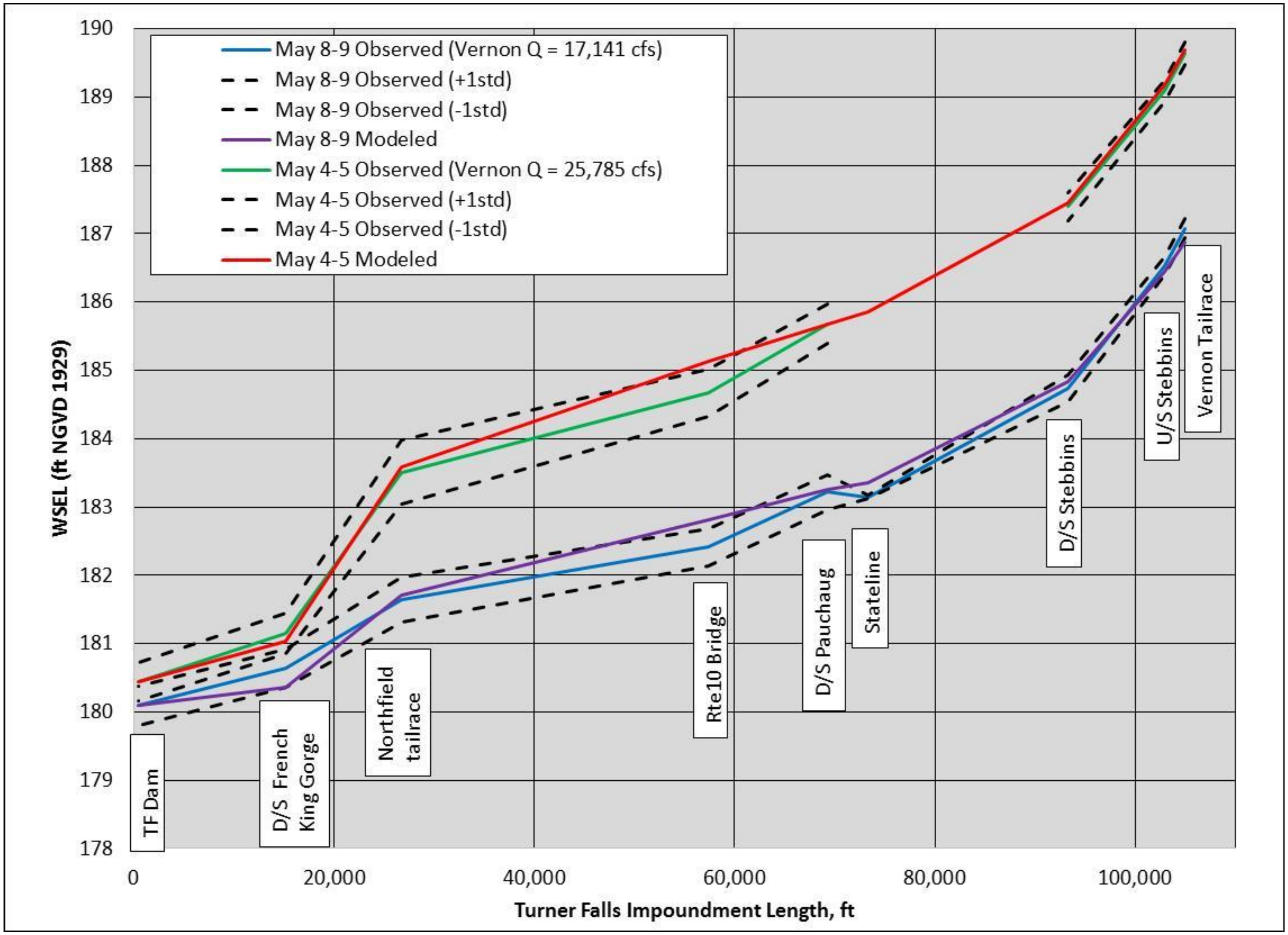


Figure 4.1.3-1: Vernon Discharge, Northfield Mountain Pump/Gen Flows and Water Surface Elevations at the Water Level Loggers for the Period August 24 to September 3, 2014

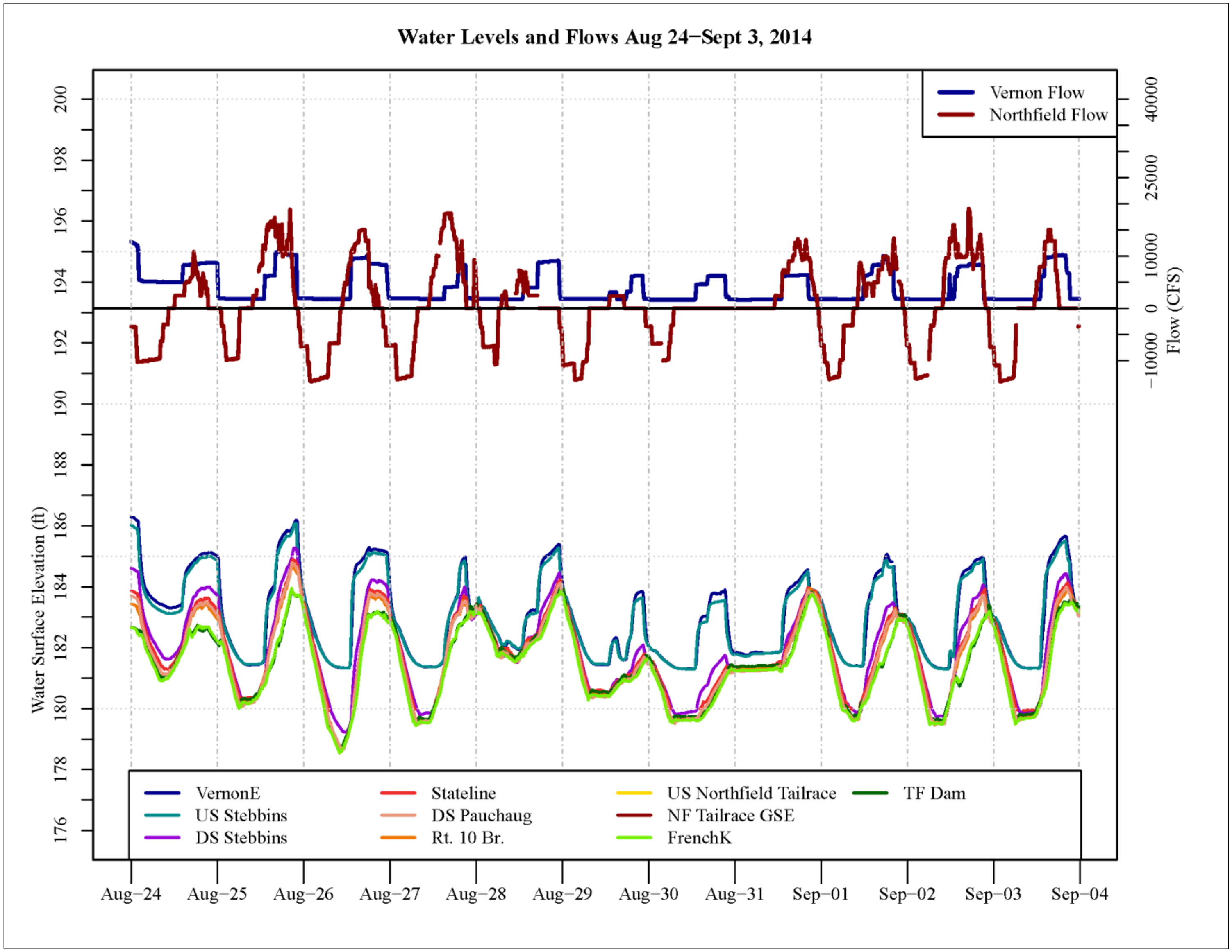


Figure 4.1.3-2: Comparison of Observed and Modeled WSELs at the *Vernon Tailrace* for the period August 24-September 3, 2014

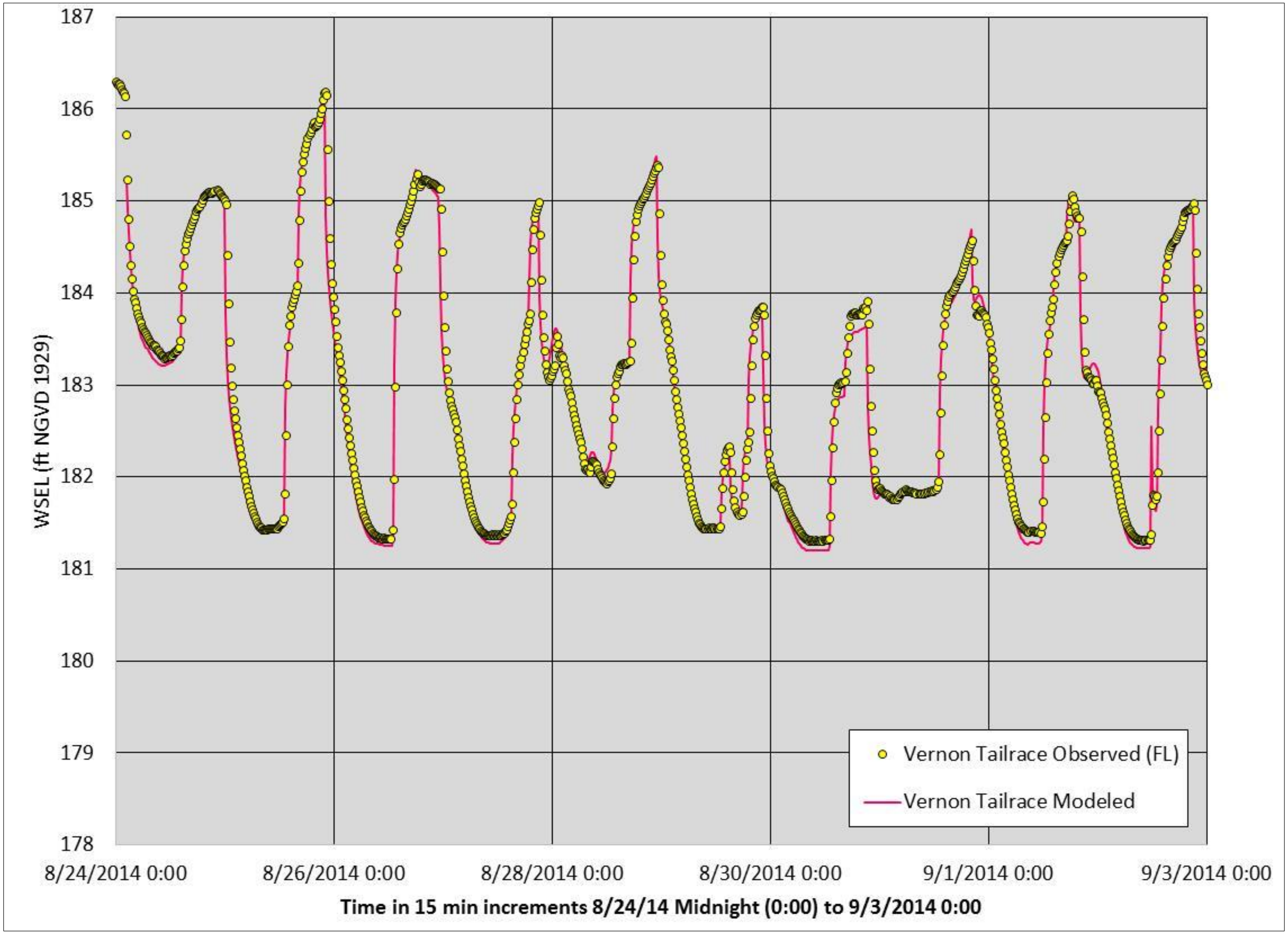


Figure 4.1.3-3: Comparison of Observed and Modeled WSELs *Upstream of Stebbins Island* for the period August 24-September 3, 2014

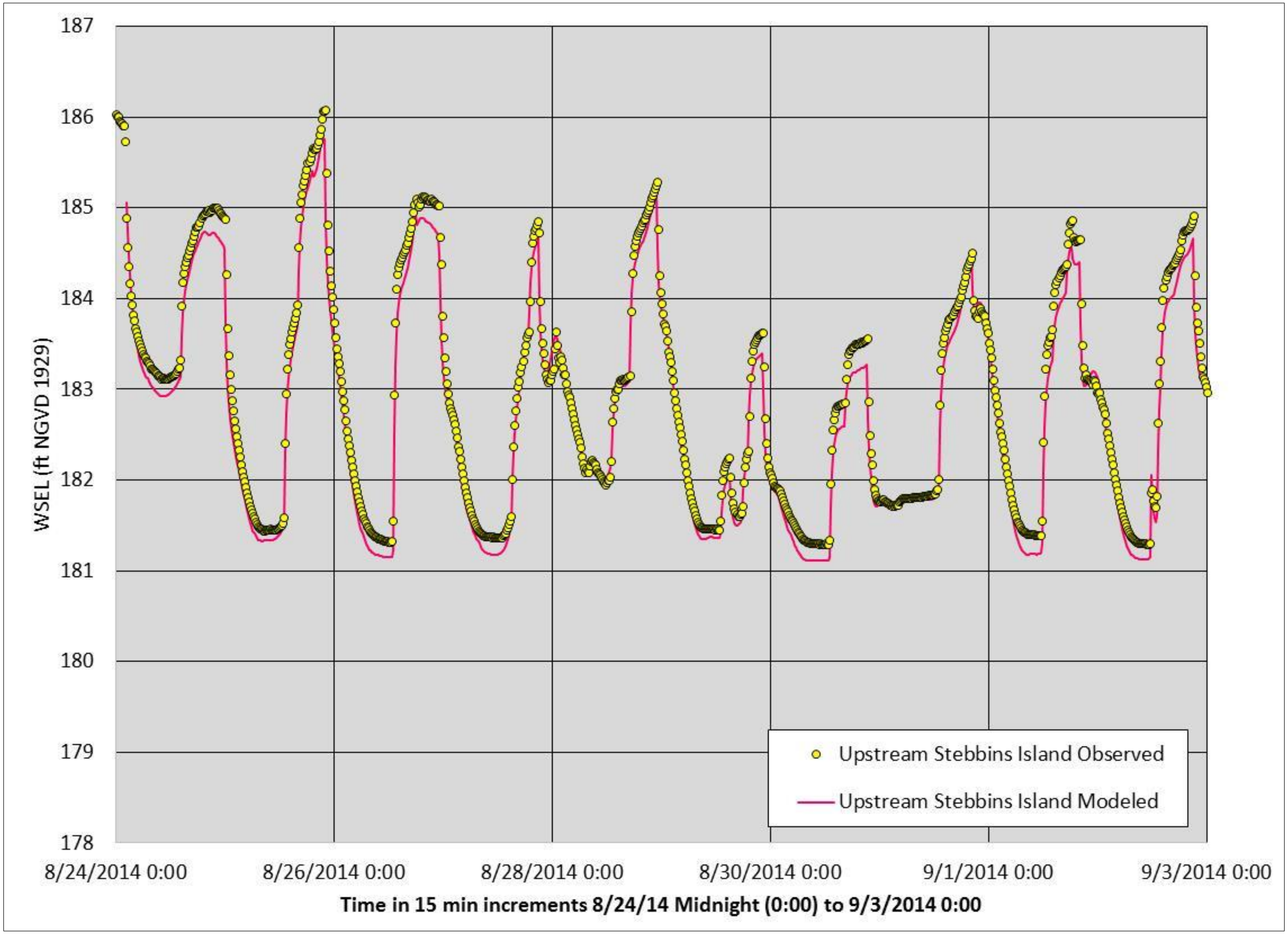


Figure 4.1.3-4: Comparison of Observed and Modeled WSELs *Downstream of Stebbins Island* for the period August 24-September 3, 2014

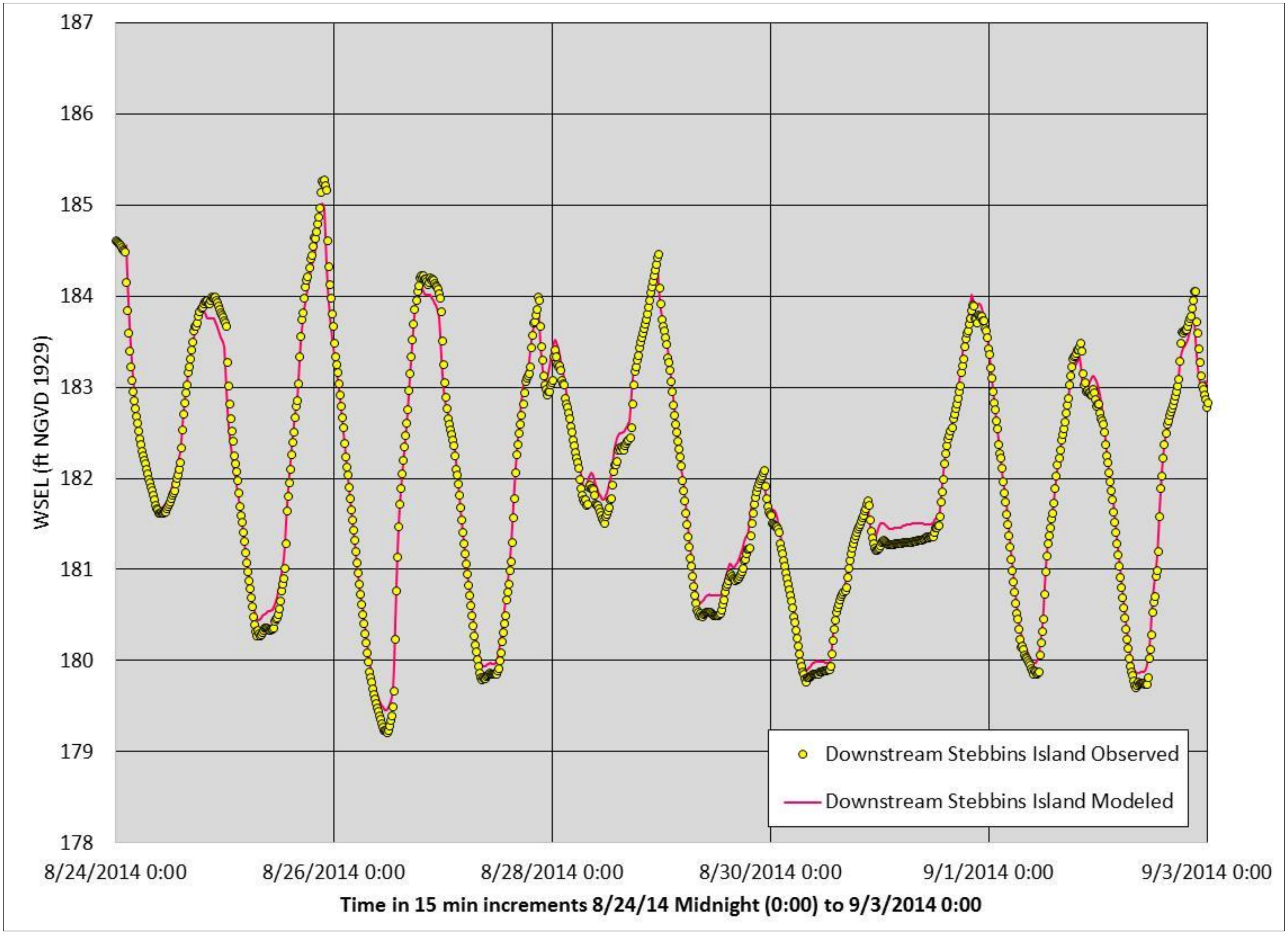


Figure 4.1.3-5: Comparison of Observed and Modeled WSELs at the *Stateline* for the period August 24-September 3, 2014

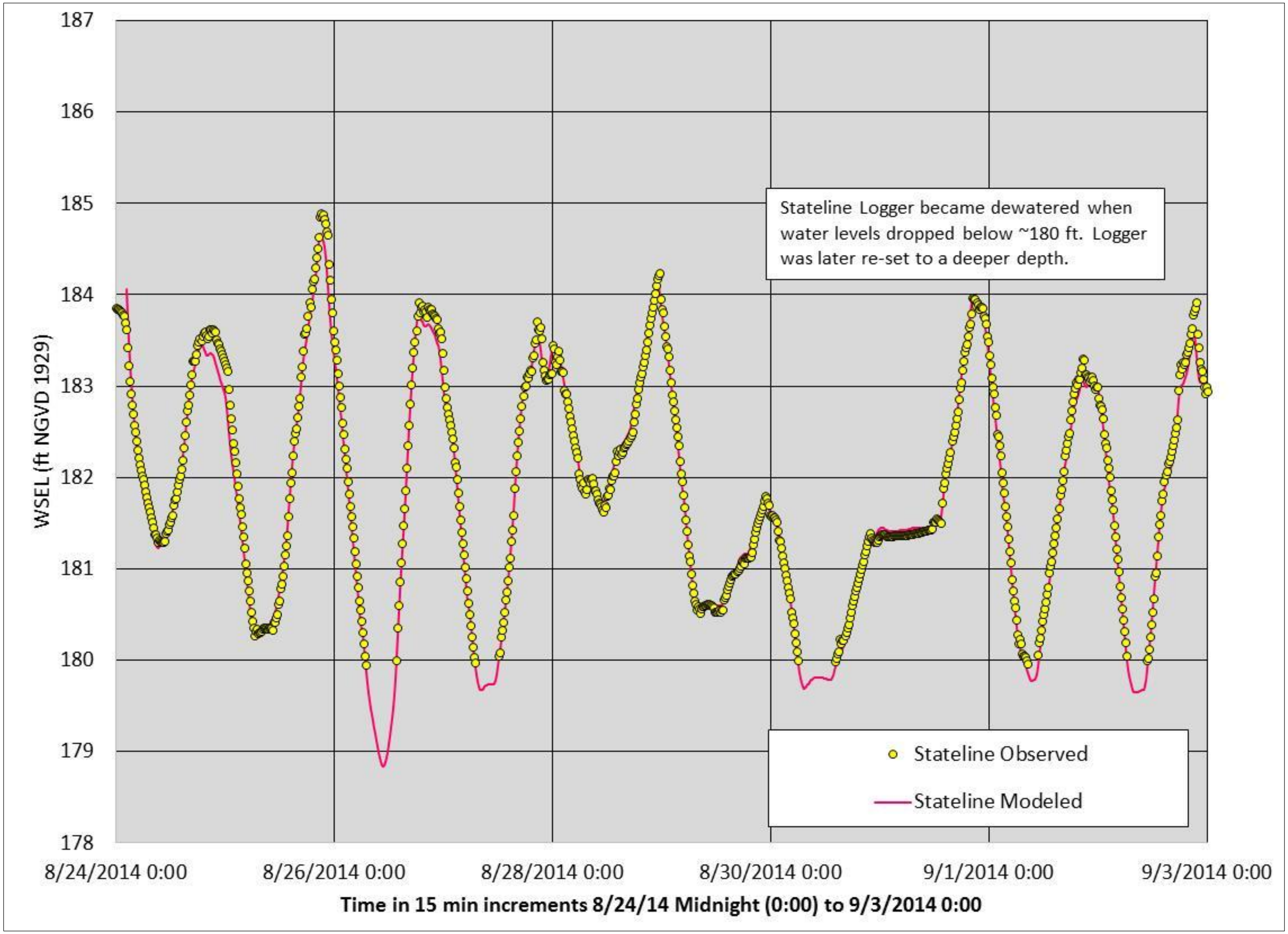


Figure 4.1.3-6: Comparison of Observed and Modeled WSELs *Downstream of Pauchaug Brook* for the period August 24-September 3, 2014

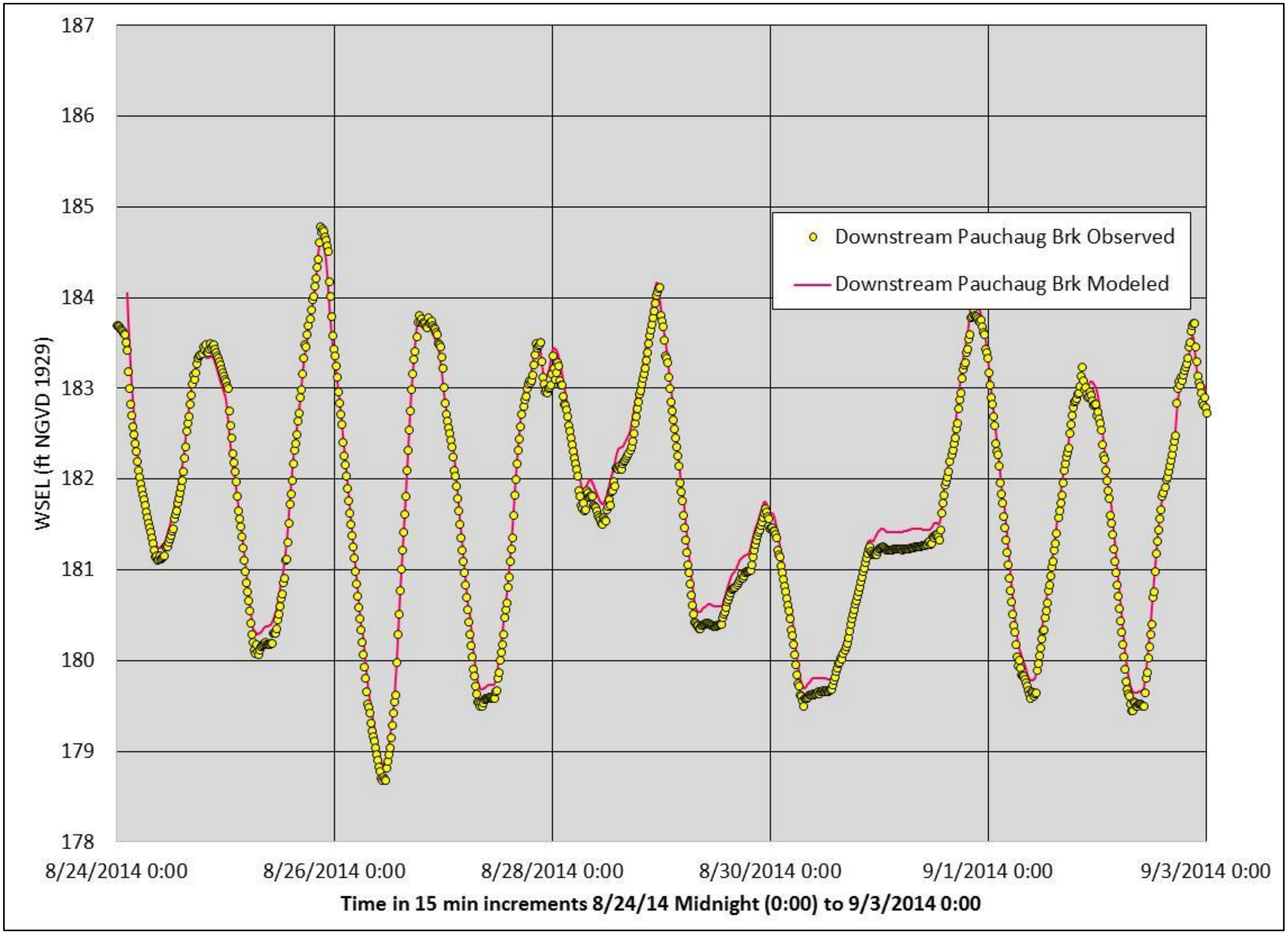


Figure 4.1.3-7: Comparison of Observed and Modeled WSELs at the *Route 10 Bridge* for the period August 24-September 3, 2014

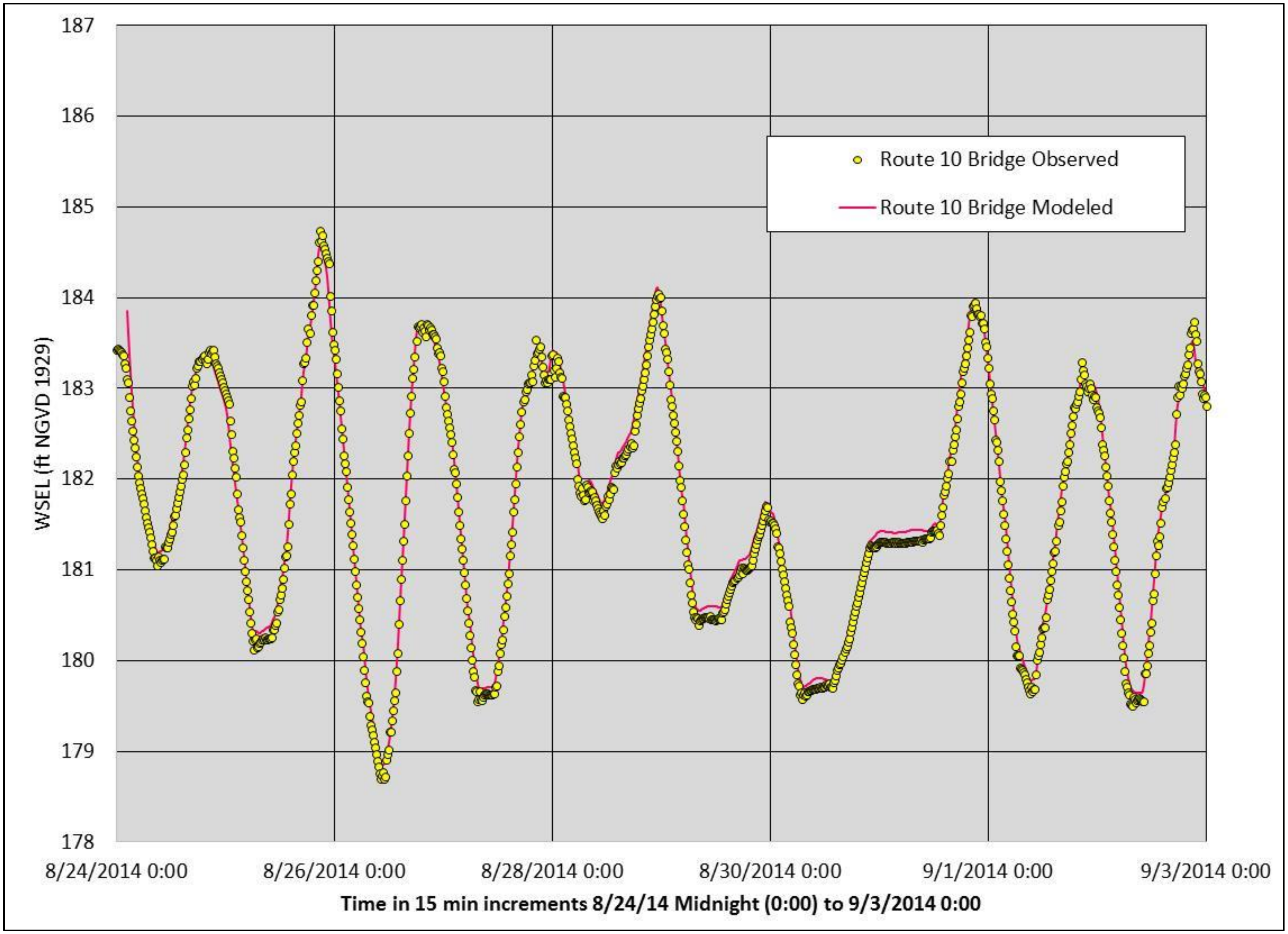


Figure 4.1.3-8: Comparison of Observed and Modeled WSELs at the *Northfield Tailrace* for the period August 24-September 3, 2014

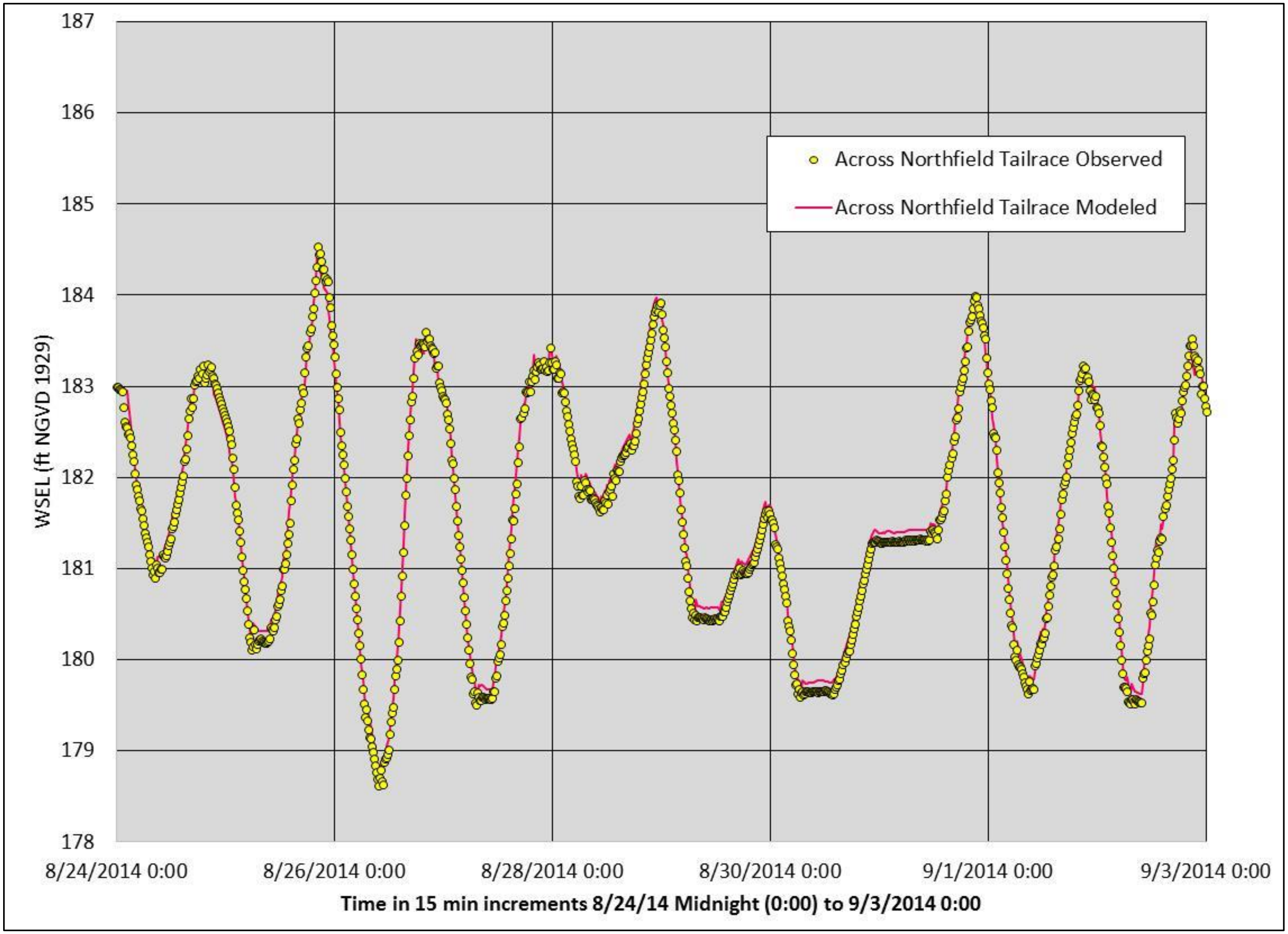


Figure 4.1.3-9: Comparison of Observed and Modeled WSELs *Downstream of French King Gorge* for the period August 24-September 3, 2014

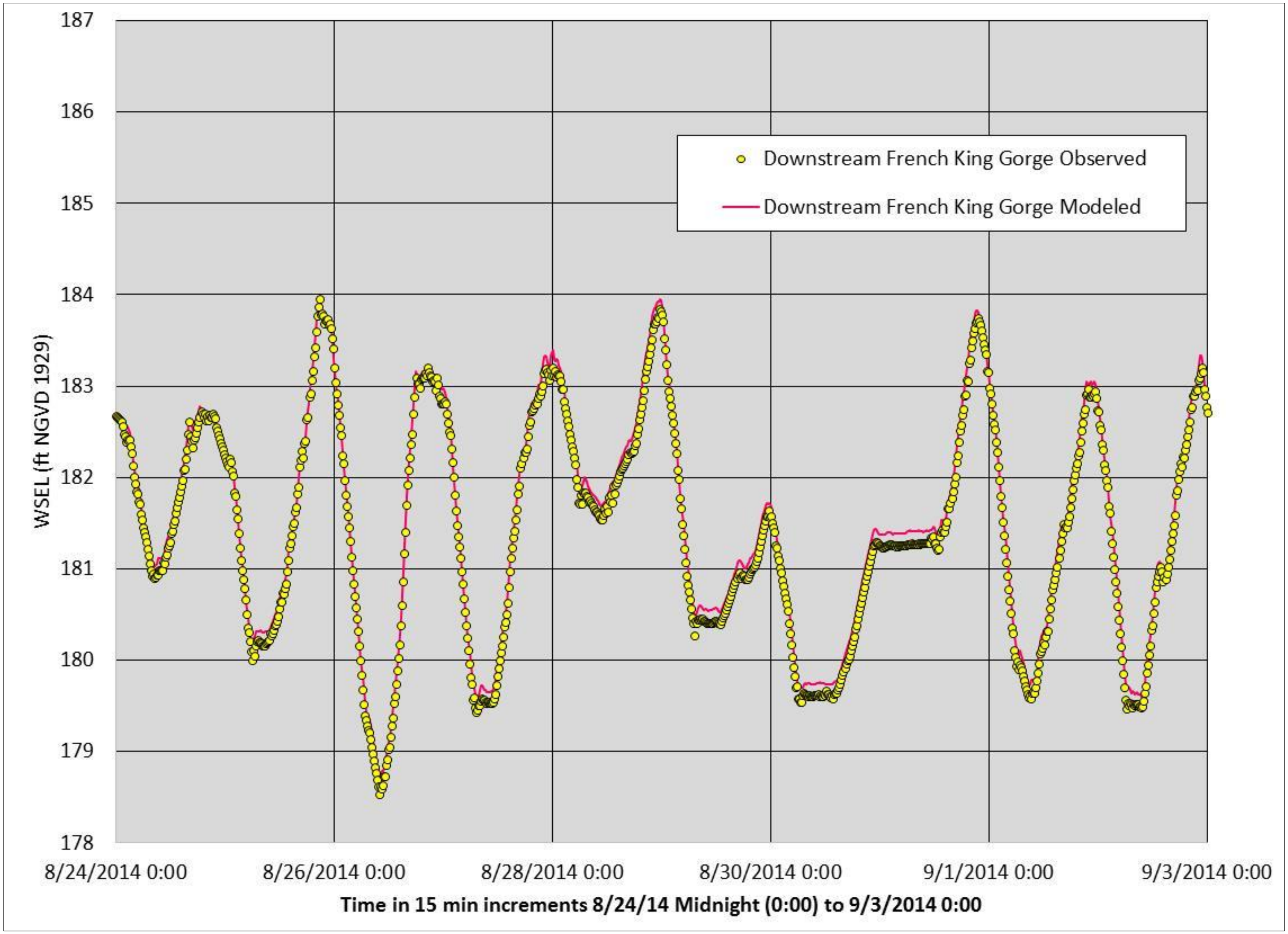


Figure 4.2.1-1 Montague Gage Flows and Water Surface Elevations at the Water Level Loggers for the Period June 3 -5, 2012.

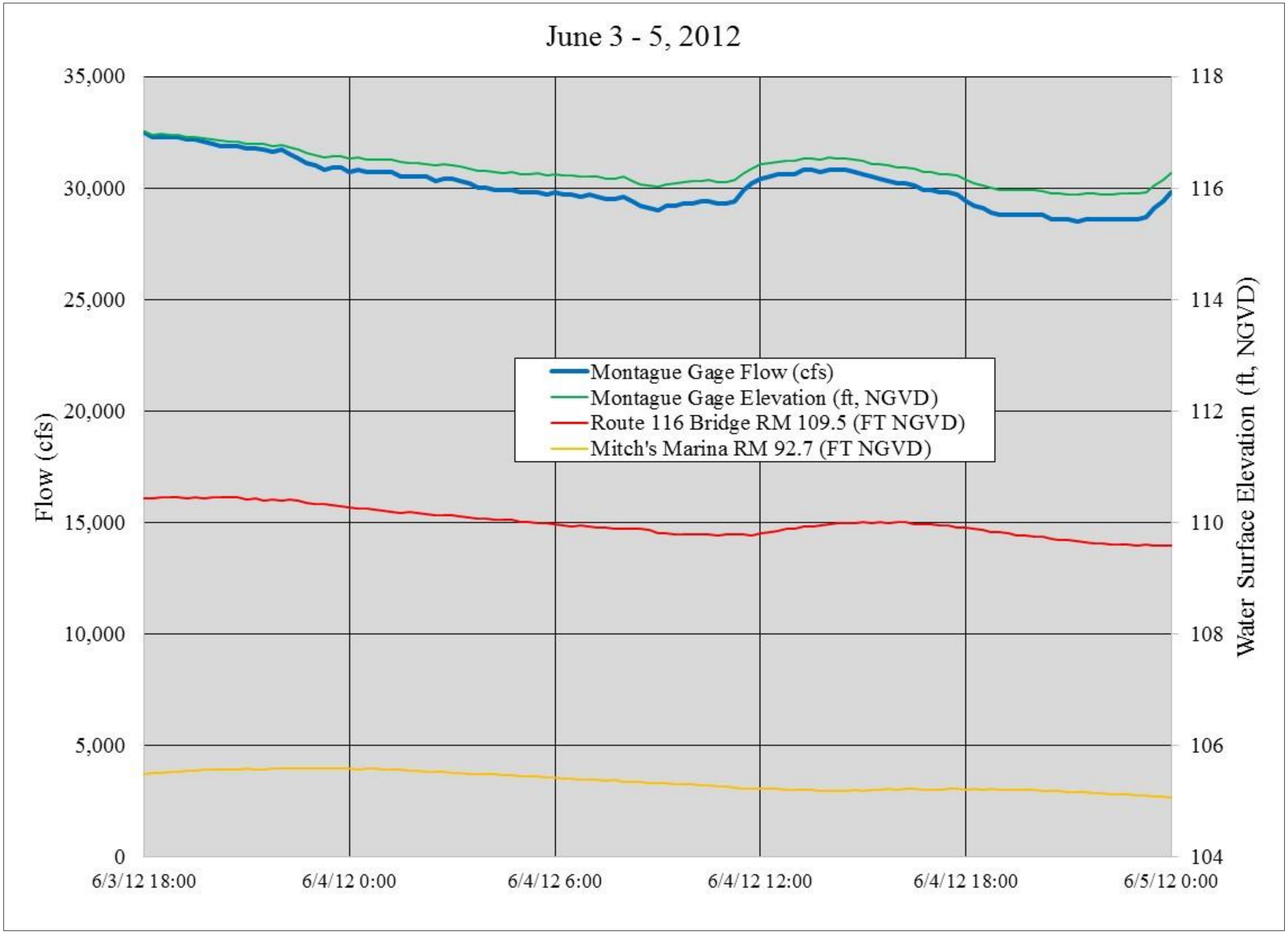


Figure 4.2.1-2 Montague Gage Flows and Water Surface Elevations at the Water Level Loggers for the Period July 20-23, 2012.

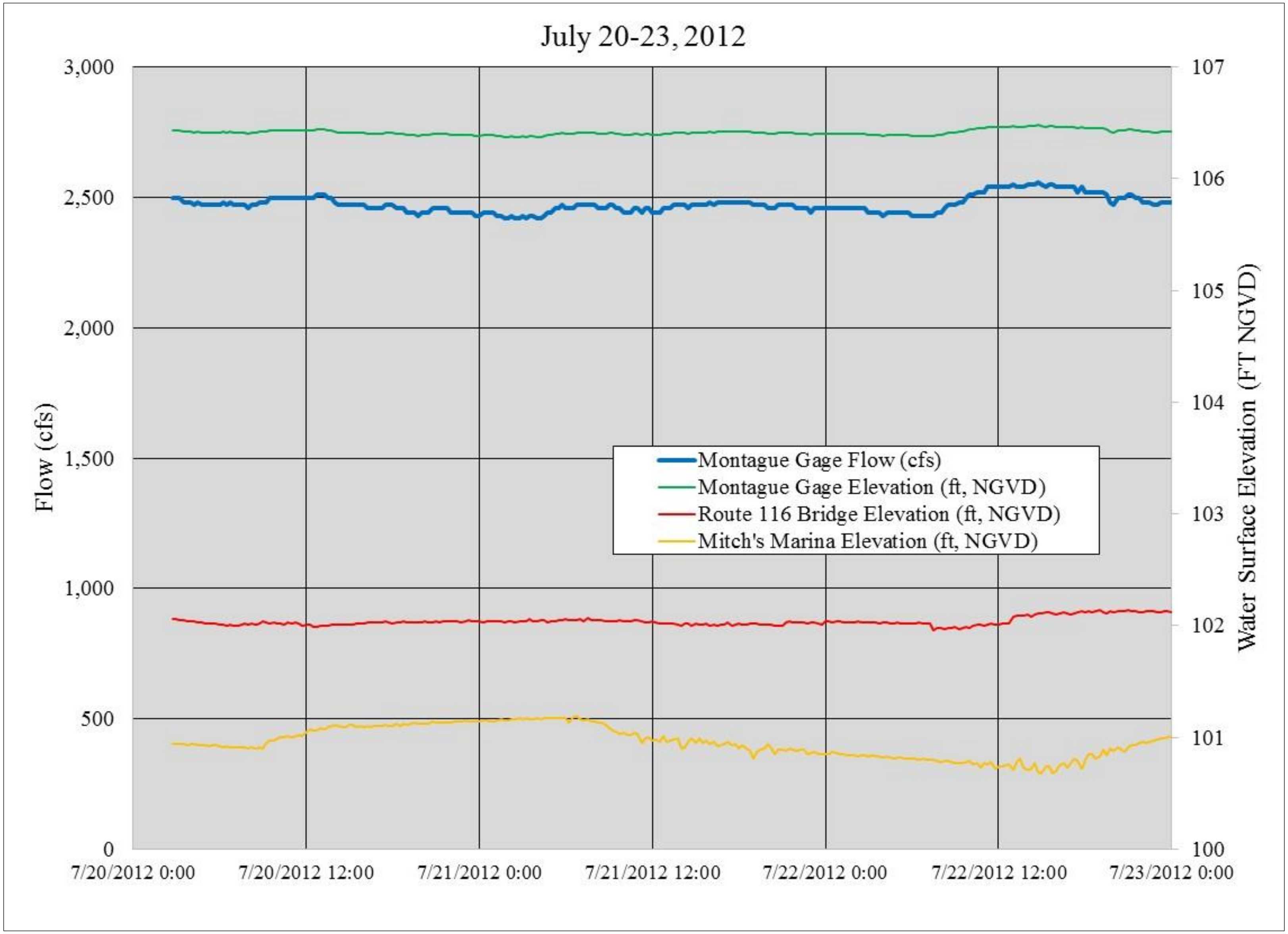


Figure 4.2.3-1: Montague Gage Flows and Water Surface Elevations at the Water Level Loggers for the Period May 22 to June 1, 2012

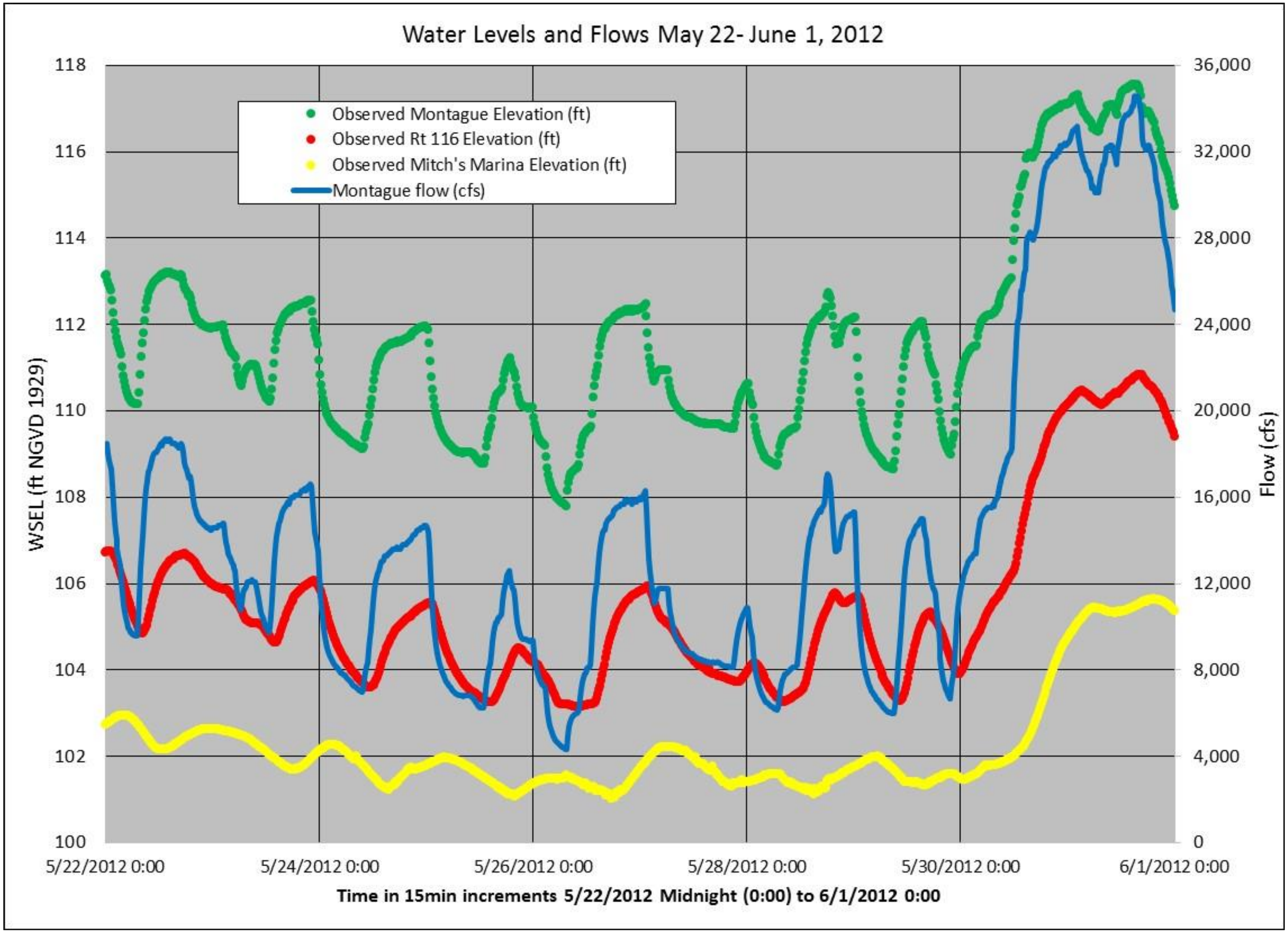


Figure 4.2.3-2: Comparison of Observed and Modeled WSELs *at the Montague Gage* for the period May 22 to June 1, 2012

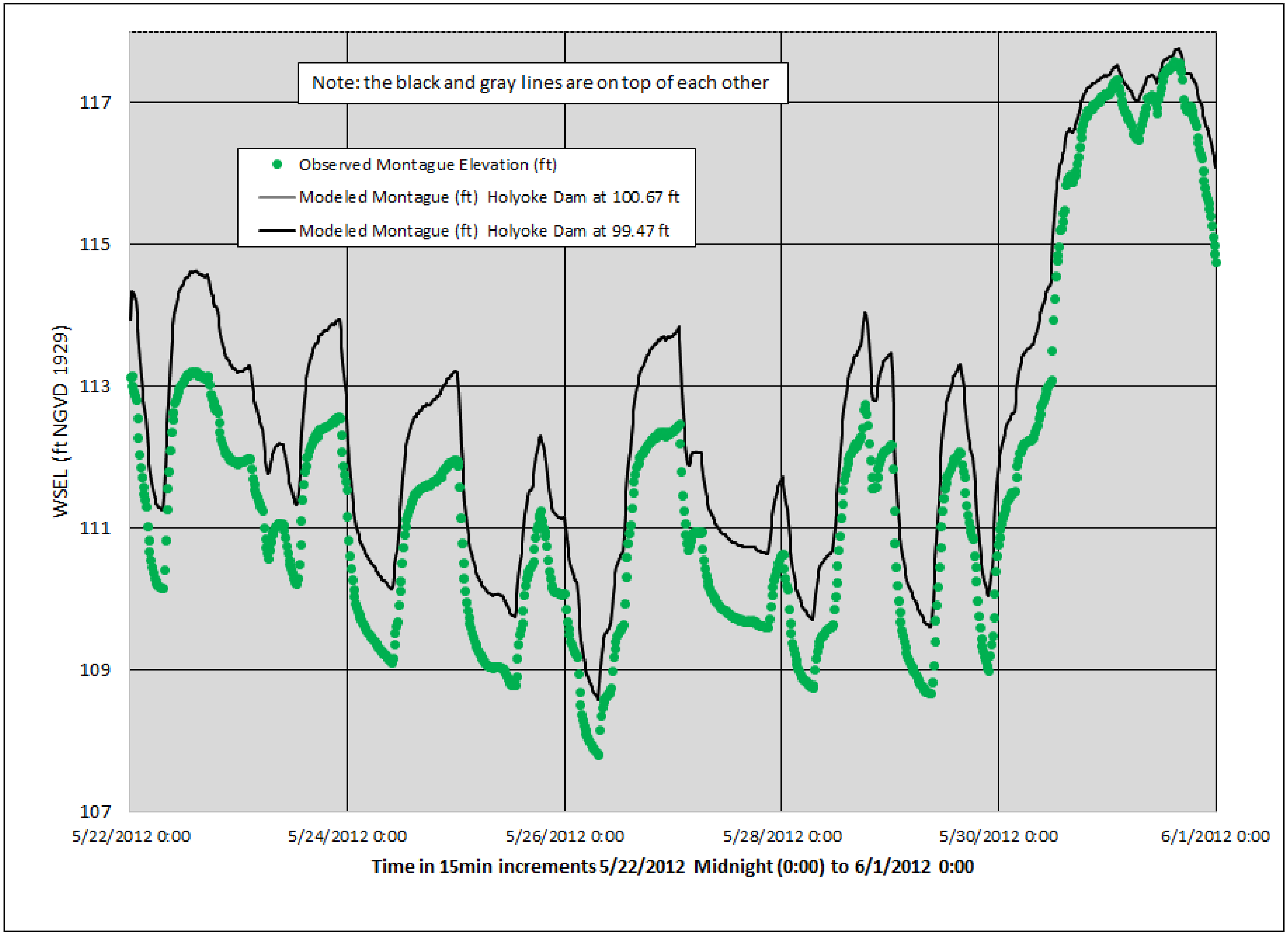


Figure 4.2.3-3: Comparison of Observed and Modeled WSELs *at the Route 116 Bridge* for the period May 22 to June 1, 2012

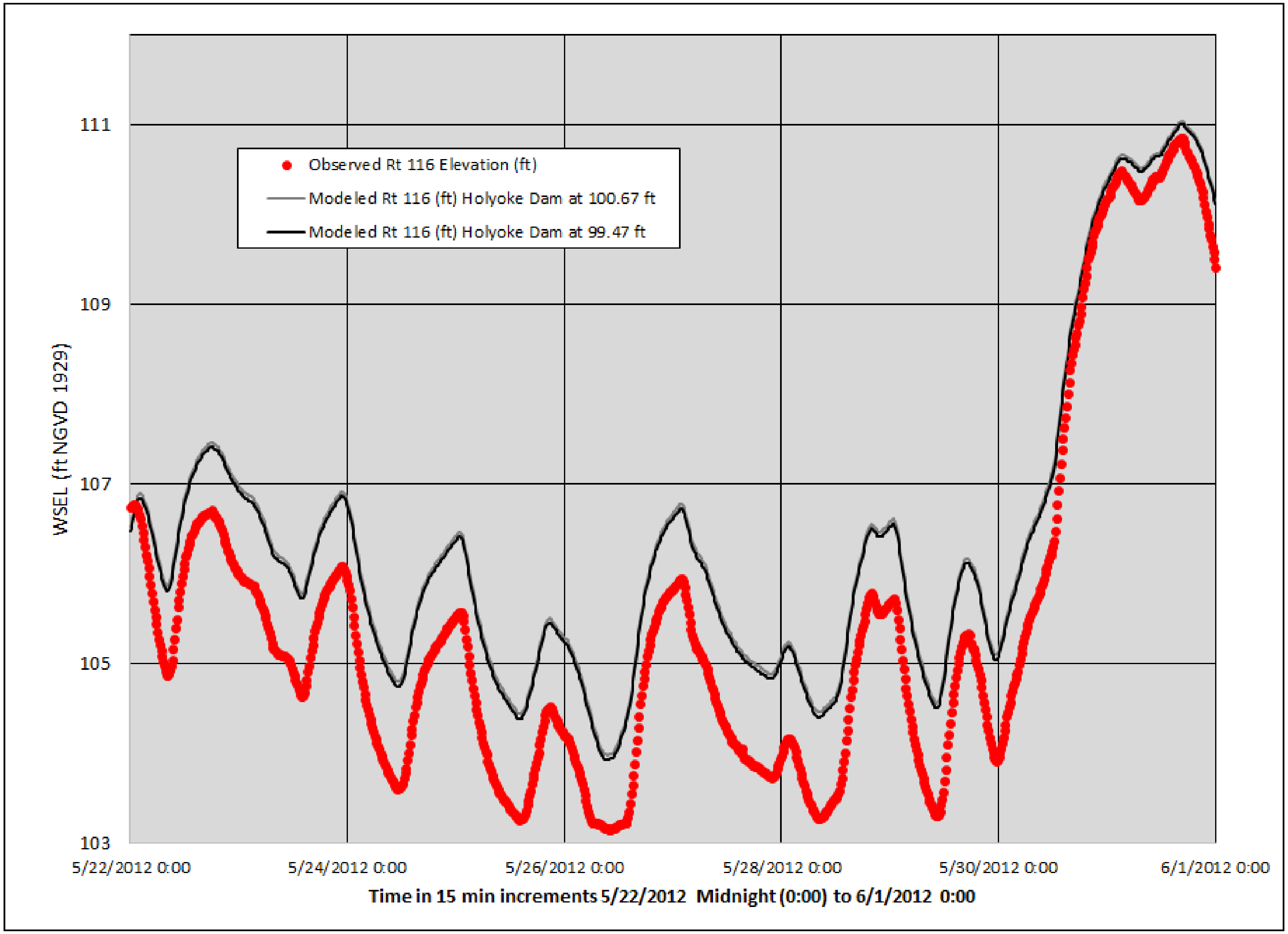


Figure 4.2.3-4: Comparison of Observed and Modeled WSELs *at Mitch's Marina* for the period May 22 to June 1, 2012

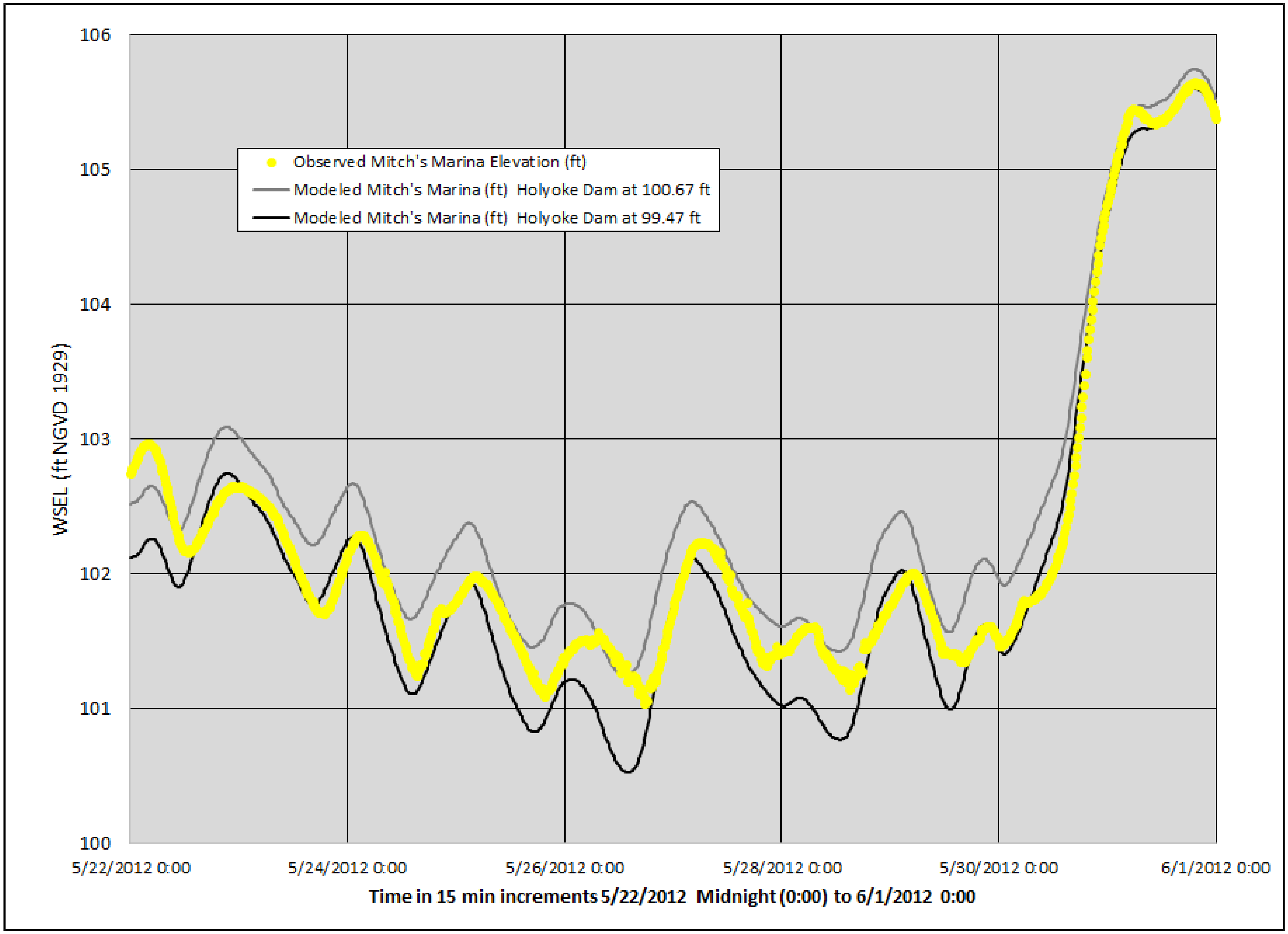


Figure 4.2.3-5: Montague Gage Flows and Water Surface Elevations at the Water Level Loggers for the Period July 1-11, 2012

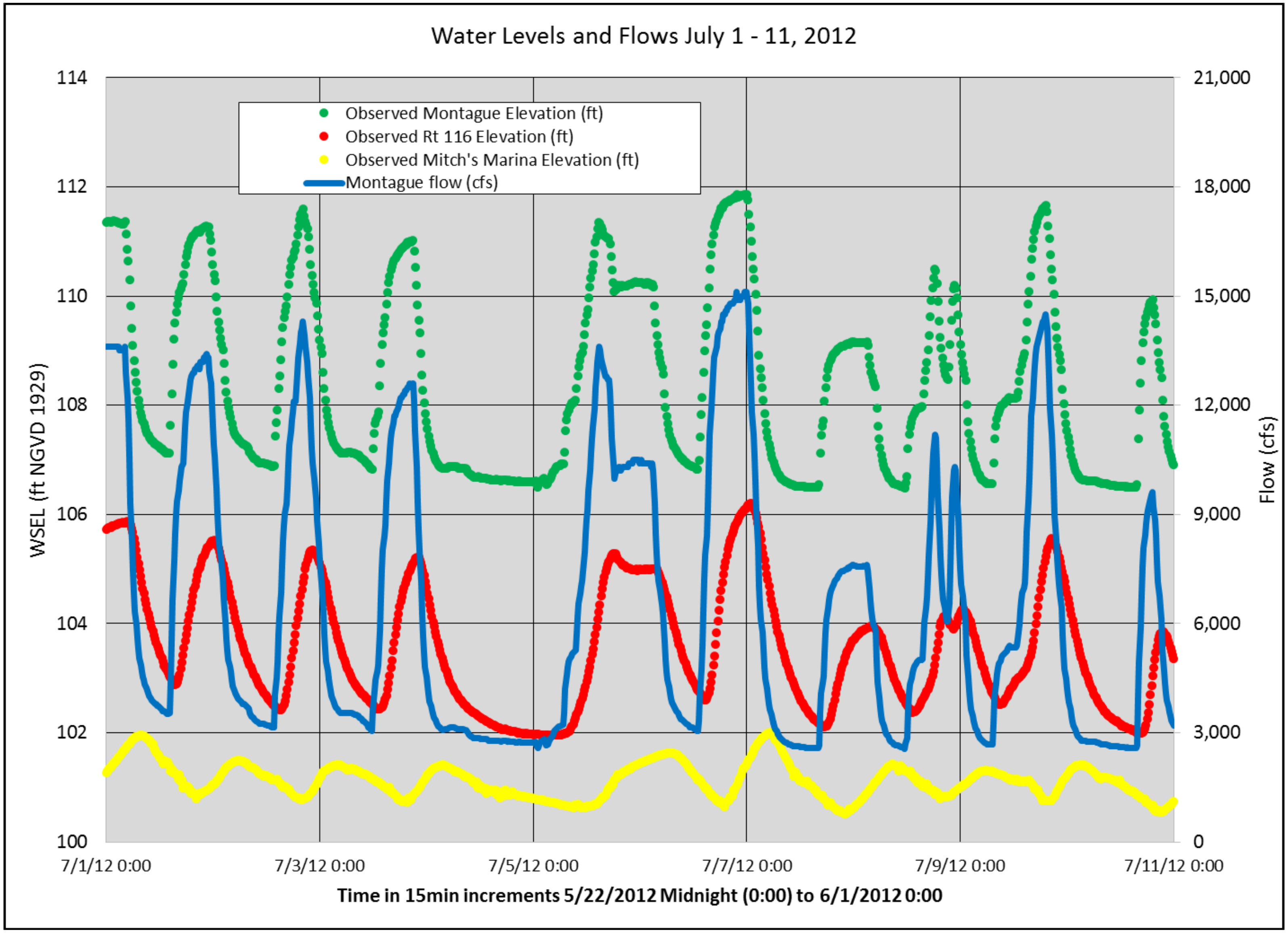


Figure 4.2.3-6: Comparison of Observed and Modeled WSELs *at the Montague Gage* for the period July 1 to 11, 2012

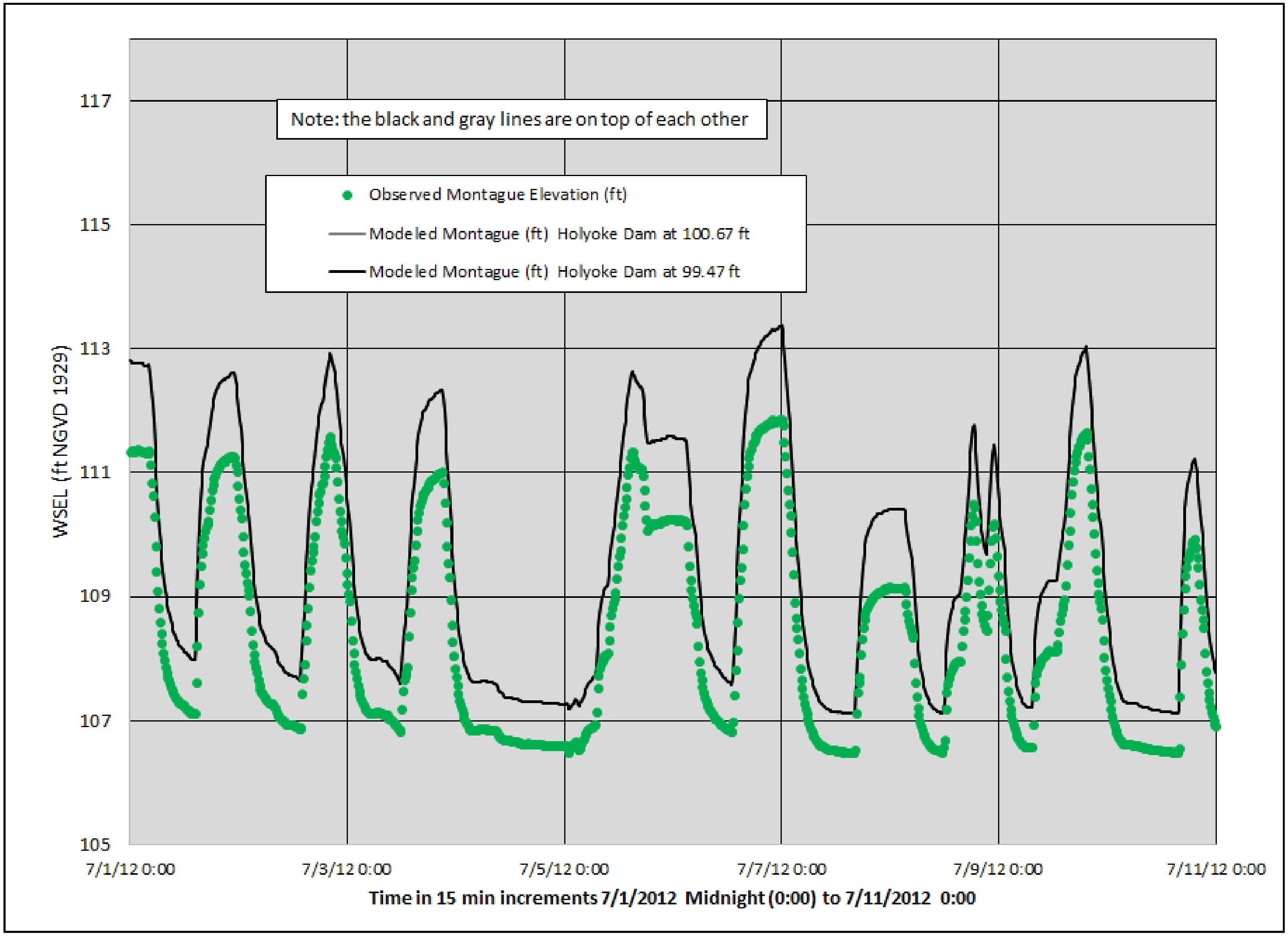


Figure 4.2.3-7: Comparison of Observed and Modeled WSELs *at the Route 116 Bridge* for the period July 1 to 11, 2012

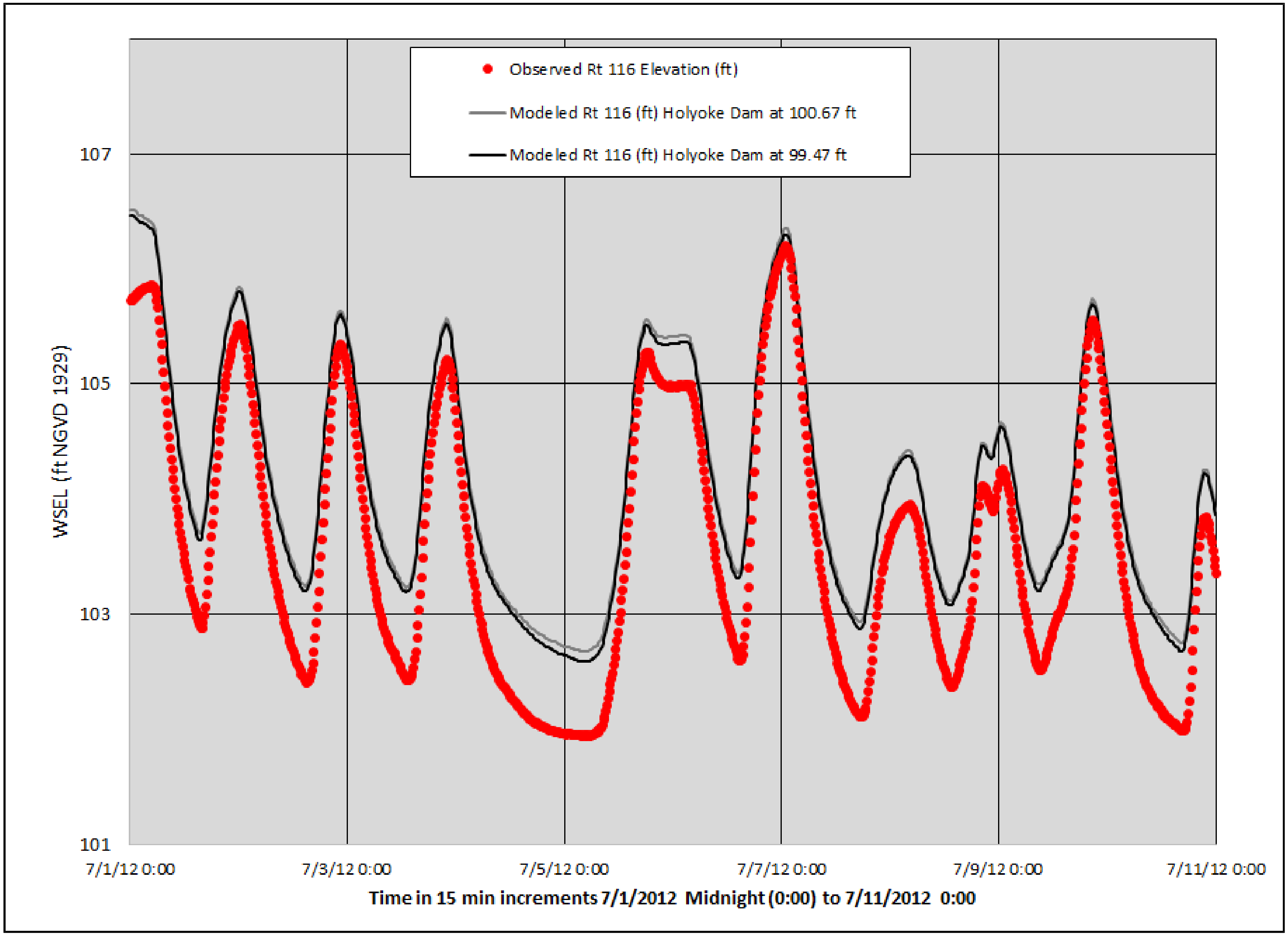
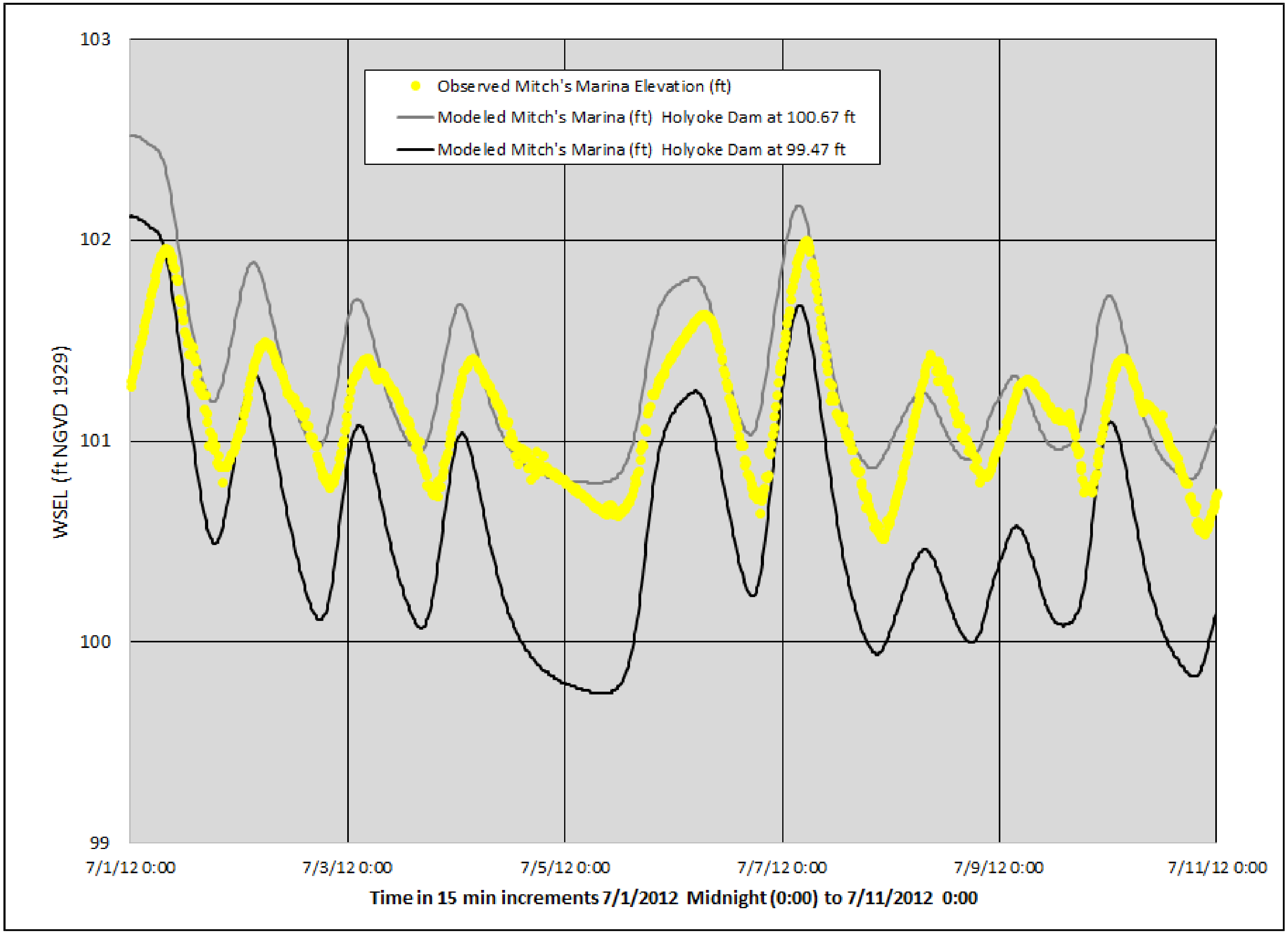


Figure 4.2.3-8: Comparison of Observed and Modeled WSELs *at Mitch's Marina* for the period July 1 to 11, 2012



5 HEC-RAS SCENARIOS (PER RSP)

5.1 Vernon Dam to Turners Falls Dam: Turners Falls Impoundment

5.1.1 Turners Falls Impoundment: Steady-State Modeling Results

Task 4 of the RSP requires the simulation of various steady-state "scenarios". Table 5.1.1-1 lists the scenarios simulated in the HEC-RAS model.

Table 5.1.1-1: Steady-State Hydraulic Modeling Scenarios for the Turners Falls Impoundment

	Vernon Project		Northfield Mountain Project			Turners Impoundment El. at Dam		
Scenario Number	Max Gen Flow (cfs)	Min Flow (cfs)	Max Gen Flow (cfs)	Max Pump Flow (cfs)	Off	Max Imp. Elev. (ft)	Median Imp. Elev. (ft)	Min Imp. Elev. (ft)
Flow (cfs)	17,130	1,250	20,000	-15,200		185 ft	181.3 ft	176 ft
1	X		X			X		
2	X		X				X	
3	X		X					X
4	X			X		X		
5	X			X			X	
6	X			X				X
7	X				X	X		
8	X				X		X	
9	X				X			X
10		X	X			X		
11		X	X				X	
12		X	X					X
13		X			X	X		
14		X			X		X	
15		X			X			X

Note that the original scenario table in the RSP included three other scenarios including operating Northfield Mountain at its maximum pump capacity, Vernon releasing its minimum flow and under three different downstream boundary conditions- 176 ft, 181.3 ft (median) and 185 ft. These scenarios were simulated, but with little inflow (1,250 cfs Vernon release) and maximum pumping of 15,200 cfs, it depletes the Impoundment storage resulting in lowering the water levels to a point where the model became unstable. Given this, it was not possible to simulate these three scenarios.

All scenarios assumed the following:

- There was no inflow from the Millers and Ashuelot Rivers. This was purposely done to eliminate any masking of the effects caused by the Vernon Project operations or the Northfield Mountain Project operations.

- Vernon Max Gen Flow: Vernon operates at its peak hydraulic capacity of 17,130 cfs.
- Vernon Min Flow: Vernon operates at its minimum flow of 1,250 cfs over 24 hours.
- Northfield Mountain Maximum Generation Flow: Northfield Mountain operates at its maximum generation hydraulic capacity of all 4 units or 20,000 cfs.
- Northfield Mountain Maximum Pump Flow: Northfield Mountain operates at its maximum pump hydraulic capacity of all 4 pumps or 15,200 cfs.
- Northfield Mountain Idle: Northfield Mountain does not pump or generate.
- The HEC-RAS model requires the user to enter the starting downstream boundary condition—in this case the WSEL at the Turners Falls Dam. Three different elevations were used- the lowest FERC-licensed elevation of 176 ft, the maximum FERC-licensed elevation of 185 feet, and the median observed (2000-2009) long-term elevation of 181.3 feet.

Each of the 15 scenarios listed in Table 5.1.1-1 were simulated in the HEC-RAS model under steady state conditions. Shown in Table 5.1.1-2 (end of this section) are the modeled WSELs for Scenarios 1-15 at the following water level logger locations: Northfield tailrace, Route 10 Bridge, Stateline, Downstream of Stebbins Island and the Vernon tailrace. The findings in Table 5.1.1-2 are also shown graphically in Figure 5.1.1-1. On the bar chart in Figure 5.1.1-1 are three water level loggers: Vernon Tailrace, Downstream of Stebbins Island and the Northfield Tailrace.

The findings provide valuable input on how the Vernon Project and Northfield Mountain Project impact WSEL's throughout the Impoundment. A comparison of the model findings where the starting downstream WSEL at the Turners Falls Dam was always 181.3 ft is summarized below (other than as described in the subheading of: "Impact of the WSEL at the Turners Falls Dam Under Steady State Conditions".)

Impact of Vernon Peaking Operations Under Steady State Conditions:

- With Northfield Mountain idle (0 cfs), the difference in the WSEL with Vernon at its maximum discharge (17,130 cfs) versus Vernon at its minimum flow (1,250 cfs) is as follows (difference in WSEL between Scenarios 8 and 14):
  - At the Vernon tailrace 6.28 ft,
  - Downstream of Stebbins Island 3.58 ft,
  - At the Northfield tailrace 1.14 ft.

Impact of Northfield Operations Under Steady State Conditions:

- With Vernon at its maximum discharge (17,130 cfs), the difference in the WSEL when Northfield Mountain is at maximum generation (20,000 cfs- Scenario 2) versus maximum pumping (15,200 cfs) is as follows (difference in WSEL between Scenarios 2 and 5):
  - At the Vernon tailrace 0.89 ft,

- Downstream of Stebbins Island 2.36 ft,
- At the Northfield tailrace 4.15 ft.

- With Vernon at its maximum discharge (17,130 cfs) and Northfield Mountain idle (0 cfs, Scenario 8), the difference in the WSEL at the Vernon tailrace, with Northfield Mountain pumping (15,200 cfs, Scenario 5) is -0.12 feet, and with Northfield generation (20,000 cfs, Scenario 2) is 0.77 feet.

- With Vernon at its minimum flow (1,250 cfs), the difference in the WSEL when Northfield Mountain is at its maximum generation (20,000 cfs, Scenario 11) versus when Northfield Mountain is idle (0 cfs, Scenario 14) is as follows:
    - At the Vernon tailrace 1.29 ft,
    - Downstream of Stebbins Island 1.68 ft,
    - At the Northfield tailrace 1.67 ft.

Impact of the WSEL at the Turners Falls Dam Under Steady State Conditions:

- With Vernon at its maximum discharge (17,130 cfs) and Northfield Mountain idle (0 cfs) , the difference caused by a Turners Falls Dam WSEL of 185 ft (Scenario 7) to 176 ft (Scenario 9) is as follows:
    - At the Vernon tailrace 1.07 ft,
    - Downstream of Stebbins Island 3.07 ft,
    - At the Northfield tailrace 6.71 ft.

- With Vernon at its minimum flow (1,250 cfs) and Northfield Mountain idle (0 cfs), the Vernon tailrace WSEL with starting downstream boundary condition of 176.0, 181.3 and 185 feet is as follows:
    - Vernon tailrace WSEL with dam elevation of 176.0 feet: 181.16 ft
    - Vernon tailrace WSEL with dam elevation of 181.3 feet: 181.85 ft
    - Vernon tailrace WSEL with dam elevation of 185.0 feet: 185.05 ft

  At the Vernon tailrace, the difference between a Turners Falls Dam WSEL of 185 and 181.3 ft (Scenarios 13 and 14) is 3.20 ft, but only 0.69 between a Turners Falls Dam WSEL of 181.3 and 176 ft (Scenarios 14 and 15), indicating a hydraulic control section located just downstream of Vernon Dam which limits the WSEL fall to below 181.0 ft.

- With Vernon at its minimum flow (1,250 cfs), Northfield Mountain idle (0 cfs), and Turners Falls Dam WSELs of 185 ft (Scenario 13) and 181.3 ft (Scenario 14), the impoundment WSELs are very flat. At a Turners Falls Dam WSEL of 176.0 ft (Scenario 15), the WSEL varies from 181.16 ft at the Vernon Tailrace to 176.02 ft at the Northfield Mountain tailrace, indicating more of a riverine condition in the upper and middle sections of the Impoundment and a limited WSEL change between the Northfield Mountain tailrace and the Turners Falls Dam.

- With Vernon at its minimum flow (1,250 cfs) and Northfield Mountain at its maximum generation (20,000 cfs), the WSELs in the Impoundment are very flat due to the minimum WSEL changes at the locations in Scenarios 10, 11, and 12. Only with a Turners Falls Dam WSEL of 176 ft is there a noticeable difference in the WSEL at the upper end of the Impoundment as indicated by a Vernon tailrace elevation of 181.33 ft, which also indicates a hydraulic control section in the river downstream of Vernon Dam.

- With Vernon at its maximum discharge (17,130 cfs), and a Turners Falls Dam elevation of 181.3 feet, the difference in Vernon tailrace elevation with Northfield Mountain idle (0 cfs, Scenario 8) versus Northfield Mountain at its maximum pumping (15,200 cfs, Scenario 5) is 0.12 feet.

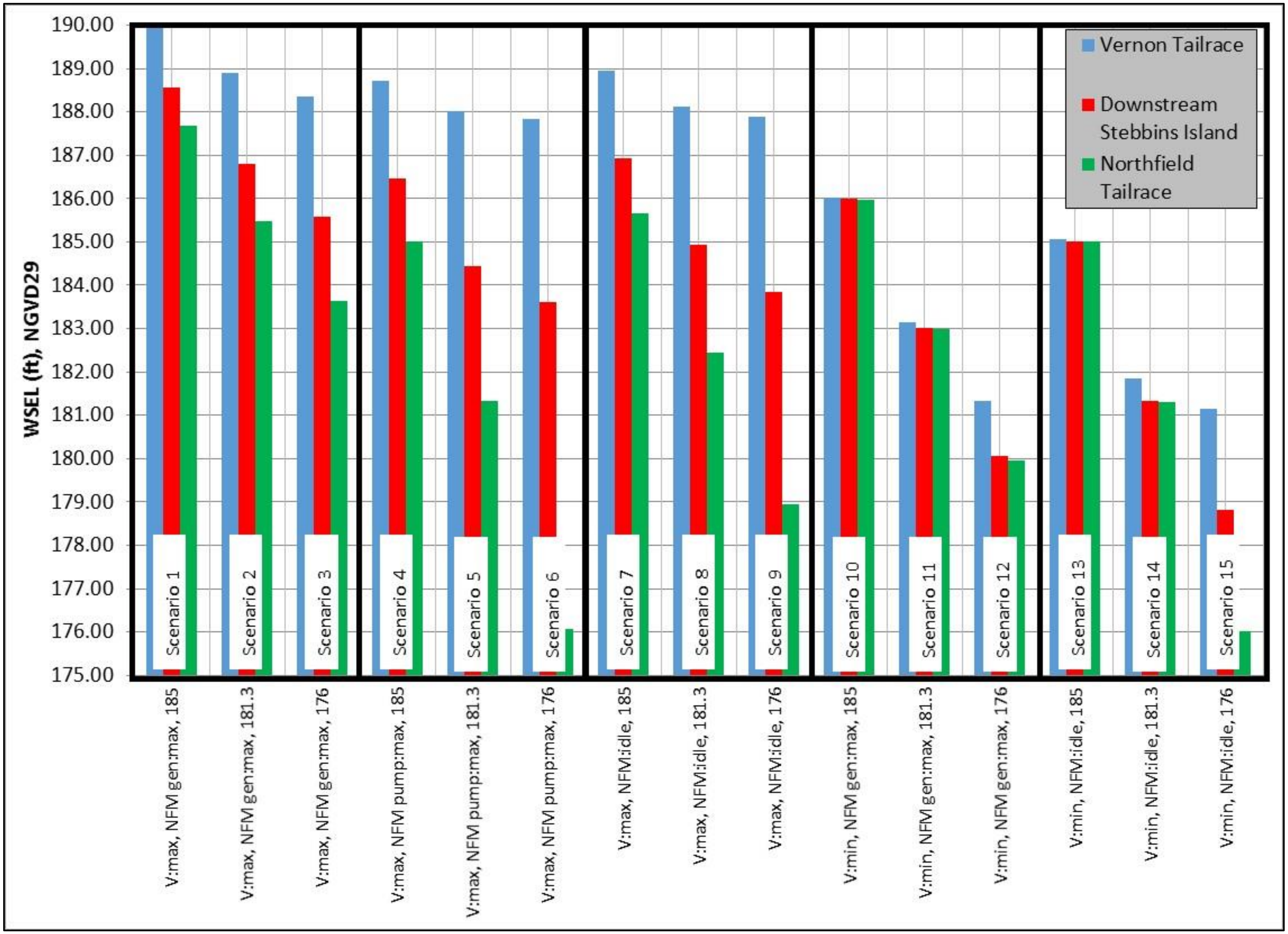
Impact of the French King Gorge Restriction Under Steady State Conditions:

- Under low flow conditions, such as Scenario 14 and others, the French King Gorge does not have substantial effect on the WSEL in the Turners Falls Impoundment.
- At higher flow conditions, especially above 20,000 cfs, the French King Gorge becomes more of a hydraulic control affecting the WSELs in the middle and upper Impoundment. This is most clearly shown in results of Scenario 2, (Vernon at its maximum discharge, and Northfield Mountain at its maximum generating capacity- total flow below the Northfield Mountain tailrace of 37,130 cfs) versus Scenario 14 (Vernon at its minimum flow and Northfield Mountain idle). The difference in the WSEL at the Northfield tailrace between these scenarios is 4.17 ft.

Table 5.1.1-2: Turners Falls Impoundment- Steady State Conditions- Scenarios 1-15, Modeled WSELs

	Vernon Project		**Northfield Mountain Project**			**Turners Impoundment El. at Dam**			**Modeled Elevations (ft)**				
Scenario Number	Max Gen Flow (cfs)	Min Flow (cfs)	Max Gen Flow (cfs)	Max Pump Flow (cfs)	Off or Idle	Max Imp. Elev. (ft)	Median Imp. Elev. (ft)	Min Imp. Elev. (ft)	Northfield Mountain Tailrace	Route 10 Bridge	Stateline	Downstream of Stebbins Island	Vernon Tailrace
Flow (cfs)	17,130	1,250	20,000	15,200		185 ft	181.3 ft	176 ft					
1	X		X			X			187.67	188.00	188.14	188.56	189.96
2	X		X				X		185.47	185.94	186.15	186.81	188.90
3	X		X					X	183.63	184.30	184.61	185.58	188.35
4	X			X		X			185.01	185.49	185.72	186.45	188.72
5	X			X			X		181.32	182.39	182.88	184.45	188.01
6	X			X				X	176.06	179.87	180.91	183.60	187.84
7	X				X	X			185.65	186.08	186.28	186.92	188.95
8	X				X		X		182.45	183.28	183.67	184.92	188.13
9	X				X			X	178.94	180.89	181.65	183.85	187.88
10		X	X			X			185.98	185.99	185.99	185.99	186.02
11		X	X				X		182.98	183.00	183.01	183.02	183.14
12		X	X					X	179.95	179.98	179.99	180.06	181.33
13		X			X	X			185.00	185.01	185.01	185.01	185.05
14		X			X		X		181.31	181.31	181.32	181.34	181.85
15		X			X			X	176.02	176.10	176.14	178.81	181.16

Figure 5.1.1-1: Turners Falls Impoundment- WSELs at 3 Locations under Steady-State Conditions (Scenarios 1-15)



5.1.2 Turners Falls Impoundment: Unsteady-State Modeling Results

Task 4 of the RSP requires the simulation of unsteady flow conditions. Time varying flows were simulated to determine changes in the WSEL at selected locations in the Turners Falls Impoundment. As shown in Table 5.1.2-1, 11 unsteady scenarios were developed to evaluate the effects of discharges from Vernon, operation of Northfield Mountain, and the water level at the Turners Falls Dam.

Table 5.1.2-1: Unsteady-State Hydraulic Modeling Scenarios for the Turners Falls Impoundment

Scenario	Vernon Conditions	Northfield Conditions	Turners Falls Impoundment Elevation (ft)
1	On a daily basis: Vernon 17,130 cfs for 8 hours and 1,250 cfs for 16 hours	Idle	181.3
2	On a daily basis: Vernon 17,130 cfs for 8 hours and 1,250 cfs for 16 hours	Idle	176.0
3	On a daily basis: Vernon 17,130 cfs for 8 hours and 1,250 cfs for 16 hours	Idle	185.0
4	Vernon Minimum Flow: 1,250 cfs	Daily maximum pumping (-15,200 cfs for 9.75 hours) and generation (20,000 cfs for 7.5 hours)	181.3
5	Vernon Minimum Flow: 1,250 cfs	Daily maximum pumping (-15,200 cfs for 9.75 hours) and generation (20,000 cfs for 7.5 hours)	185.0
6	Vernon Constant flow of 8, 000 cfs	Daily maximum pumping (-15,200 cfs for 9.75 hours) and generation (20,000 cfs for 7.5 hours)	181.3
7	Vernon Constant flow of 8, 000 cfs	Daily maximum pumping (-15,200 cfs for 9.75 hours) and generation (20,000 cfs for 7.5 hours)	176.0
8	Vernon Constant flow of 8, 000 cfs	Daily maximum pumping (-15,200 cfs for 9.75 hours) and generation (20,000 cfs for 7.5 hours)	185.0
9	Vernon Constant flow of 17,130 cfs	Daily maximum pumping (-15,200 cfs for 9.75 hours) and generation (20,000 cfs for 7.5 hours)	181.3
10	Vernon Constant flow of 17,130 cfs	Daily maximum pumping (-15,200 cfs for 9.75 hours) and generation (20,000 cfs for 7.5 hours)	176.0
11	Vernon Constant flow of 17,130 cfs	Daily maximum pumping (-15,200 cfs for 9.75 hours) and generation (20,000 cfs for 7.5 hours)	185.0

Notes: The duration of all model scenarios were 7 days, but shorter time periods are shown on the figures.
The licensed upper and lower WSEL at the Turners Falls Dam are 185.0 and 176.0 ft, respectively.
181.3 ft is the median WSEL as measured at the Turners Falls Dam over the 2000-2009 time period.

All of these scenarios used similar assumptions as were used in the steady state modeling, such as no tributary inflow and the downstream boundary conditions. Similar to the steady state modeling condition, a scenario with Vernon at its minimum flow (1,250 cfs), and Northfield Mountain at its maximum pumping capacity (15,200 cfs) and a Turners Falls Dam WSEL of 176 ft could not be modeled due to depletion of the Impoundment resulting in model instability. In practice, this scenario is not truly realistic- FirstLight would not deplete the Impoundment storage. Figures 5.1.2-1 to 5.1.2-11 provide the WSEL variation at key points in the Impoundment during the eleven scenarios described in Table 5.1.2-1.

A summary of the findings are below.

Impact of Vernon Peaking Operations Under Unsteady State Conditions:

- The highest daily variation in the upper Impoundment as measured at the Vernon tailrace and downstream of Stebbins Island, occurred with Vernon is at its maximum discharge (17,130 cfs), Northfield idle (0 cfs) and a WSEL of at the Turners Falls Dam of 176 ft (Scenario 2). Under this scenario, daily variations at the Vernon tailrace were about 6 feet, and downstream of Stebbins Island and Stateline, about 4 feet.
- As seen in the shape of the WSELs curves (Figures 5.1.2-1, -2 and -3) for the locations below the Vernon Tailrace in Scenarios 1, 2, and 3 (Northfield Mountain idle, Vernon peaking), when the WSEL is low at Turners Falls Dam (176.0 ft, 181.3 ft), the impoundment operates as more of a riverine condition, as compared to the 'blockier' WSELs curves when the WSEL at the Turners Falls Dam is higher (185.0 ft).
- With Vernon at its maximum discharge (17,130 cfs), it takes approximately 8 hours for the peak flow to reach the lower Impoundment.

Impact of Northfield Operations Under Unsteady State Conditions:

- Of the scenarios modeled, the maximum daily fluctuation throughout the Impoundment occurred under Scenario 4 (Figure 5.1.2-4) high Northfield Mountain pumping/generating, Vernon at its minimum flow and Turners Falls Dam WSEL at 181.3 ft. Maximum daily fluctuations through the Impoundment were less at a higher Turners Falls Dam WSEL of 185.0 ft (Scenario 5-Figure 5.1.2-5).
- Even during a constant Vernon discharge of 8,000 or 17,130 cfs, during maximum Northfield Mountain pumping/generating, the WSEL in most of the Impoundment fluctuates between 3 to 4 feet. However, these flows reduce the daily variation in WSELs noticed at the Vernon Tailrace and to a lesser extent downstream of Stebbins Island.
- During maximum Northfield Mountain pumping/generating, Vernon at its minimum flow, and Turners Falls Dam WSEL of 181.3 or 185 (Scenarios 4 and 5), Northfield Mountain operations control the WSELs in the majority of the Impoundment.

Impact of the WSEL at the Turners Falls Dam Under Unsteady State Conditions:

- There is about a 1 foot difference in the WSEL at Vernon Tailrace under Vernon at its maximum discharge and Northfield Mountain idle with a Turners Falls Dam WSEL of 181.3, 176, and 185 (Scenarios 1, 2, and 3).
- In general, a flatter Impoundment WSEL slope occurs at higher WSELs at the Turners Falls Dam and a steeper WSEL slope occurs at lower WSELs at the Turners Falls Dam.

Impact of the French King Gorge Restriction Under Unsteady State Conditions:

- Under low flow conditions, the French King Gorge does not have a substantial effect on the WSEL in the impoundment.
- Under periods of high flow periods, the effects of the French King Gorge constriction is evident by a substantial WSEL difference between Below French King Gorge and the upstream locations, especially when Northfield Mountain is generating as opposed to pumping.

Figure 5.1.2-1: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 1)

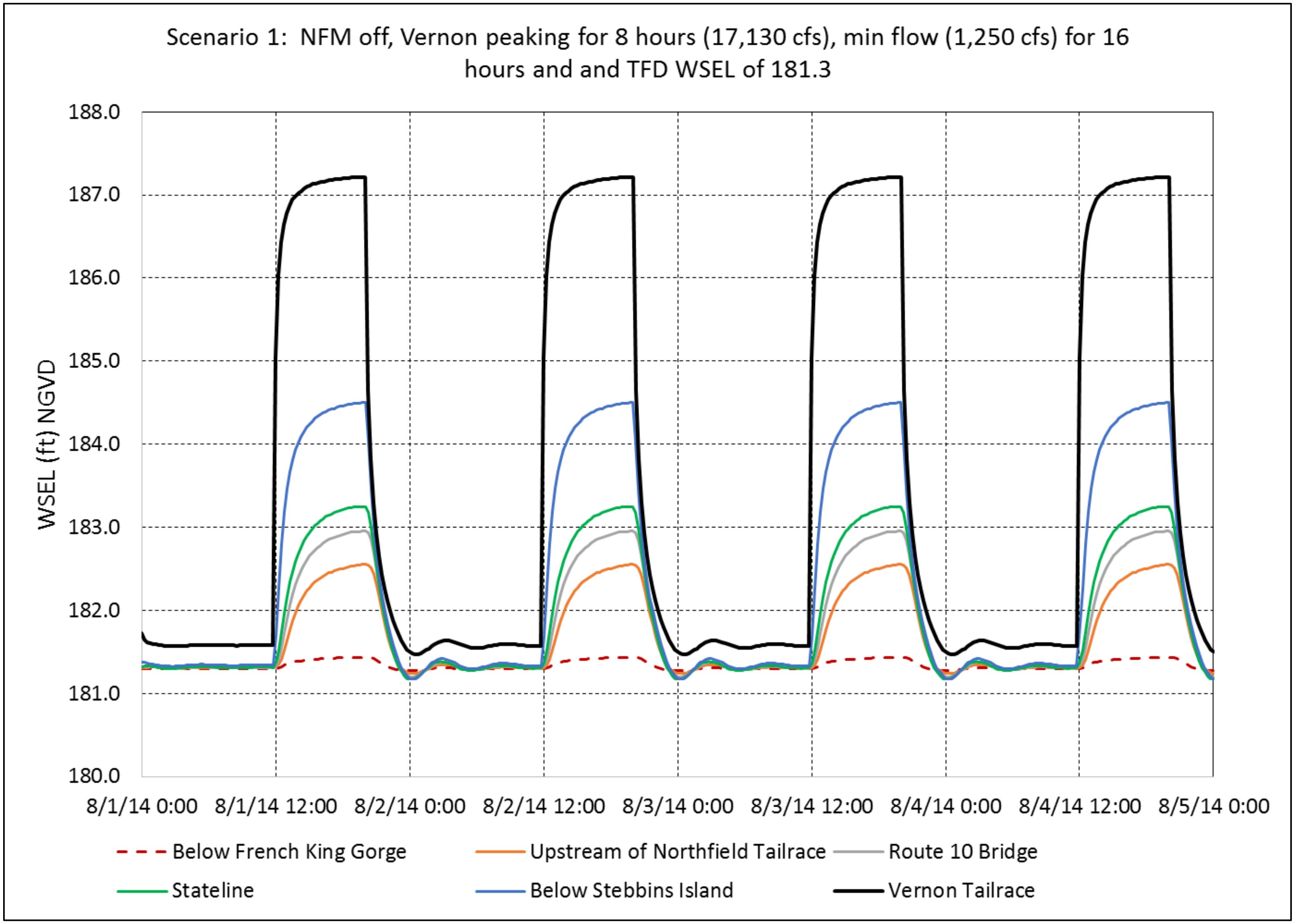


Figure 5.1.2-2: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 2)

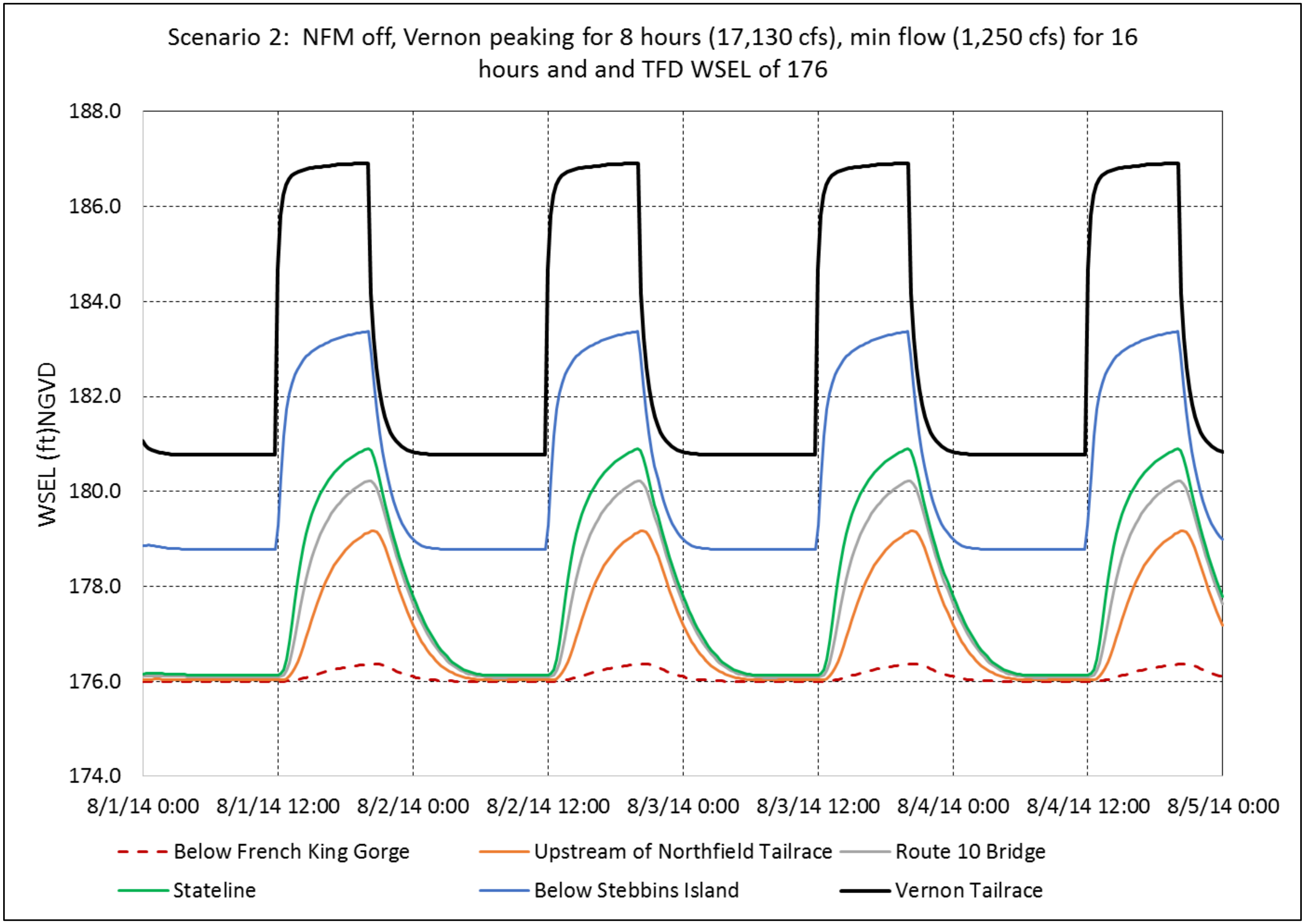


Figure 5.1.2-3: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 3)

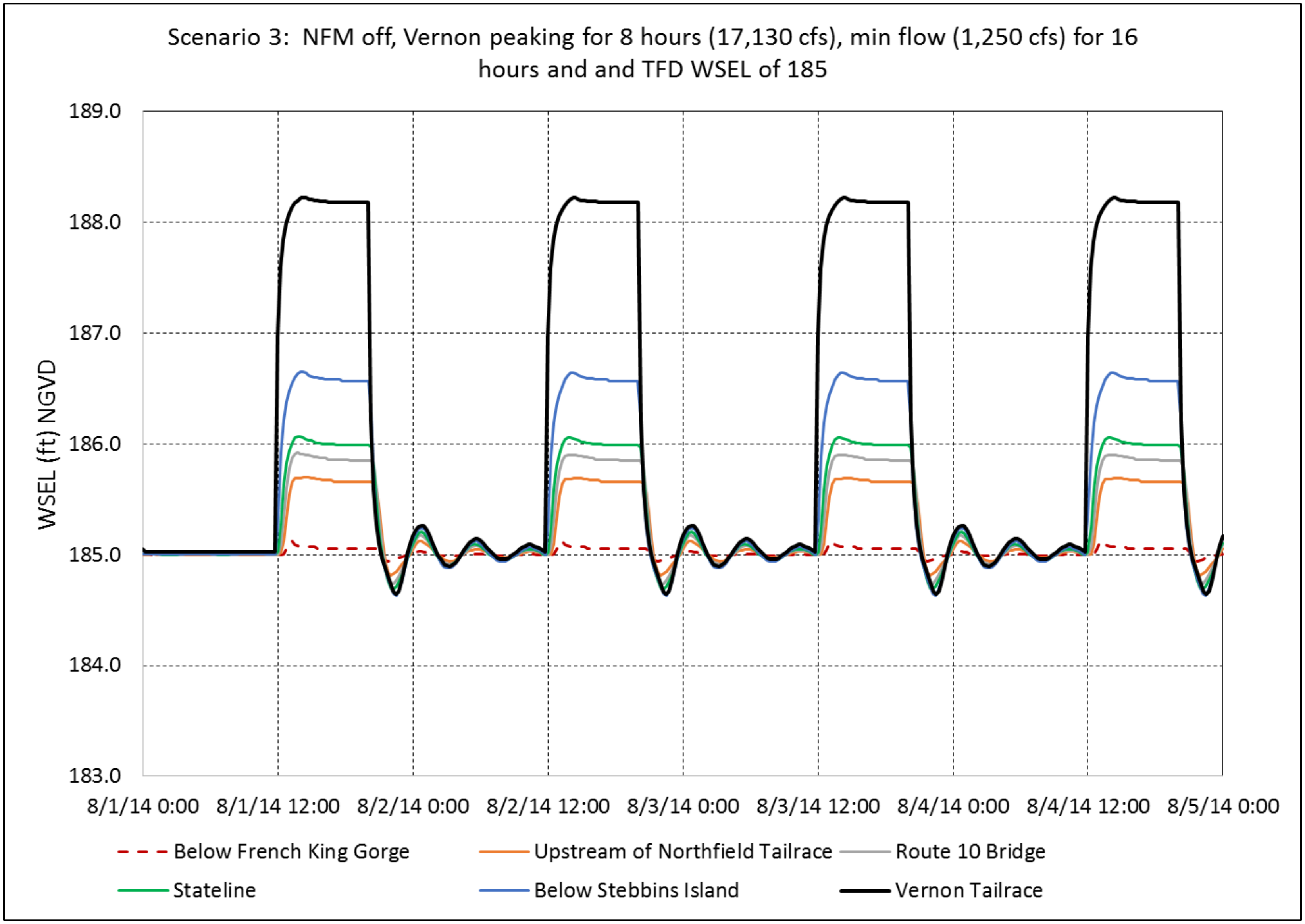


Figure 5.1.2-4: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 4)

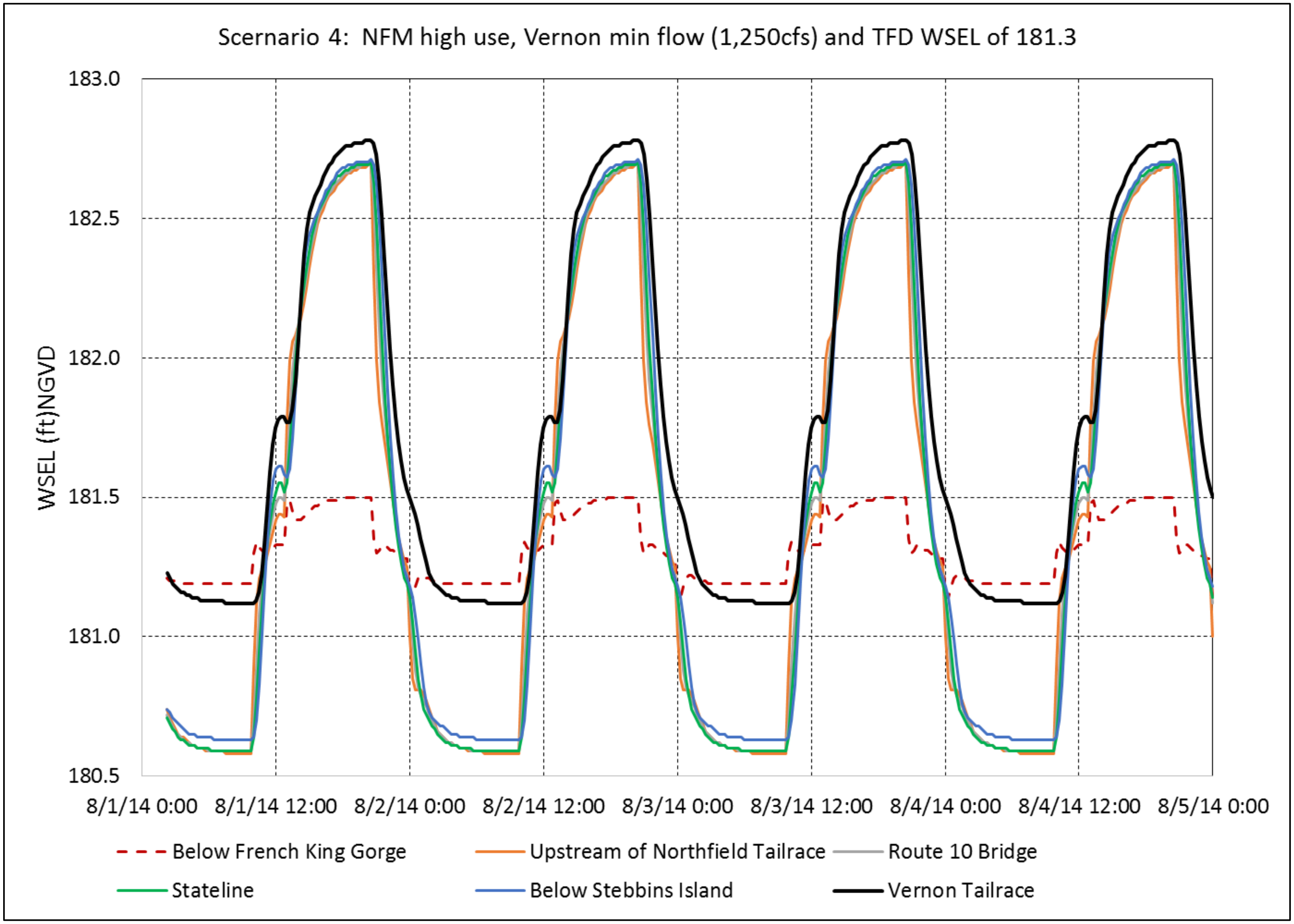


Figure 5.1.2-5: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 5)

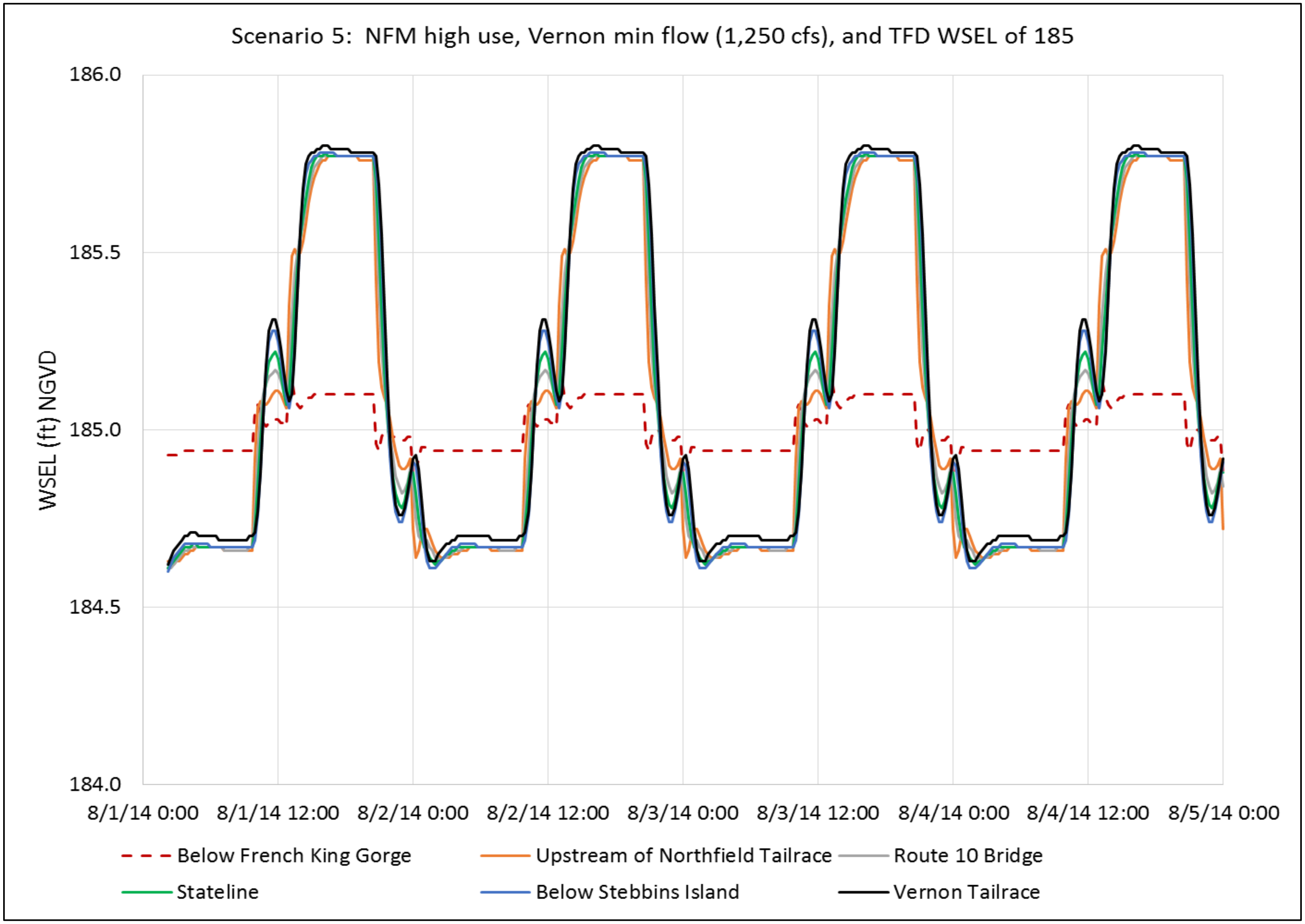


Figure 5.1.2-6: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 6)

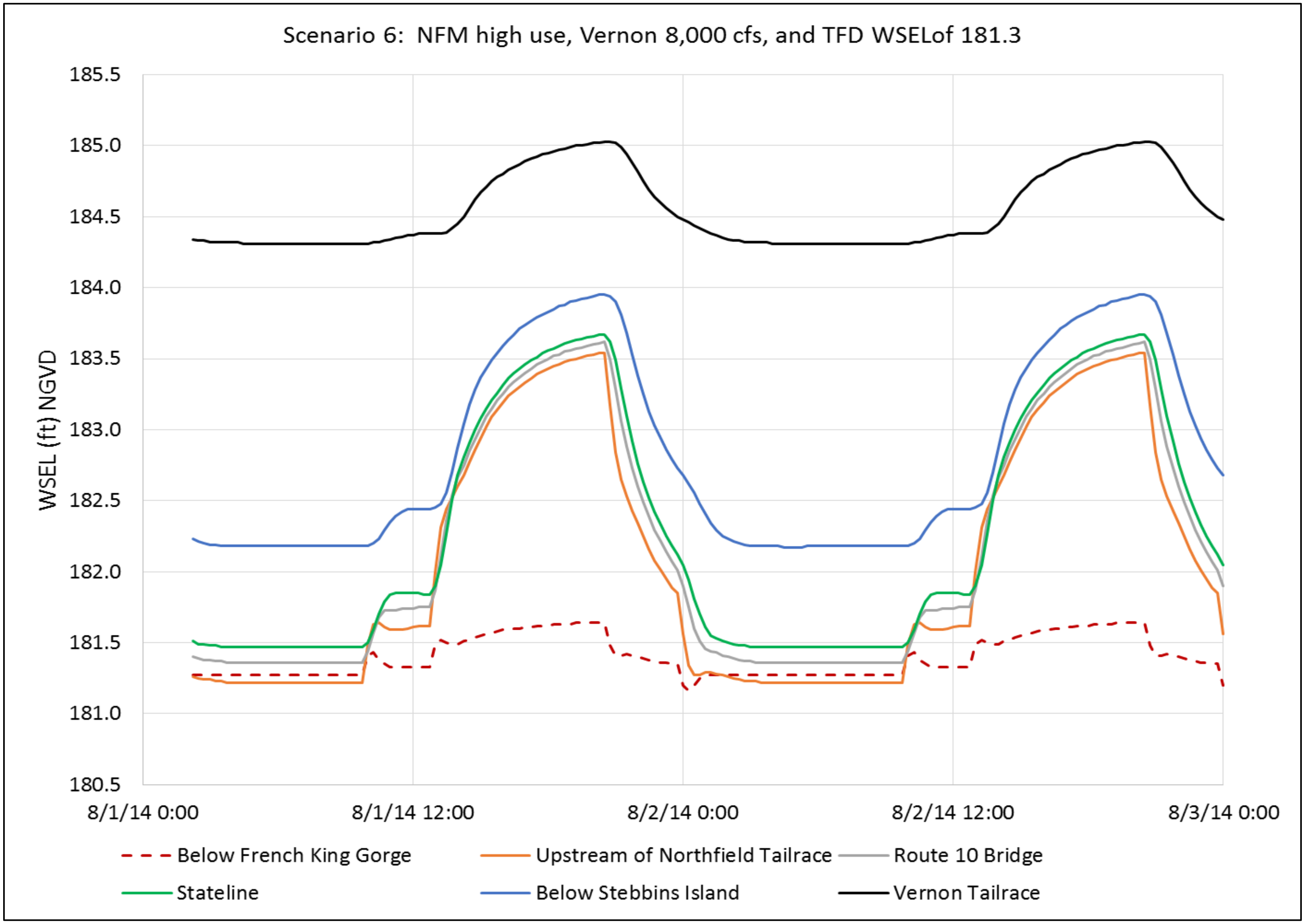


Figure 5.1.2-7: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 7)

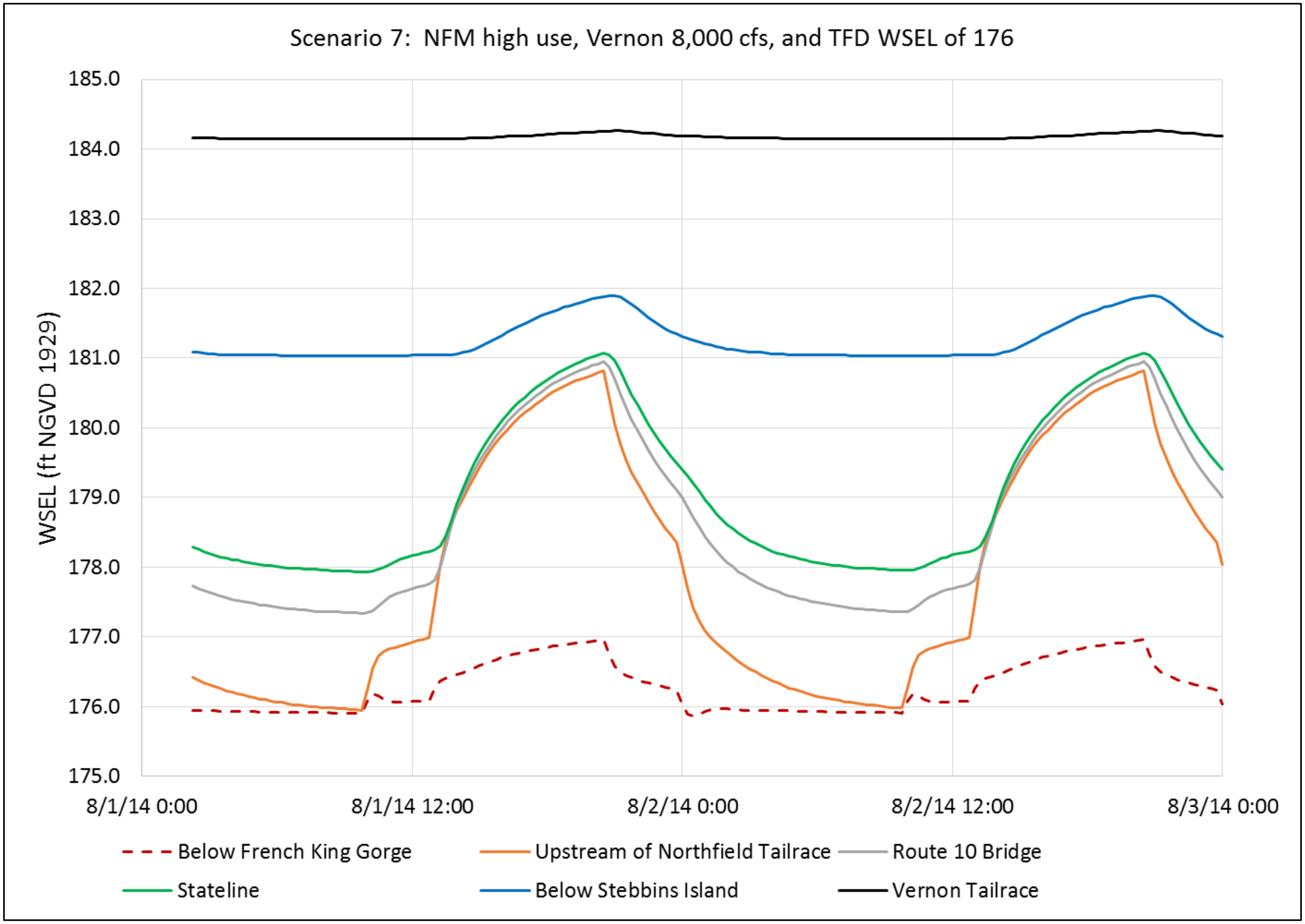


Figure 5.1.2-8: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 8)

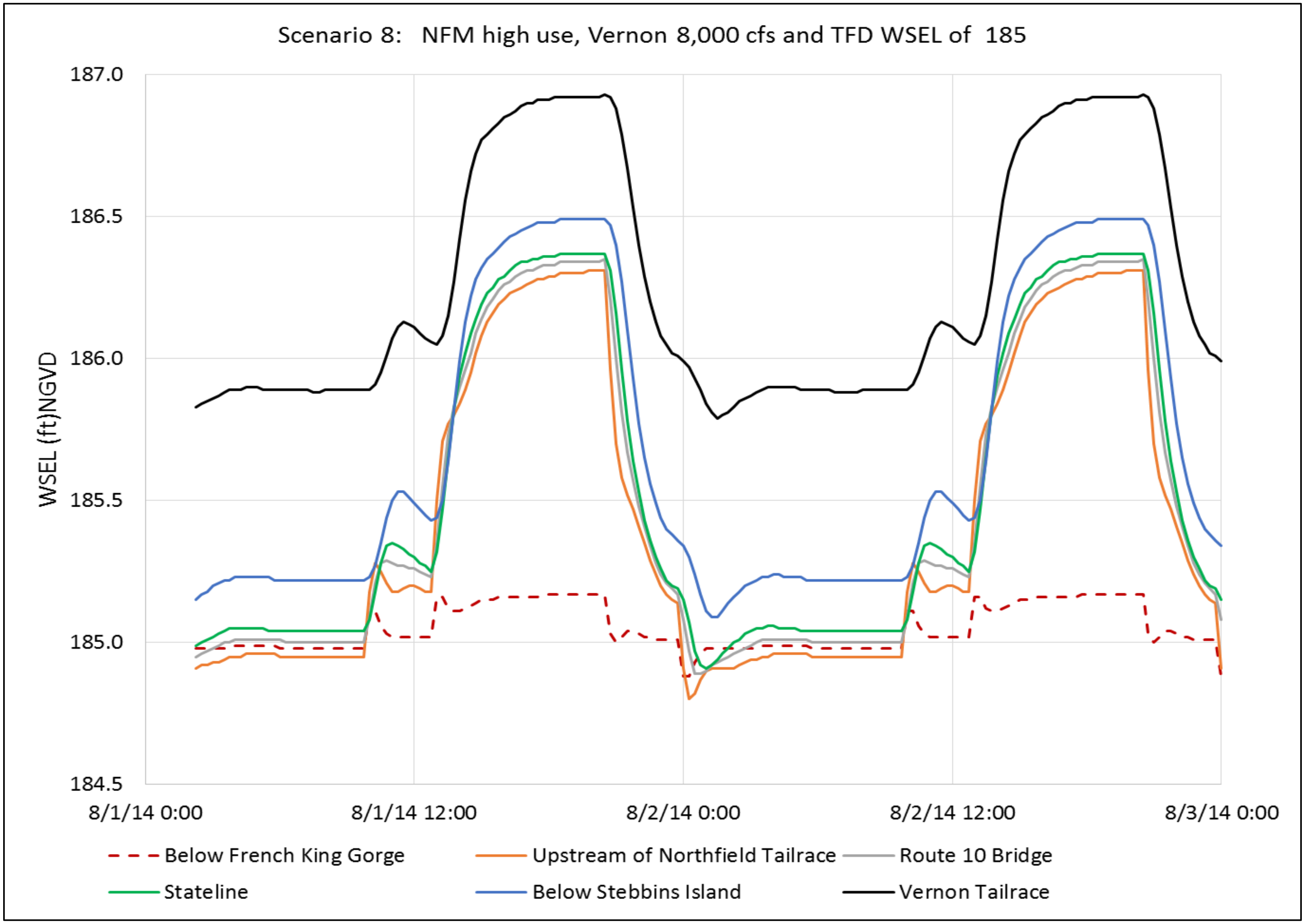


Figure 5.1.2-9: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 9)

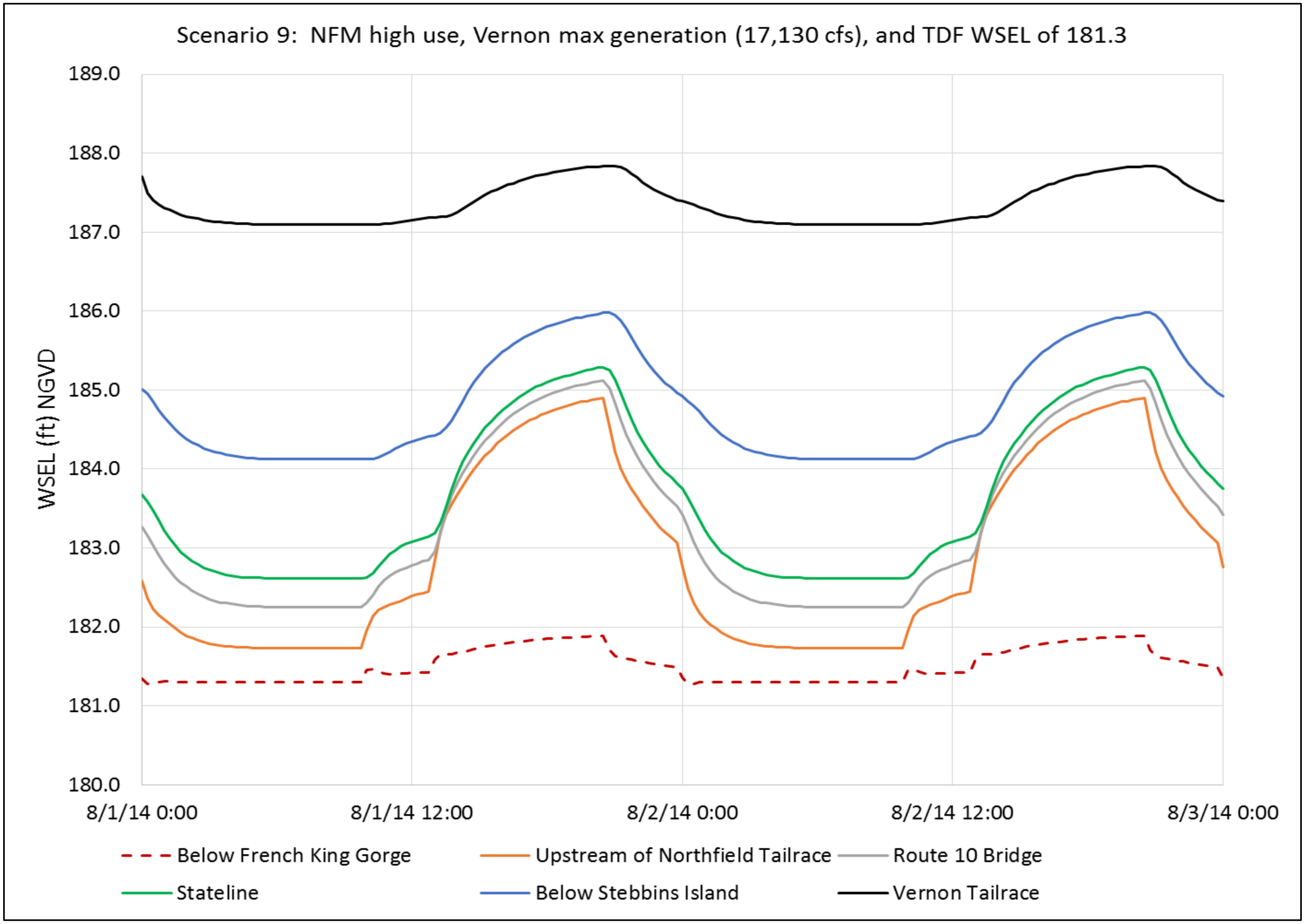


Figure 5.1.2-10: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 10)

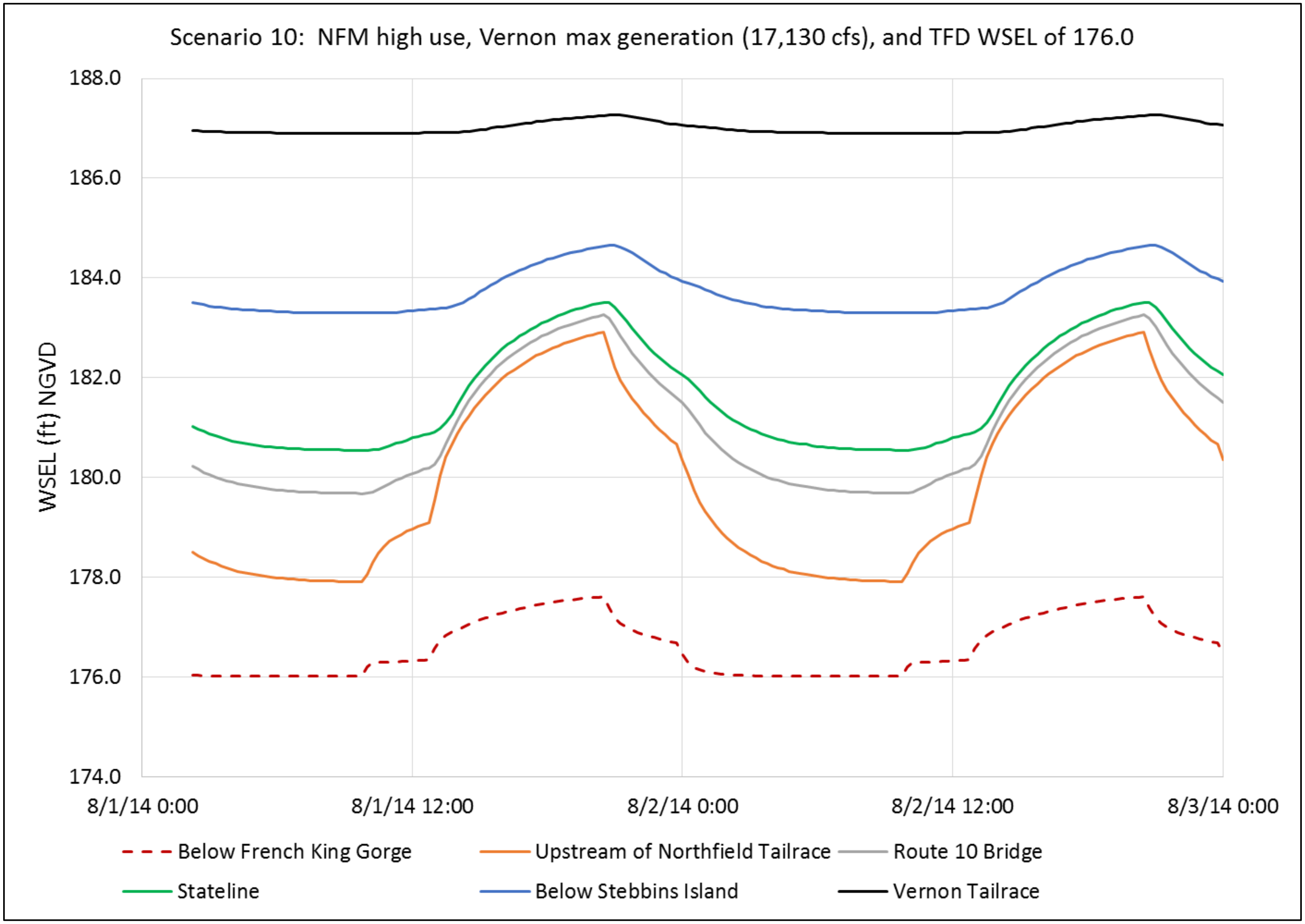
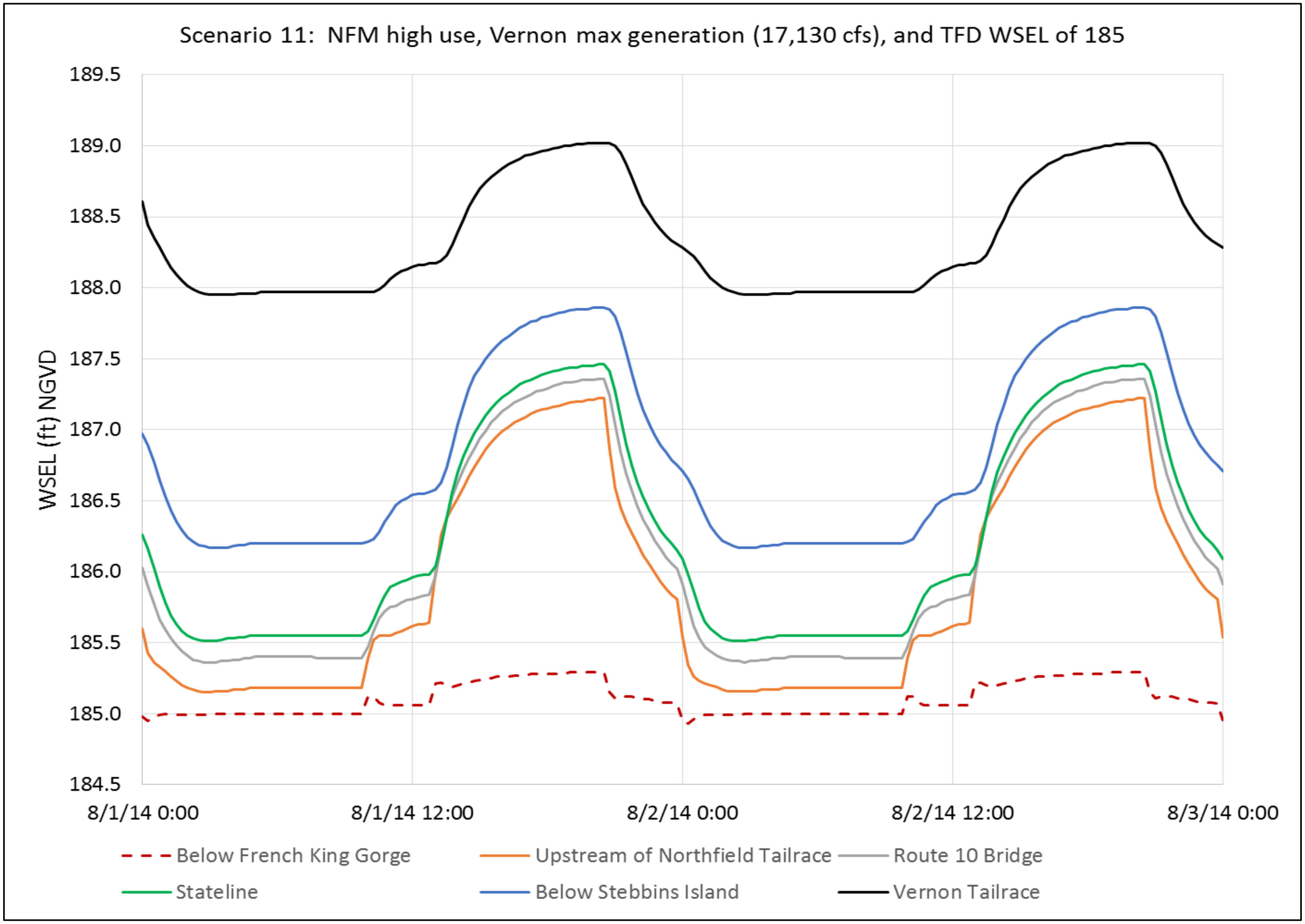


Figure 5.1.2-11: Turners Falls Impoundment- WSELs at 6 Locations under Unsteady-State Conditions (Scenario 11)



5.2 Montague USGS Gage to Holyoke Dam

5.2.1 Montague USGS Gage to Holyoke Dam: Steady-State Modeling Results

Task 7 of the RSP requires the simulation of various steady-state scenarios. Table 5.2.1-1 lists the scenarios simulated in the HEC-RAS model.

Table 5.2.1-1: Steady-State Hydraulic Modeling Scenarios

	Turners Falls Project		Deerfield River Project - Station No.2		Holyoke Impoundment Elev. At Dam	
Scenario	**Max Gen Flow**	**Min Flow**	**Max Gen Flow**	**Min Flow**	**Max Imp. Elev.**	**Min Imp. Elev.**
Flow (cfs)	**15,938**	**1,433**	**1,450**	**200**	**100.67 ft**	**99.47 ft**
1	X		X		X	
2	X		X			X
3	X			X	X	
4	X			X		X
5		X	X		X	
6		X	X			X
7		X		X	X	
8		X		X		X

All scenarios assumed the following:

- There was no inflow from the minor tributaries downstream of the Deerfield River. This was purposely done to eliminate any masking of the effects caused by the operation of the Turners Falls Project (Cabot and Station No. 1 powerhouses) or the peaking operations of the Deerfield River Projects. In addition, during the sensitive and normally low flow periods in the summer, the contributions of these minor tributaries account for only about 5% of the drainage area to Holyoke Dam.

- The hydrographs from peaking operations at the Turners Falls Project and the Deerfield River Project were entered as the hydrograph at the Montague Gage. This is a conservative approach since in reality the hydrographs from these two projects would be flattened and decreased especially during short generation periods.

- Turners Falls Project Maximum Generation Flow: Cabot (13,728 cfs) and Station No. 1 (2,210 cfs) operate at their combined peak hydraulic capacity of 15,938 cfs.

- Turners Falls Project Minimum Flow: The Turners Falls Project operates at its FERC-required minimum flow of 1,433 cfs over 24 hours.

- Deerfield River Project Station No. 2 Maximum Generation Flow: Deerfield River Project Station No. 2 operates at its peak hydraulic capacity of 1,450 cfs.

- Deerfield River Project Station No. 2 Minimum Generation Flow: Deerfield River Project Station No. 2 operates at its minimum flow 200 cfs.

- The HEC-RAS model requires the user to enter the starting downstream boundary condition—in this case the WSEL at the Holyoke Dam. Two different elevations were used- the maximum FERC-licensed elevation of 100.67 ft and the minimum FERC-licensed elevation of 99.47 ft.

Each of the eight (8) scenarios listed in Table 5.2.1-1 were simulated in the HEC-RAS model under steady state conditions. Shown in Table 5.2.1-2 (end of this section) are the modeled WSELs for Scenarios 1-8 at the following locations: Montague Gage, Route 116 Bridge, and Mitch's Marina. The findings in Table 5.2.1-2 are also shown graphically in Figure 5.2.1-1. On the bar chart in Figure 5.2.1-1 are three water level loggers: Montague Gage, Route 116 Bridge, and Mitch's Marina.

Impact of Turners Falls Project Peaking Operations Under Steady State Conditions:

- The WSEL difference between maximum generation at the Turners Falls Project and Deerfield River Project (Scenarios 1 and 2) and maximum generation at the Deerfield River project only (Turners Falls at its minimum flow, Scenarios 5 and 6) is as follows:
  - At Mitch's Marina — 2.06 ft (when Holyoke Dam is at elevation 100.67)
    2.75 ft (when Holyoke Dam is at elevation 99.47 ft)
  - At the Route 116 Bridge — 4.80 ft (when Holyoke Dam is at elevation 100.67)
    4.80 ft (when Holyoke Dam is at elevation 99.47 ft)
  - At the Montague Gage — 7.23 ft (when Holyoke Dam is at elevation 100.67 ft)
    7.22 ft (when Holyoke Dam is at elevation 99.47 ft)

- The WSEL difference between maximum generation at the Turners Falls Project and minimum flows at the Deerfield River Project (Scenarios 3 and 4) and minimum flows for both Projects (Scenarios 7 and 8) is as follows:
  - At Mitch's Marina — 1.92 ft (when Holyoke Dam is at elevation 100.67)
    2.63 ft (when Holyoke Dam is at elevation 99.47 ft)
  - At the Route 116 Bridge — 5.29 ft (when Holyoke Dam is at elevation 100.67)
    5.47 ft (when Holyoke Dam is at elevation 99.47 ft)
  - At the Montague Gage — 8.25 ft (when Holyoke Dam is at elevation 100.67 ft)
    8.26 ft (when Holyoke Dam is at elevation 99.47 ft)

Impact of Deerfield River Project Peaking Operations Under Steady State Conditions:

- The WSEL difference between maximum generation at both the Turners Falls Project and Deerfield River Project (Scenarios 1 and 2) and maximum generation only the Turners Falls Project (Scenarios 3 and 4) is as follows:

  - At Mitch's Marina — 0.21 ft (when Holyoke Dam is at elevation 100.67)

    0.24 ft (when Holyoke Dam is at elevation 99.47 ft)
  - At the Route 116 Bridge — 0.34 ft (when Holyoke Dam is at elevation 100.67)

    0.35 ft (when Holyoke Dam is at elevation 99.47 ft)
  - At the Montague Gage — 0.45 ft (when Holyoke Dam is at elevation 100.67 ft)
    0.44 ft (when Holyoke Dam is at elevation 99.47 ft)

- The WSEL difference between minimum flows from the Turners Falls Project and maximum generation at the Deerfield River Project (Scenarios 5 and 6) and minimum flows from the both projects (Scenarios 7 and 8) is as follows:
  - At Mitch's Marina — 0.07 ft (when Holyoke Dam is at elevation 100.67)

    0.12 ft (when Holyoke Dam is at elevation 99.47 ft)
  - At the Route 116 Bridge — 0.83 ft (when Holyoke Dam is at elevation 100.67)

    1.02 ft (when Holyoke Dam is at elevation 99.47 ft)
  - At the Montague Gage — 1.47 ft (when Holyoke Dam is at elevation 100.67 ft)
    1.48 ft (when Holyoke Dam is at elevation 99.47)

Impact of the WSEL at the Holyoke Dam Under Steady State Conditions:

- The WSEL difference between Turners Falls Project at maximum generation and the Deerfield River Project at maximum generation (Scenarios 1 and 2) or minimum flow (Scenarios 3 and 4) is as follows:
  - At Mitch's Marina — 0.21 ft (when Holyoke Dam is at elevation 100.67)

    0.24 ft (when Holyoke Dam is at elevation 99.47 ft)
  - At the Route 116 Bridge — 0.34 ft (when Holyoke Dam is at elevation 100.67)

    0.35 ft (when Holyoke Dam is at elevation 99.47 ft)
  - At the Montague Gage — 0.45 ft (when Holyoke Dam is at elevation 100.67 ft)
    0.44 ft (when Holyoke Dam is at elevation 99.47)

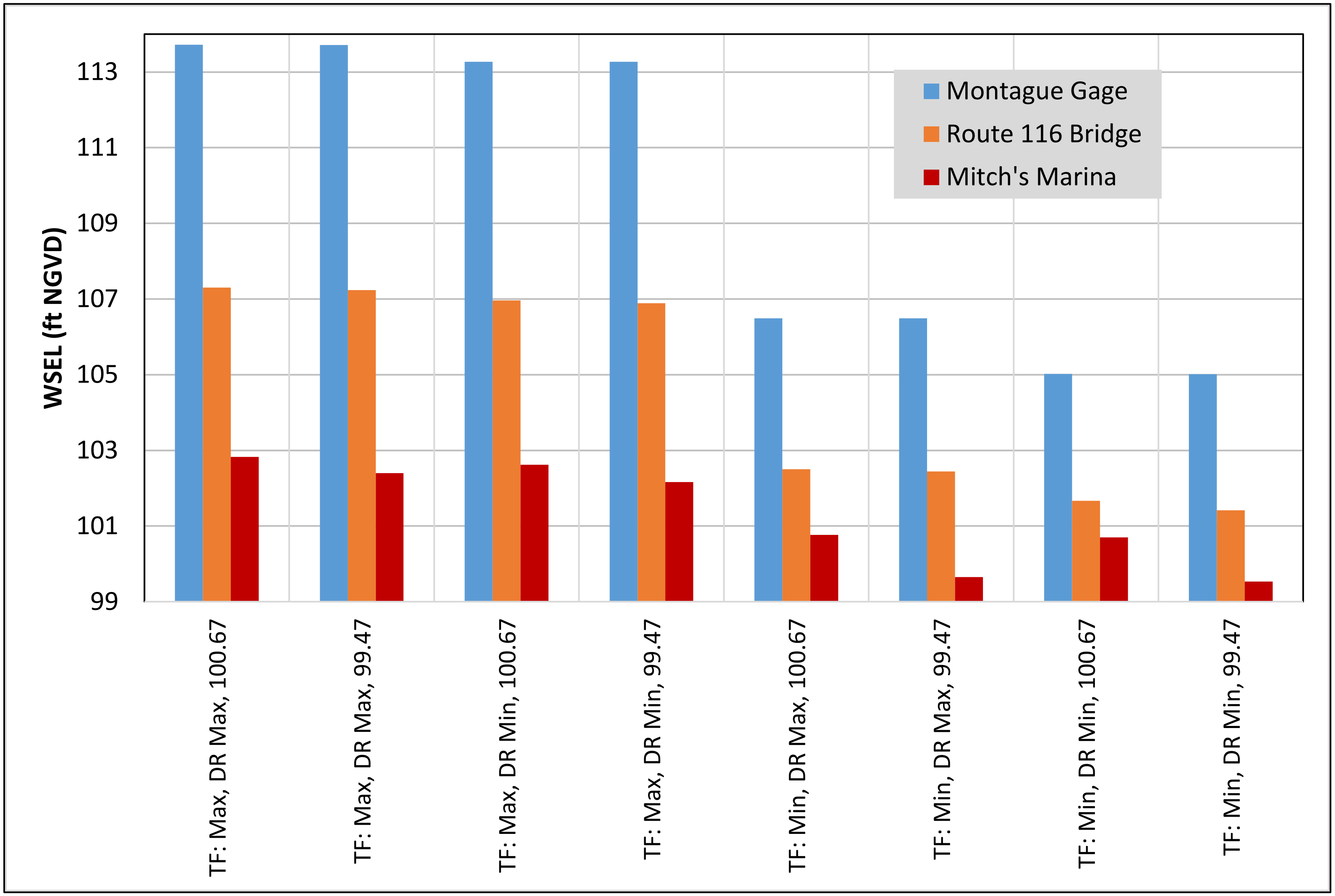
Impact of the Constriction near the Narrows about 4 miles upstream of the Holyoke Dam Under Steady State Conditions:

- At high flows as represented by maximum generation flows from the Turners Falls Project (Scenarios 1-4), the influence of the WSEL at Holyoke Dam is less than under lower flow conditions (Scenarios 5-8).

Table 5.2.1-2: Downstream of Turners Falls Project – Steady State Scenarios 1-8, Modeled WSELs

	Turners Falls Project		Deerfield River Project - Station No.2		Holyoke Impoundment Elev. At Dam		Modeled Elevations (ft)		
Scenario	Max Gen Flow	Min Flow	Max Gen Flow	Min Flow	Max Imp. Elev.	Min Imp. Elev.			
Flow (cfs)	15,938	1,433	1,450	200	100.67 ft	99.47 ft	Montague Gage	Route 116 Bridge	Mitch's Marina
1	X		X		X		113.72	107.3	102.83
2	X		X			X	113.71	107.24	102.4
3	X			X	X		113.27	106.96	102.62
4	X			X		X	113.27	106.89	102.16
5		X	X		X		106.49	102.5	100.77
6		X	X			X	106.49	102.44	99.65
7		X		X	X		105.02	101.67	100.7
8		X		X		X	105.01	101.42	99.53

Figure 5.2.1-1: Downstream of Montague- WSELs at 3 Locations under Steady-State Conditions (Scenarios 1-8)



5.2.2 Montague USGS Gage to Holyoke Dam: Unsteady-State Modeling Results

To simulate unsteady flow conditions, time varying flows were simulated to determine WSEL fluctuations at locations in the downstream reach. Sensitivity analyses were conducted to evaluate the effect of various sources on water level fluctuations from the Turners Falls Project, the Deerfield River Project, and the WSEL maintained at Holyoke Dam. Time varying discharge hydrographs from the Turners Falls Project were simulated while flows from the Deerfield River remained stable to determine the effect of the Turners Falls Project operations on water level fluctuations. Similarly, a constant discharge hydrograph from the Turners Falls Project was simulated while the Deerfield River Project discharges vary. All of these time varying hydrographs representing peaking and minimum flow conditions from the Turners Falls and the Deerfield River Projects were stimulated with a downstream boundary condition at Holyoke Dam of 100.67 and 99.47 feet NGVD. Table 5.2.2-1 lists the scenarios simulated in the unsteady HEC-RAS models.

Table 5.2.2-1: Unsteady-State Hydraulic Modeling Scenarios

Scenario	Turners Falls Project Flow (cfs)	Deerfield River Project Flow (cfs)	Duration (hours)	WSEL at the Holyoke Dam (ft)
1	*15,938	200	2	100.67
2	15,938	200	2	99.47
3	15,938	1,450	2	100.67
4	15,938	1,450	2	99.47
5	15,938	200	4	100.67
6	15,938	200	4	99.47
7	15,938	1,450	4	100.67
8	15,938	1,450	4	99.47
9	15,938	200	8	100.67
10	15,938	200	8	99.47
11	15,938	1,450	8	100.67
12	15,938	1,450	8	99.47
13	15,938	200	12	100.67
14	15,938	200	12	99.47
15	15,938	1,450	12	100.67
16	15,938	1,450	12	99.47
17	1,433	1,450	4	100.67
18	1,433	1,450	4	99.47
19	1,433	1,450	12	100.67
20	1,433	1,450	12	99.47

*The hydraulic capacity of Cabot is 13,728 cfs and Station No. 1 is 2,210 cfs. The total hydraulic capacity, 15,938 cfs was simulated in the HEC-RAS model; however, in reality Station No. 1 is not cycled- it is either on or off.

Table 5.2.2-2 provides the maximum WSEL at Mitch's Marina and at the Route 116 Bridge under the 20 unsteady scenarios. Figures 5.2.2-1 through 5.2.2-6 are graphs of the WSELs from 20 unsteady model scenarios. In the below bullets, the WSEL increases (resulting from peaking conditions) are based on the comparison to the steady-state minimum flow release condition from both projects (Scenario 7 and 8) as described in Table 5.2.1-2 Downstream of Turners Falls Project – Steady State Scenarios 1-8, Modeled WSELs on Page 5-15.

Impact of Turners Falls Project Peaking Operations Under Unsteady State Conditions:

- At Mitch's Marina, the effect on the WSEL is dependent on the duration of the peaking flow releases as seen by the difference between the minimum flow scenarios and the duration of the peaking release. For example under a 2-hour peaking release from the Turners Falls Project and minimum flow from the Deerfield River Project (Scenarios 1 and 2) the WSEL at Mitch's Marina rises only 0.27 and 0.40 ft (depending on the Holyoke Dam WSEL). However under similar conditions and a 12-hour peaking release (Scenarios 13 and 14), the WSEL rises by 1.70 and 2.36 ft (depending on the Holyoke Dam WSEL).

- Similar to the above, the arrival of the peak flow from the upstream projects is a function of both the flow rate and the duration of the release. For example, at Mitch's Marina, the peak flow from a 2-hour release occurs in about 6 hours (Scenarios 1-4) but for a 12 hour release, the peak flow and WSEL occurs after about 13 hours. The difference in the arrival time is a function of routing[22] effects through this reach and the differences in the arrival of the peak flow is due to the shorter period pulses being too brief to allow a stabilized (or steady state) maximum WSEL at the further downstream locations.

Impact of Deerfield River Project Peaking Operations Under Unsteady State Conditions:

- At Mitch's Marina, the effect on the WSEL is dependent on the length of the peaking flow releases as seen by the difference between the minimum flow scenarios and the duration of the peaking release. Under a 4-hour peaking release (Scenarios 17 and 18) from the Deerfield River Project (minimum flow from the Turners Falls Project) the WSEL rises only 0.04 and 0.07 ft. Under similar conditions and a 12-hour peaking release (Scenarios 19 and 20), the WSELs rises only slightly more, by 0.07 and 0.14. In both cases, the slightly higher increases are under the lower WSEL condition at the Holyoke Dam.

- At Mitch's Marina, a similar relationship is seen when peaking releases from the Deerfield River Project are added to the peaking releases from the Turners Falls Project. Under a 4-hour peaking release (Scenarios 7 and 8) from both projects, the WSEL rises 0.64 and 1.01 ft. This is in comparison to 0.64 and 0.91 feet when the Deerfield River Project is releasing minimum flows (Scenarios 5 and 6). Under similar conditions and a 12-hour peaking release (Scenarios 19 and 20), the WSELs rises only slightly more, by 0.07 and 0.14. In these cases, the slightly higher increases are under the lower WSEL condition at the Holyoke Dam.

Impact of the WSEL at the Holyoke Dam Under Unsteady State Conditions:

- Similar to the steady state modeling, the effects of the WSEL at Holyoke Dam are larger at low flows, including a maximum of 1.04 ft at Mitch's Marina under minimum flow conditions. Under Scenarios 15 and 16, representing the combination of the highest and longest flow durations from the upstream projects, the difference drops to 0.48 ft at Mitch's Marina.

[22] Routing includes changes in the shape of a hydrograph it moves through a river reach. In this case, the flow pulse from the upstream projects is lowered and extended as it moves downstream.

- At the Route 116 Bridge, the difference under minimum flow is 0.09 ft and under Scenarios 15 and 16 it drops to 0.08 ft. Both of these relationships are related to the impacts of the constriction at “The Narrows” about 3-miles upstream of the Holyoke Dam.

Table 5.2.2-2: Downstream of Turners Falls Project – Unsteady State Scenarios 1-20, Modeled WSELs

Scenario	Turners Falls Project Flow (cfs)	Deerfield River Project Flow (cfs)	Duration (hours)	WSEL at the Holyoke Dam (ft)	Maximum WSEL at Mitch's Marina (ft)	Maximum WSEL at the Route 116 Bridge (ft)
1	15,938	200	2	100.67	100.97	104.28
2	15,938	200	2	99.47	99.93	104.19
3	15,938	1,450	2	100.67	101.01	104.46
4	15,938	1,450	2	99.47	99.98	104.39
5	15,938	200	4	100.67	101.34	105.55
6	15,938	200	4	99.47	100.44	105.50
7	15,938	1,450	4	100.67	101.34	105.80
8	15,938	1,450	4	99.47	100.54	105.75
9	15,938	200	8	100.67	102.00	106.43
10	15,938	200	8	99.47	101.35	106.36
11	15,938	1,450	8	100.67	102.14	106.71
12	15,938	1,450	8	99.47	101.53	106.63
13	15,938	200	12	100.67	102.40	106.75
14	15,938	200	12	99.47	101.89	106.67
15	15,938	1,450	12	100.67	102.58	107.05
16	15,938	1,450	12	99.47	102.10	106.97
17	1,433	1,450	4	100.67	100.74	102.52
18	1,433	1,450	4	99.47	99.60	102.11
19	1,433	1,450	12	100.67	100.77	102.61
20	1,433	1,450	12	99.47	99.67	102.25

Figure 5.2.2-1: Downstream of the Turners Falls Project - WSELs *at Mitch's Marina* under Unsteady-State Scenarios 1 - 8

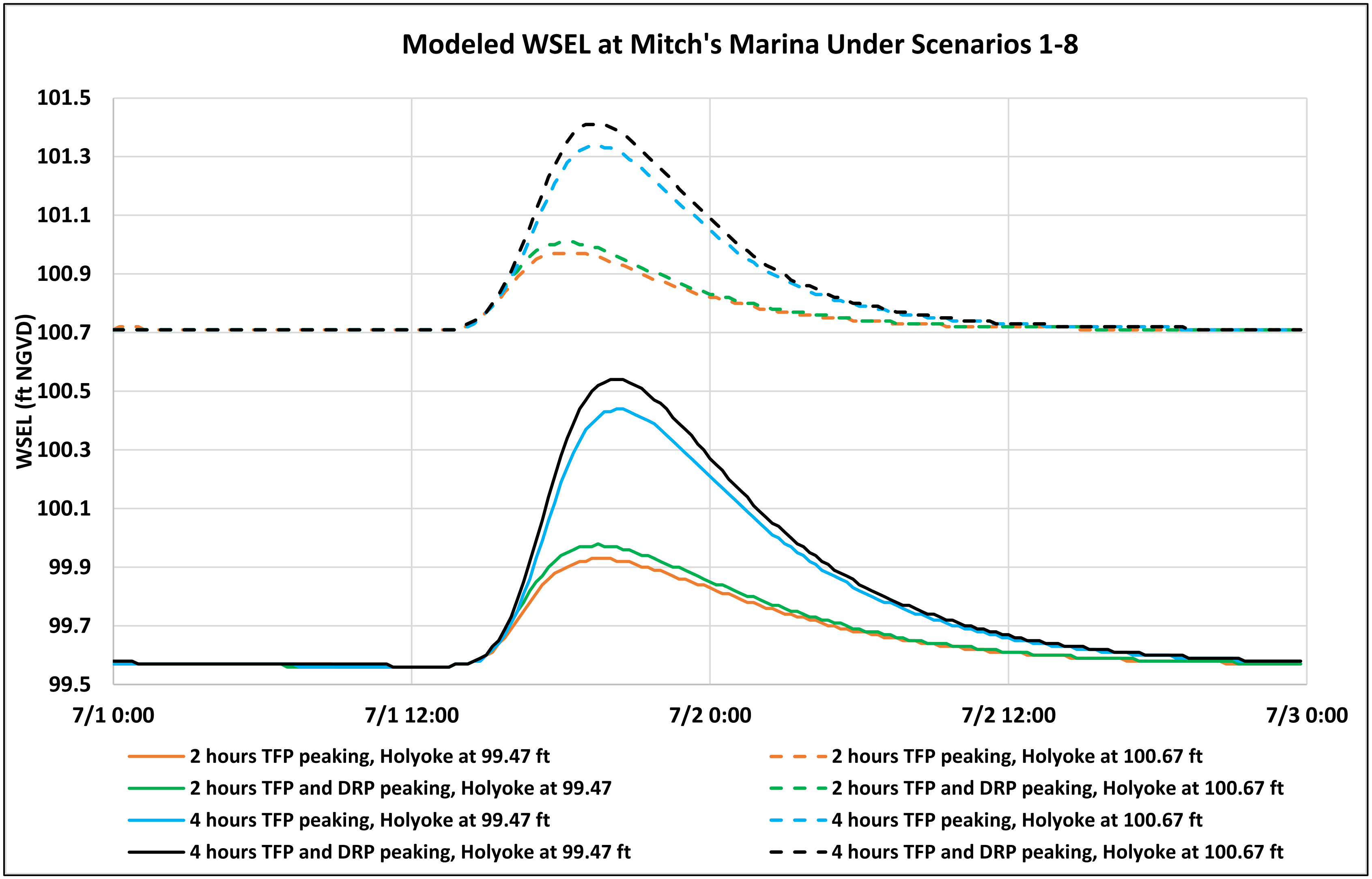


Figure 5.2.2-2: Downstream of the Turners Falls Project - WSELs at *Mitch's Marina* under Unsteady-State Scenarios 9 – 16

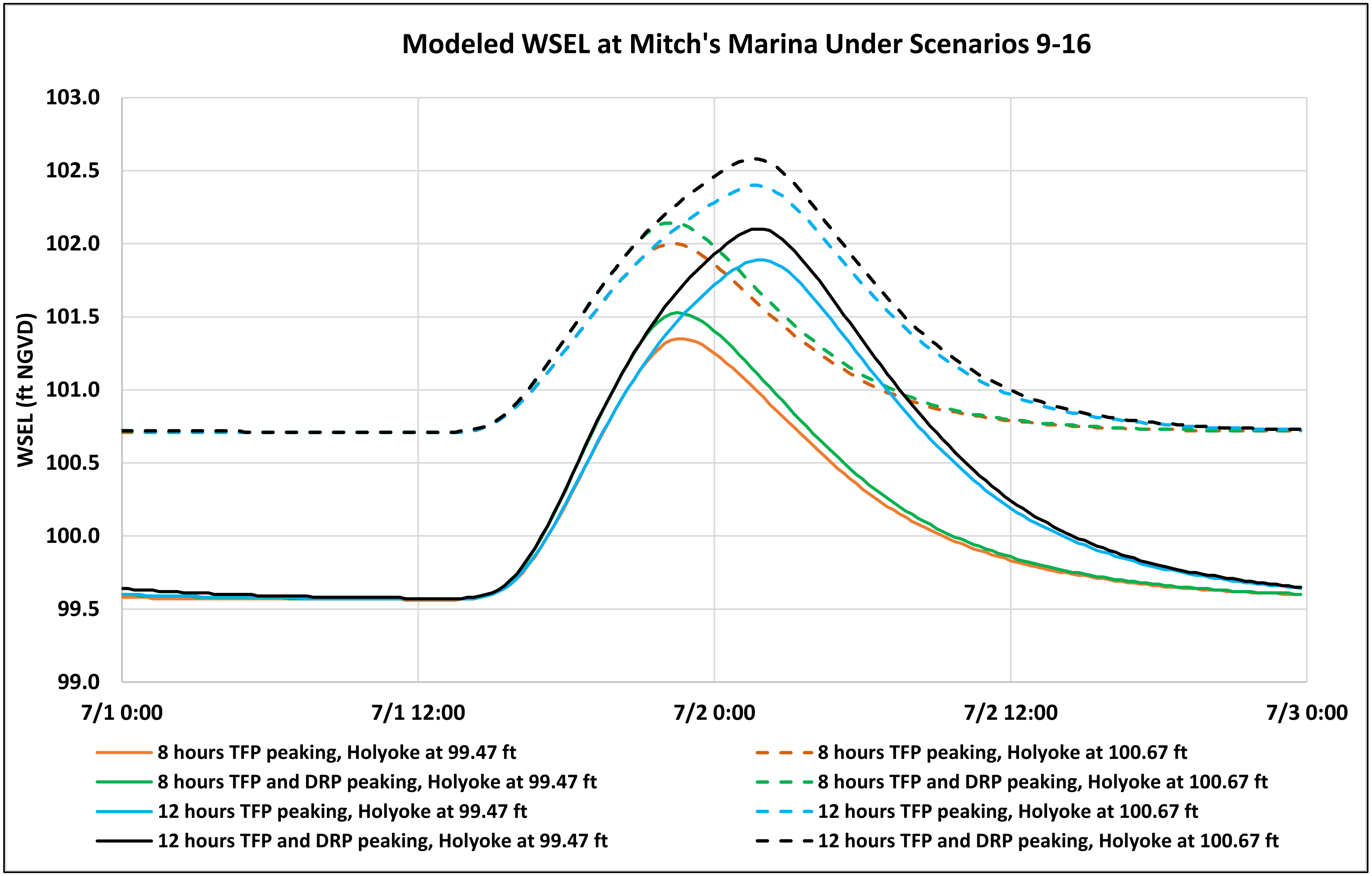


Figure 5.2.2-3: Downstream of the Turners Falls Project - WSELs at *Mitch's Marina* under Unsteady-State Scenarios 17 – 20

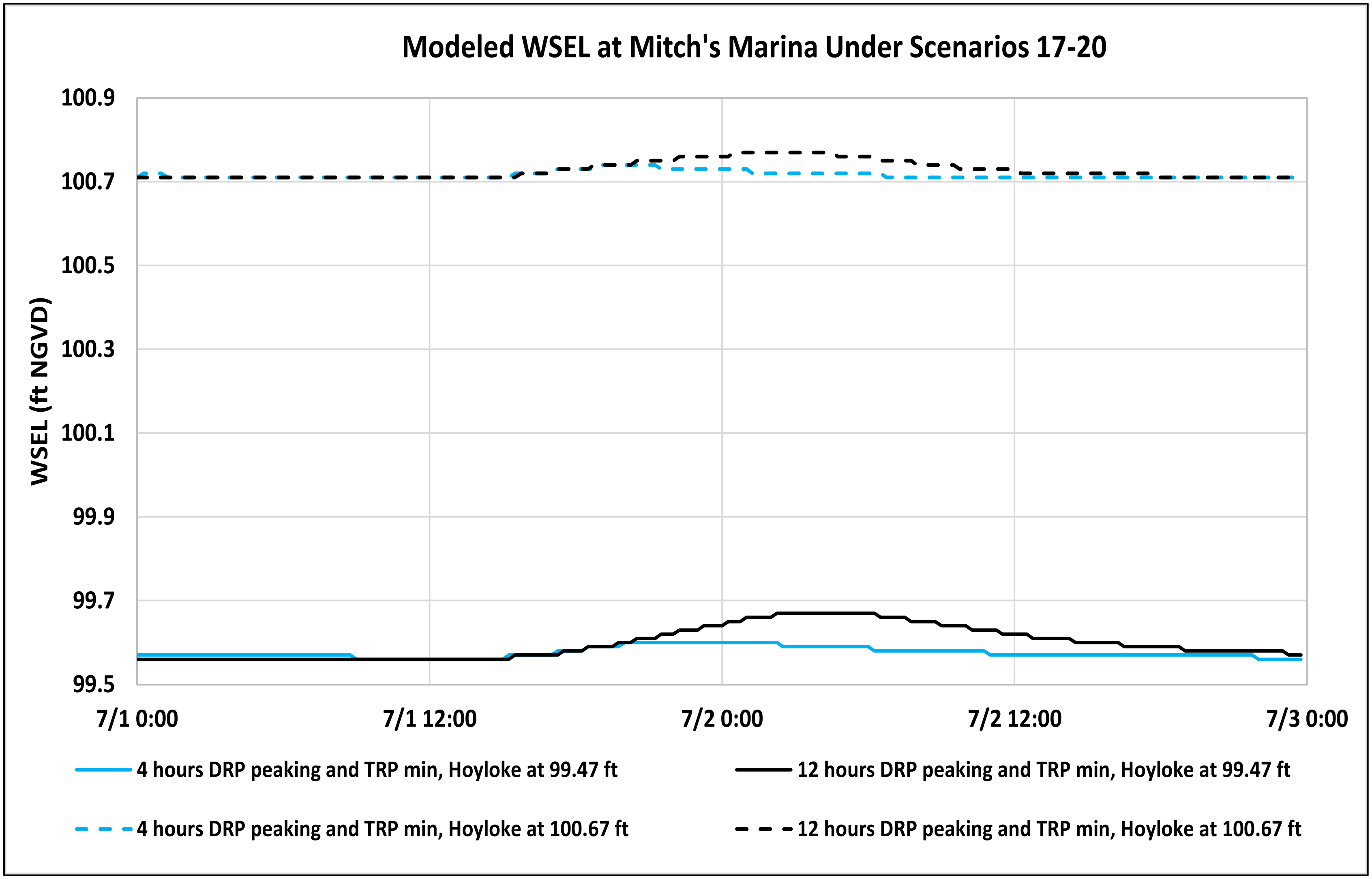


Figure 5.2.2-4: Downstream of the Turners Falls Project - WSELs at the *Route 116 Bridge* under Unsteady-State Scenarios 1 - 8

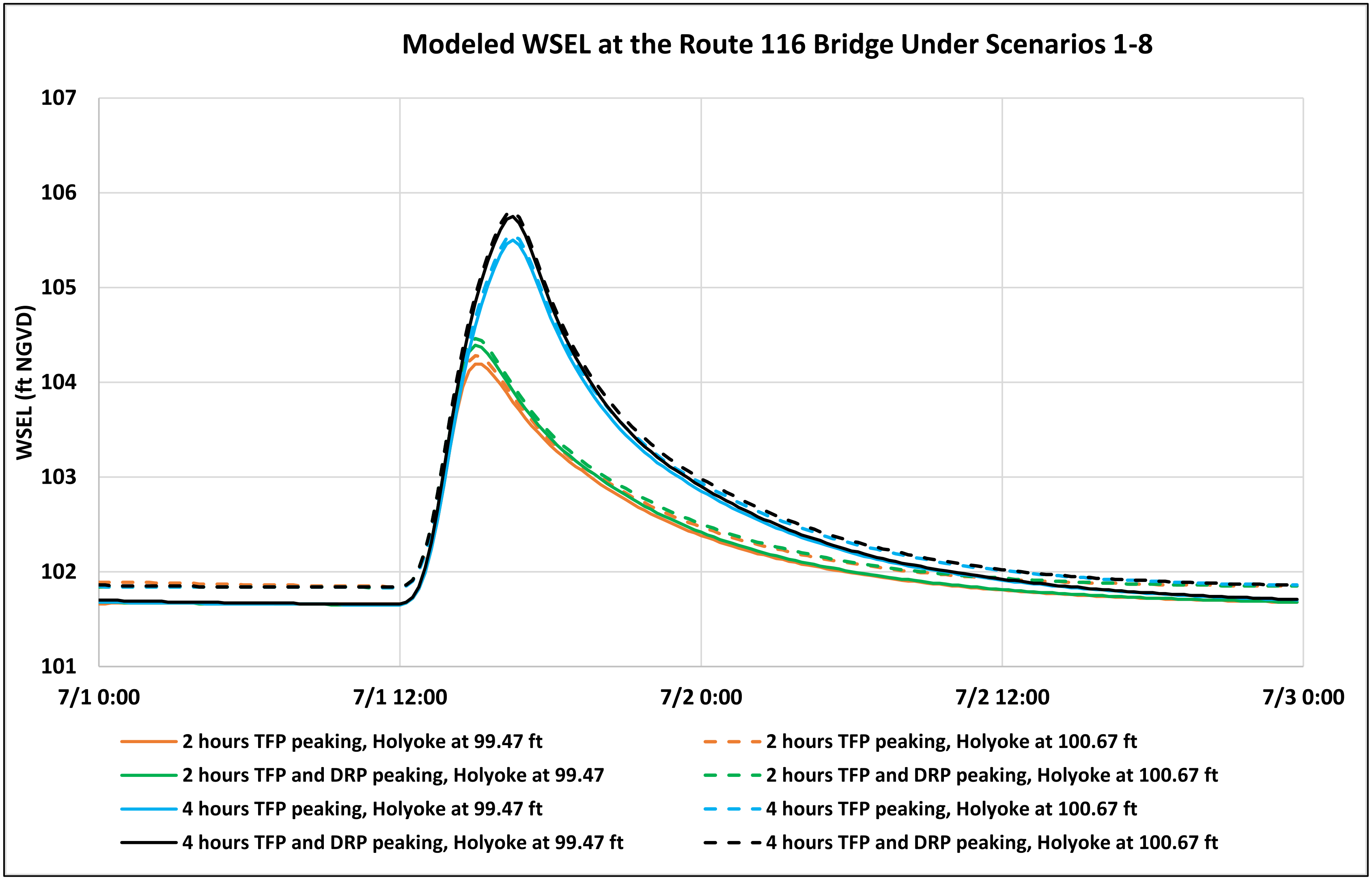


Figure 5.2.2-5: Downstream of the Turners Falls Project - WSELs at the *Route 116 Bridge* under Unsteady-State Scenarios 9 - 16

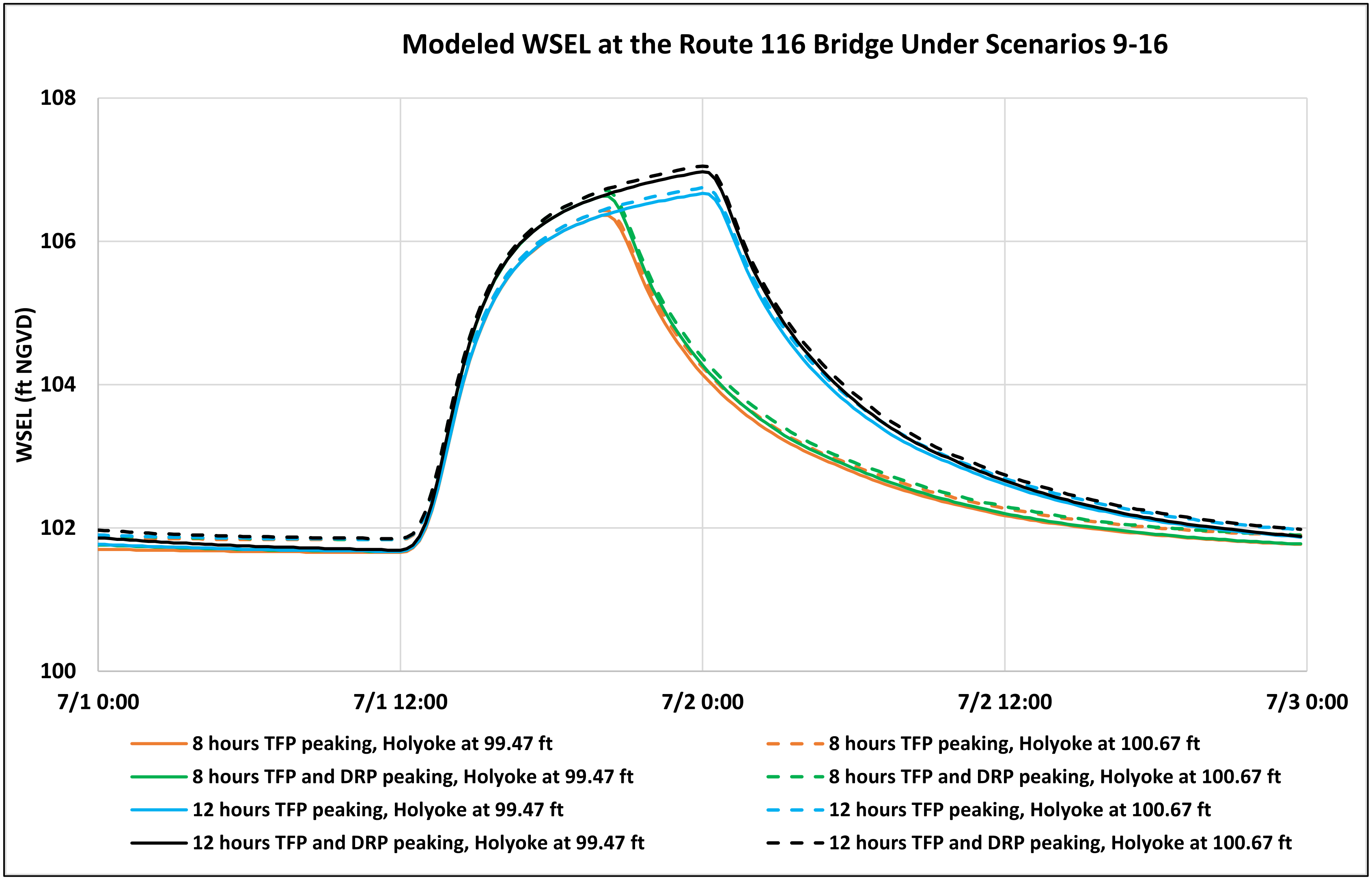
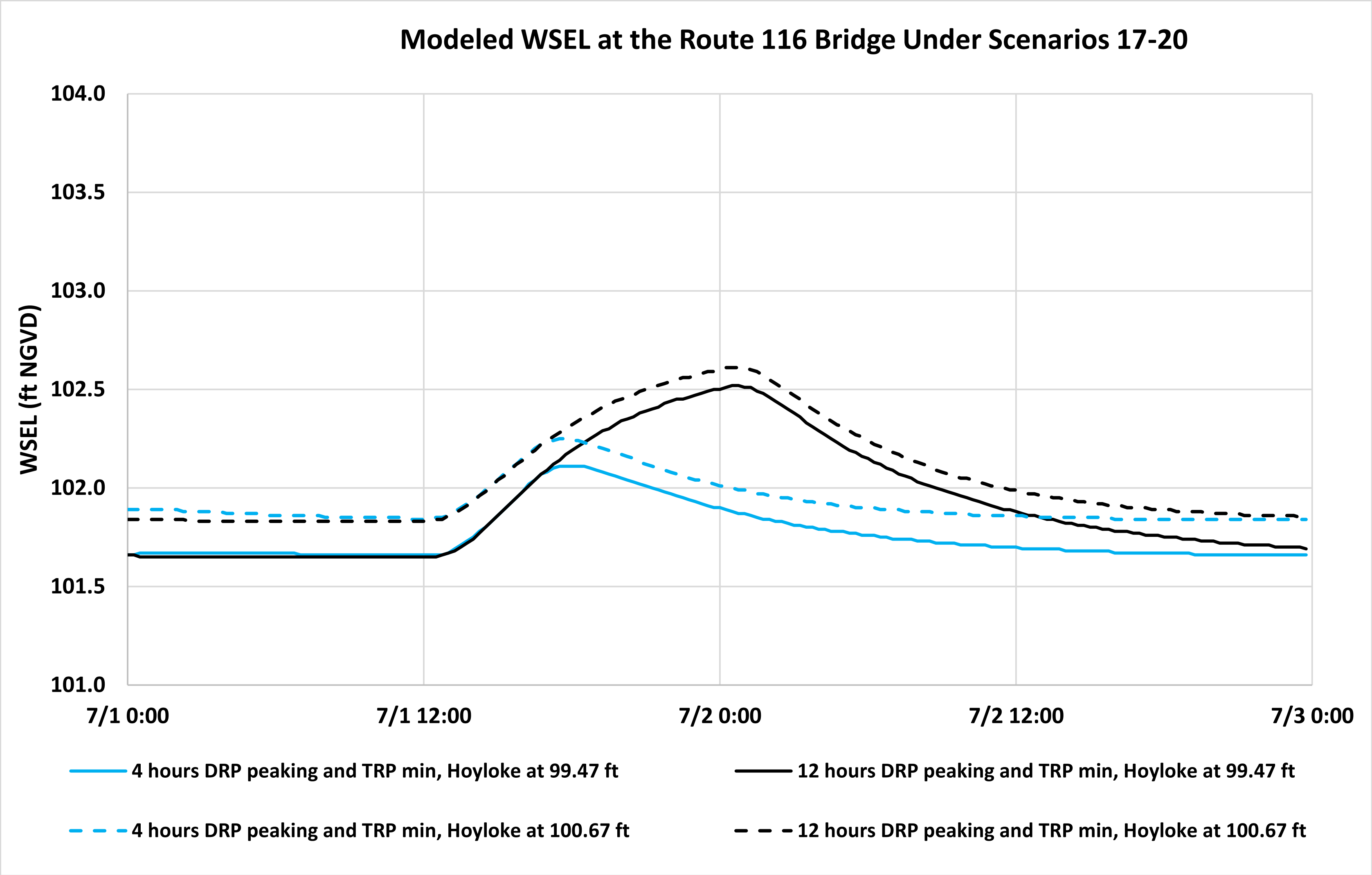


Figure 5.2.2-6: Downstream of the Turners Falls Project - WSELs at the Route *116 Bridge* under Unsteady-State Scenarios 17-20



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USGS StreamStats program (http://streamstatsags.cr.usgs.gov/ma_ss/)

United States Geological Survey Gages:
Connecticut River at Montague City, MA (Gage No. 01170500)
http://waterdata.usgs.gov/usa/nwis/uv?01170500
Deerfield River near West Deerfield, MA (Gage No. 01170000)
http://waterdata.usgs.gov/usa/nwis/uv?site_no=01170000
Ashuelot River at Hinsdale, NH (Gage No. 01161000)
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Millers River at Erving, MA (Gage No. 01166500)
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Fort River near Amherst, MA (Gage No. 01171300)
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Connecticut River at I-391 at Holyoke, MA (Gage No. 01172010)
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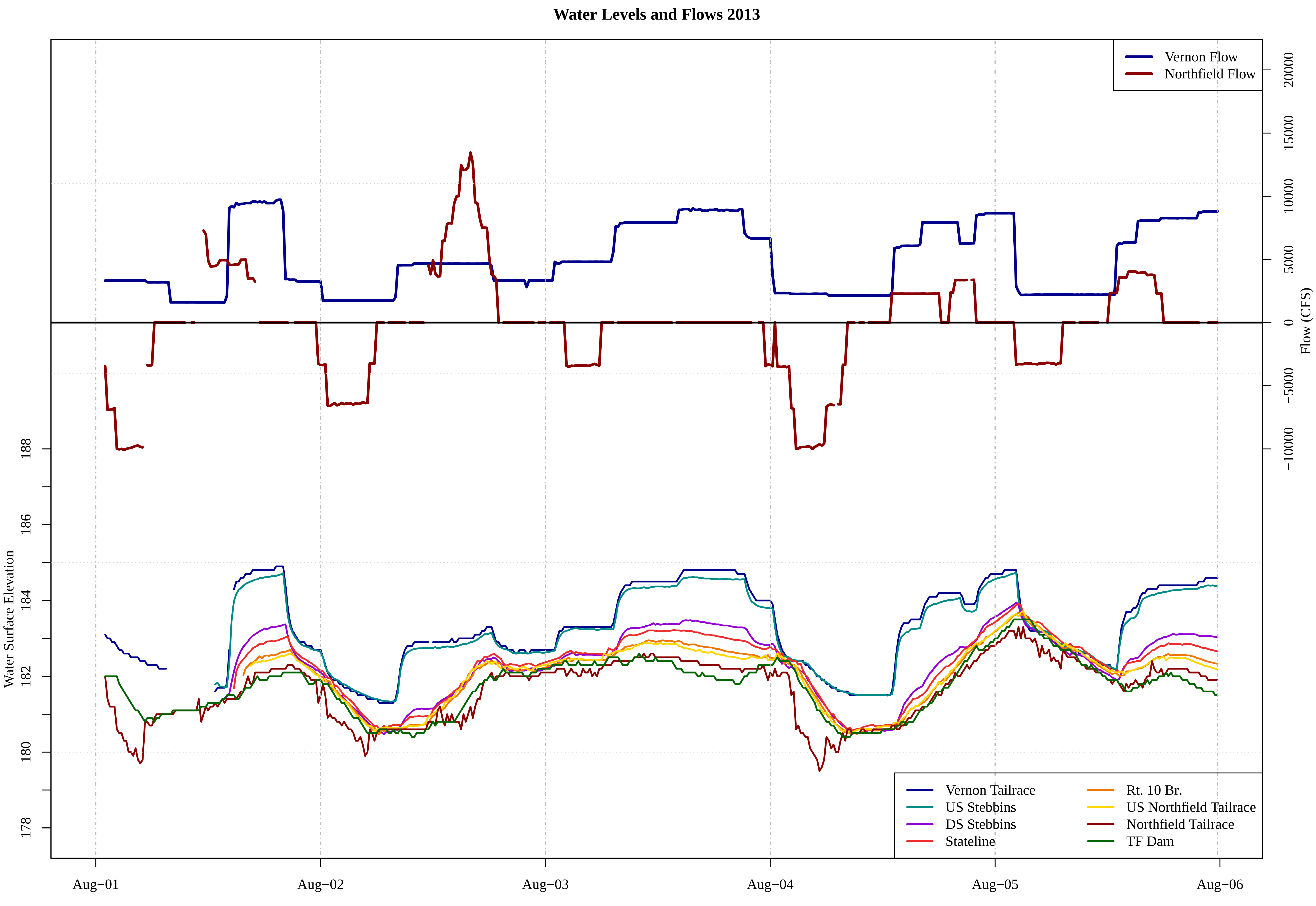
APPENDIX A- IMPOUNDMENT REACH: 2013 DATA



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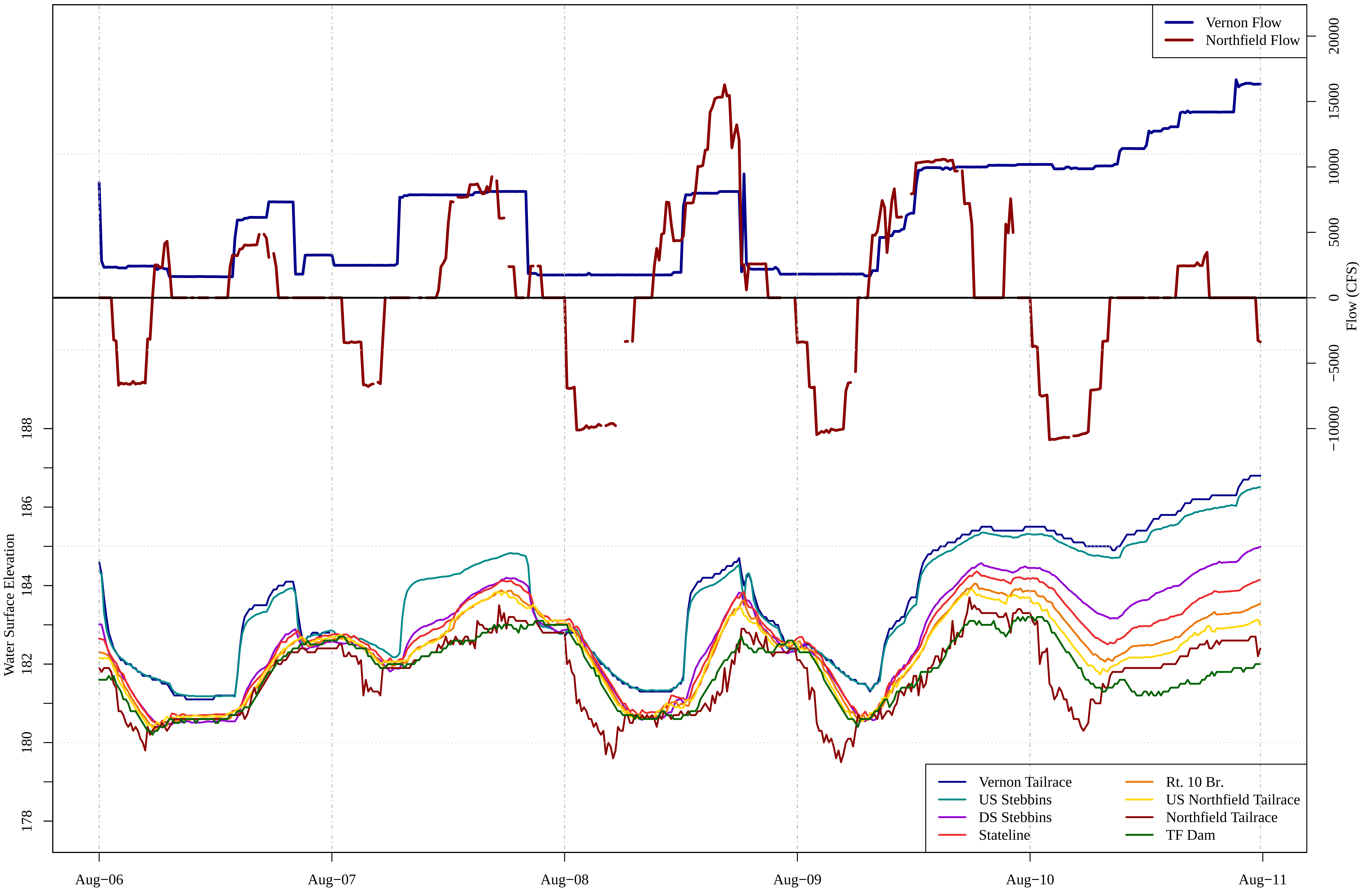
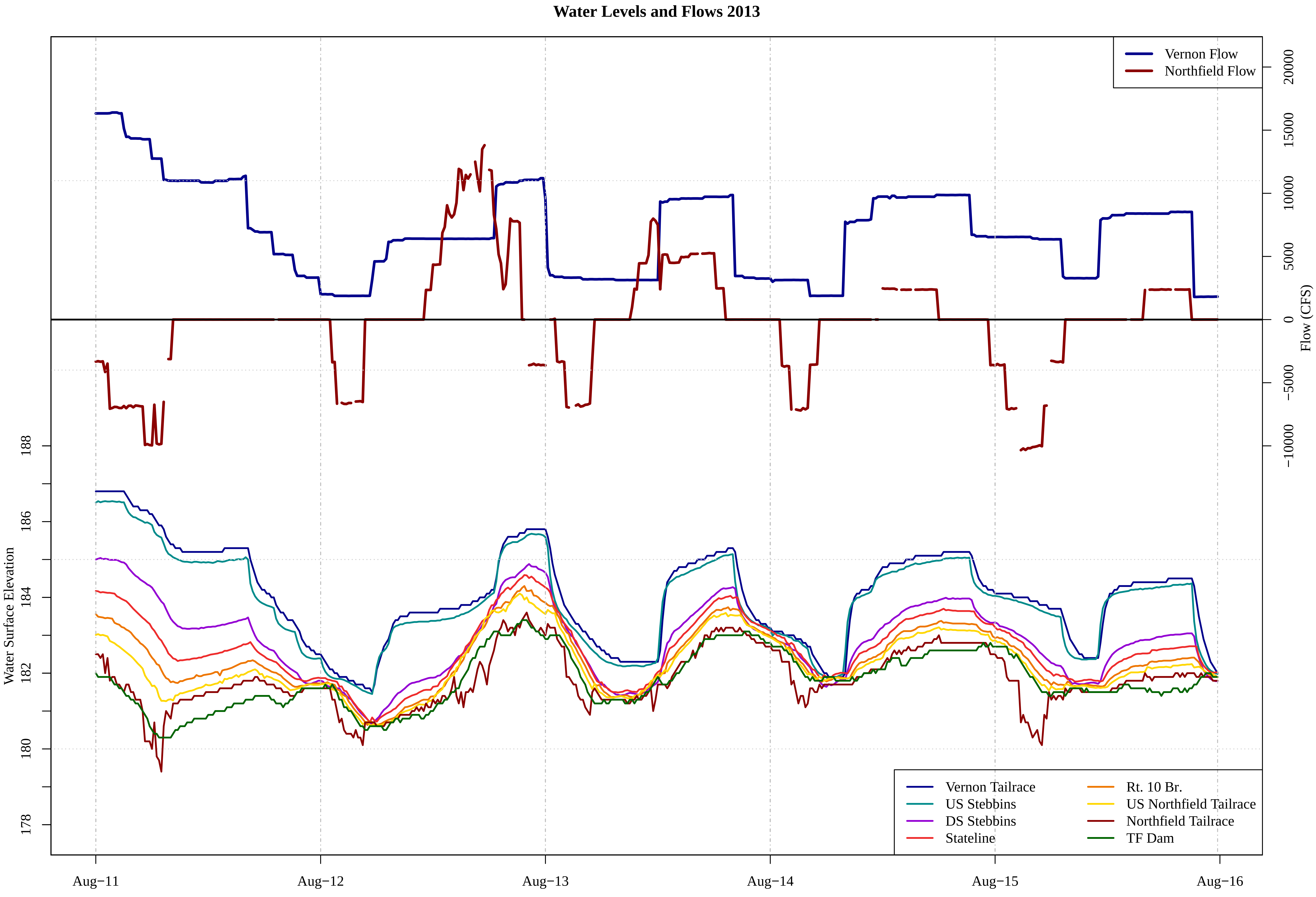
Water Levels and Flows 2013

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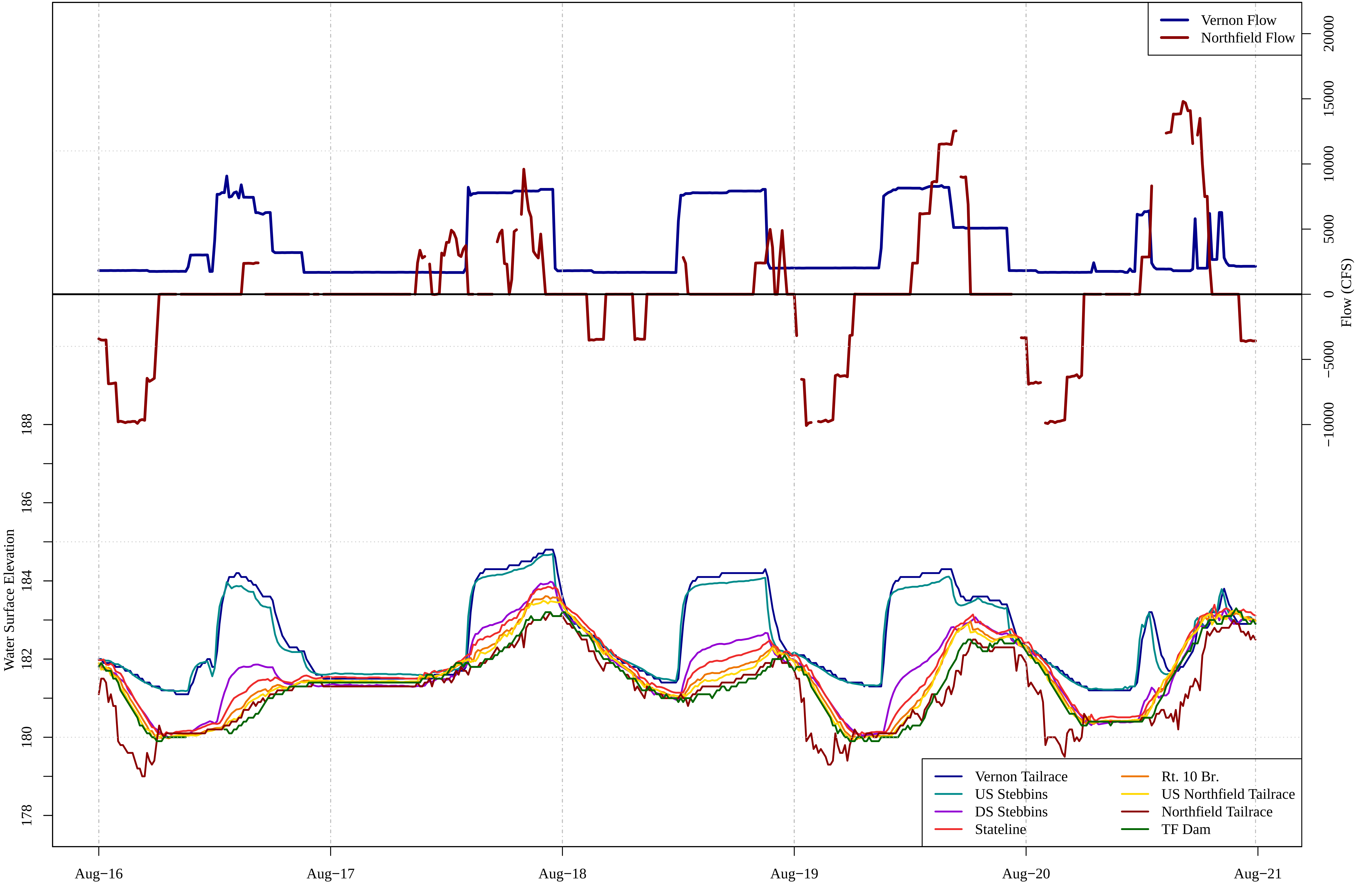

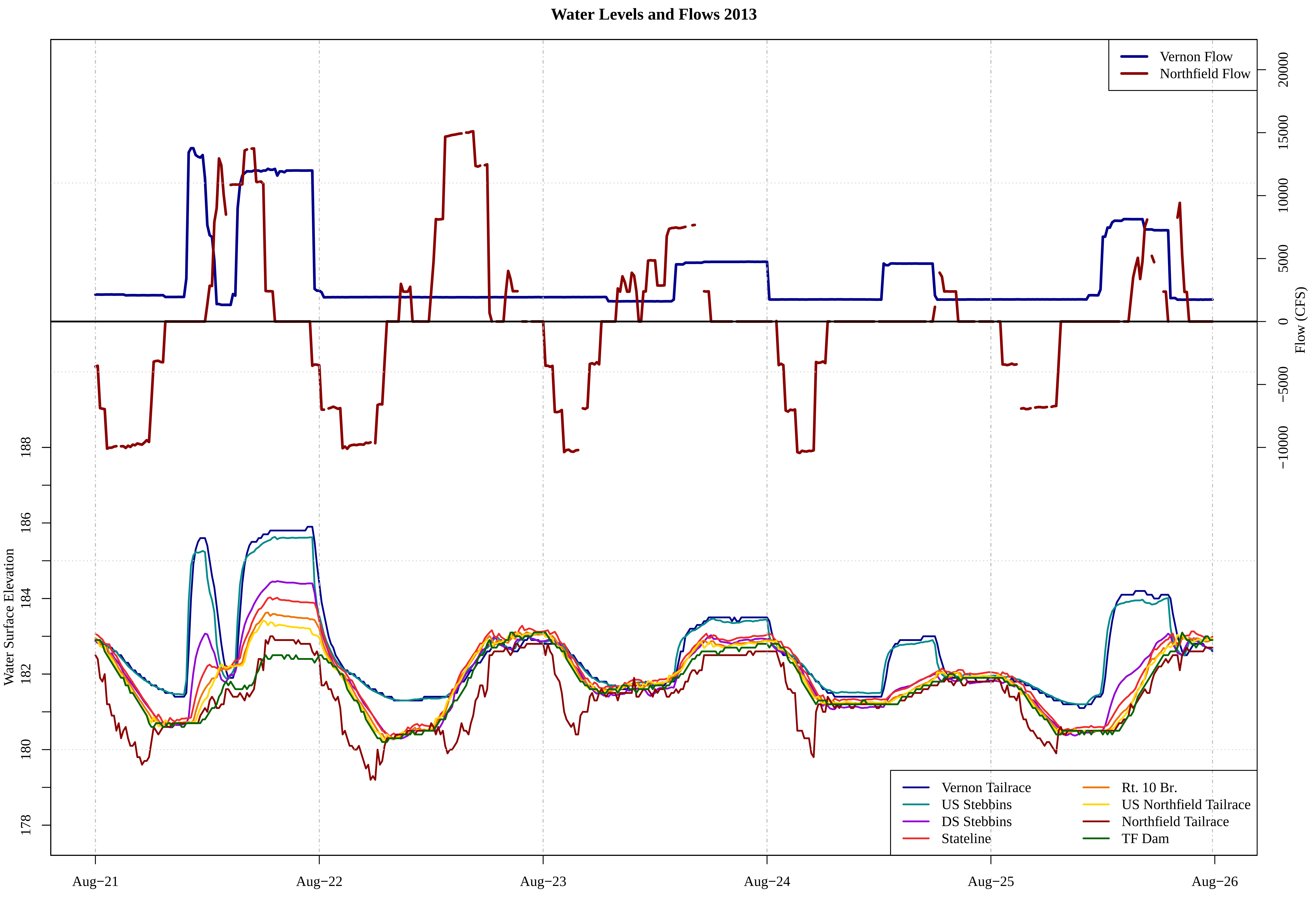

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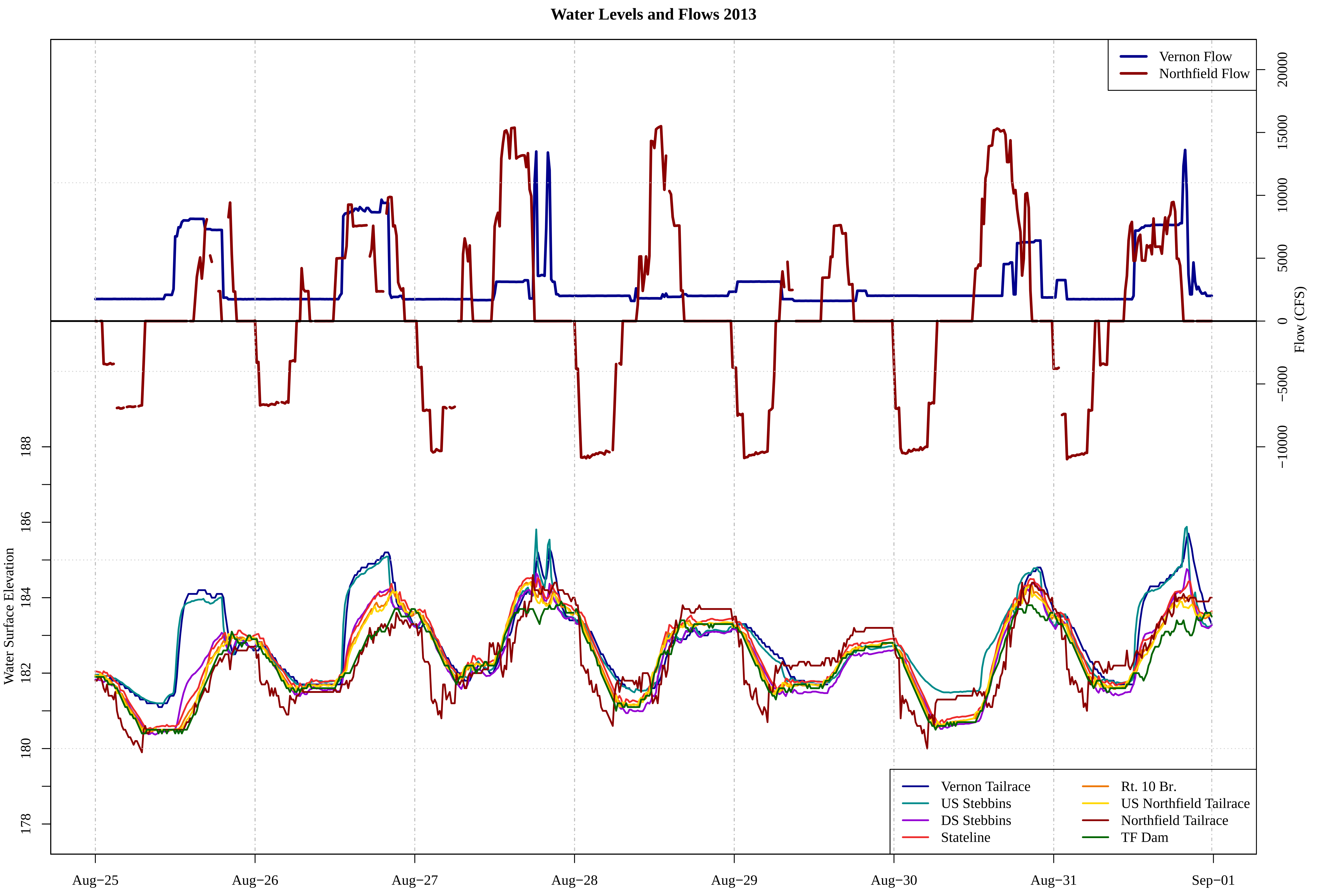

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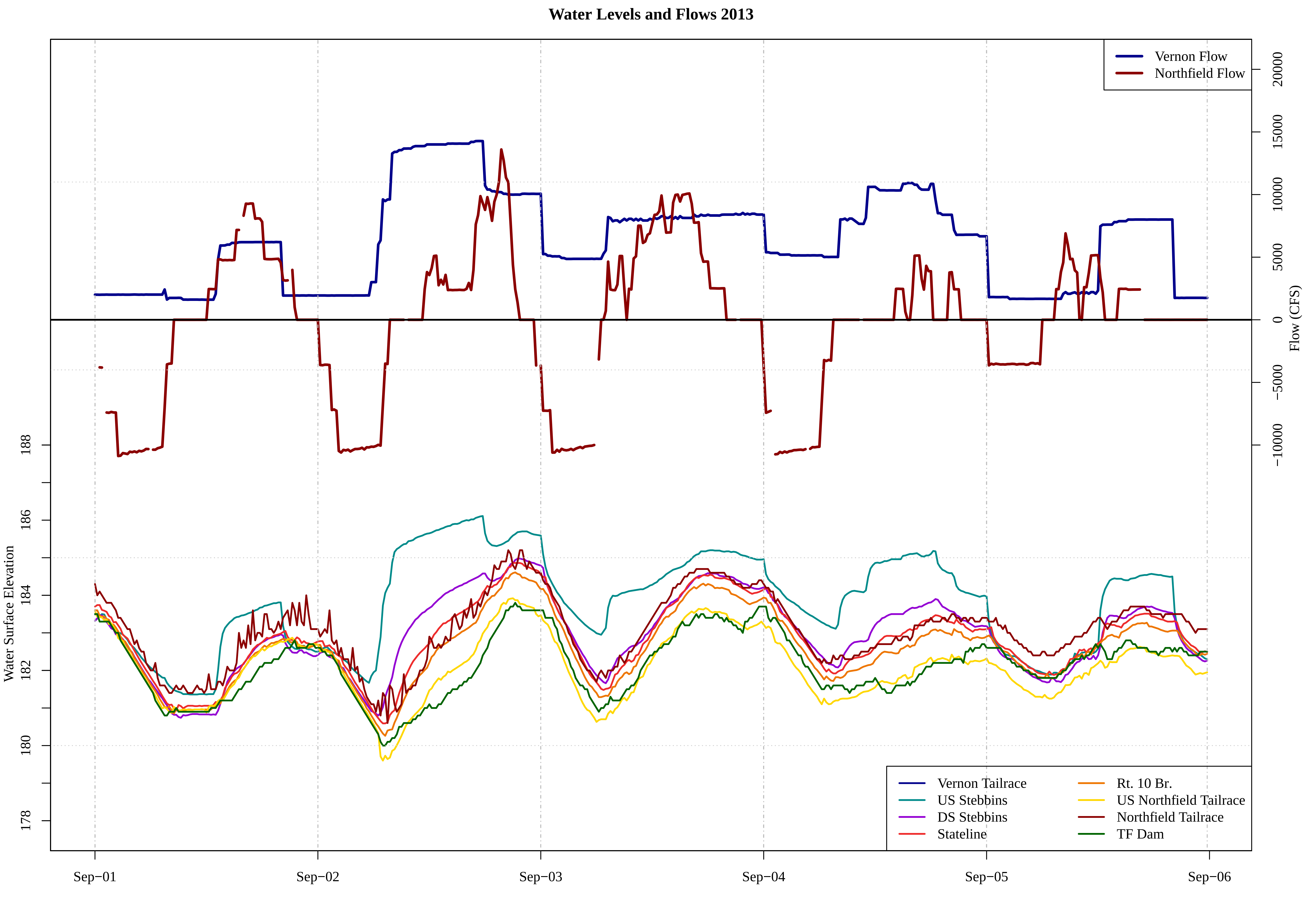
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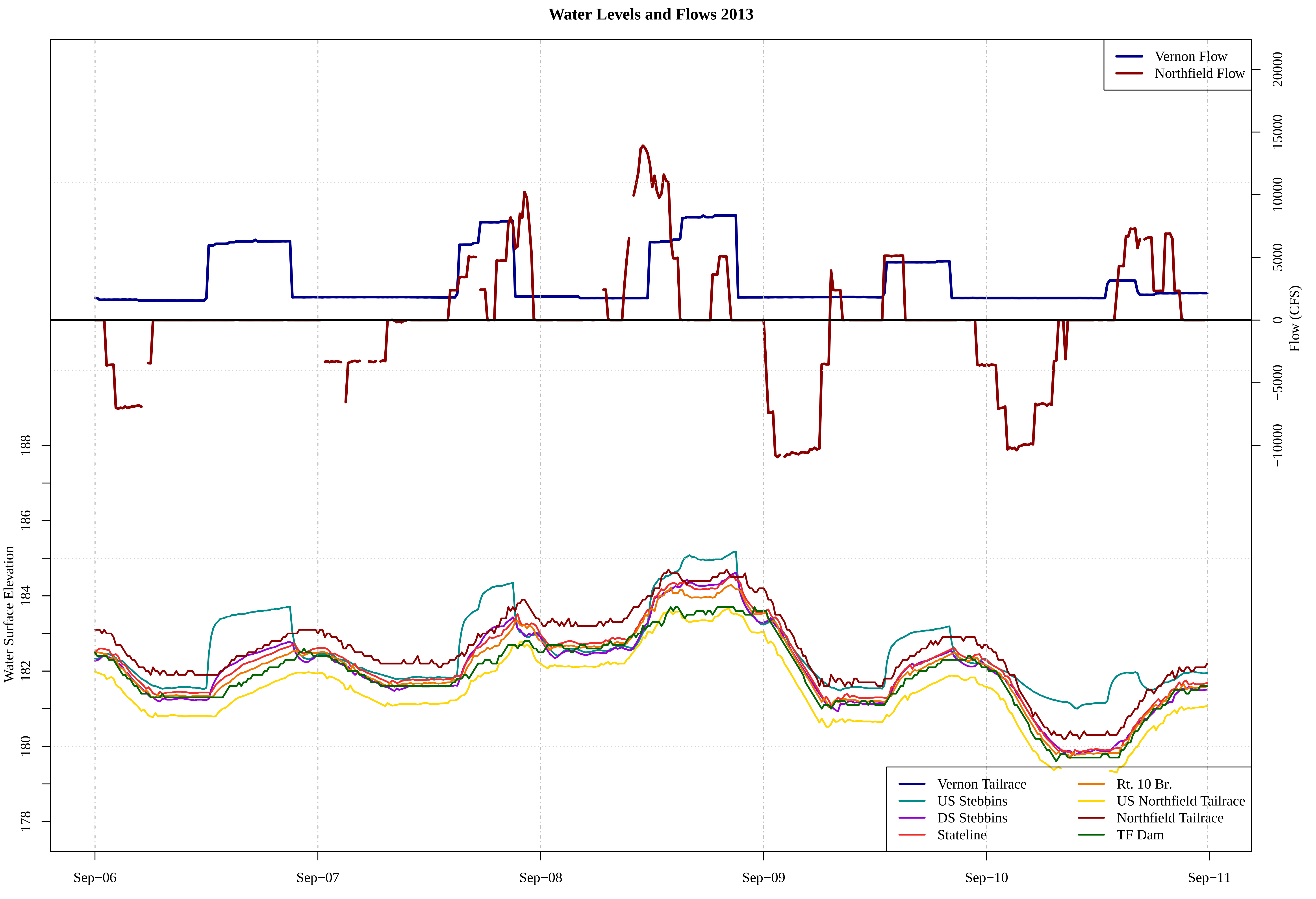

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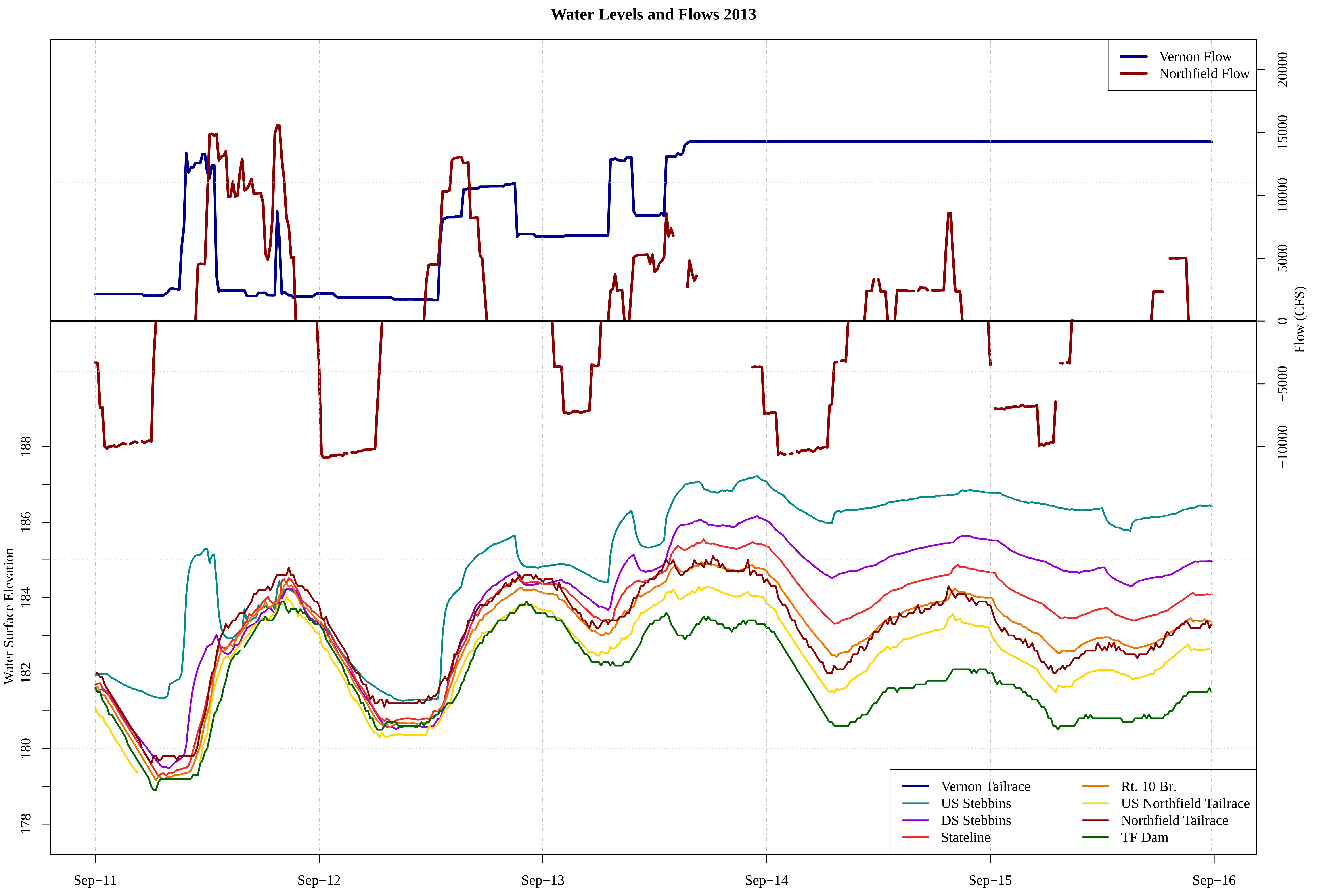

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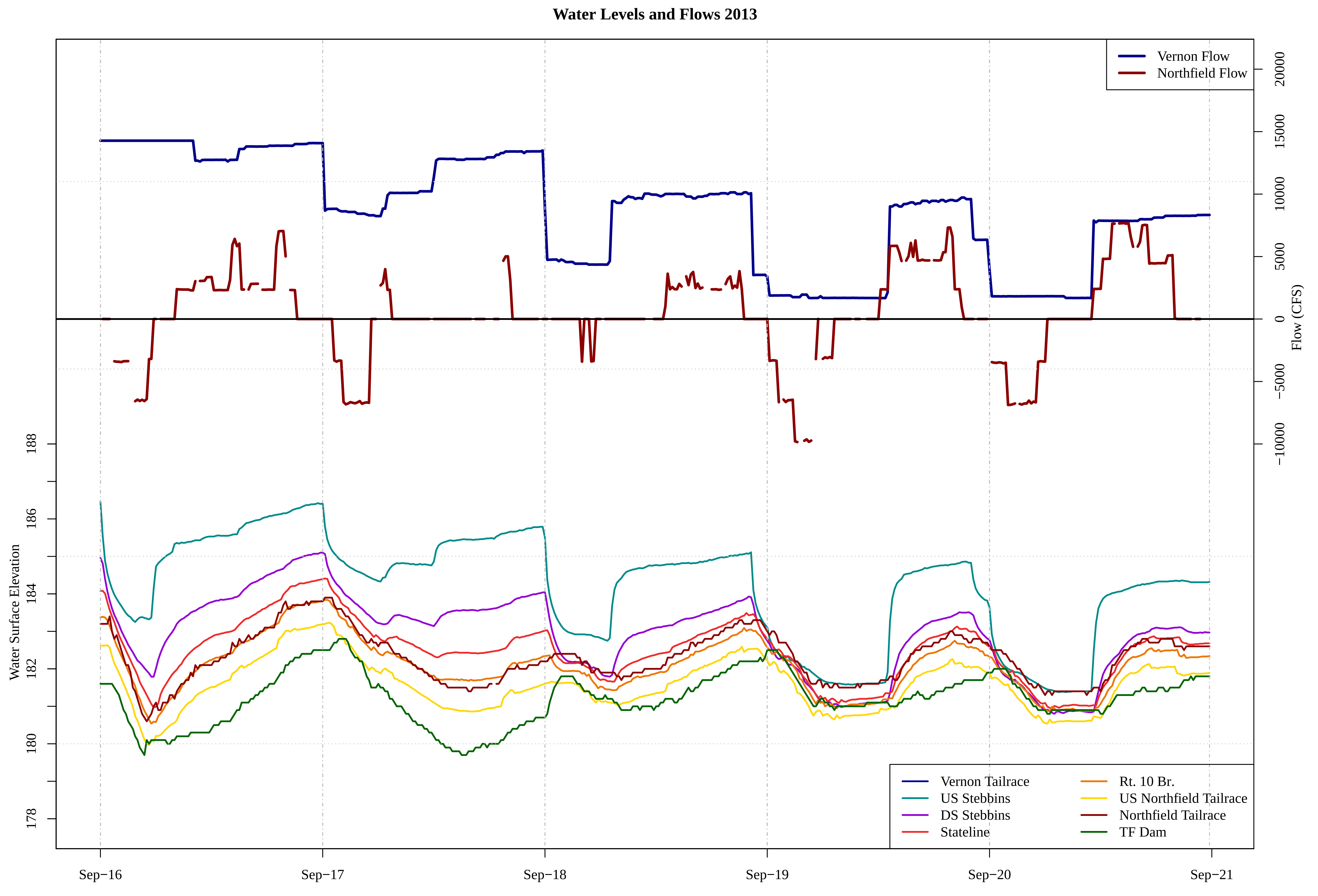
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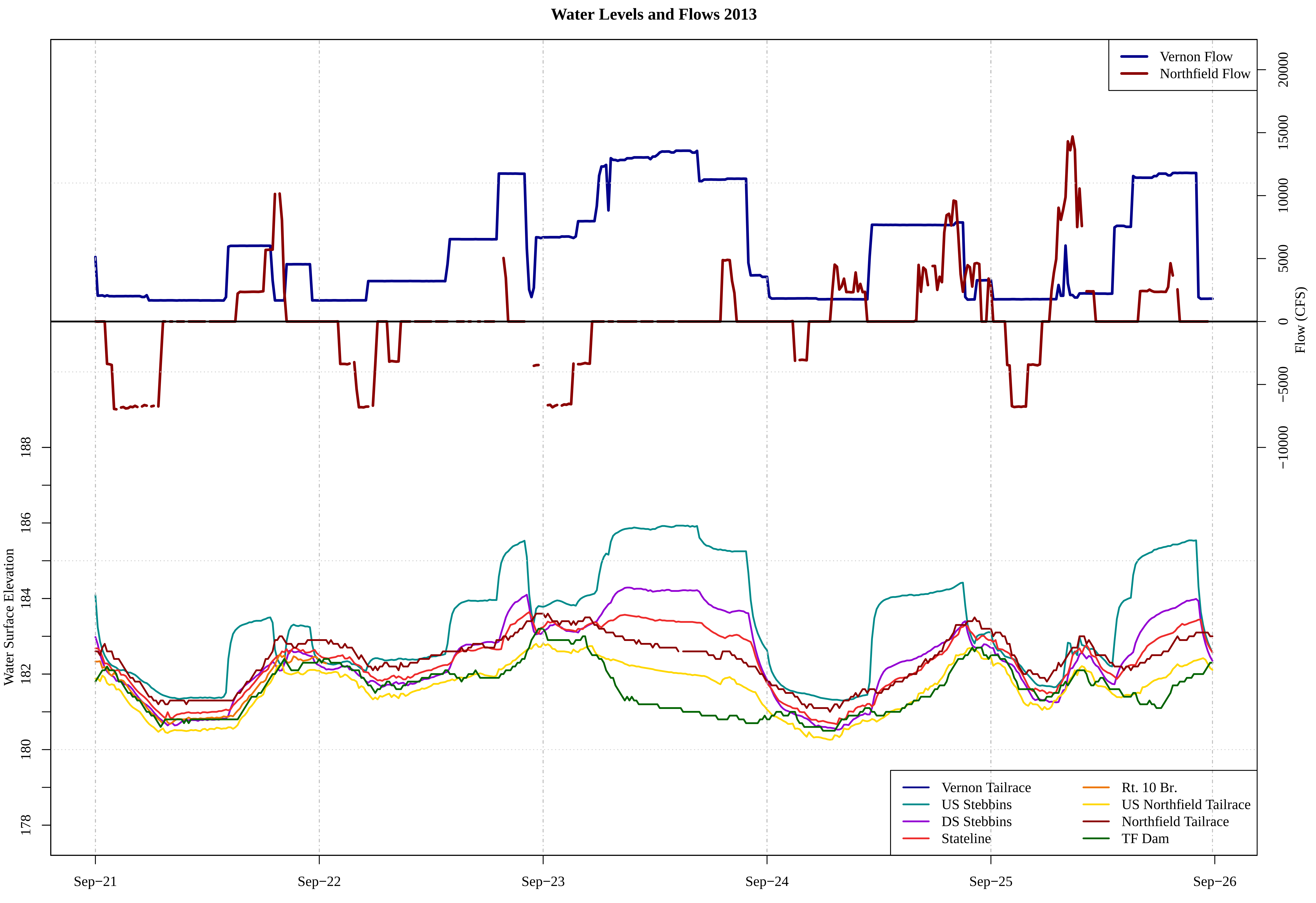

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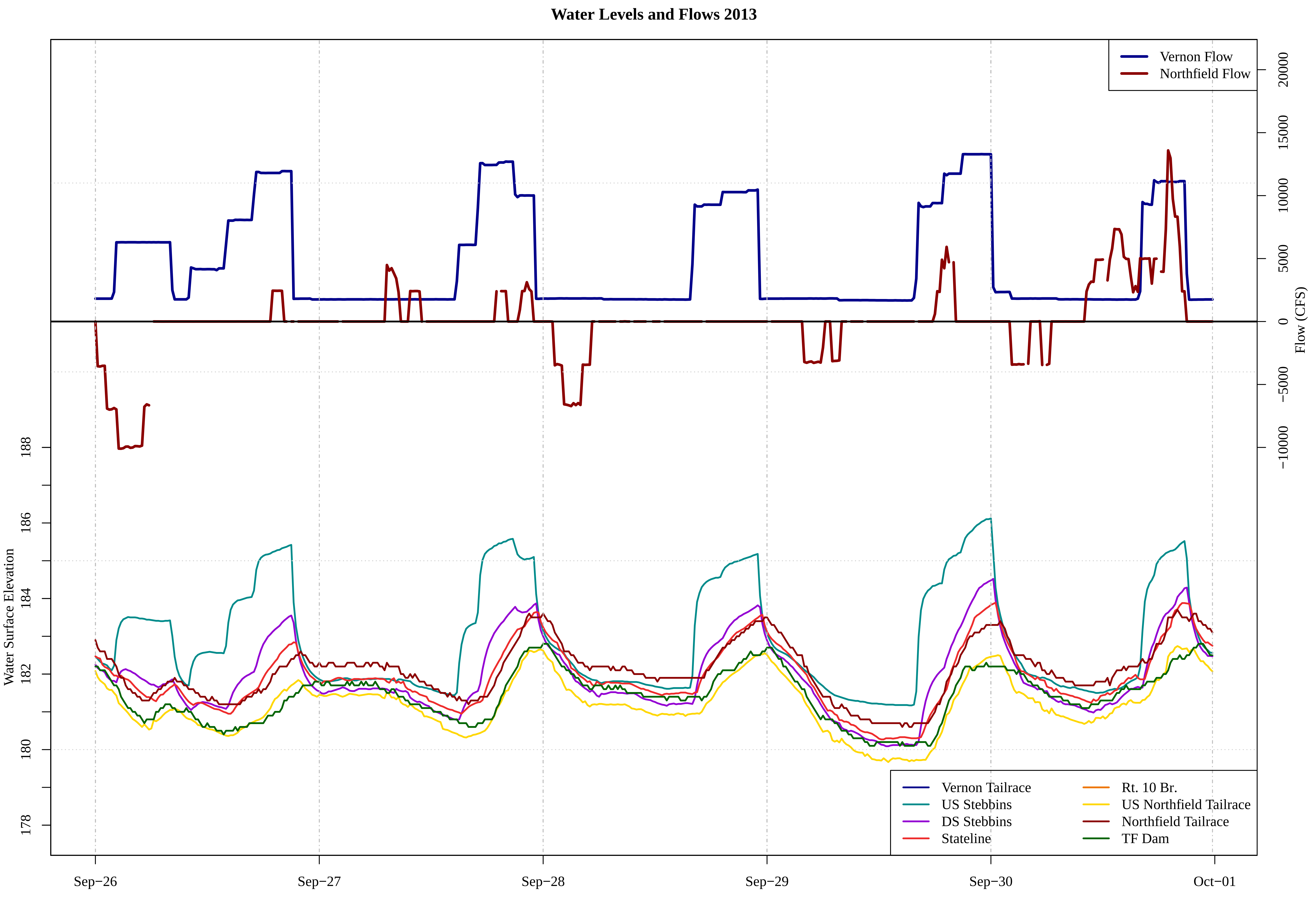

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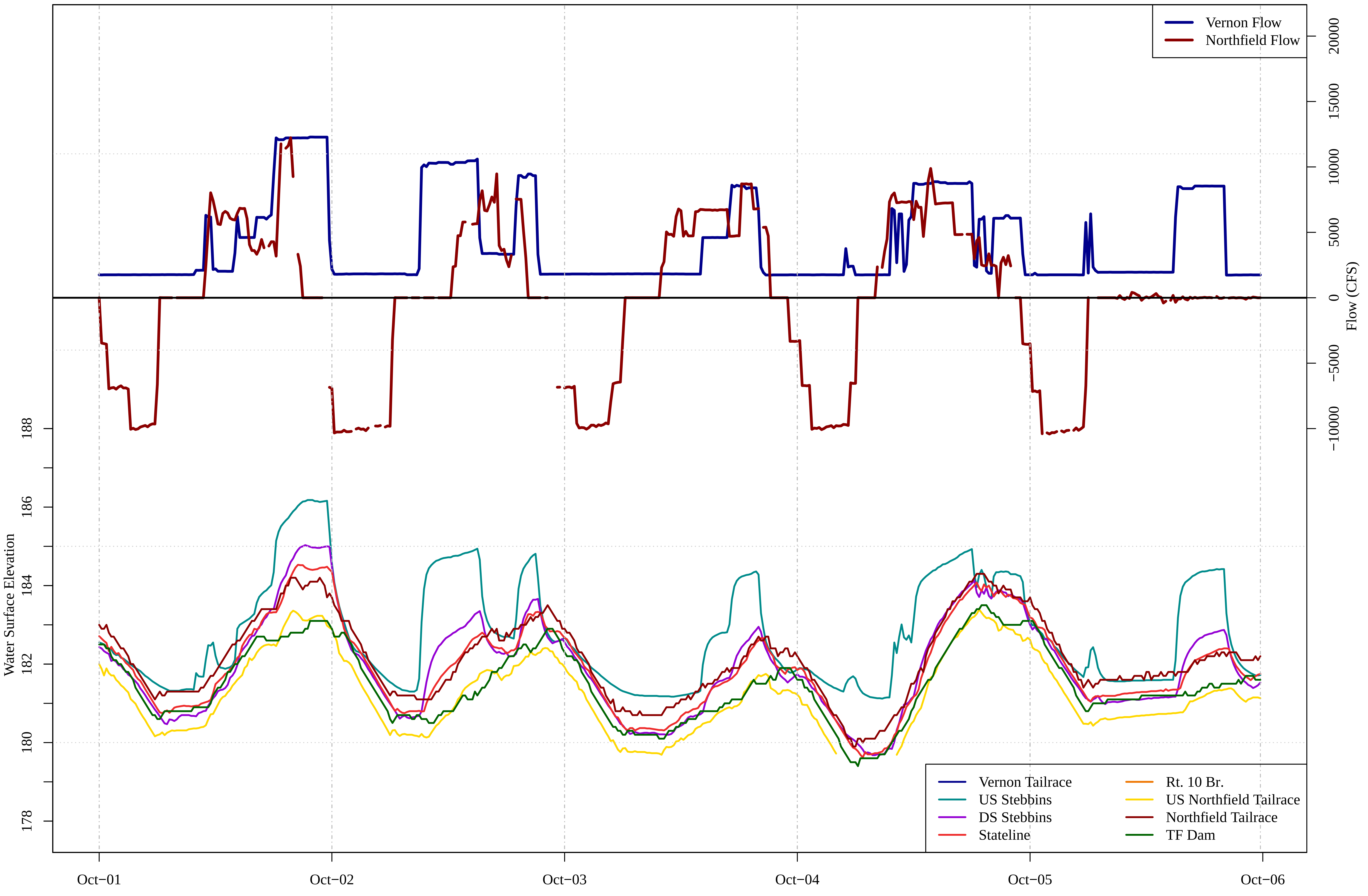

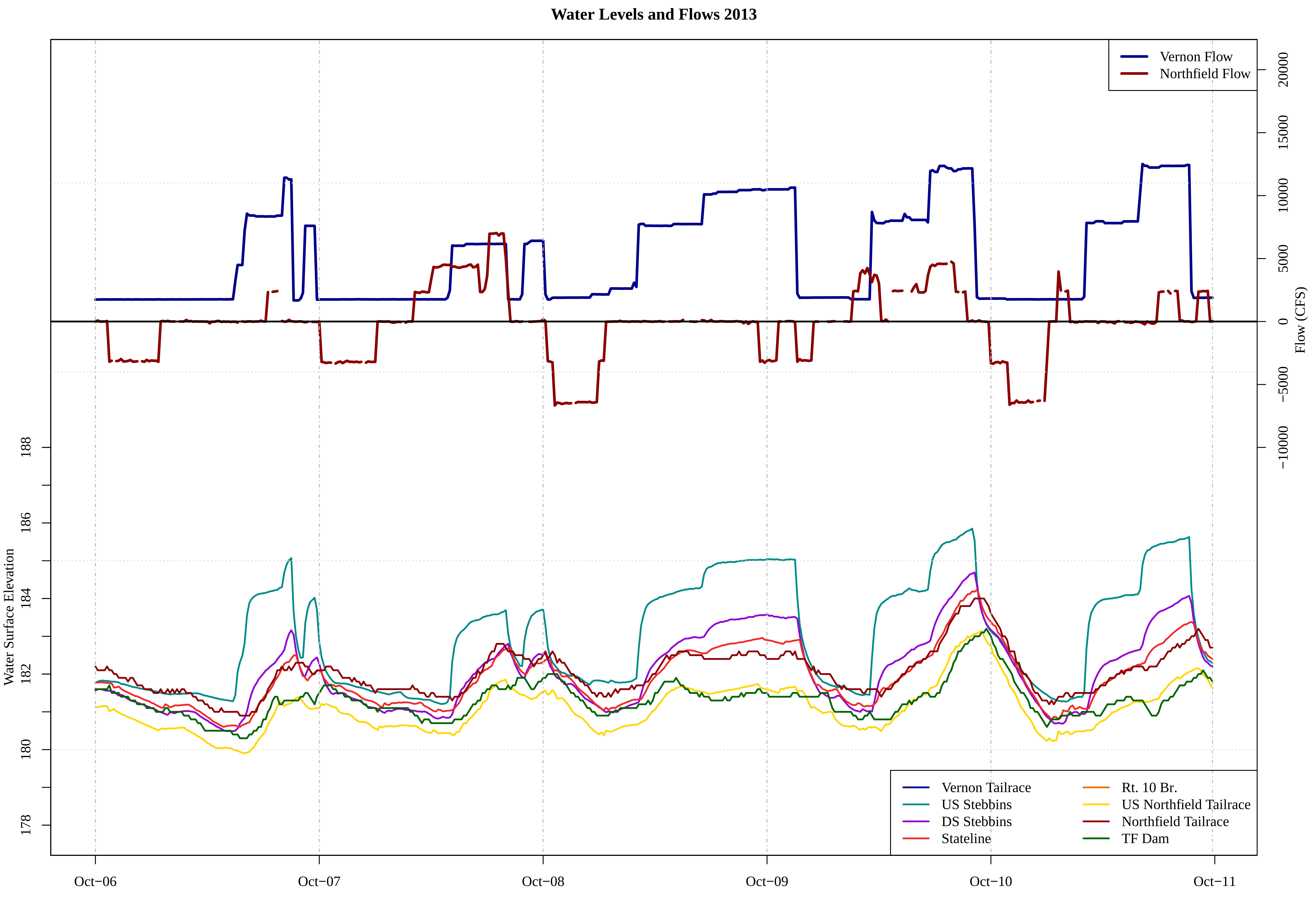
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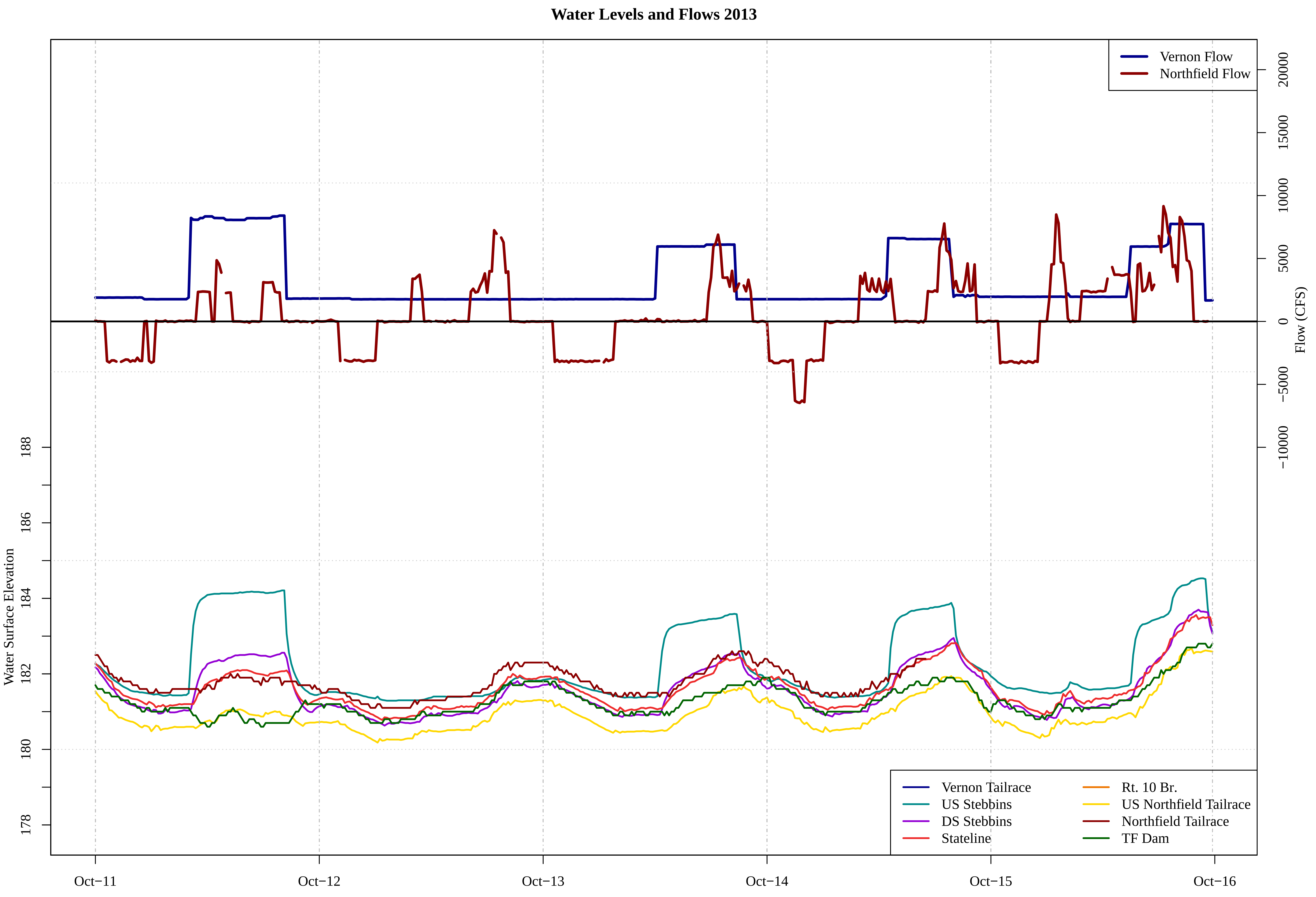

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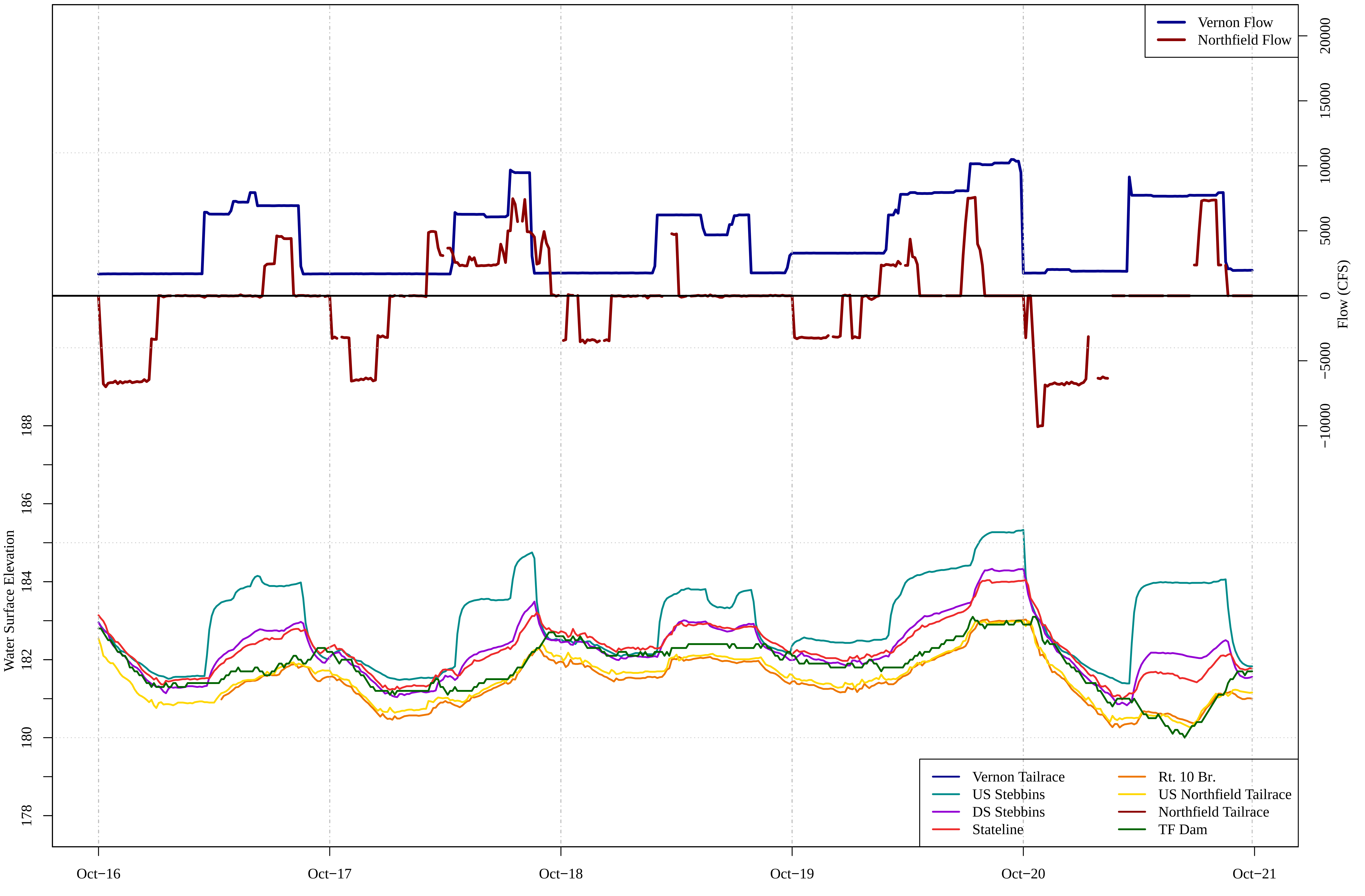

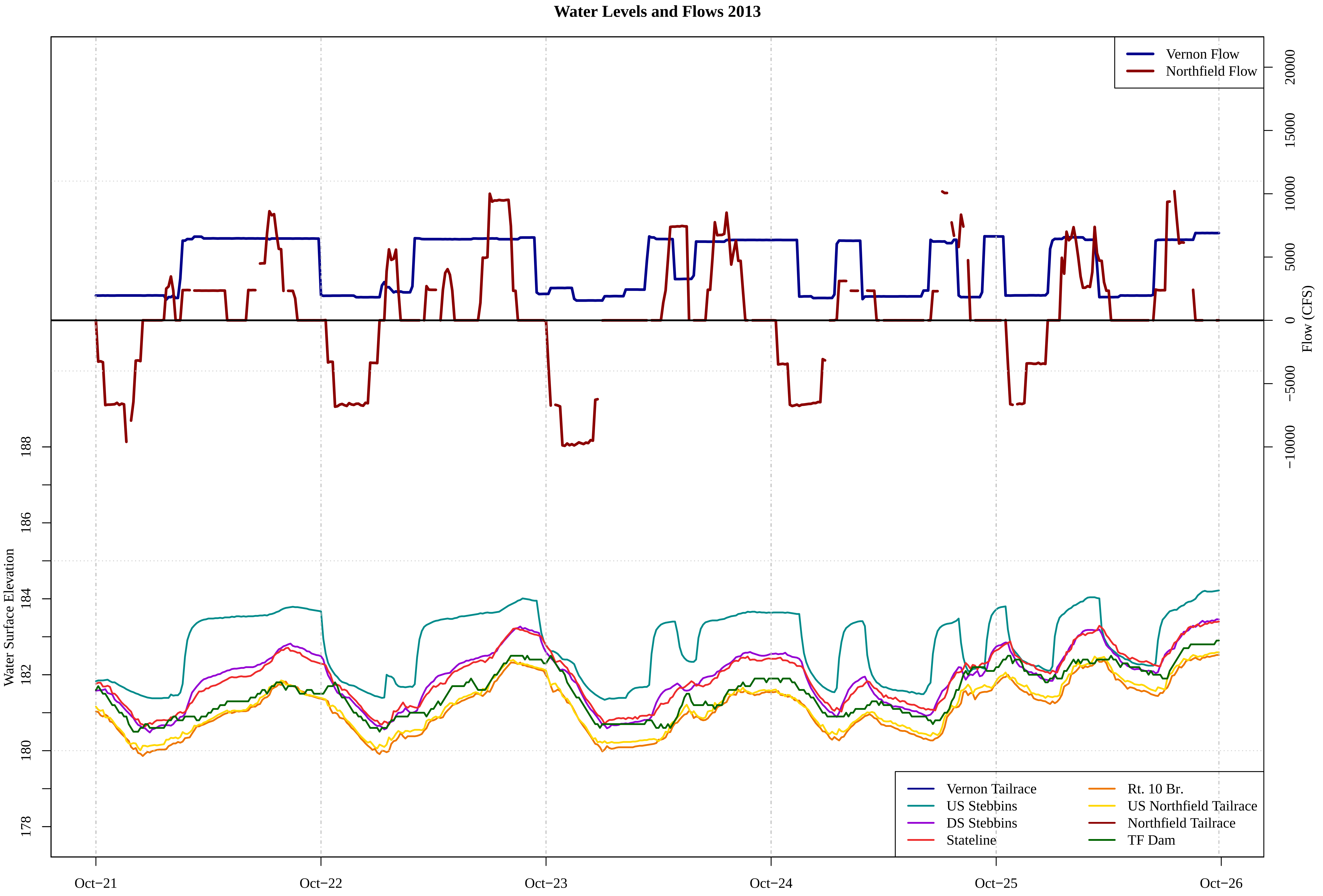

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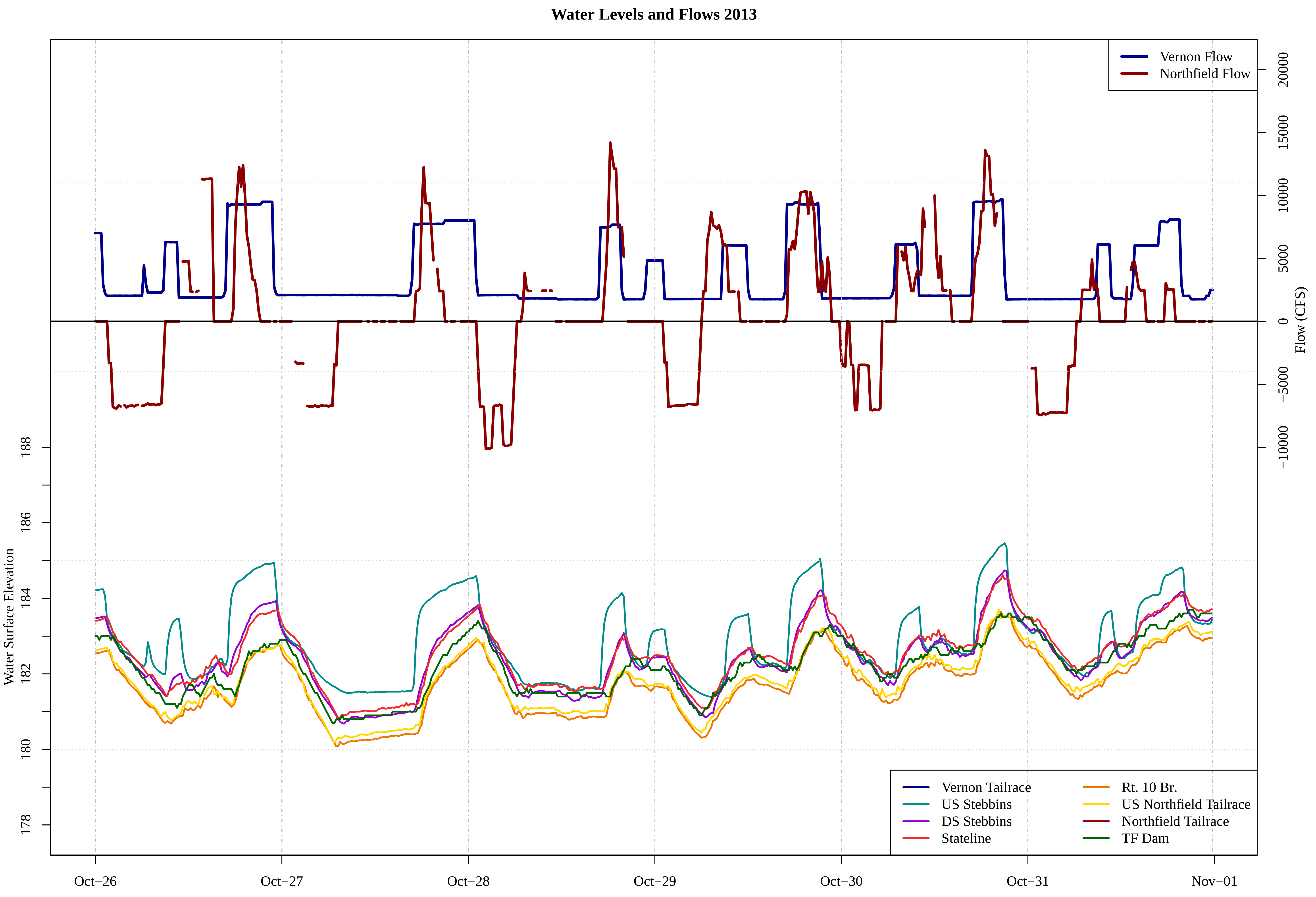

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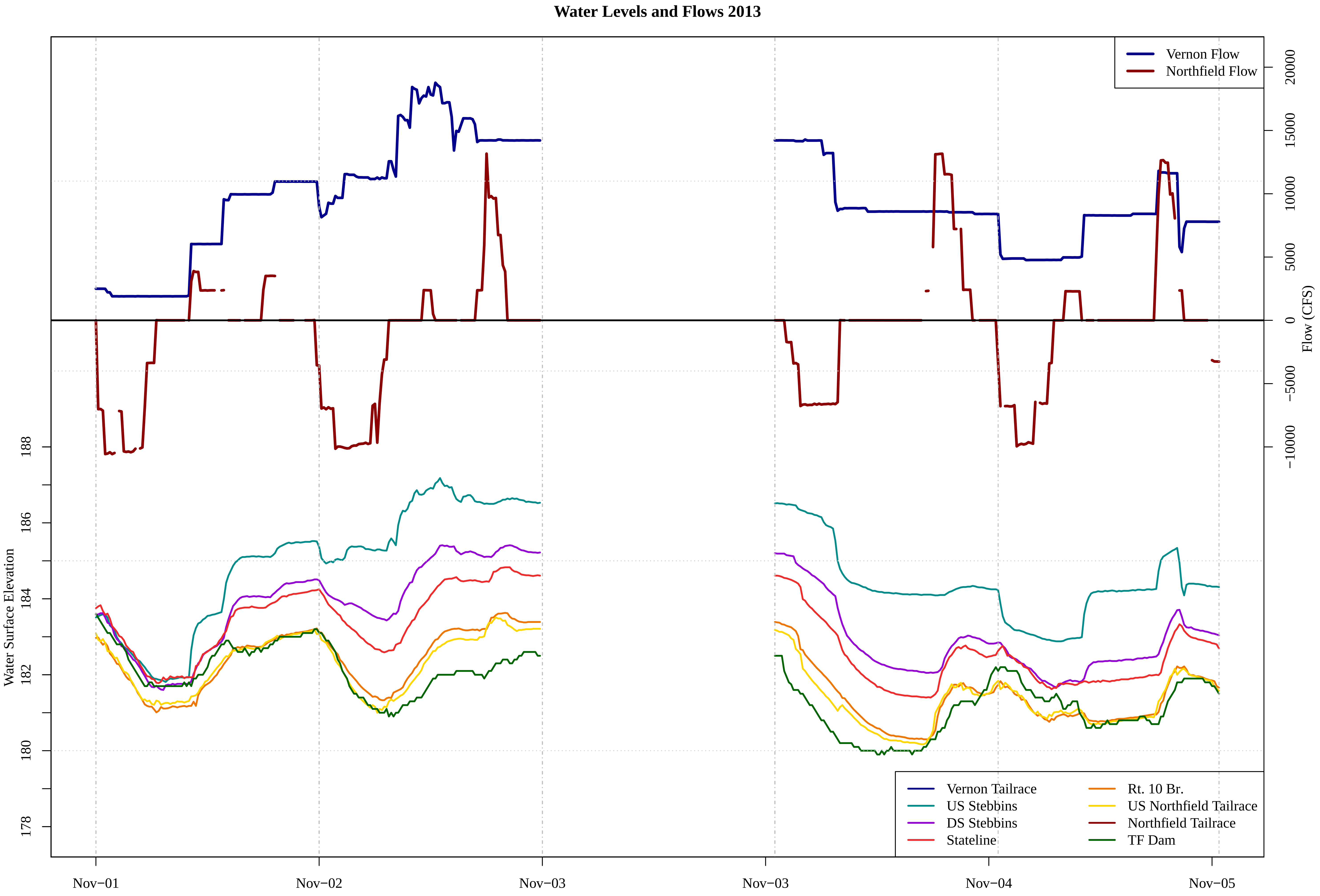
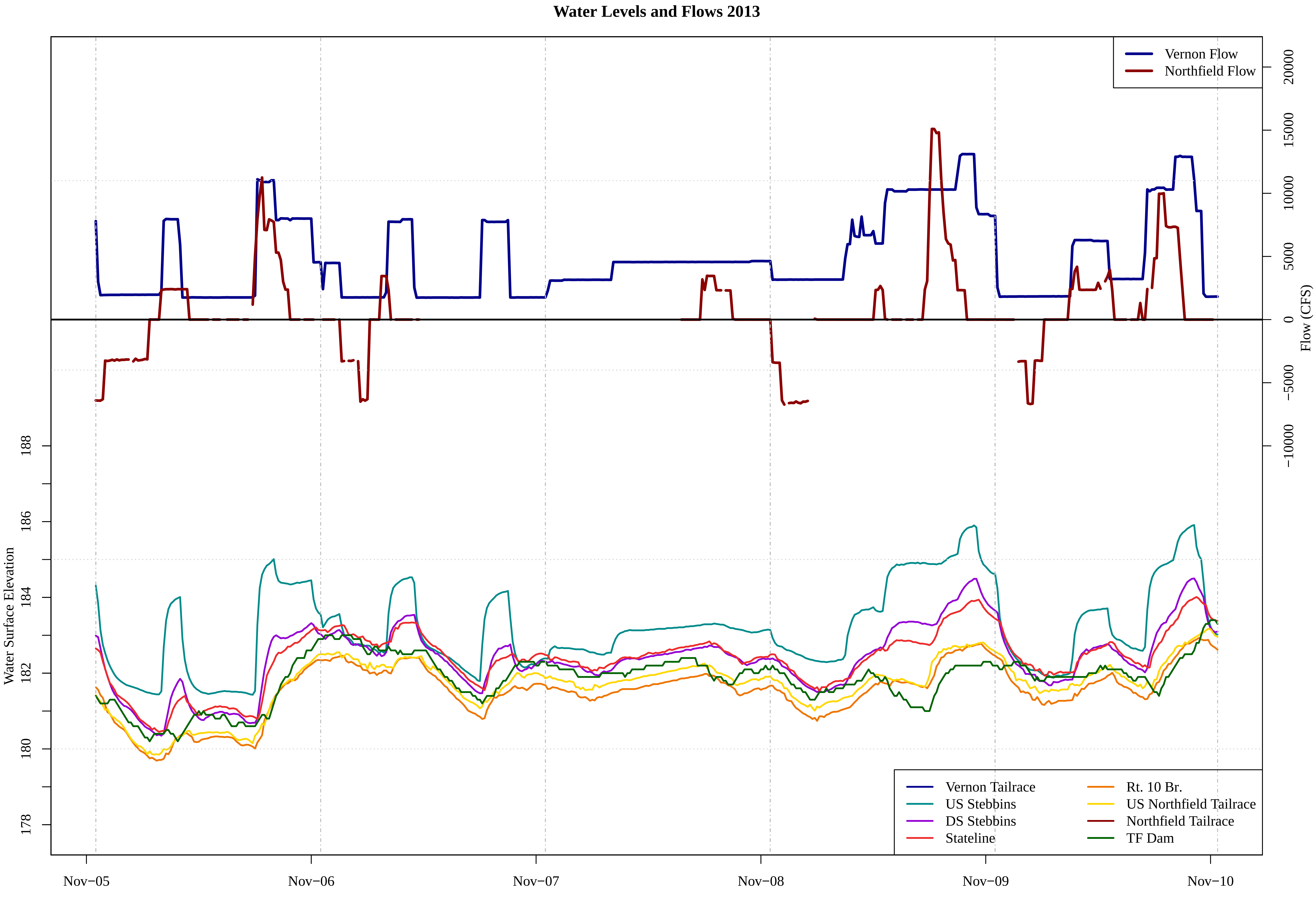
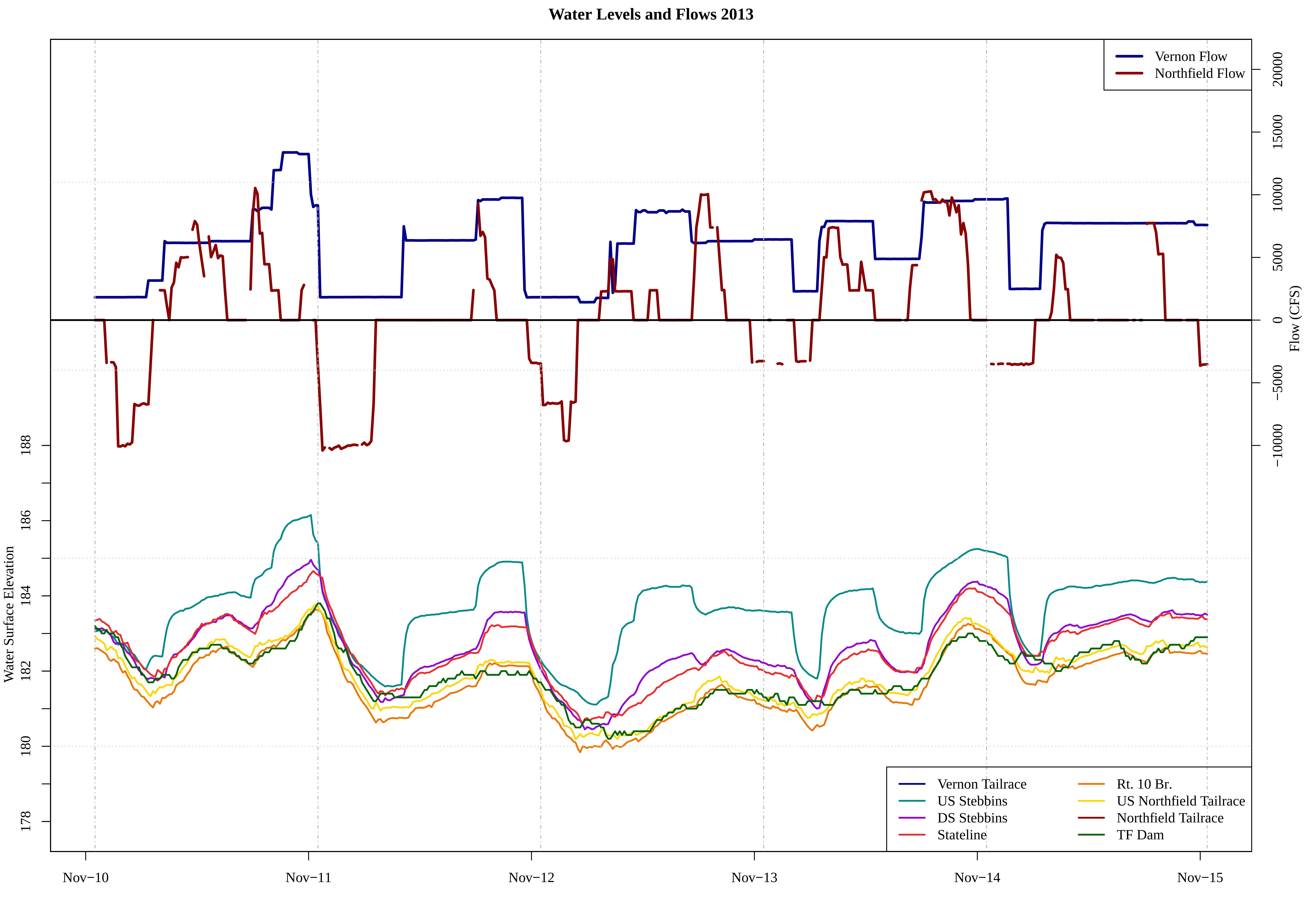
Nov−01



Water Levels and Flows 2013
Vernon Flow
Northfield Flow
Water Surface Elevation
Flow (CFS)
178
180
182
184
186
188
−10000
−5000
0
5000
10000
15000
20000
Nov−01
Nov−02
Nov−03
Nov−03
Nov−04
Nov−05
Vernon Tailrace
US Stebbins
DS Stebbins
Stateline
Rt. 10 Br.
US Northfield Tailrace
Northfield Tailrace
TF Dam

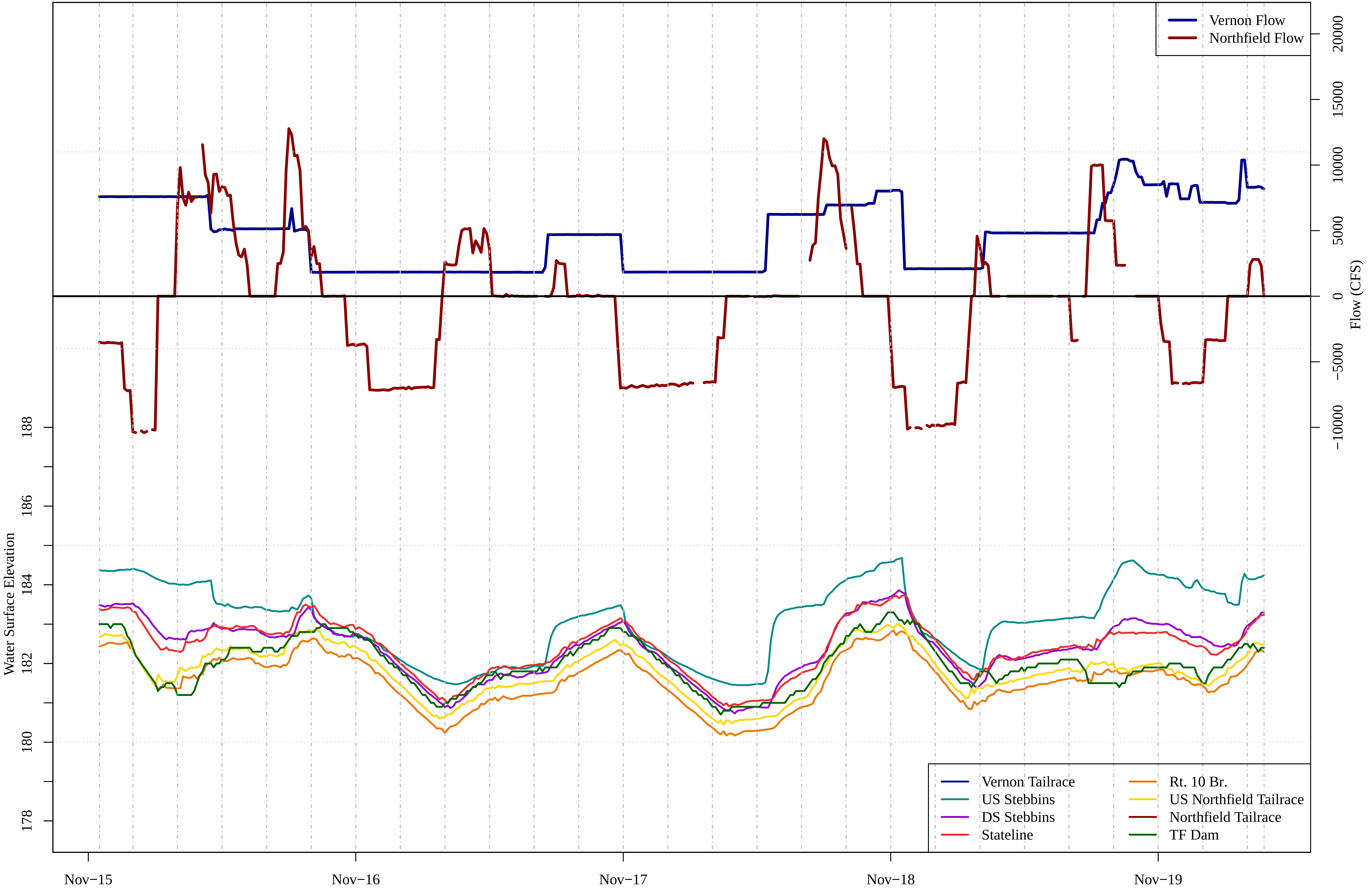


Water Levels and Flows 2013
Vernon Flow
Northfield Flow
Flow (CFS)
20000
15000
10000
5000
0
−5000
−10000
Water Surface Elevation
188
186
184
182
180
178
Vernon Tailrace
US Stebbins
DS Stebbins
Stateline
Rt. 10 Br.
US Northfield Tailrace
Northfield Tailrace
TF Dam
Nov−05
Nov−06
Nov−07
Nov−08
Nov−09
Nov−10

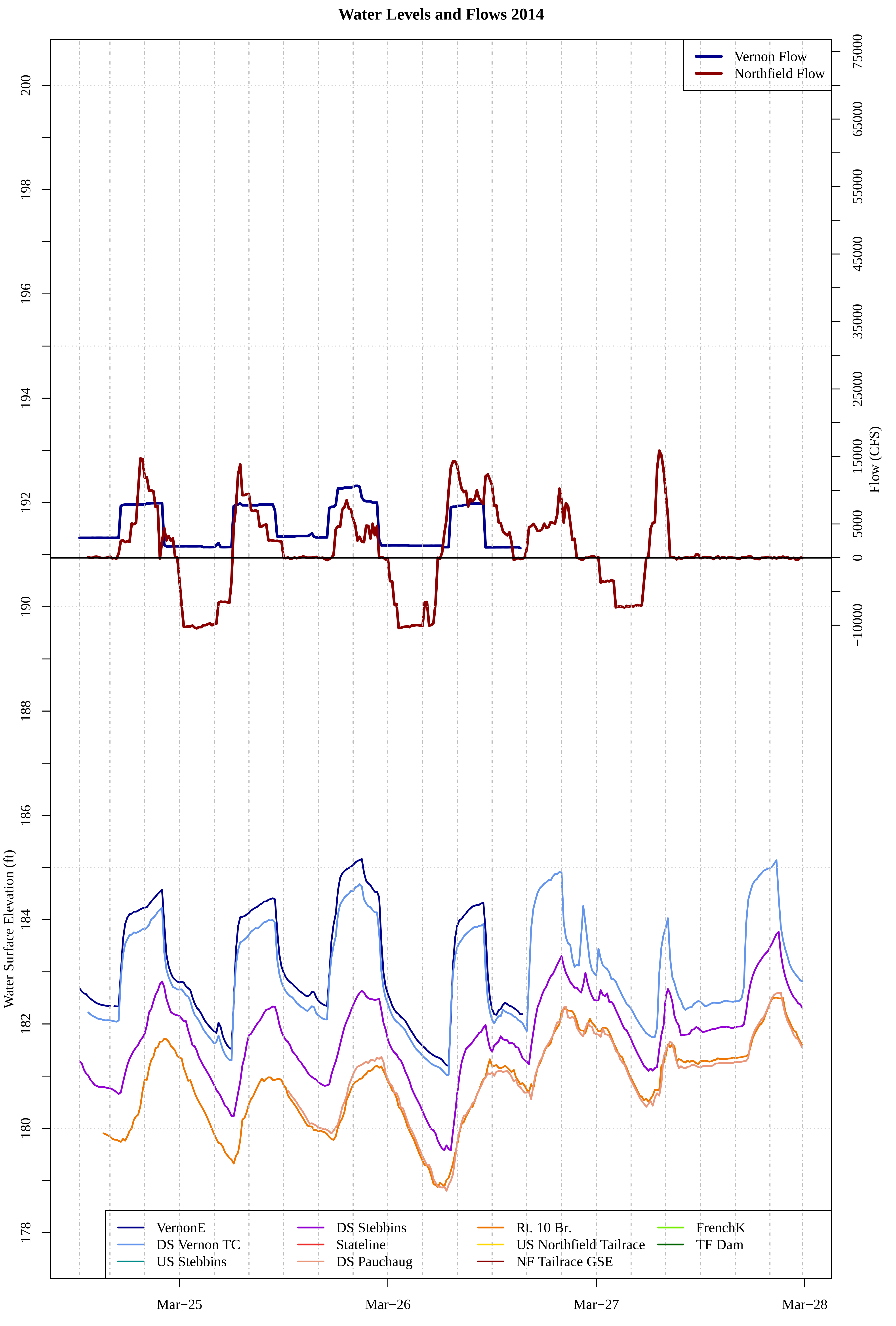


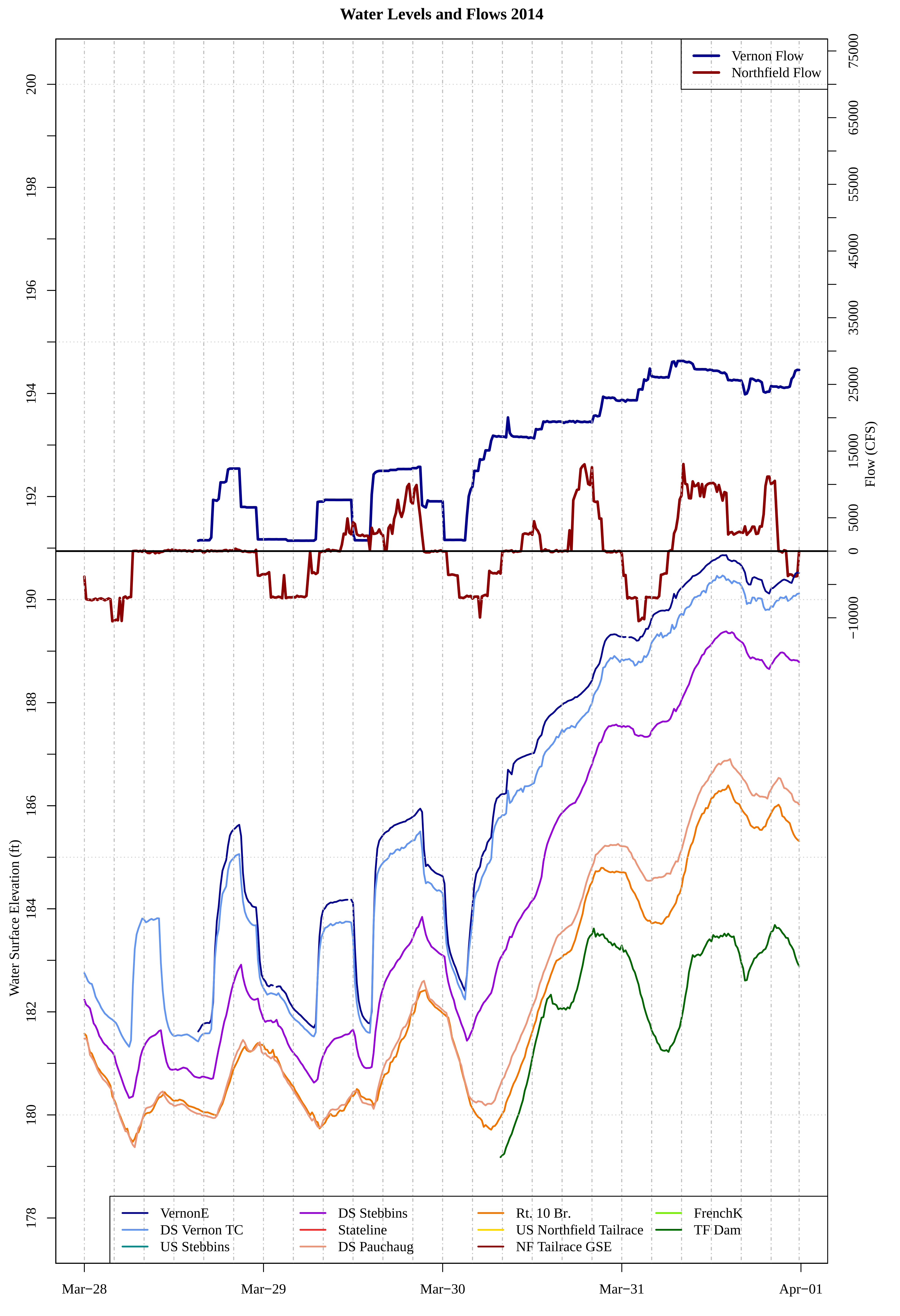
Water Levels and Flows 2013
Vernon Flow
Northfield Flow
Flow (CFS)
20000
15000
10000
5000
0
−5000
−10000
Water Surface Elevation
188
186
184
182
180
178
Vernon Tailrace
US Stebbins
DS Stebbins
Stateline
Rt. 10 Br.
US Northfield Tailrace
Northfield Tailrace
TF Dam
Nov−10
Nov−11
Nov−12
Nov−13
Nov−14
Nov−15

Water Levels and Flows 2013



APPENDIX B- IMPOUNDMENT REACH: 2014 DATA


Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
200
198
196
194
192
190
188
186
184
182
180
178
75000
65000
55000
45000
35000
25000
15000
5000
0
−10000
Mar−25
Mar−26
Mar−27
Mar−28
VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
178
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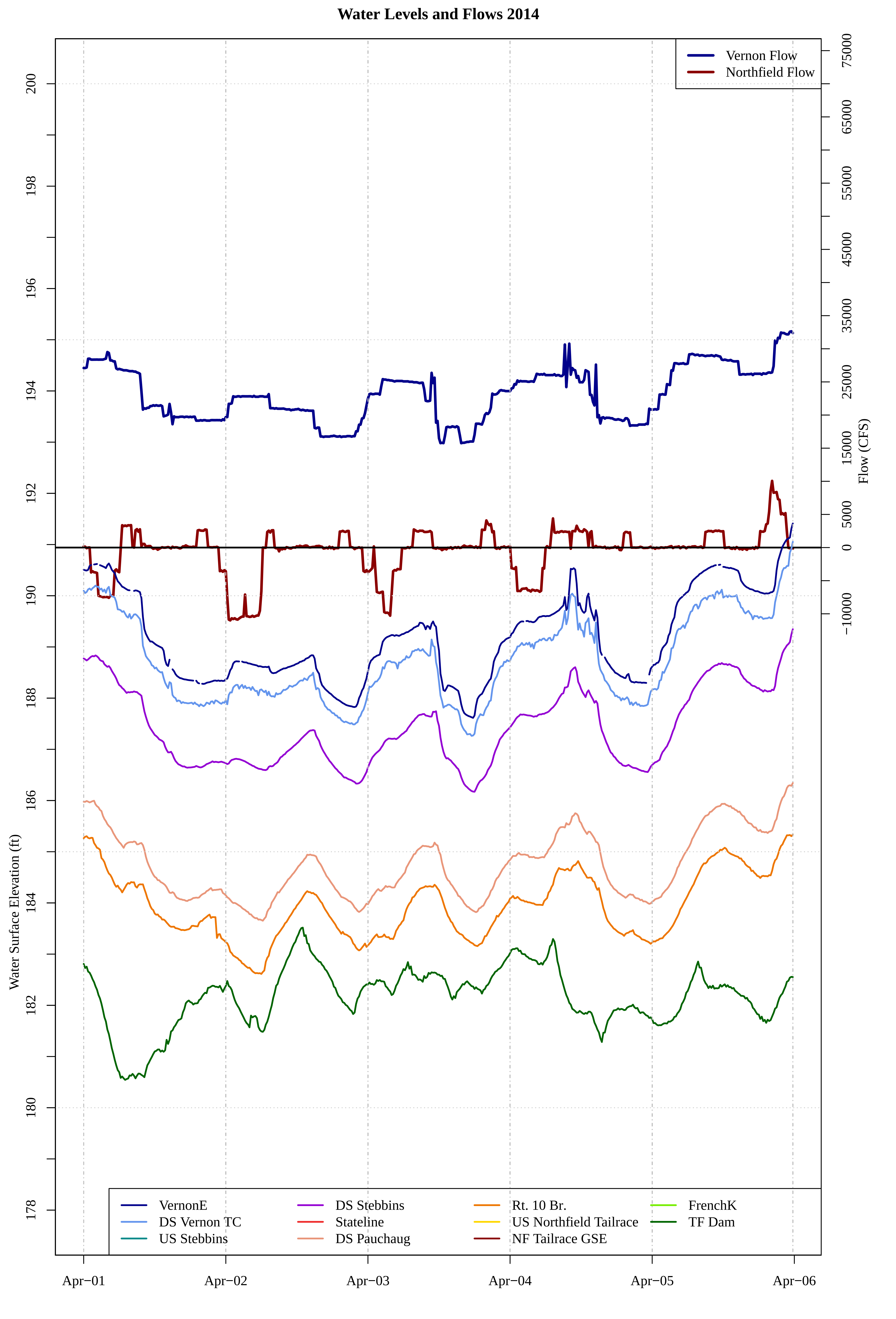
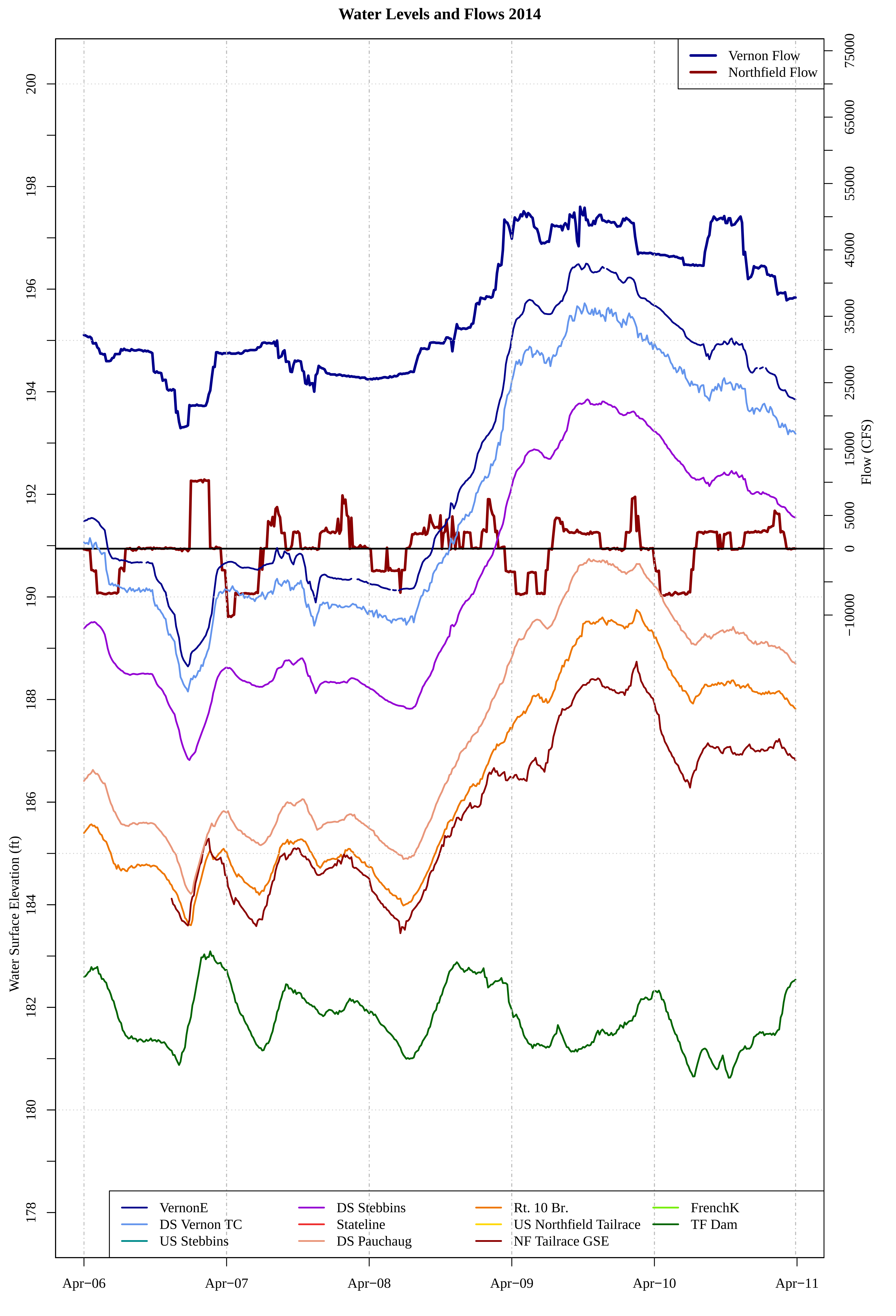
75000
Mar−28
Mar−29
Mar−30
Mar−31
Apr−01
VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam
Apr−01
Apr−02
Apr−03
Apr−04
Apr−05
Apr−06



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
178
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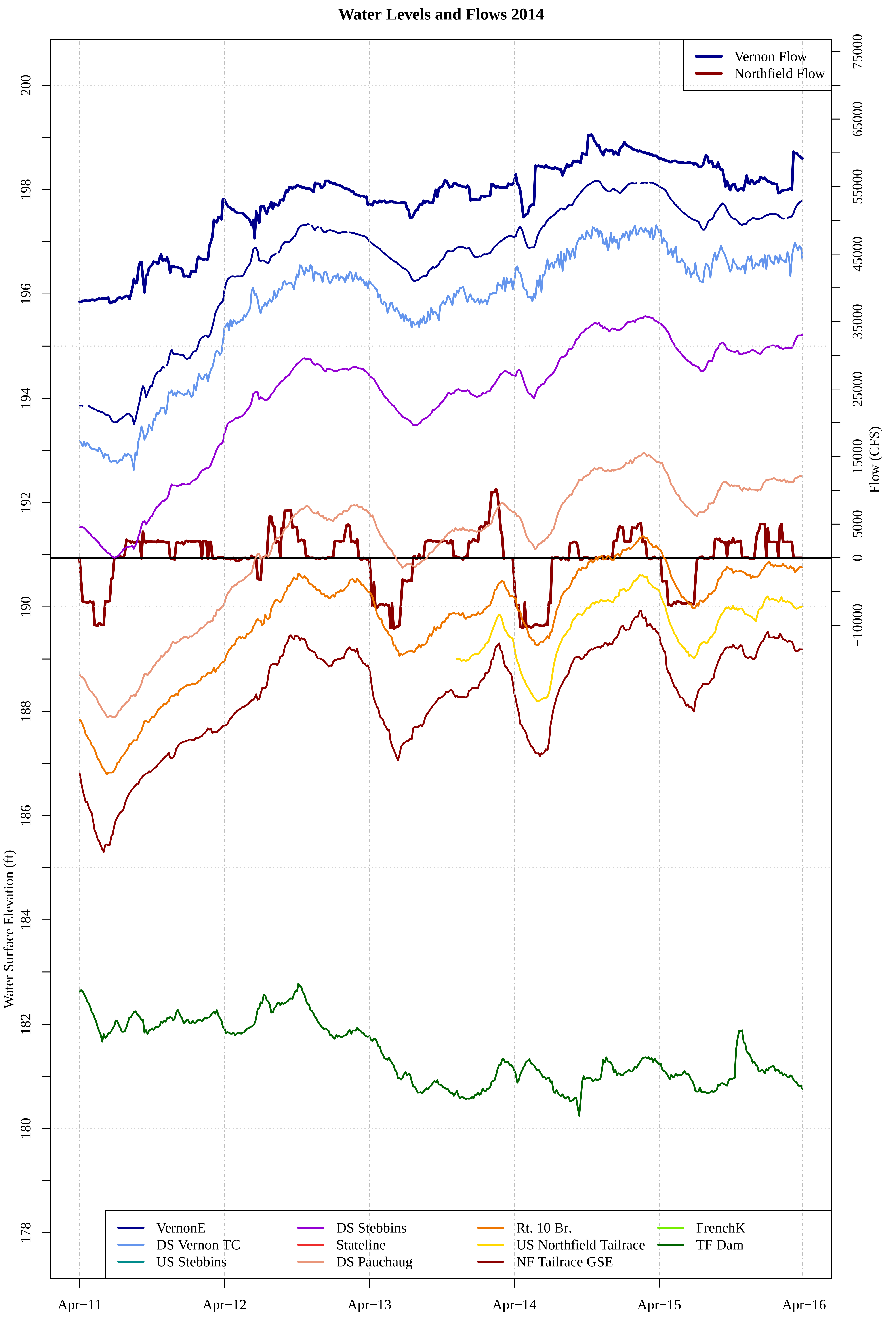
Apr−06
Apr−07
Apr−08
Apr−09
Apr−10
Apr−11
VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
178
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Apr−11
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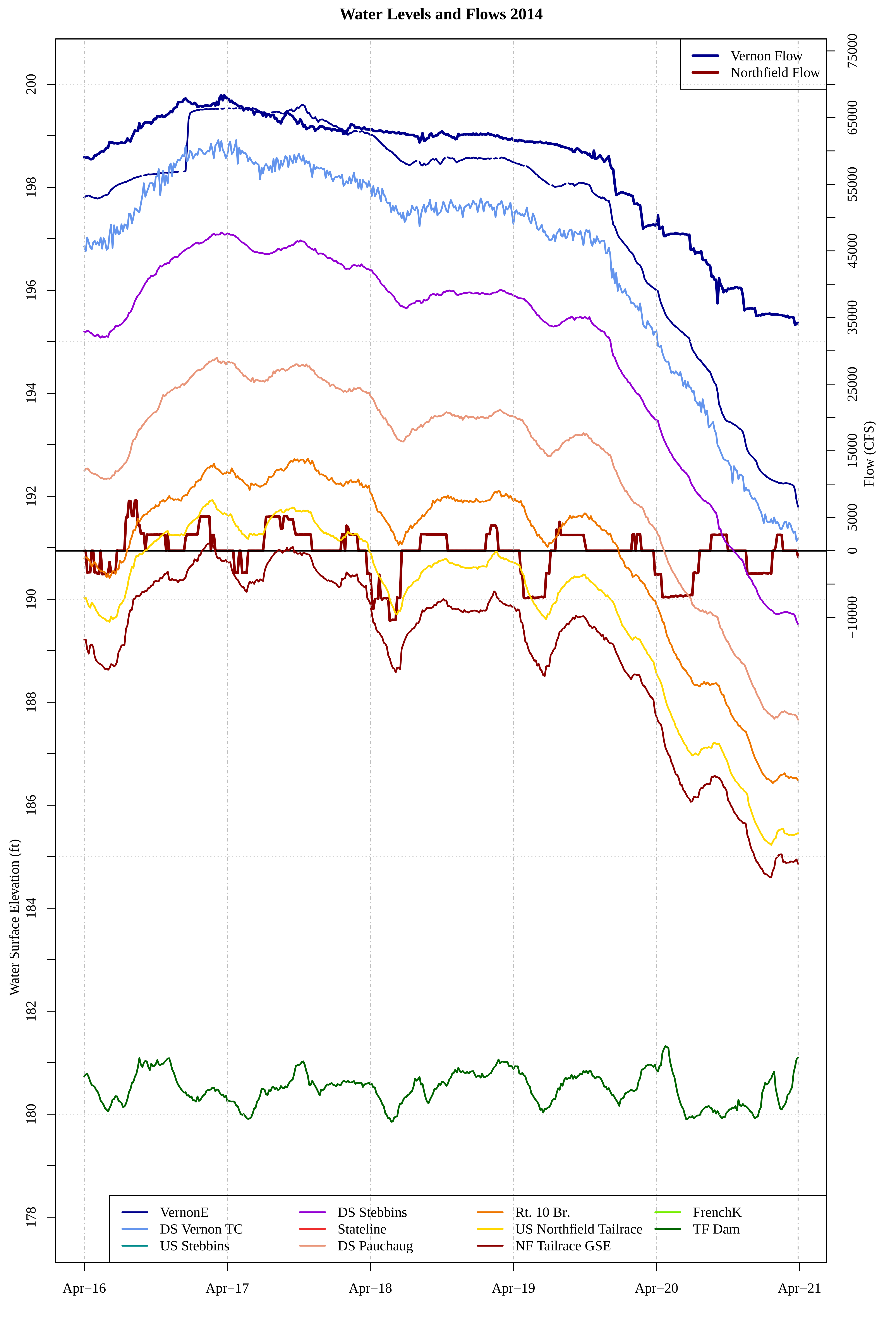
Apr−16
VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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Apr−16
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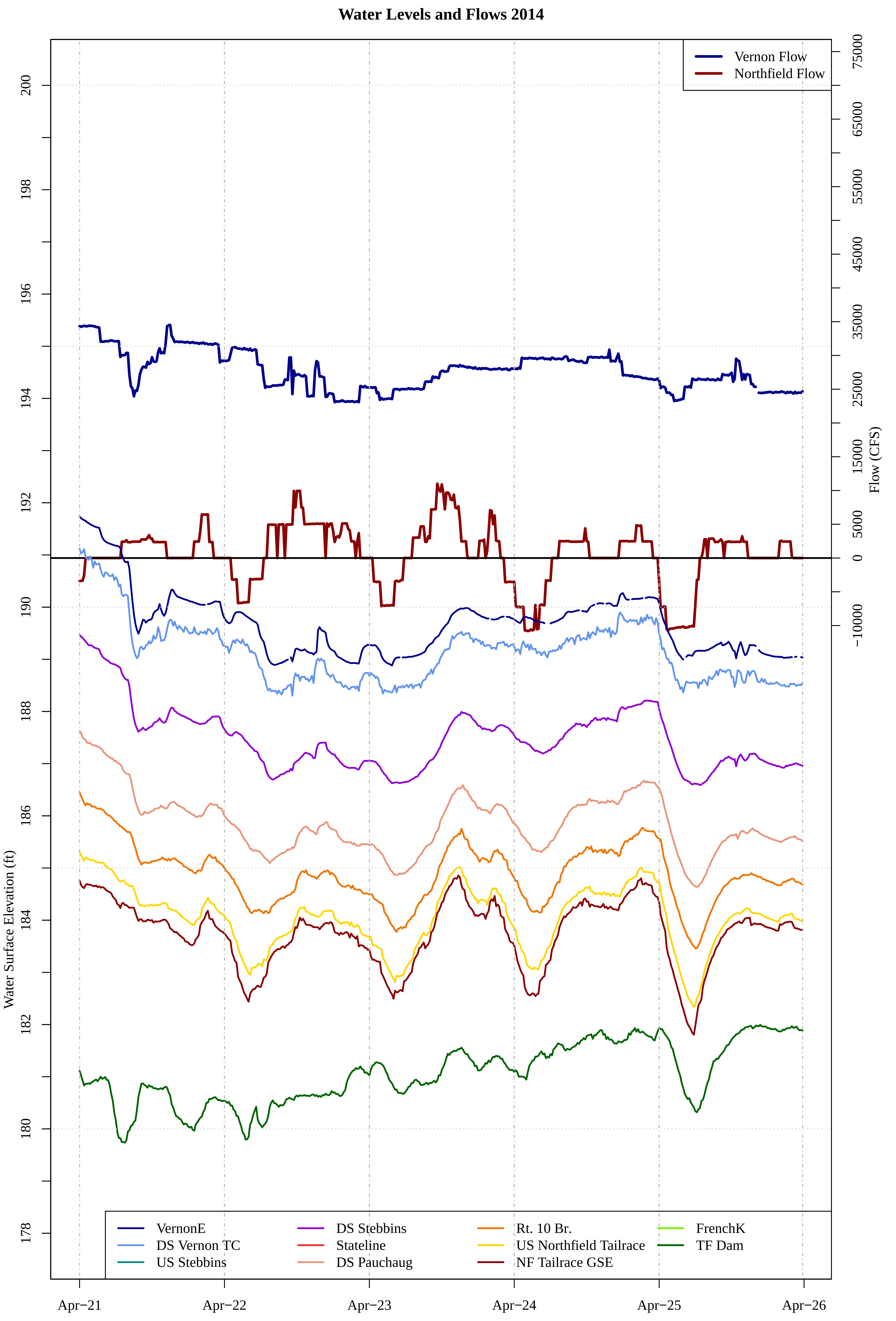
Apr−19
Apr−20
Apr−21
VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam


Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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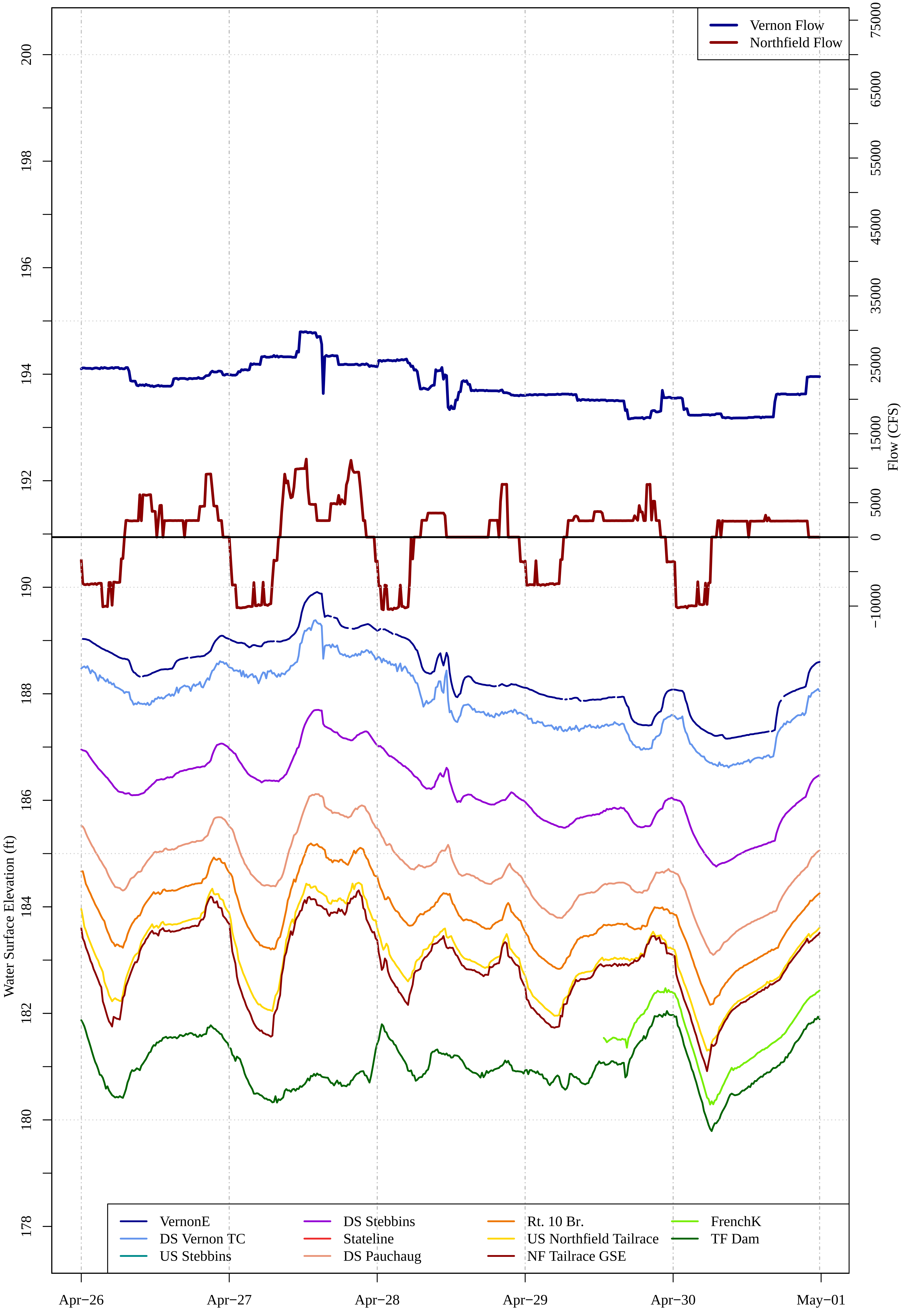
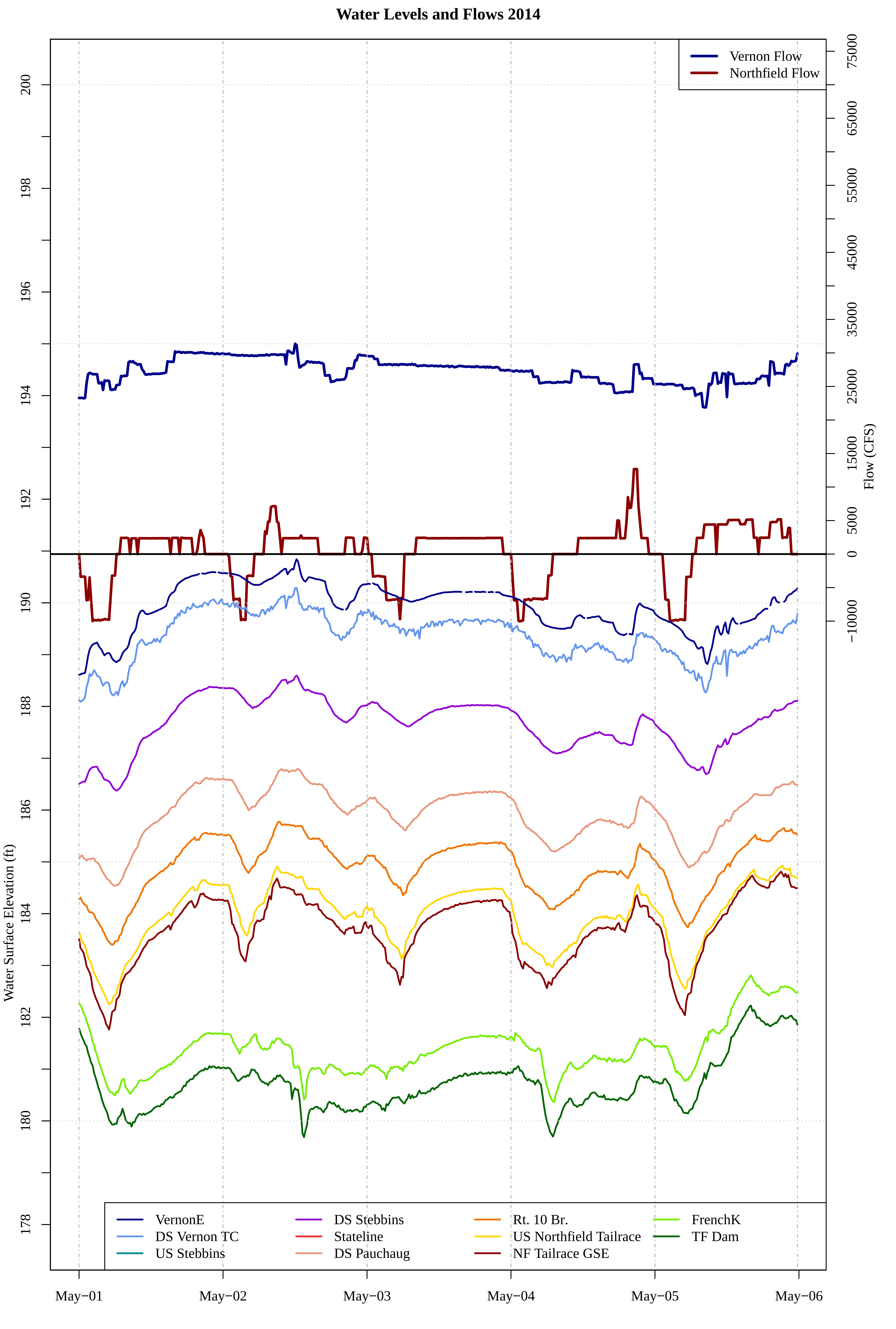
VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam

Water Levels and Flows 2014





Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam
May−01
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May−06
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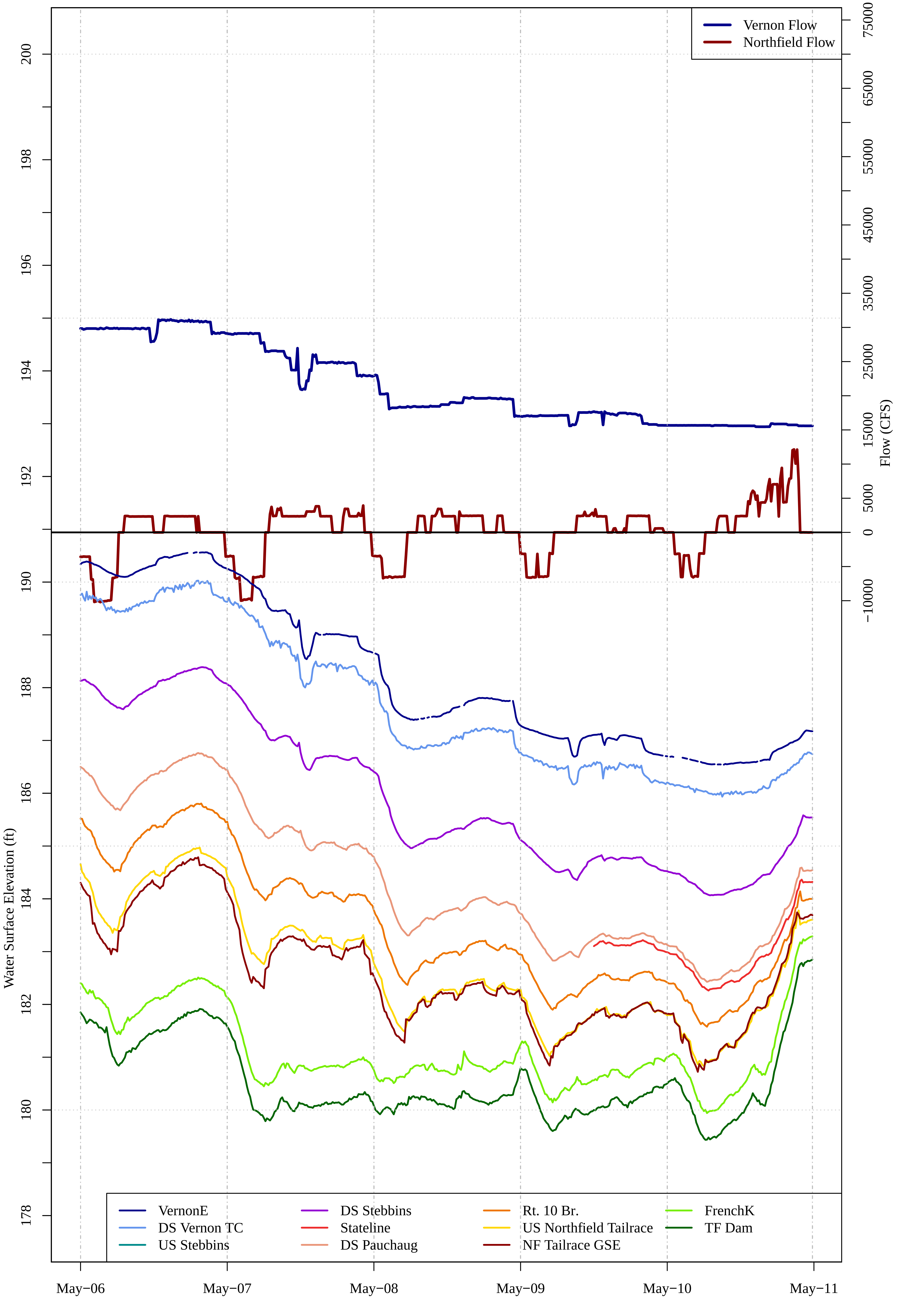
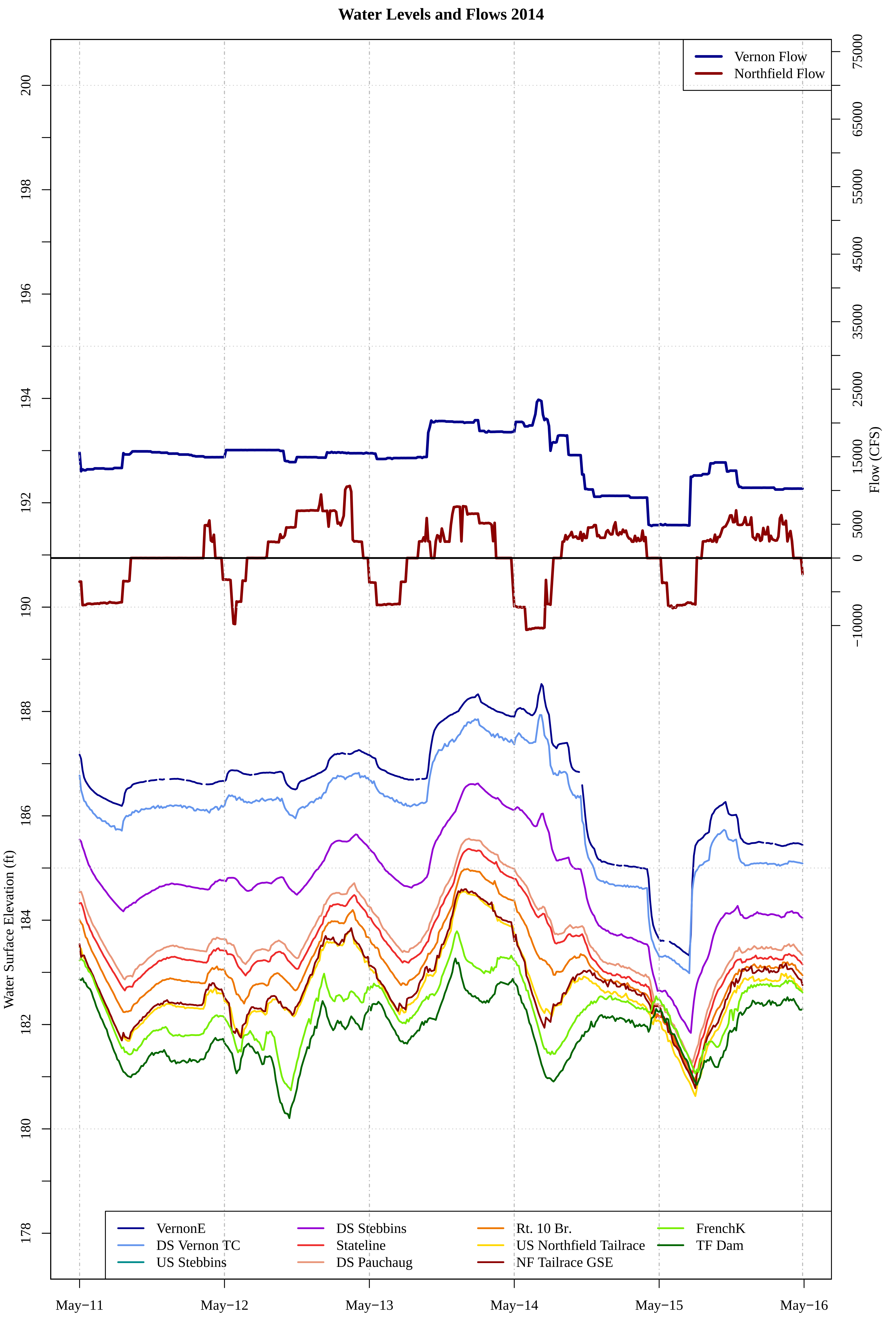
Water Levels and Flows 2014





Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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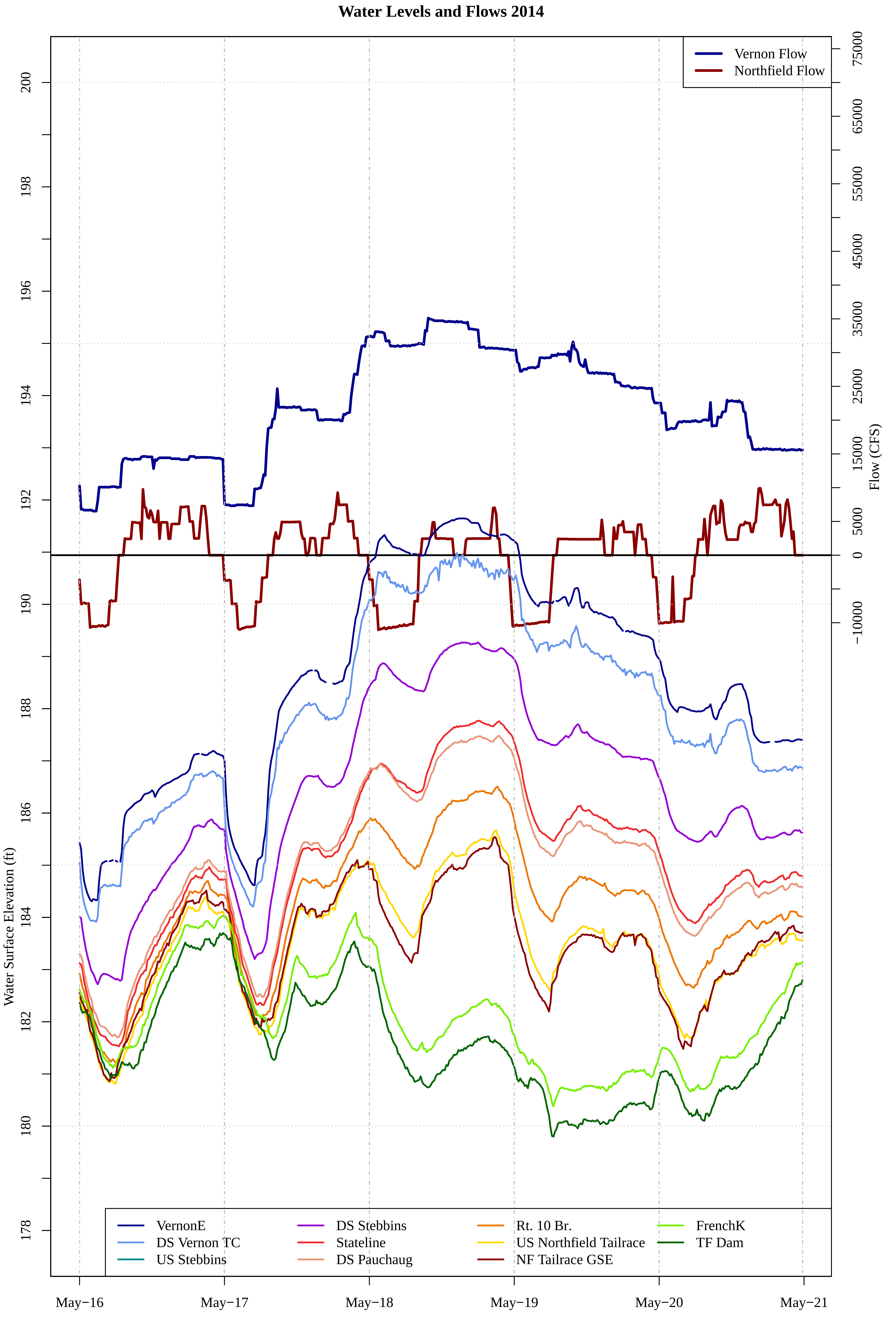
VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam


Water Levels and Flows 2014
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Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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VernonE
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DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
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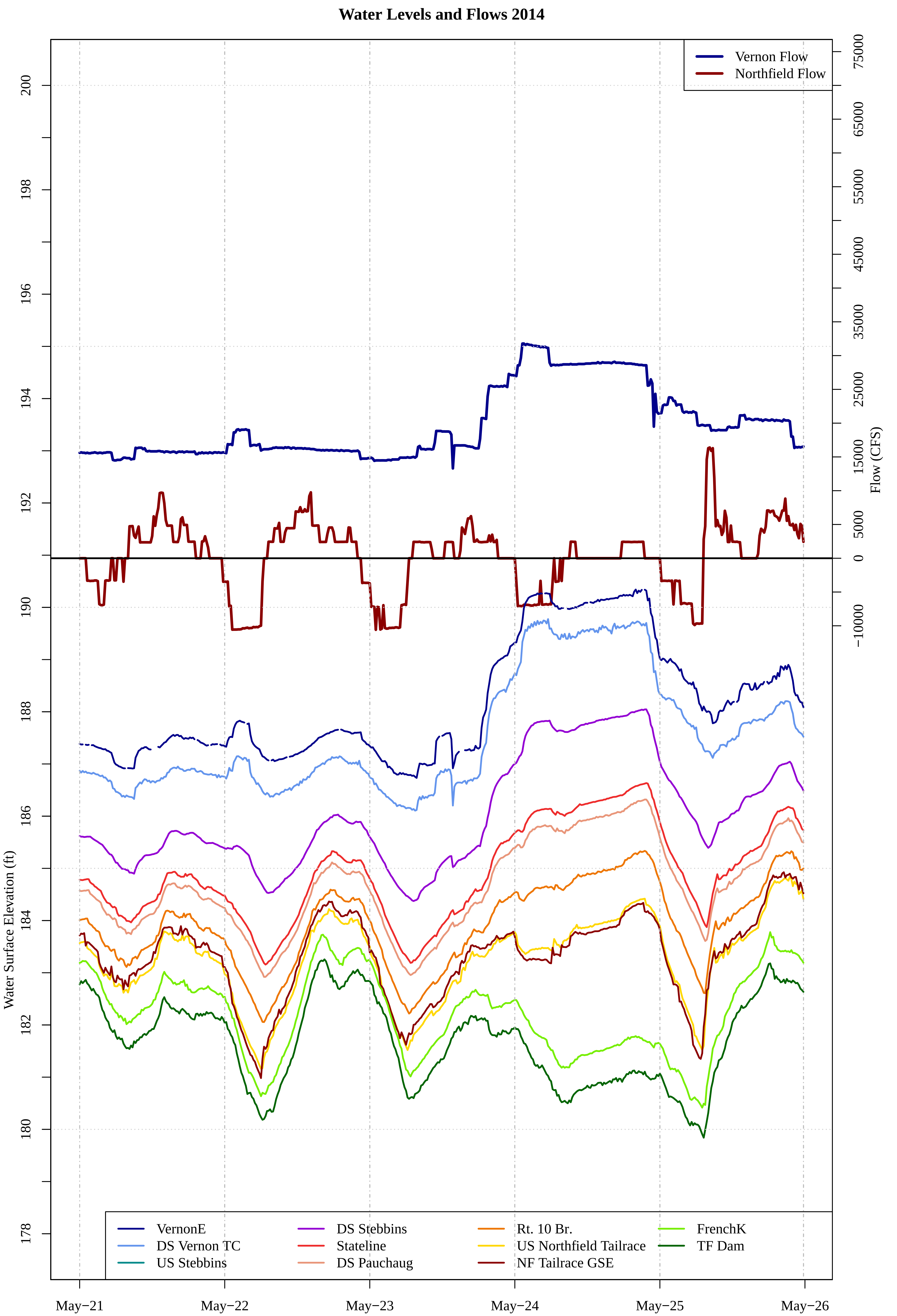

Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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DS Vernon TC
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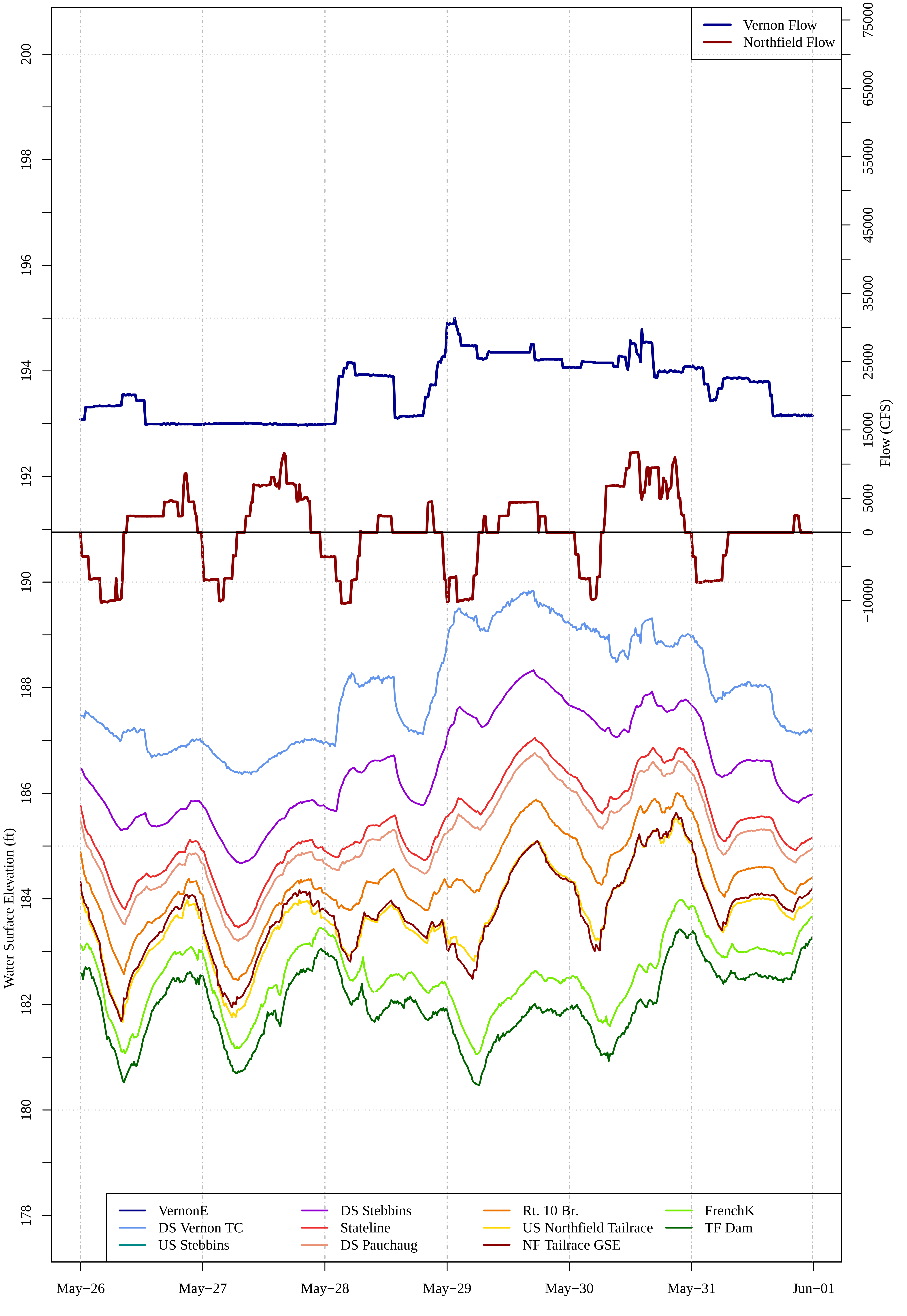
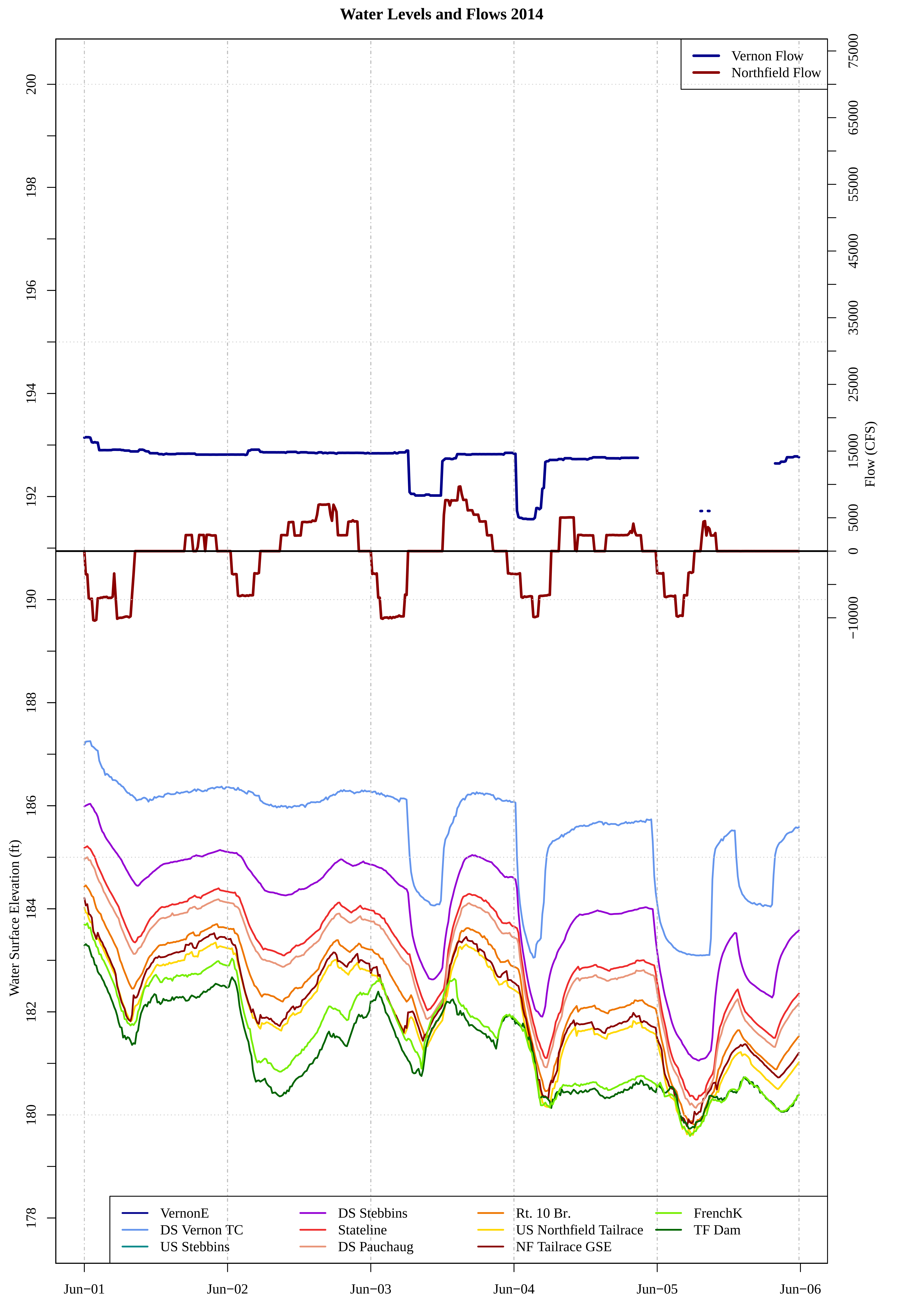
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam

Water Levels and Flows 2014





Water Levels and Flows 2014
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Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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VernonE
DS Vernon TC
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DS Stebbins
Stateline
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Rt. 10 Br.
US Northfield Tailrace
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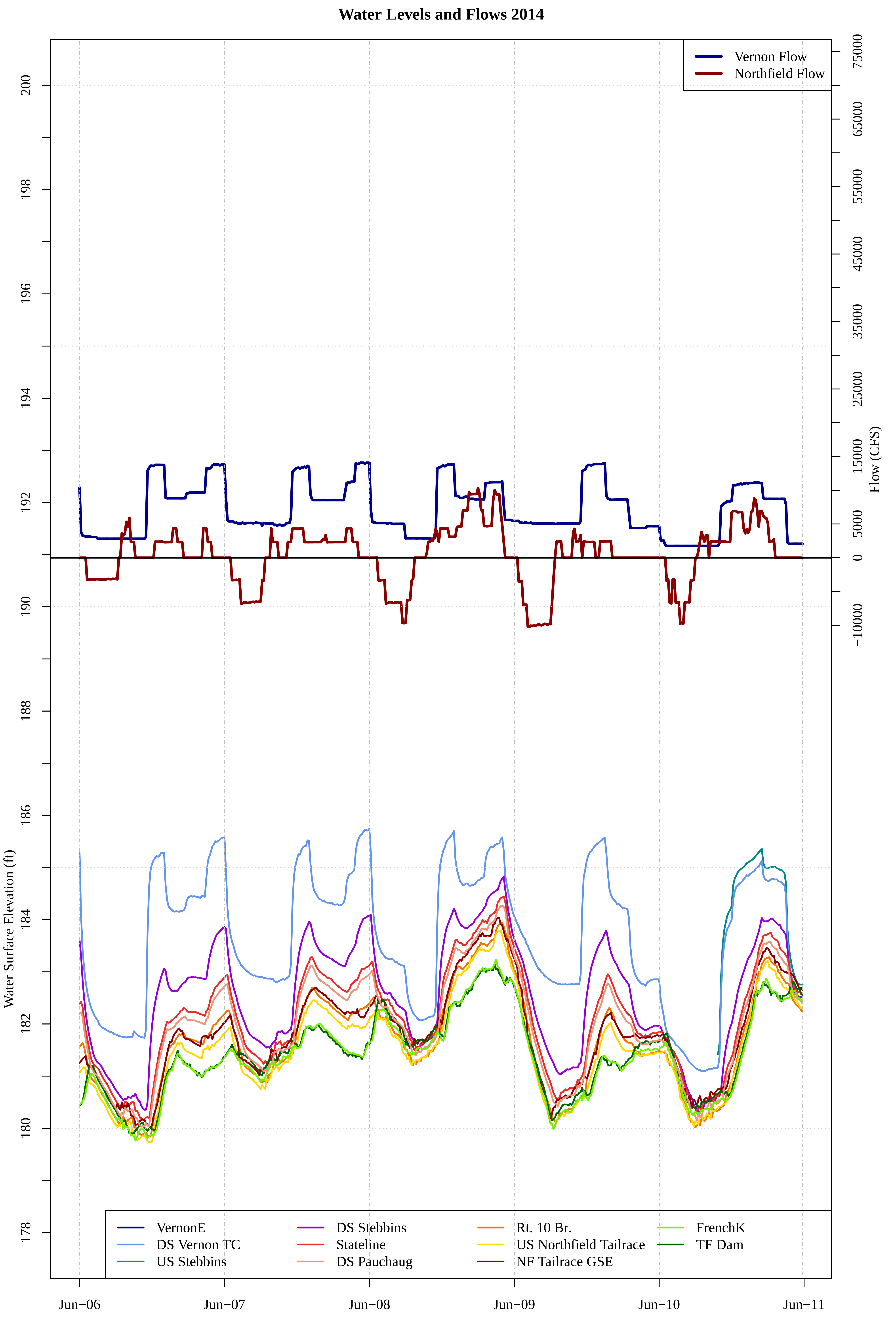
FrenchK
TF Dam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Northfield Flow
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Flow (CFS)
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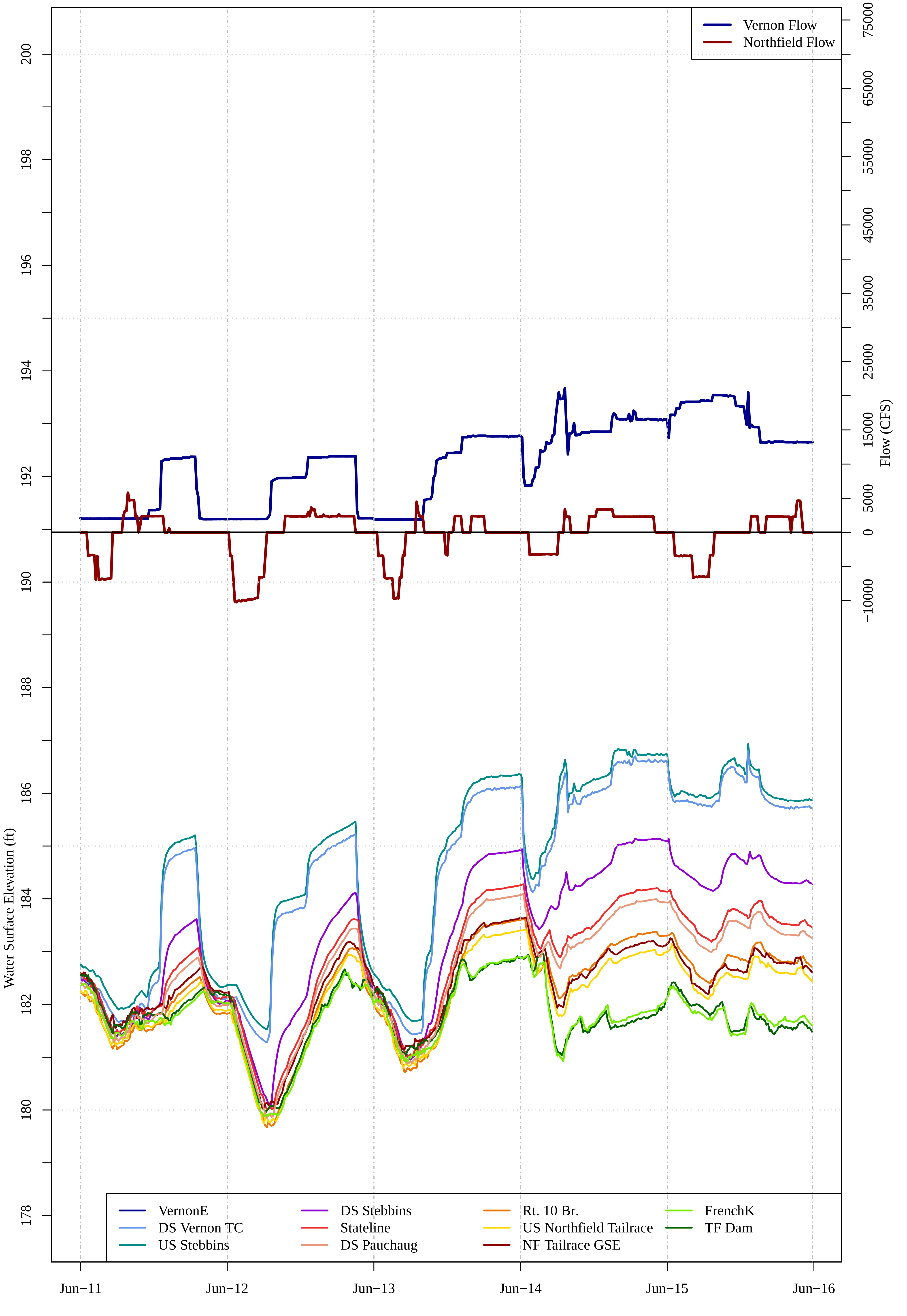
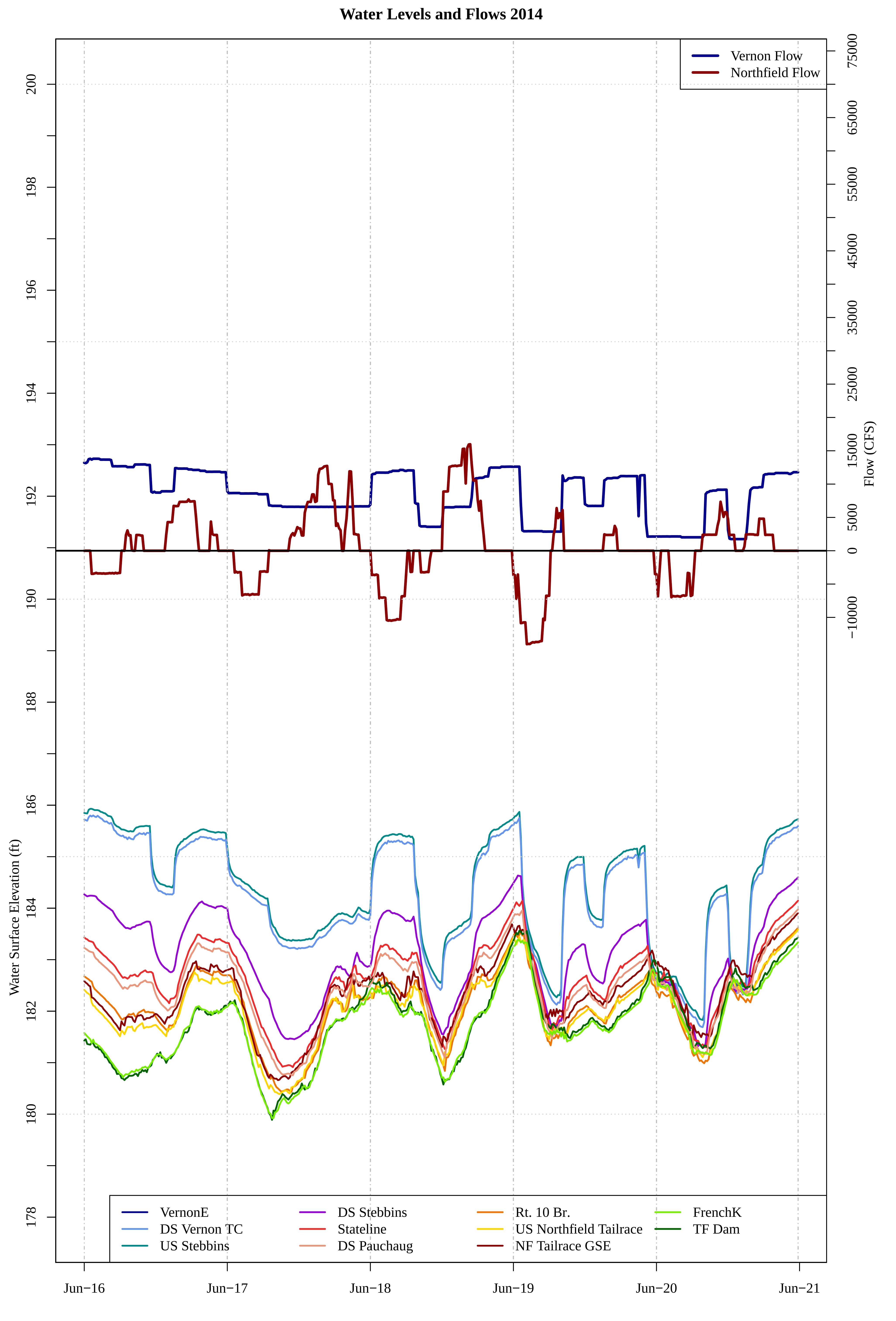
VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam

Water Levels and Flows 2014





Water Levels and Flows 2014
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Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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VernonE
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Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
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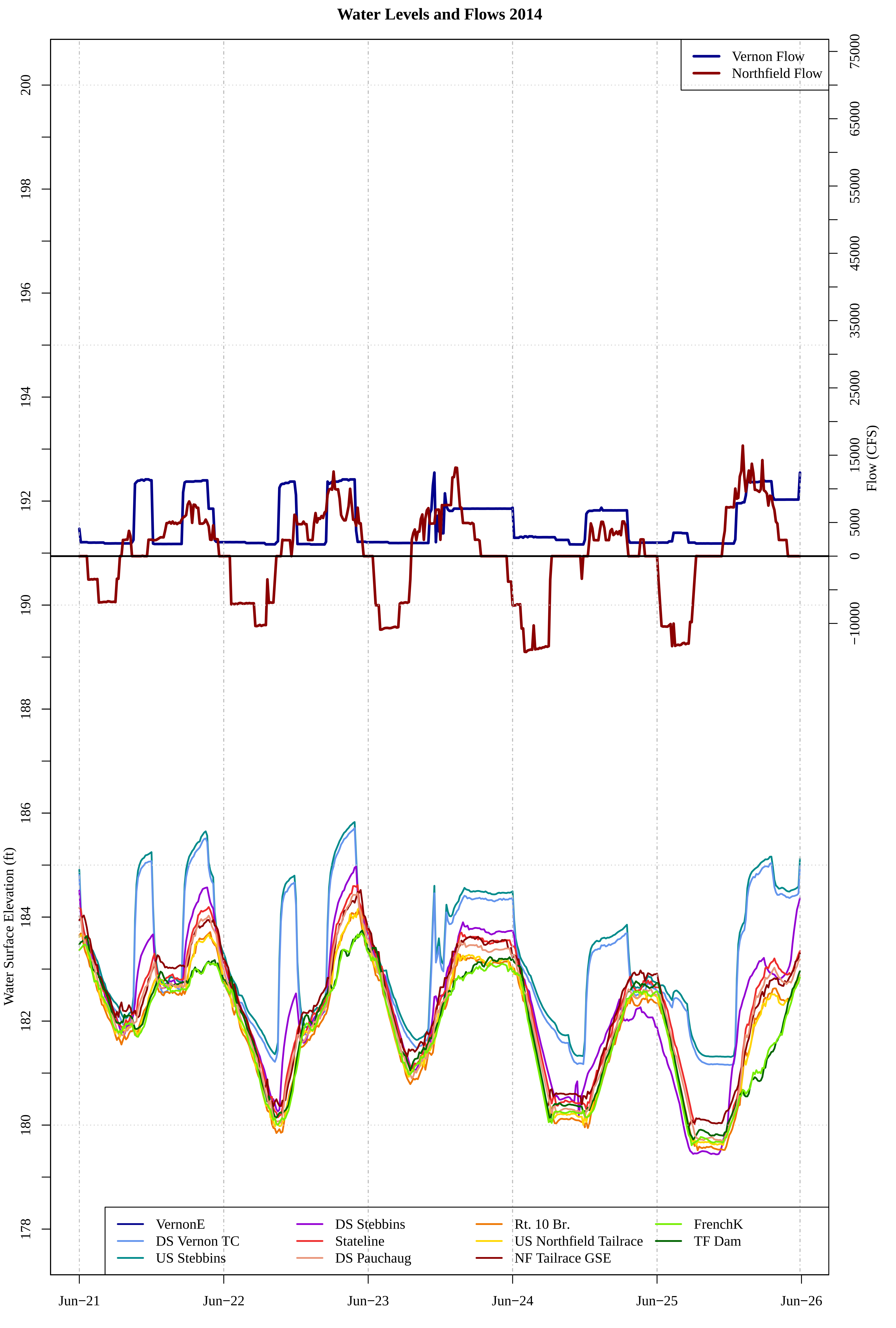
TF Dam


Water Levels and Flows 2014
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Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam
Jun−21
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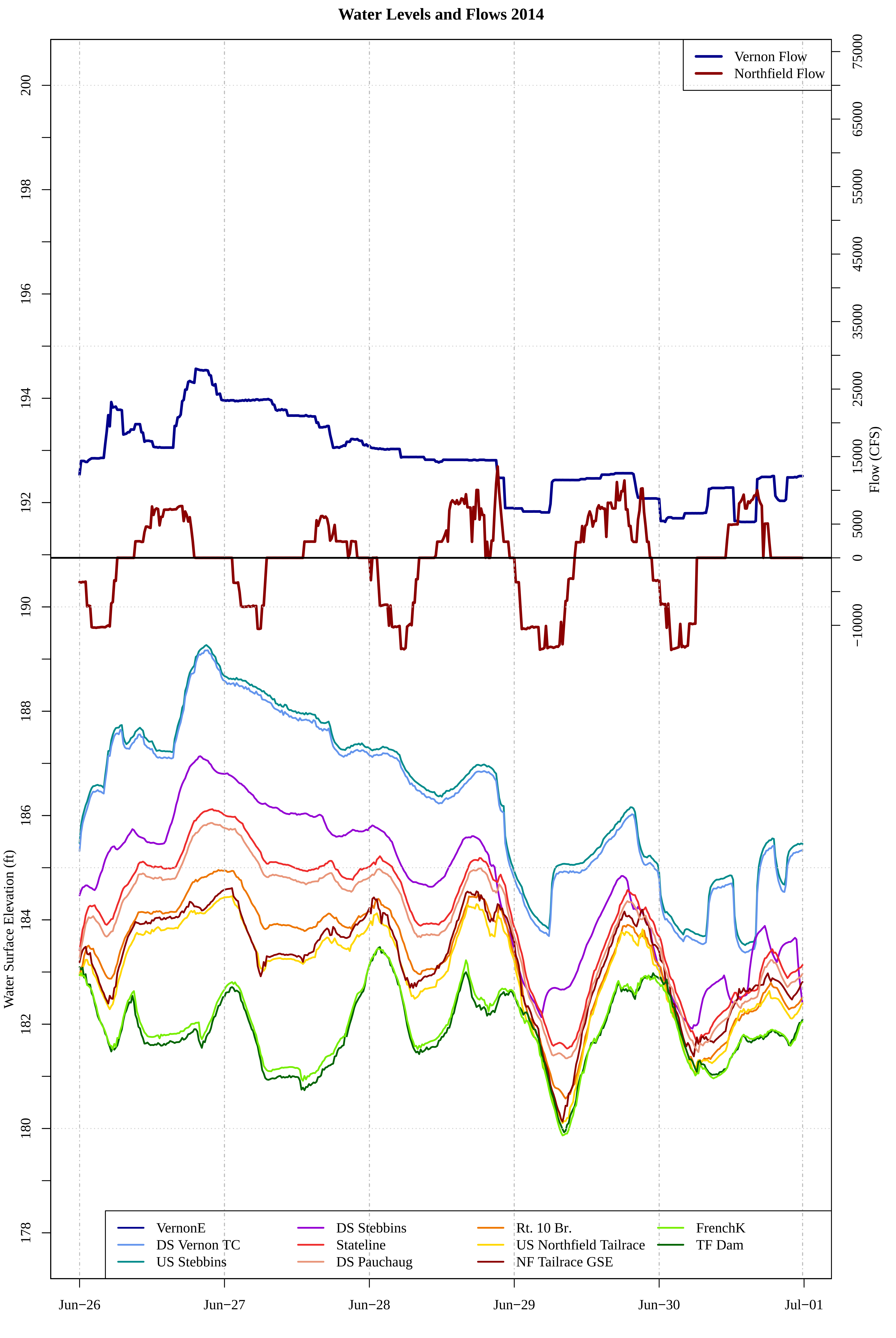
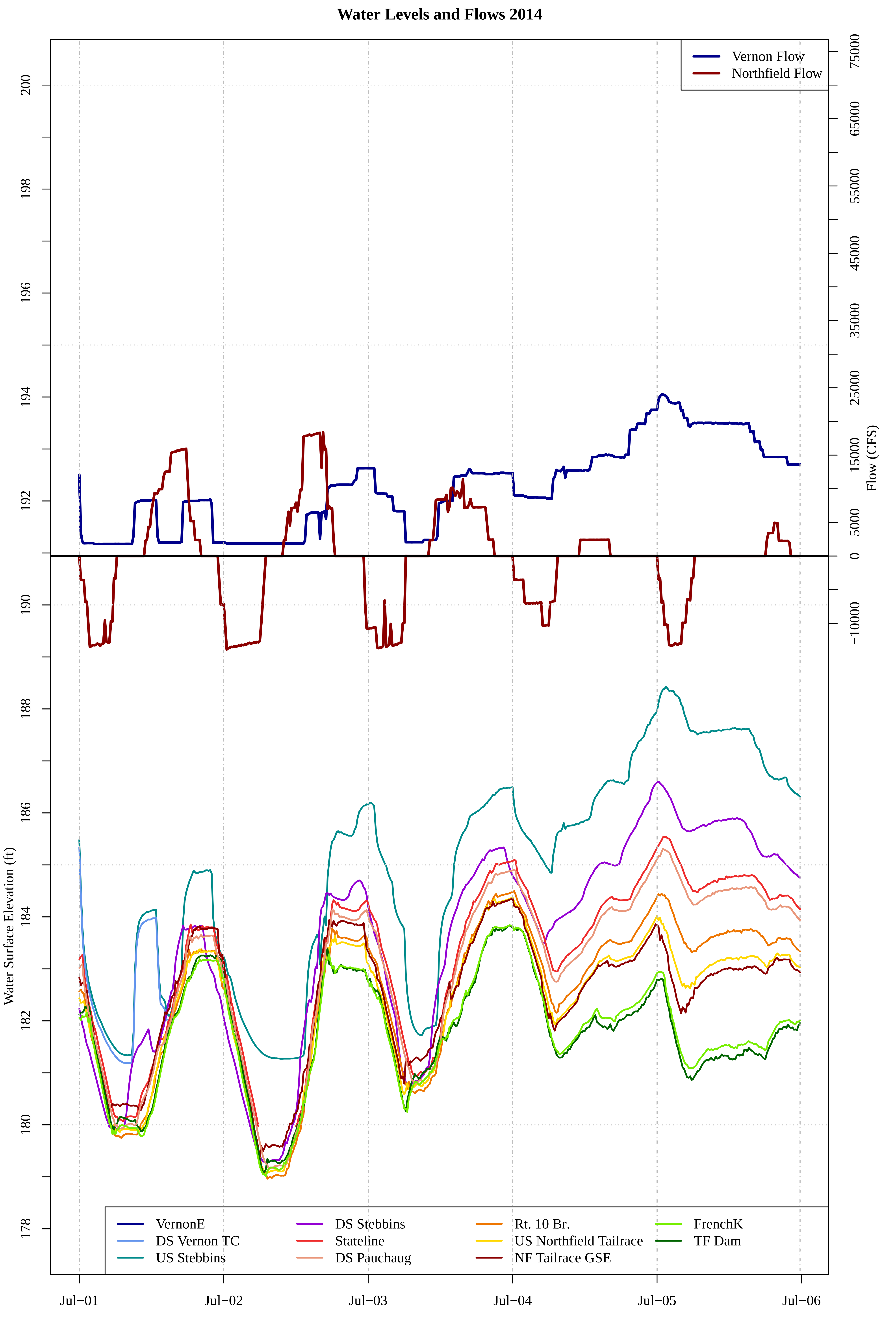
Jun−26

Water Levels and Flows 2014





Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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VernonE
DS Vernon TC
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
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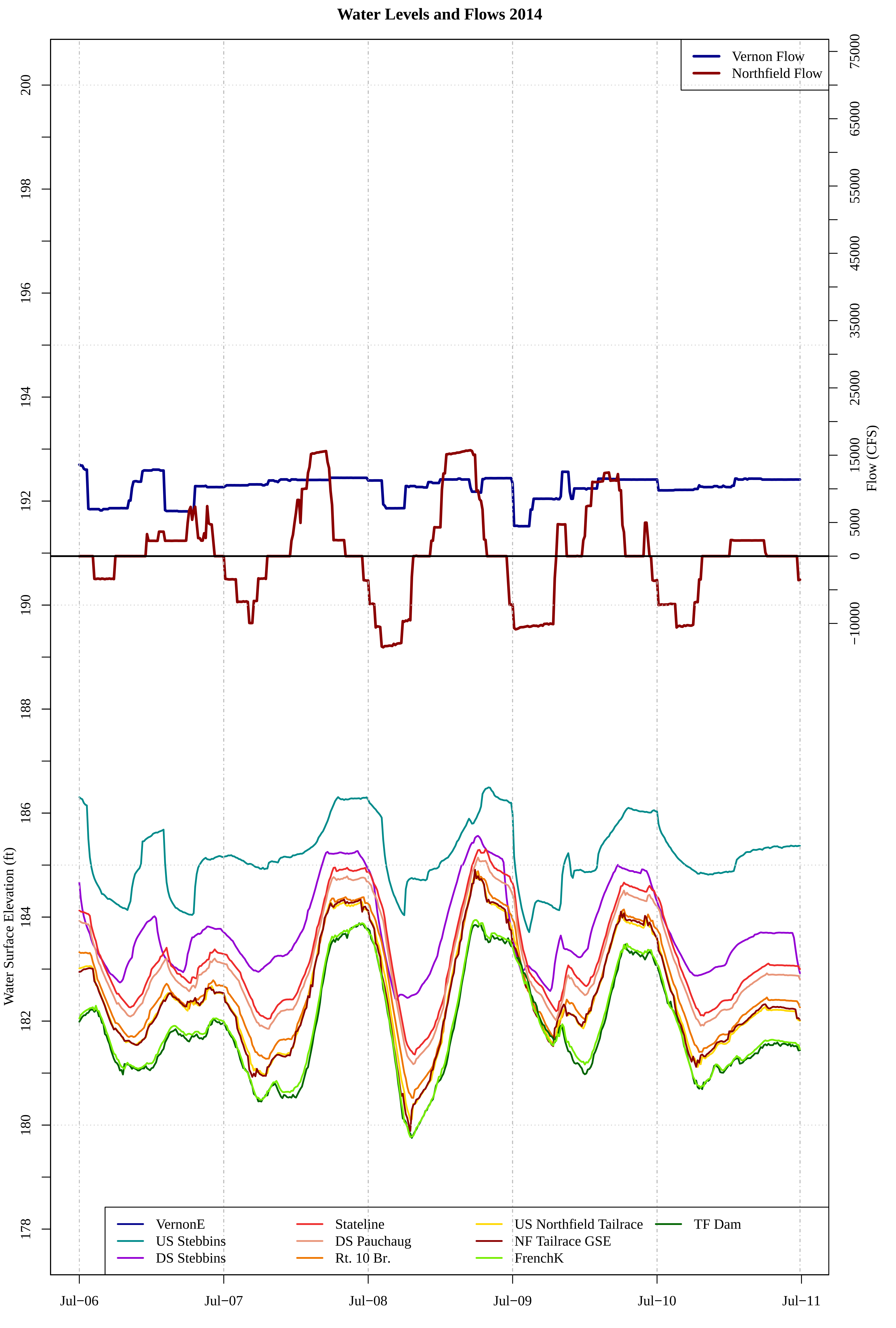
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam
Jul−06
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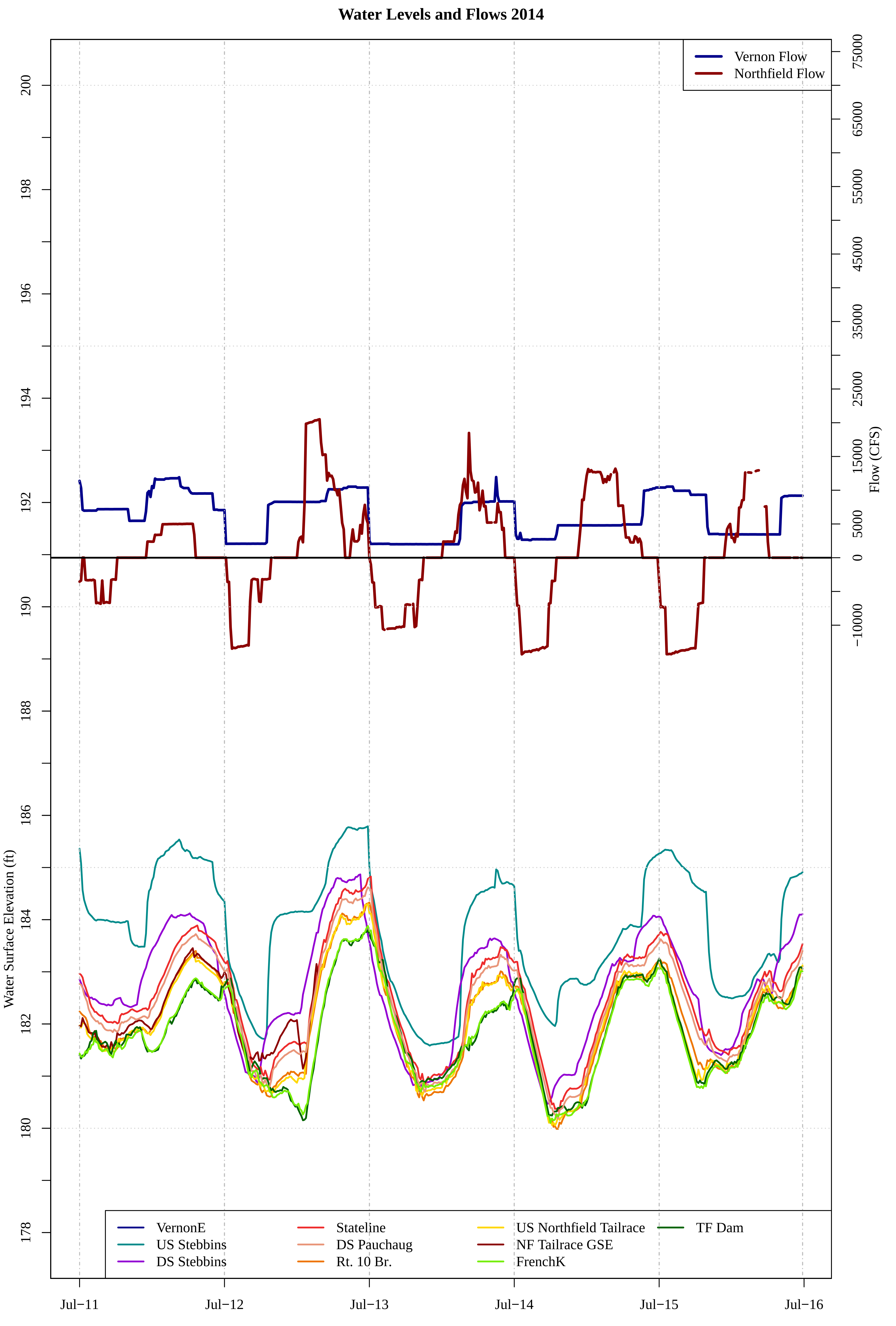
Jul−11


Water Levels and Flows 2014
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Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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DS Stebbins
Stateline
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US Northfield Tailrace
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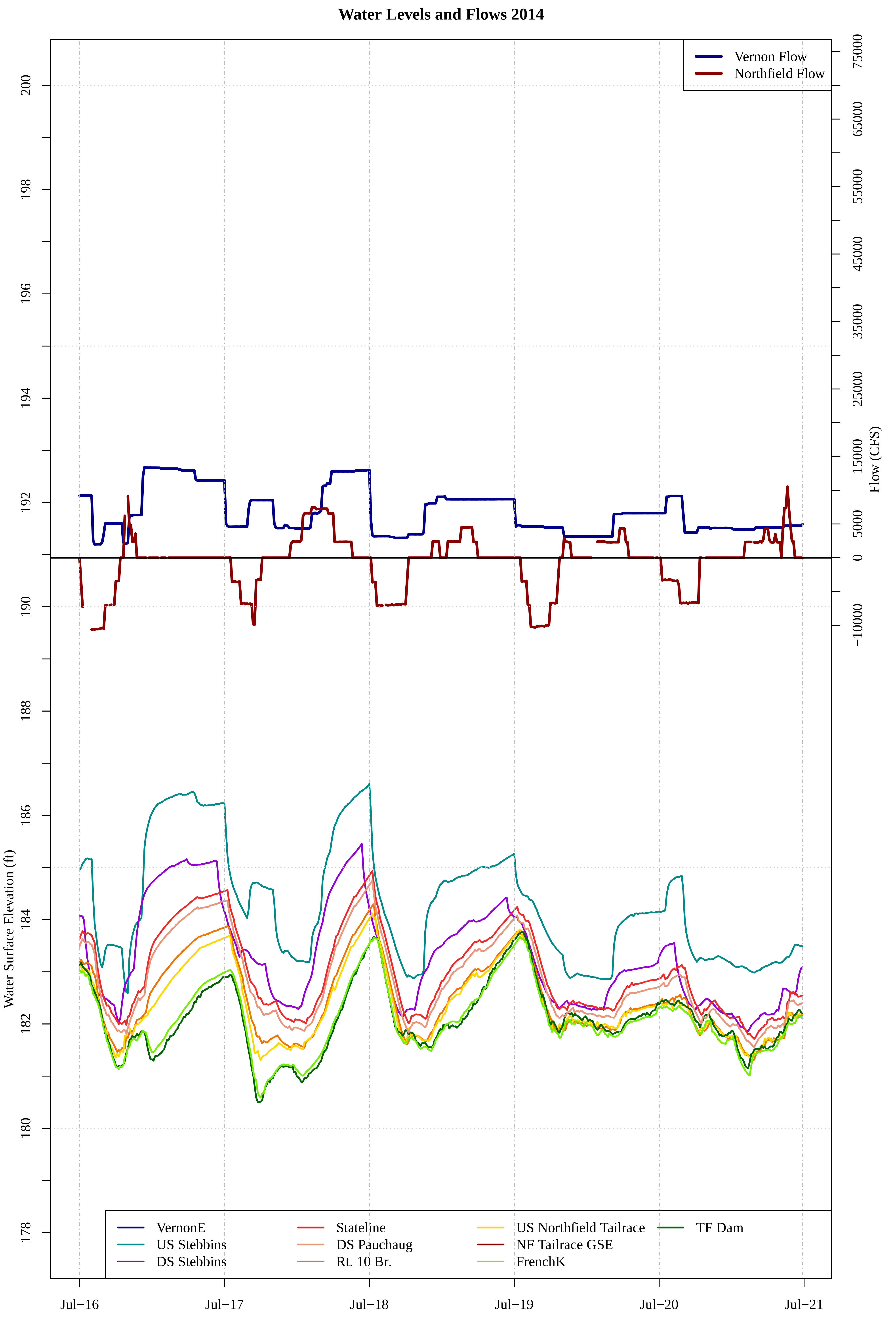
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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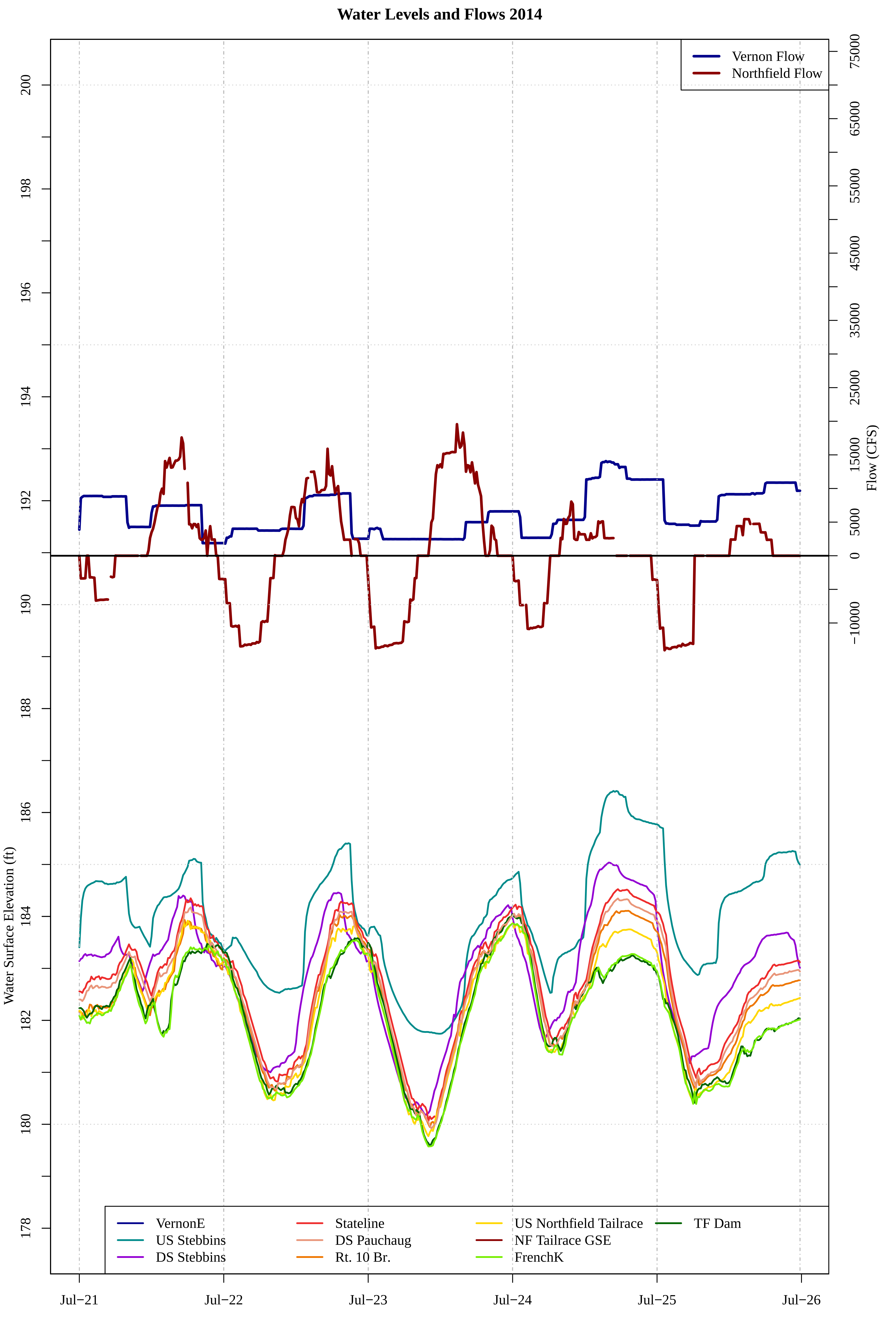

Water Levels and Flows 2014
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Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
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NF Tailrace GSE
FrenchK
TF Dam
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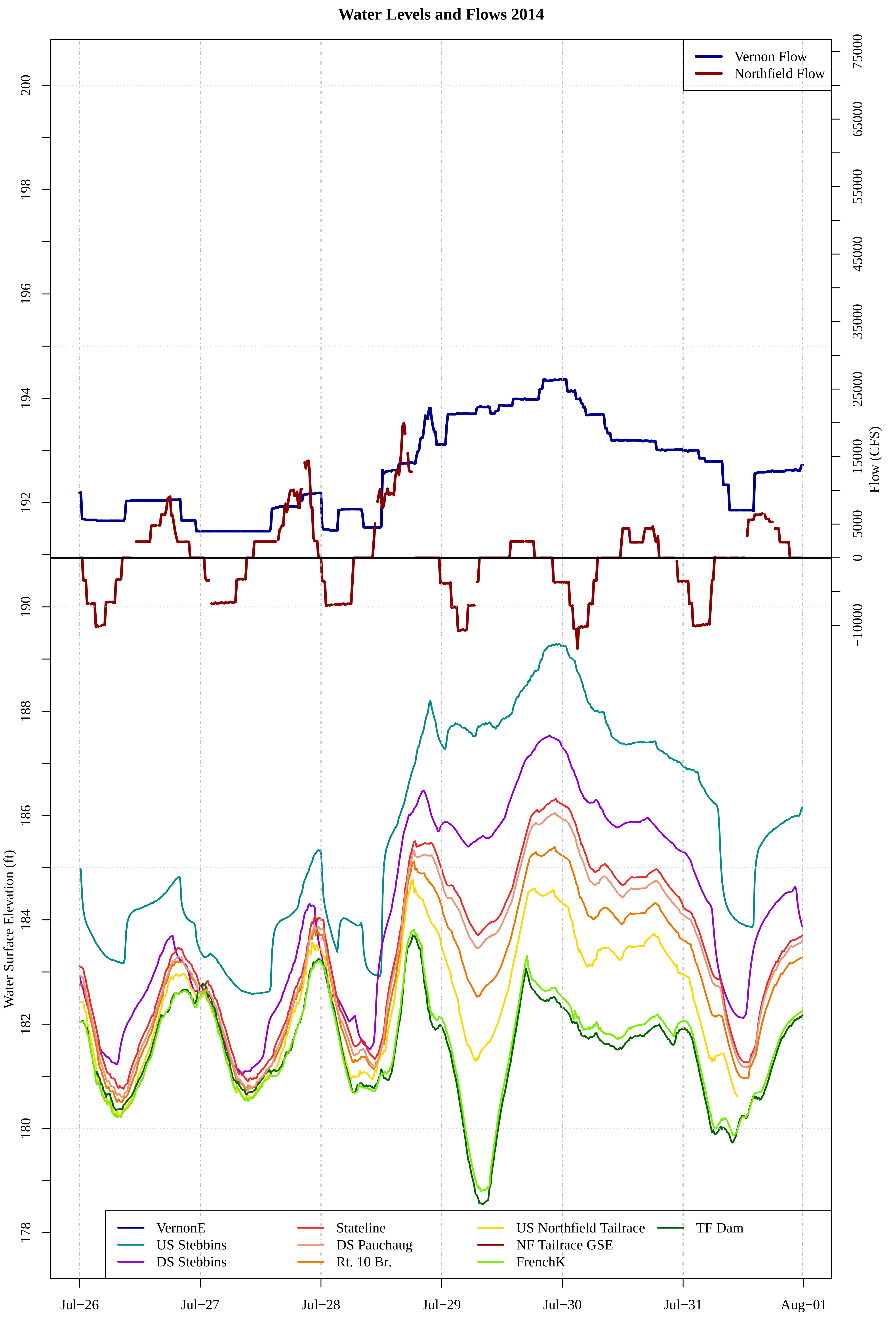

Water Levels and Flows 2014
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Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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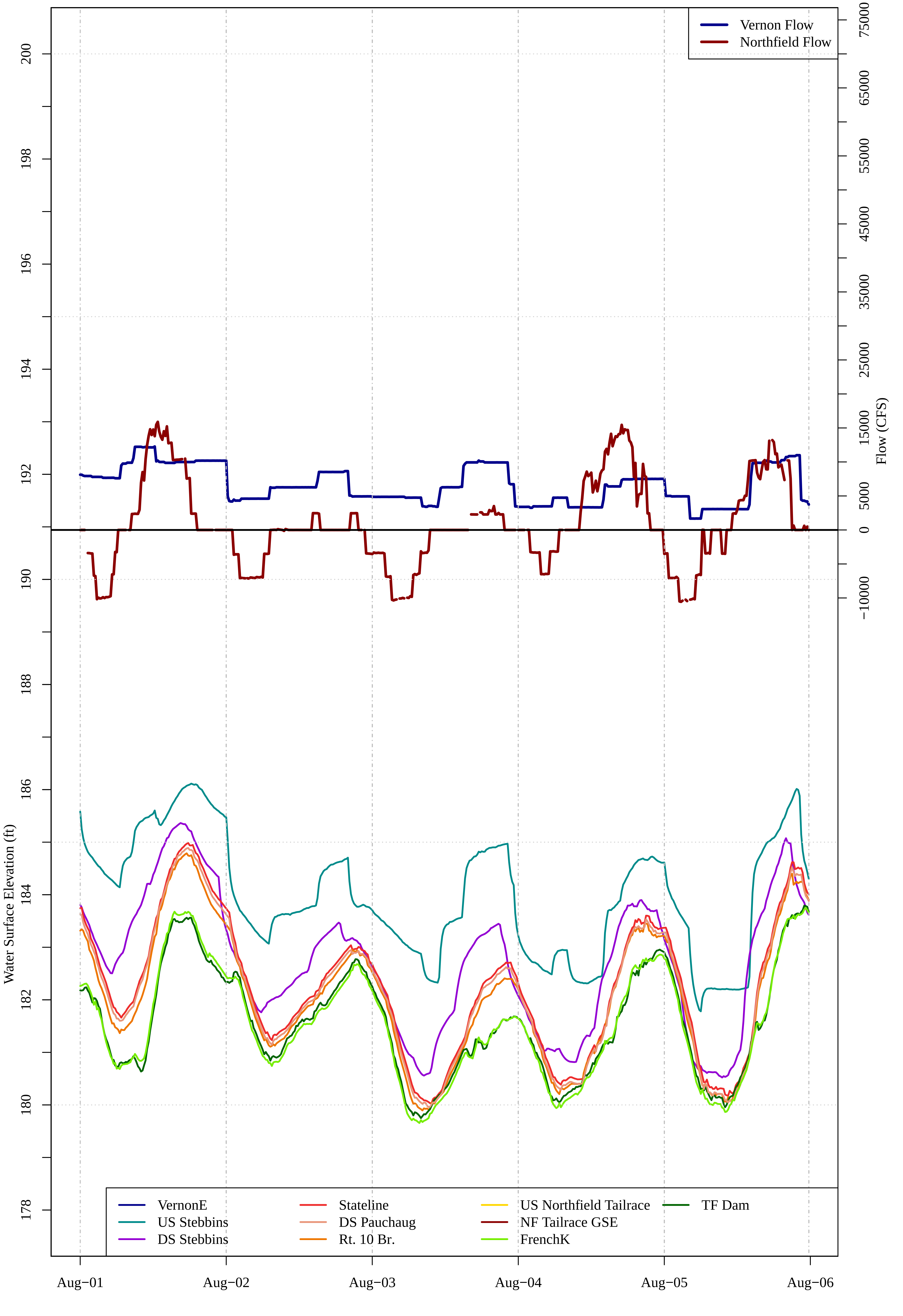
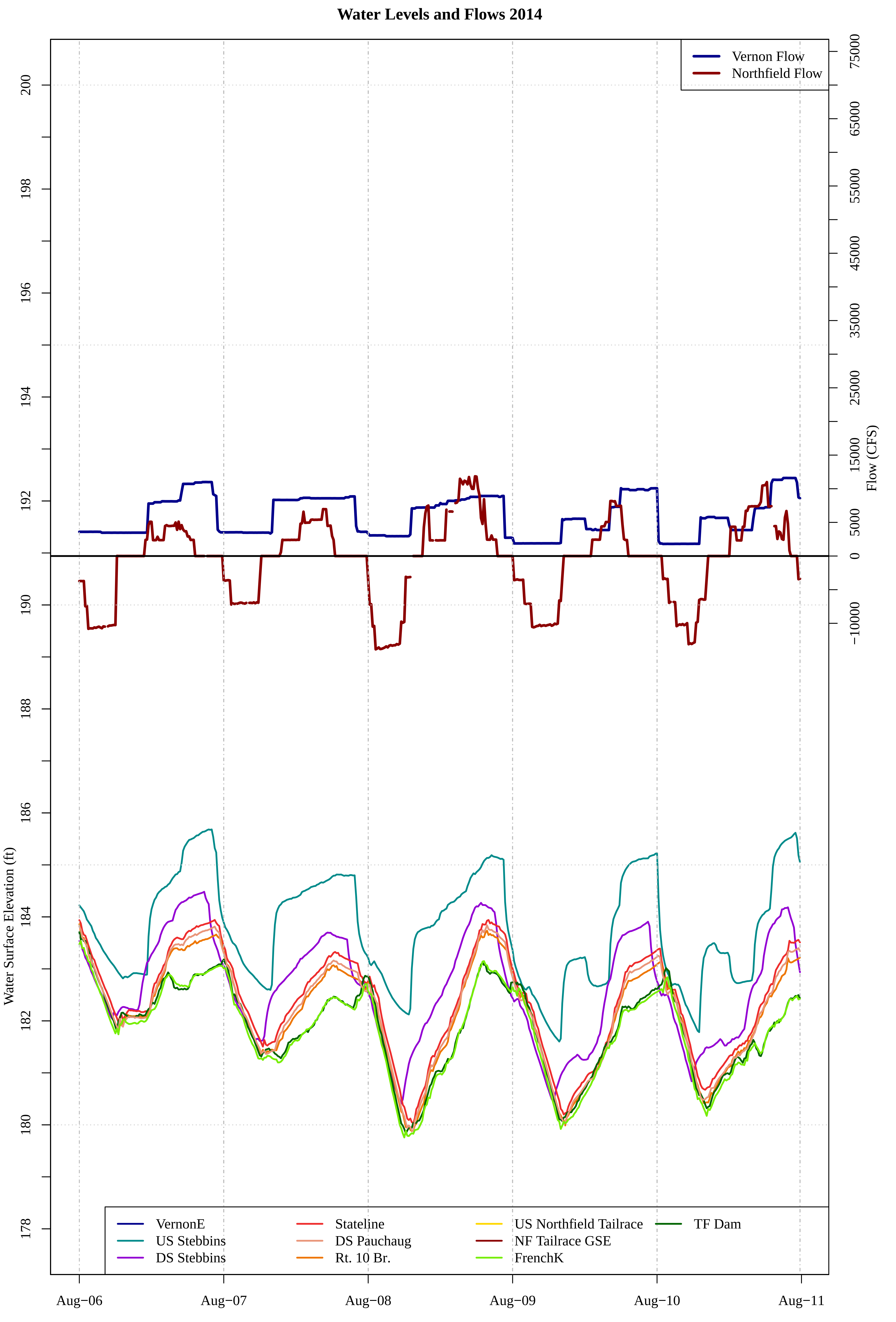
Jul−29
Jul−30
Jul−31
Aug−01
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam

Water Levels and Flows 2014




Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
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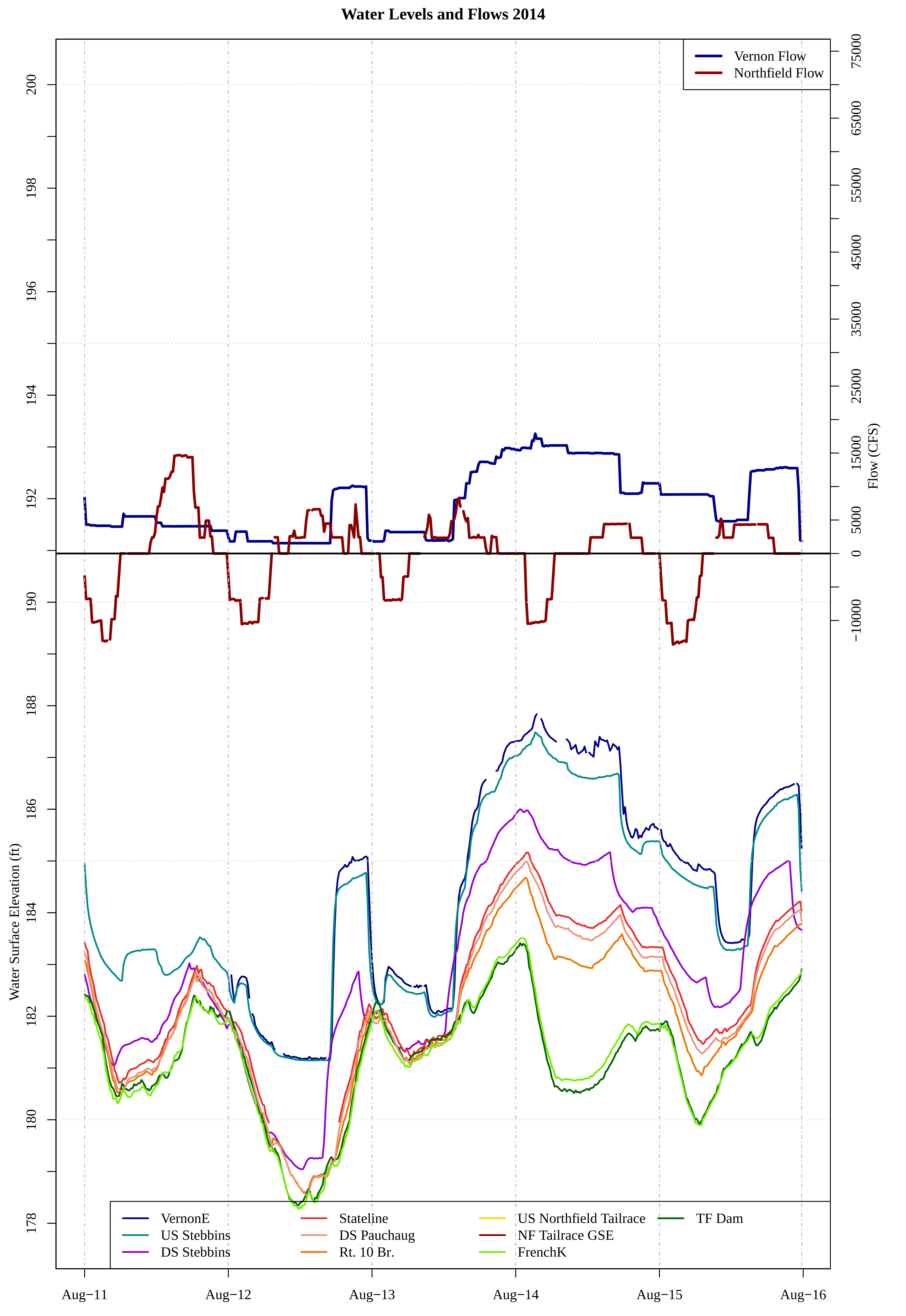
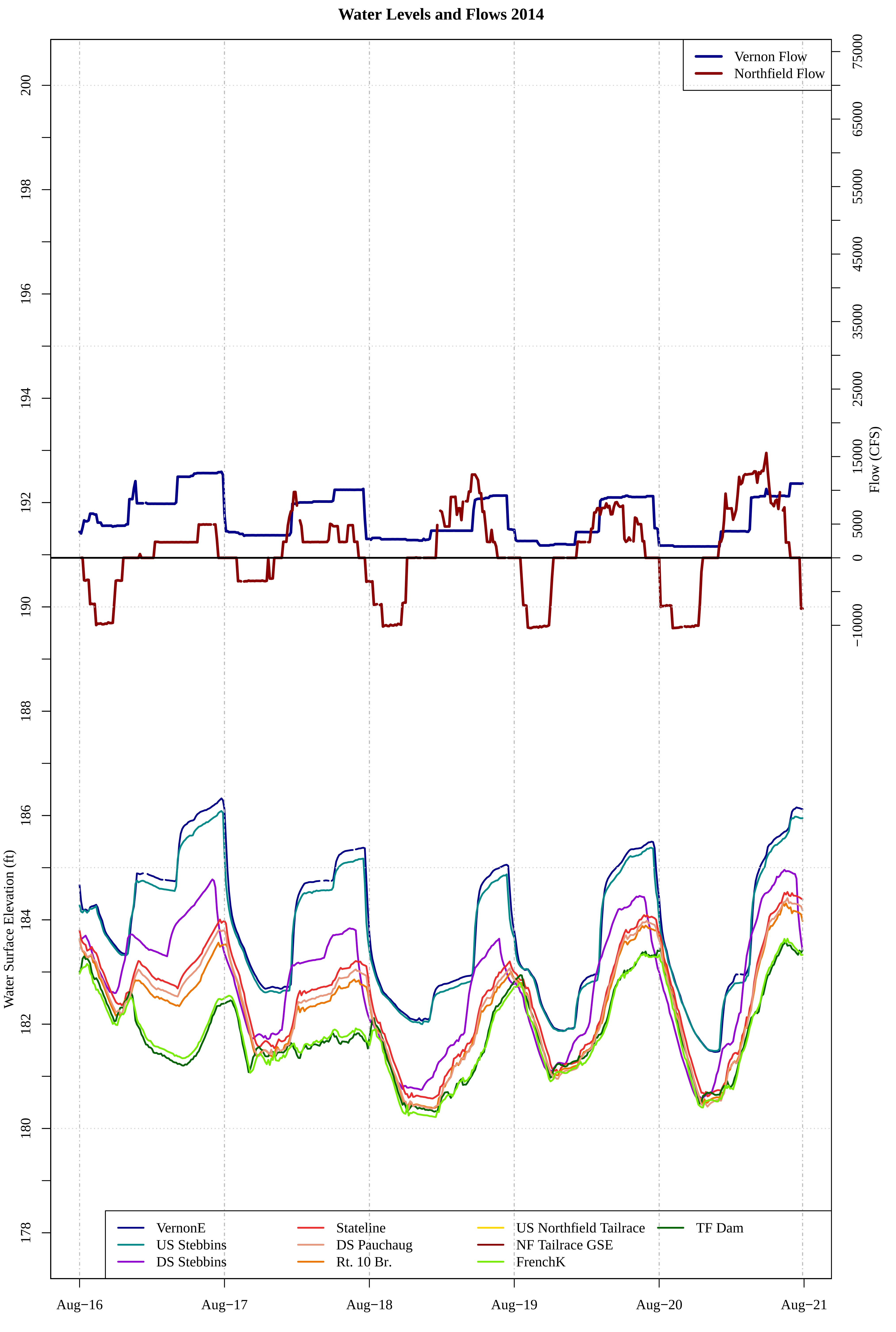
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
200
198
196
194
192
190
188
186
184
182
180
178
75000
65000
55000
45000
35000
25000
15000
5000
0
−10000
Aug−11
Aug−12
Aug−13
Aug−14
Aug−15
Aug−16
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
178
180
182
184
186
188
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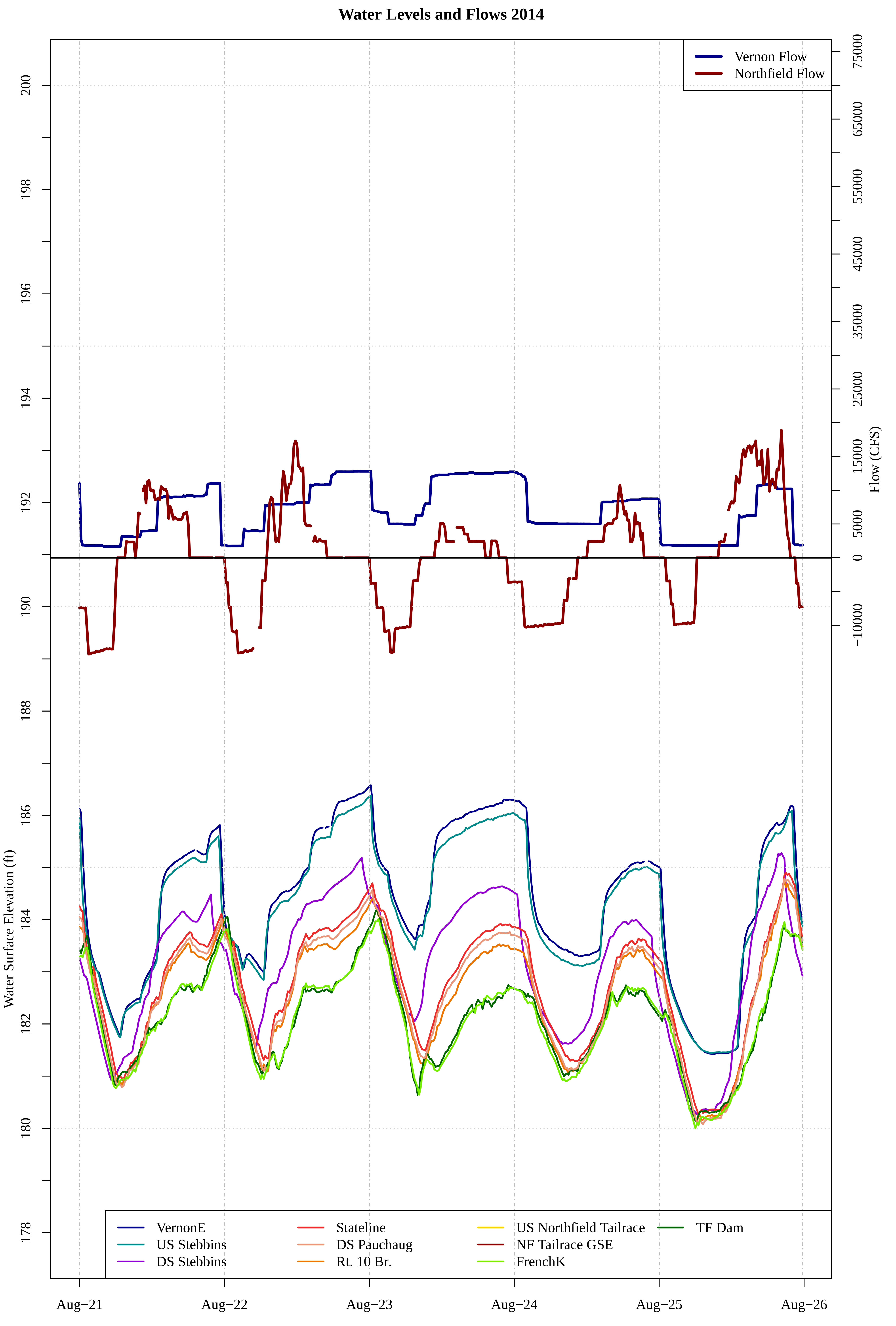
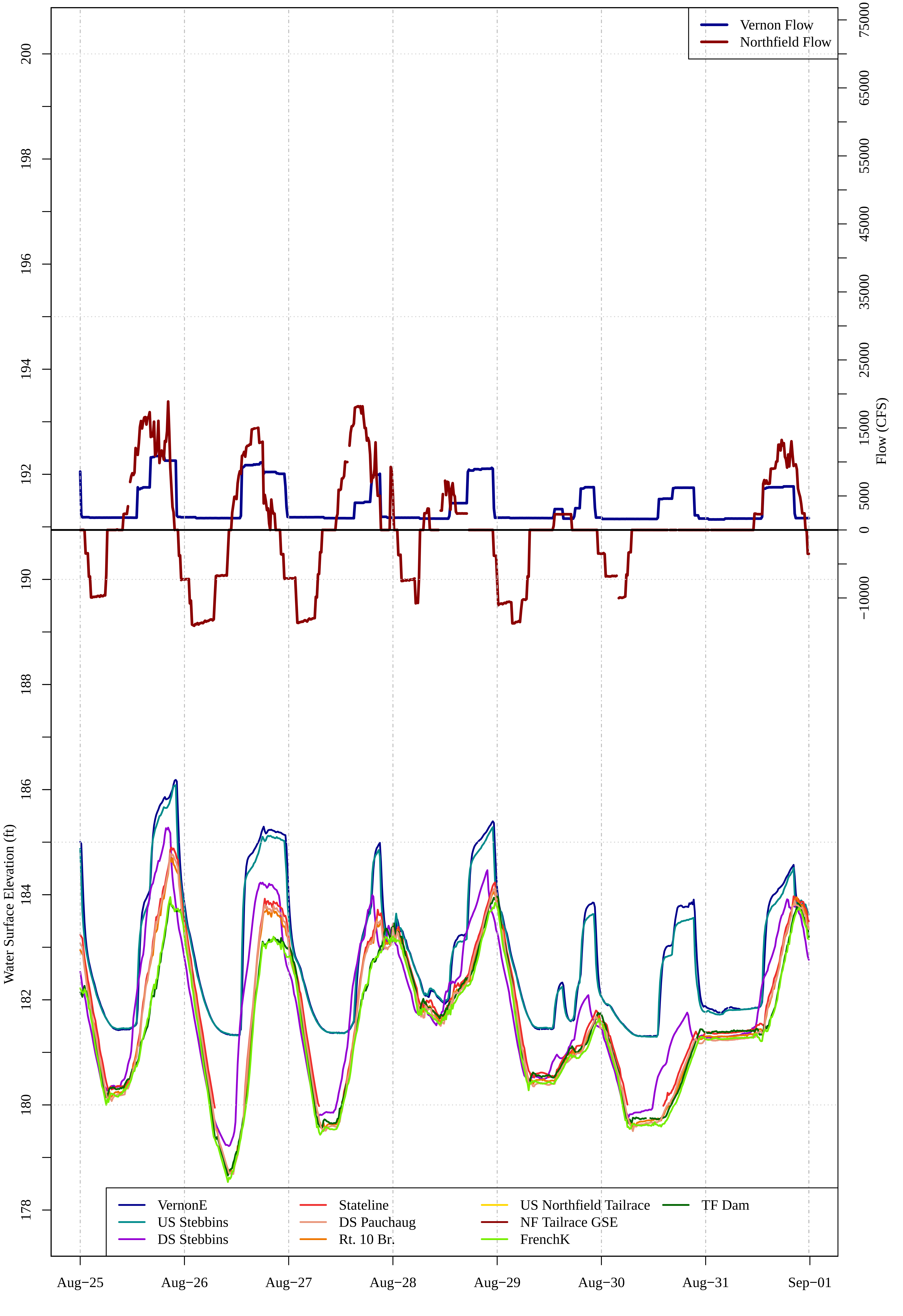
Aug−16
Aug−17
Aug−18
Aug−19
Aug−20
Aug−21
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam

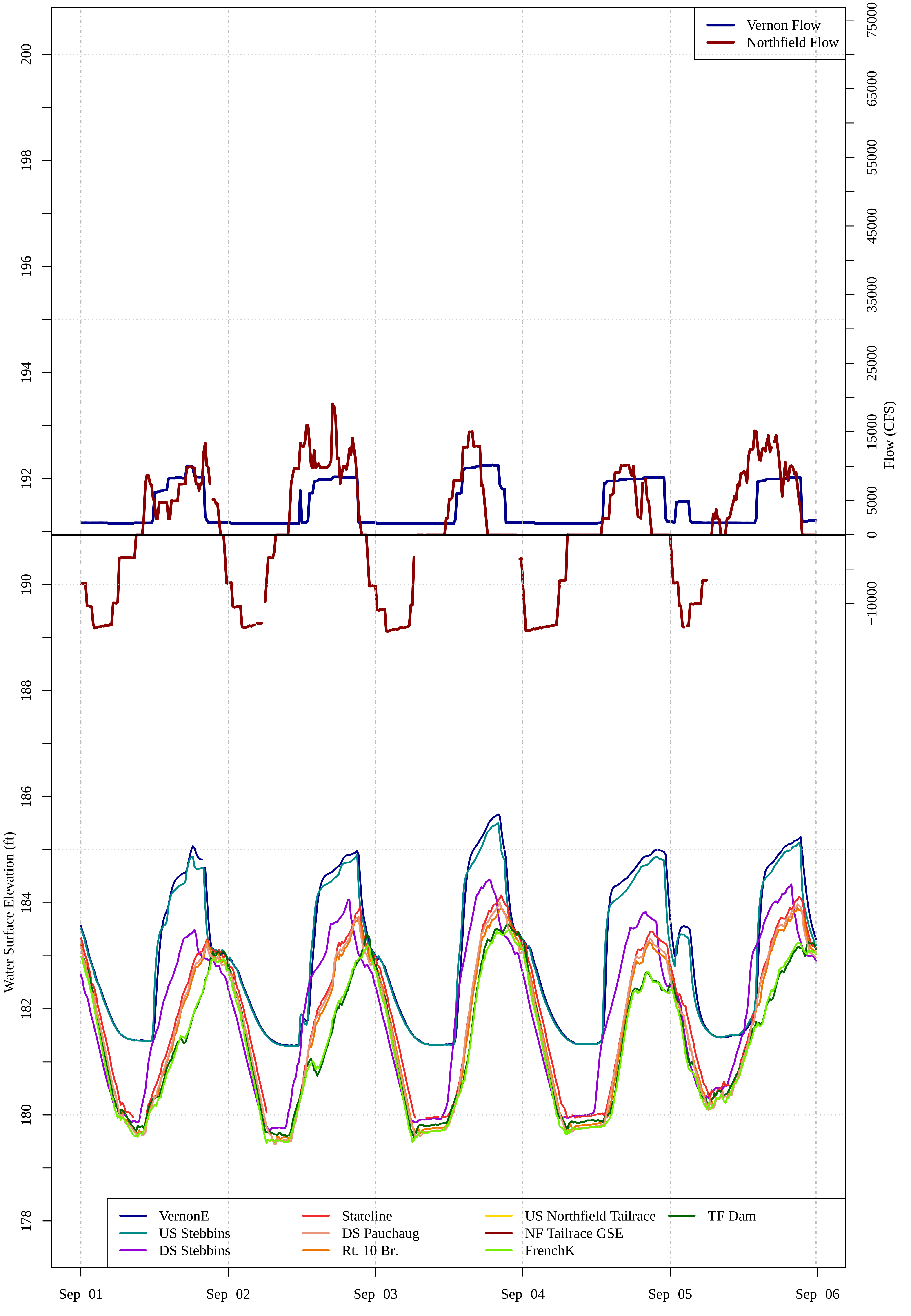


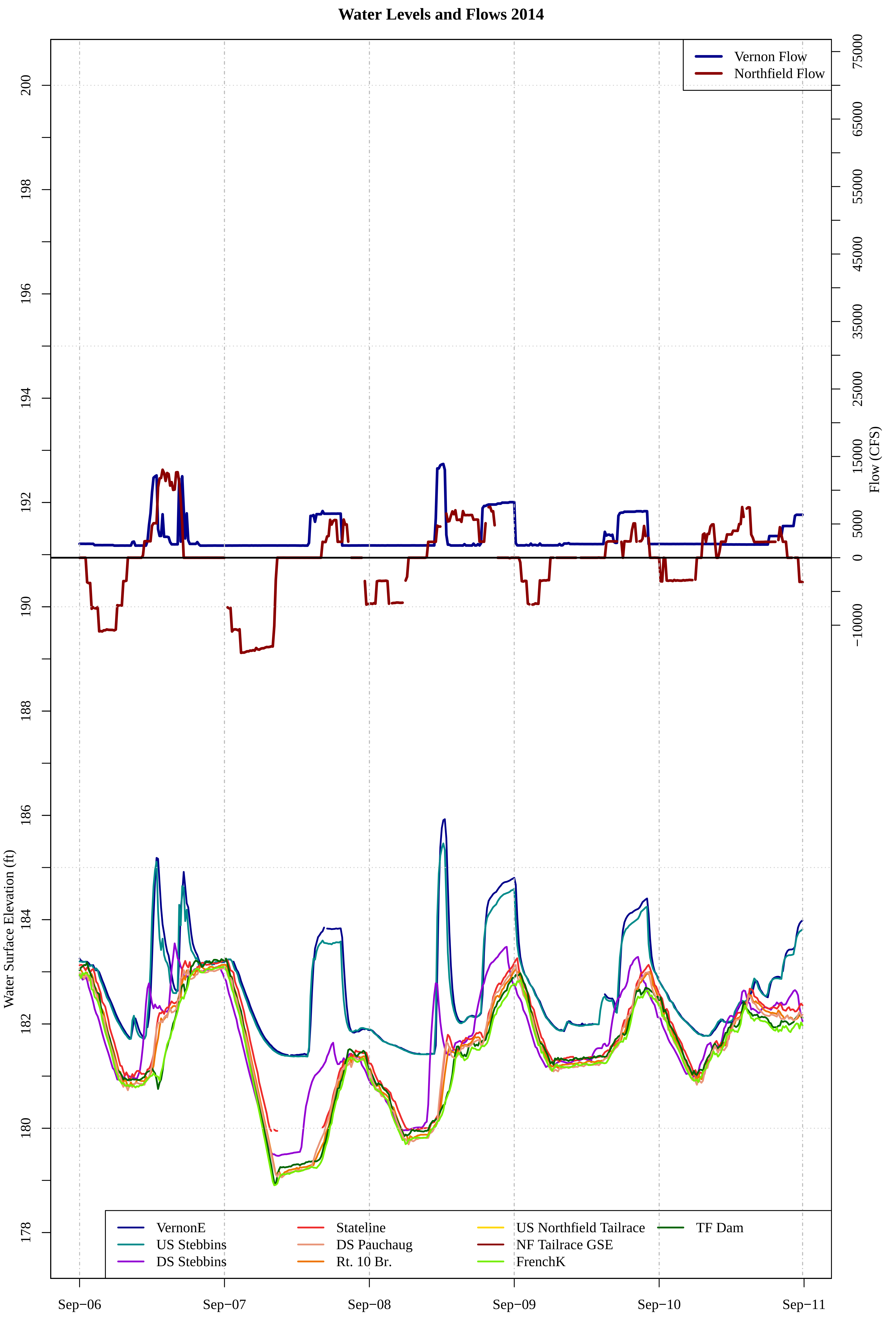
Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam
Aug−21
Aug−22
Aug−23
Aug−24
Aug−25
Aug−26

Water Levels and Flows 2014



Water Levels and Flows 2014




Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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Sep−06
Sep−07
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Sep−09
Sep−10
Sep−11
VernonE
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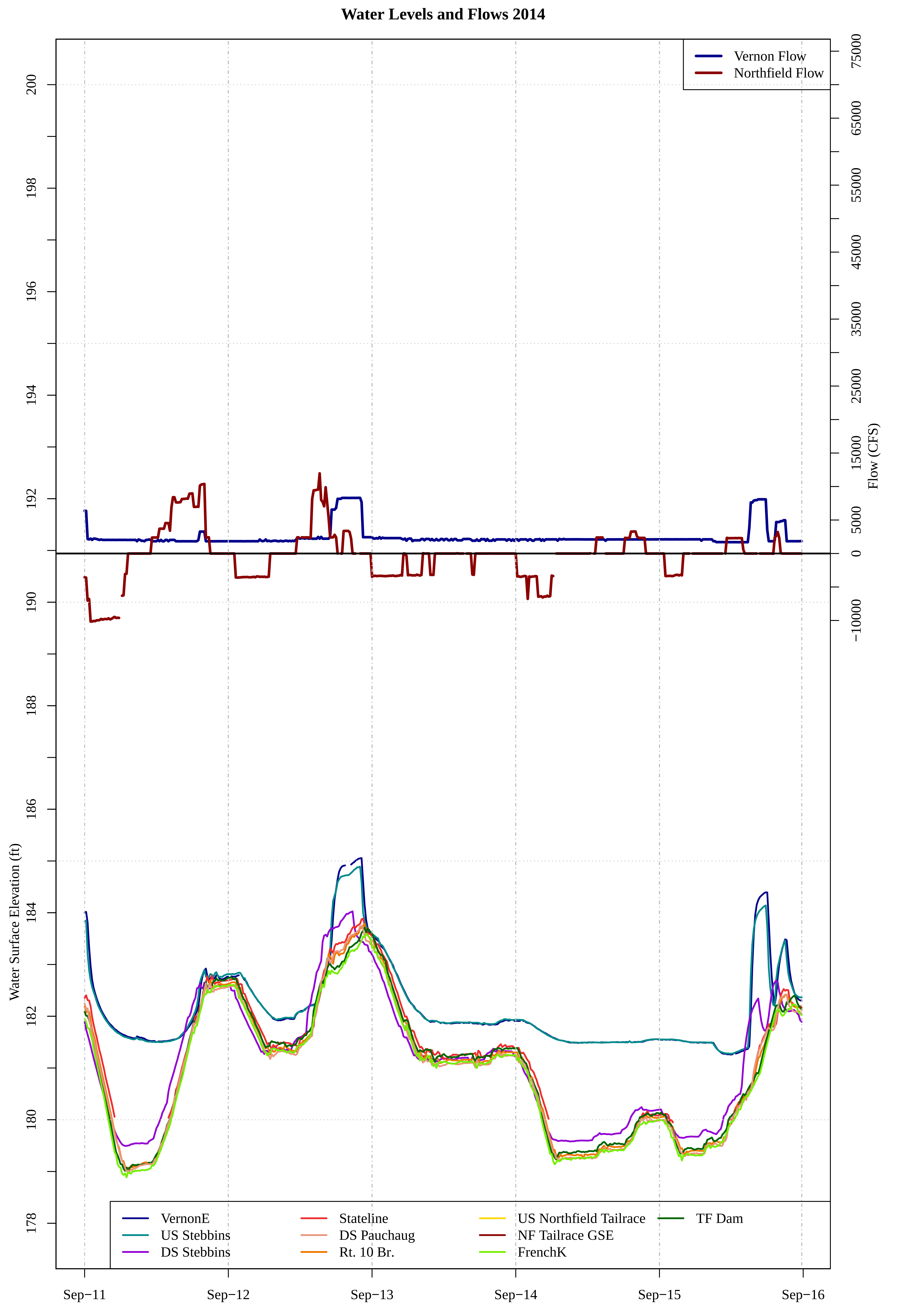
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
200
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Sep−16
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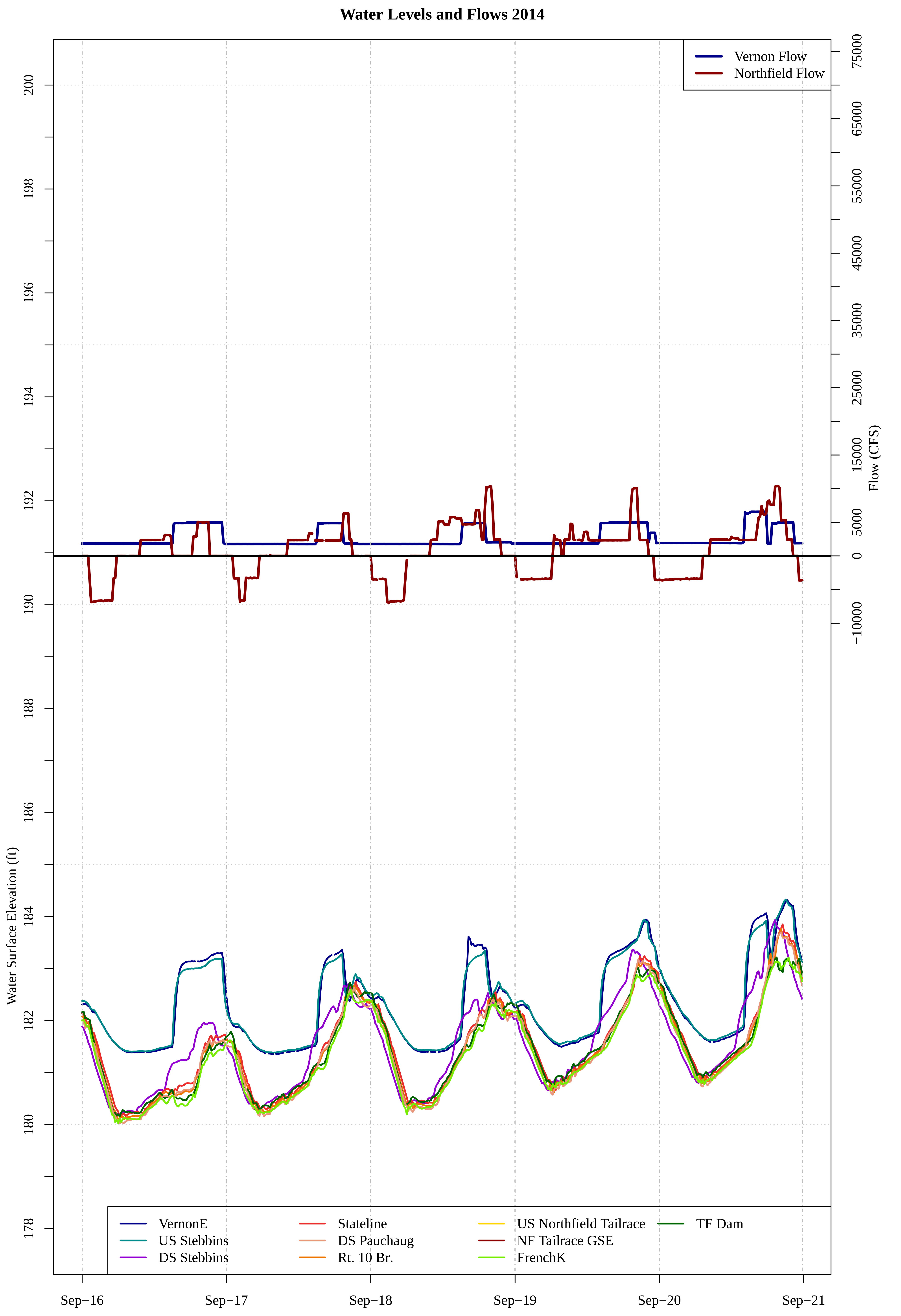
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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Sep−21
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DS Stebbins
Stateline
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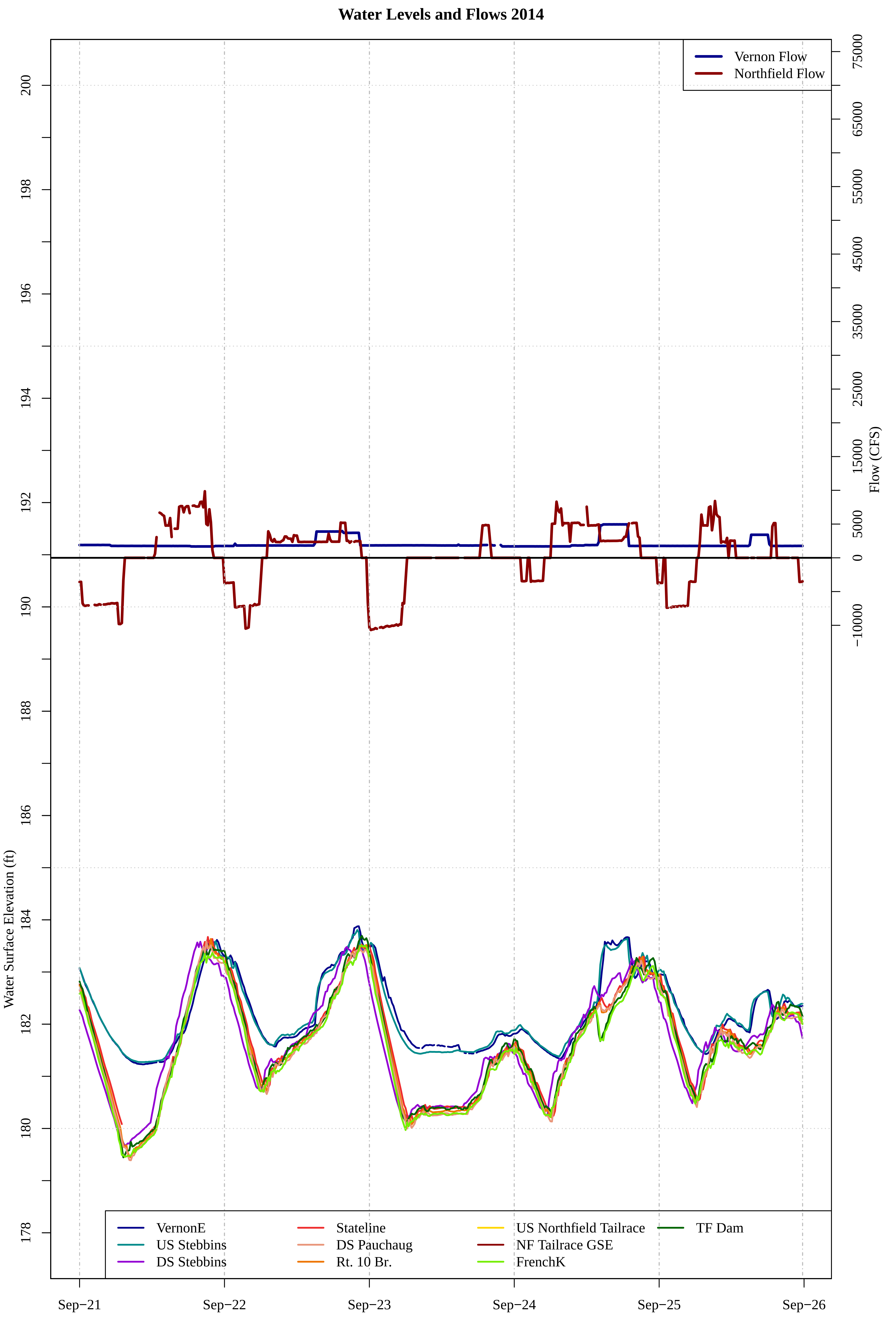
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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Sep−26
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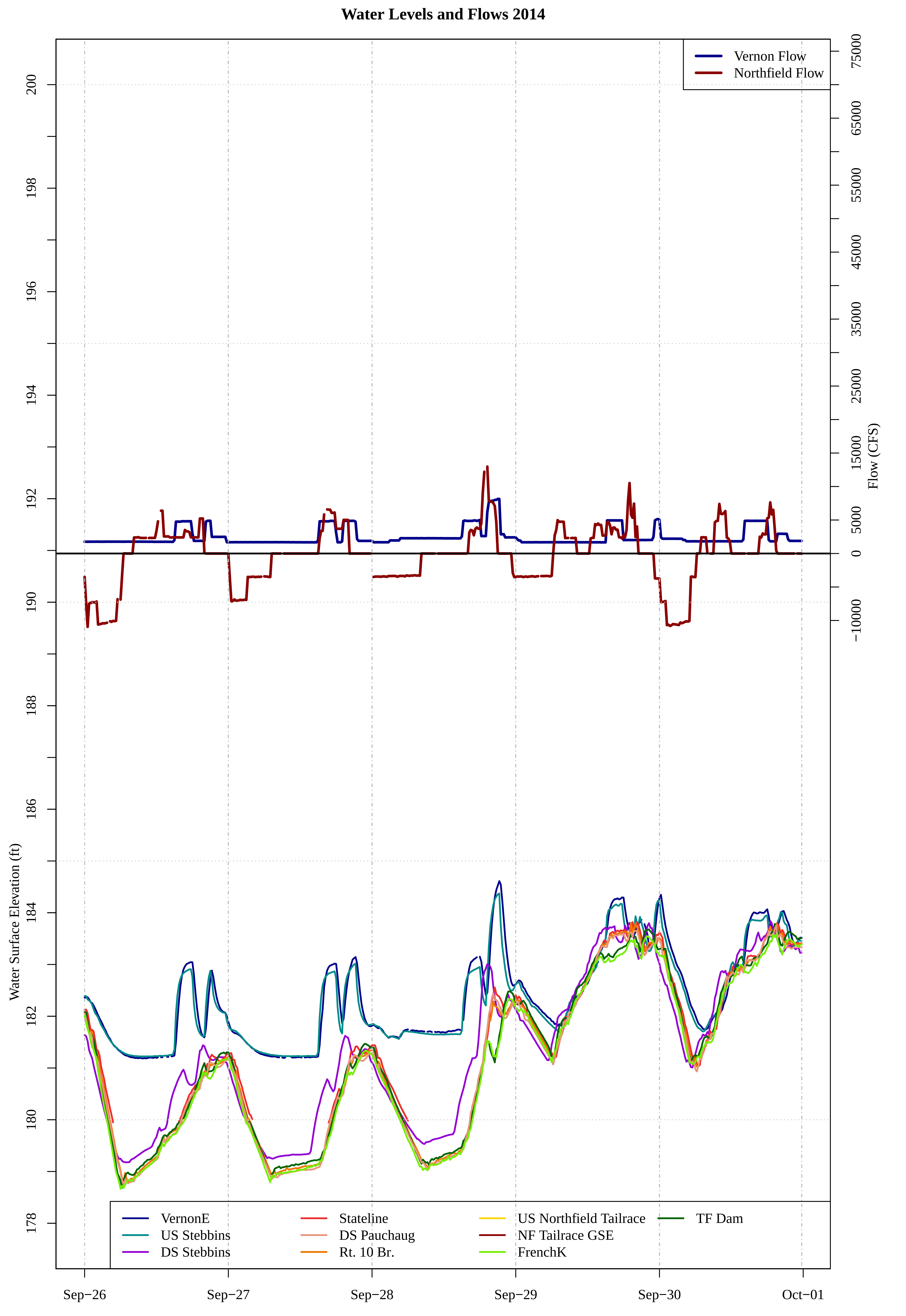
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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Sep−26
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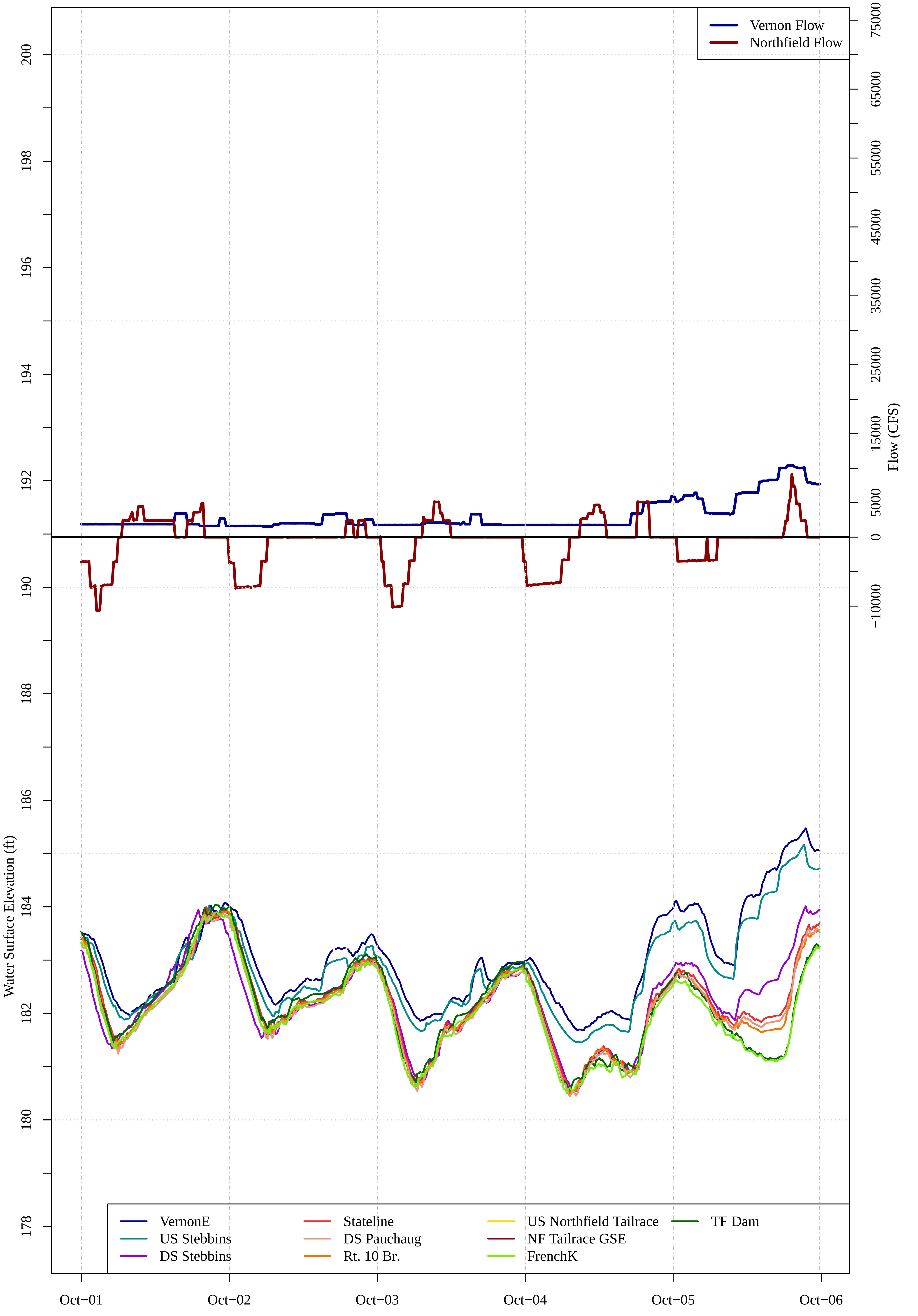
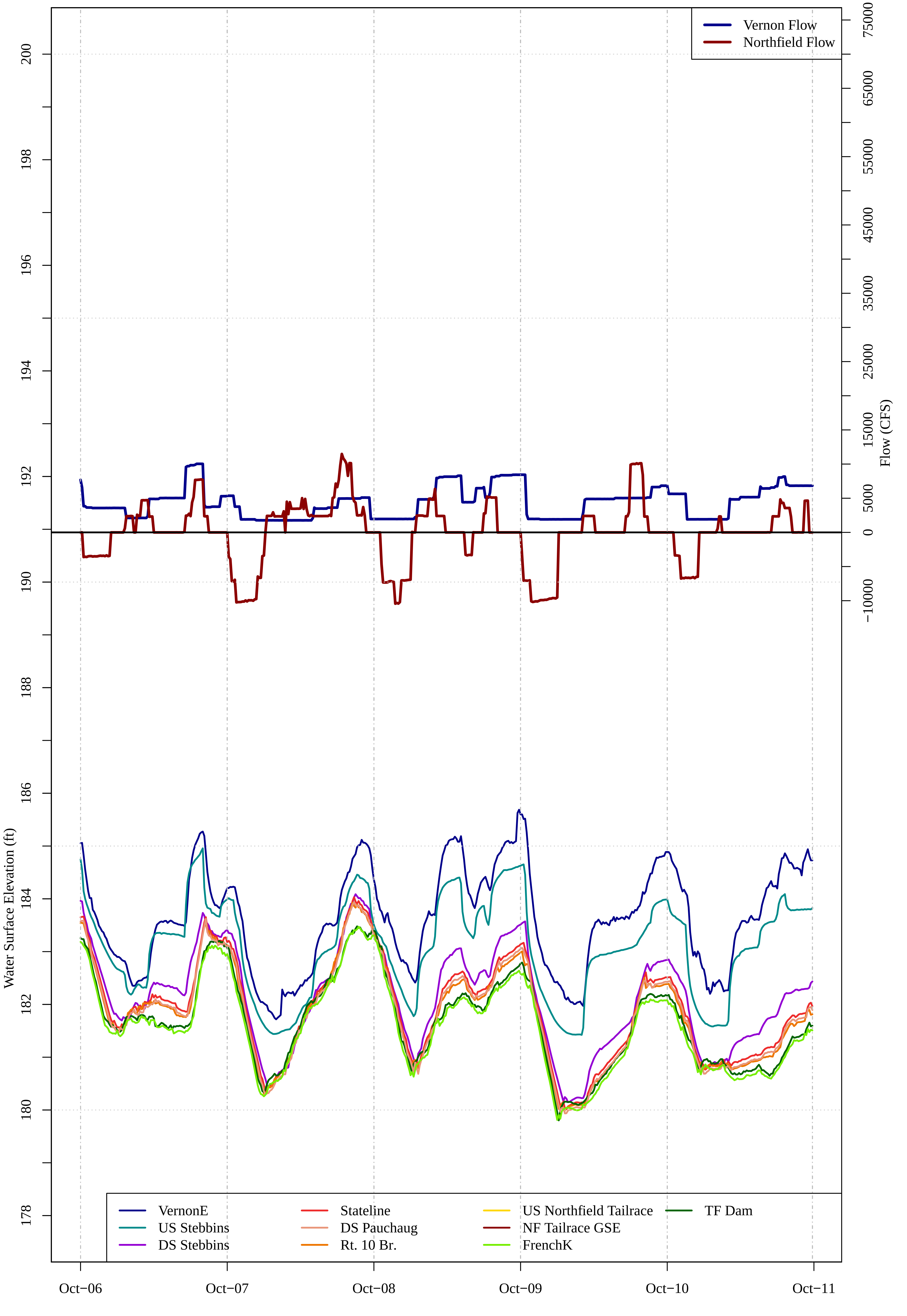
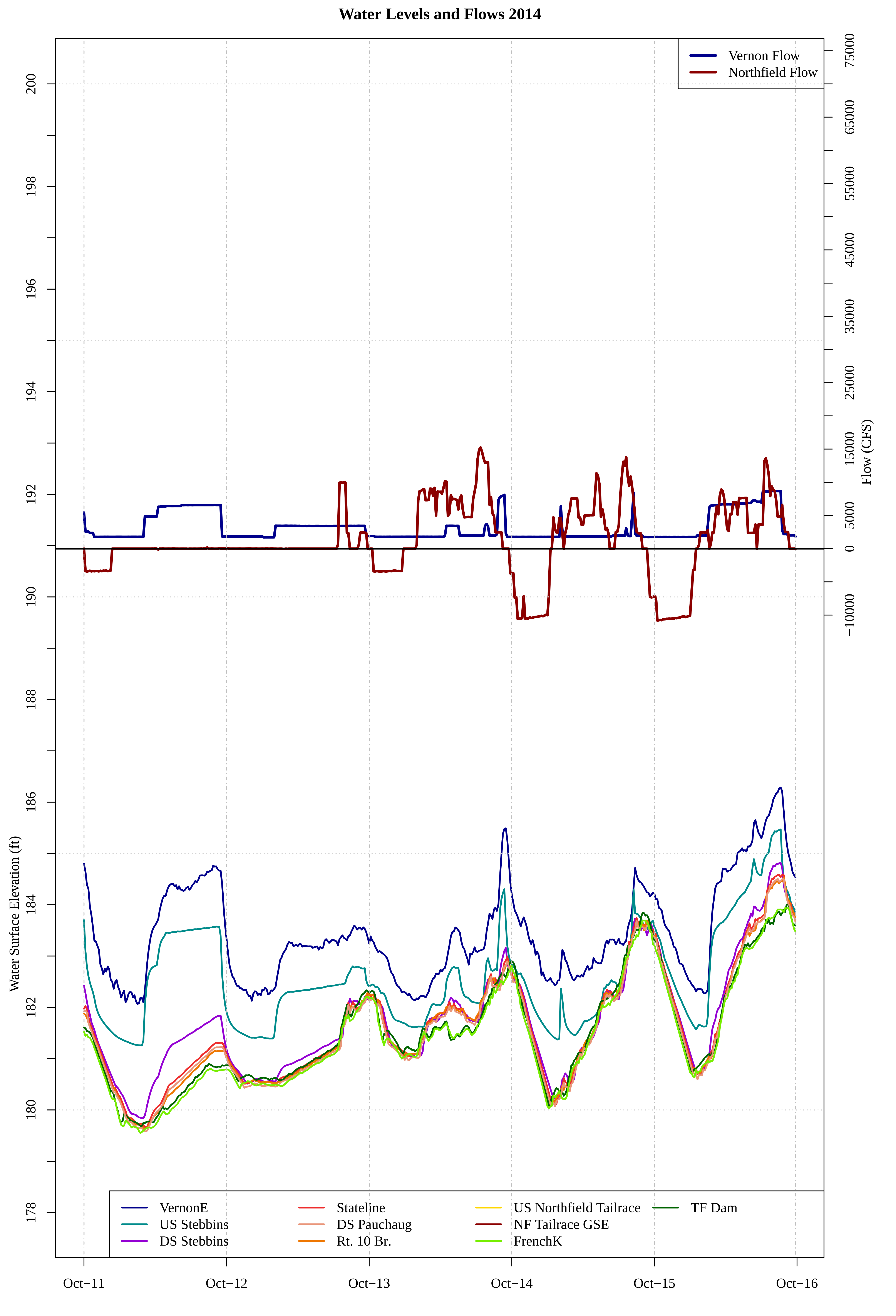
Sep−28
Sep−29
Sep−30
Oct−01
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam

Water Levels and Flows 2014



Water Levels and Flows 2014




Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
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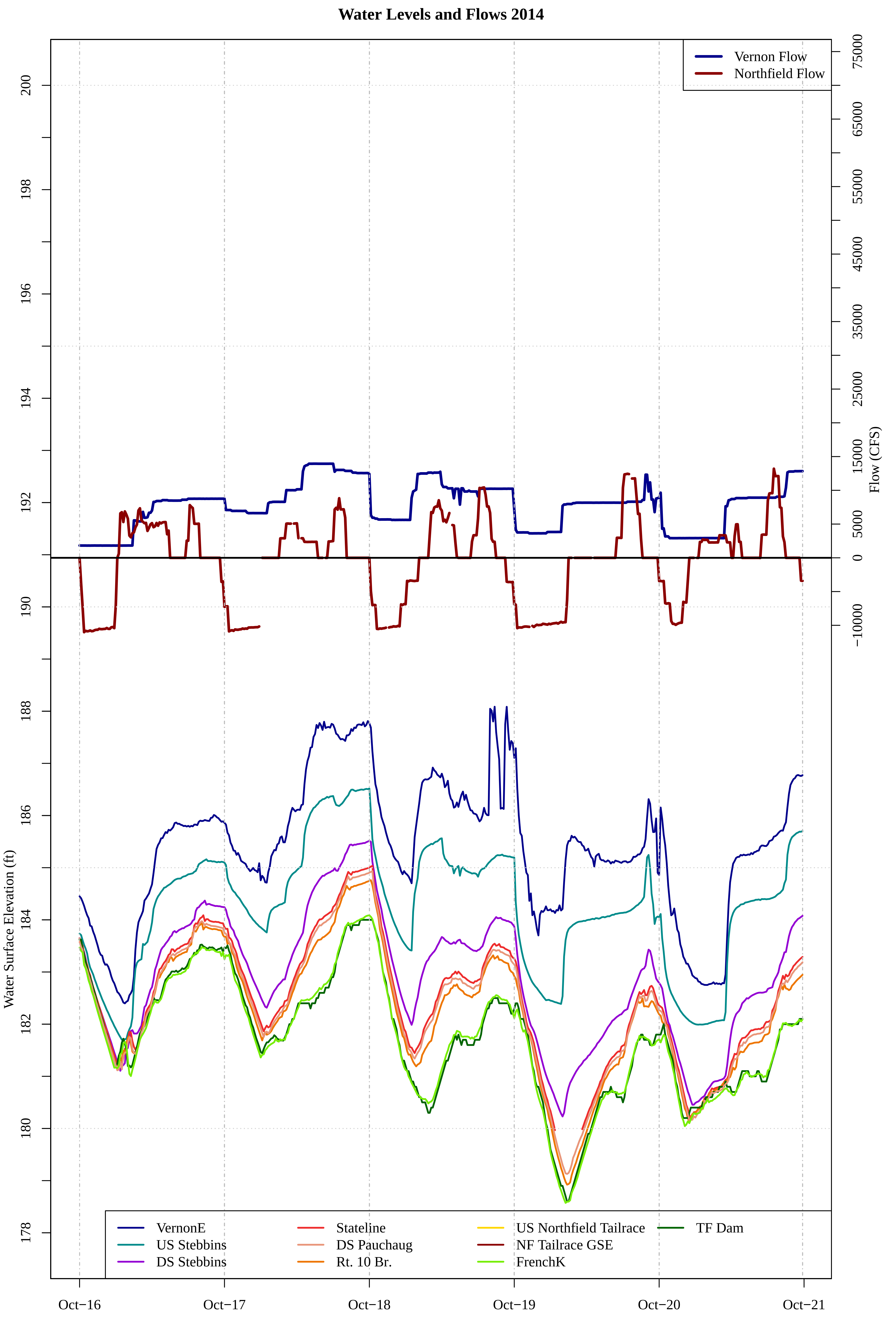
Oct−13
Oct−14
Oct−15
Oct−16
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
200
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178
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Oct−16
Oct−17
Oct−18
Oct−19
Oct−20
Oct−21
VernonE
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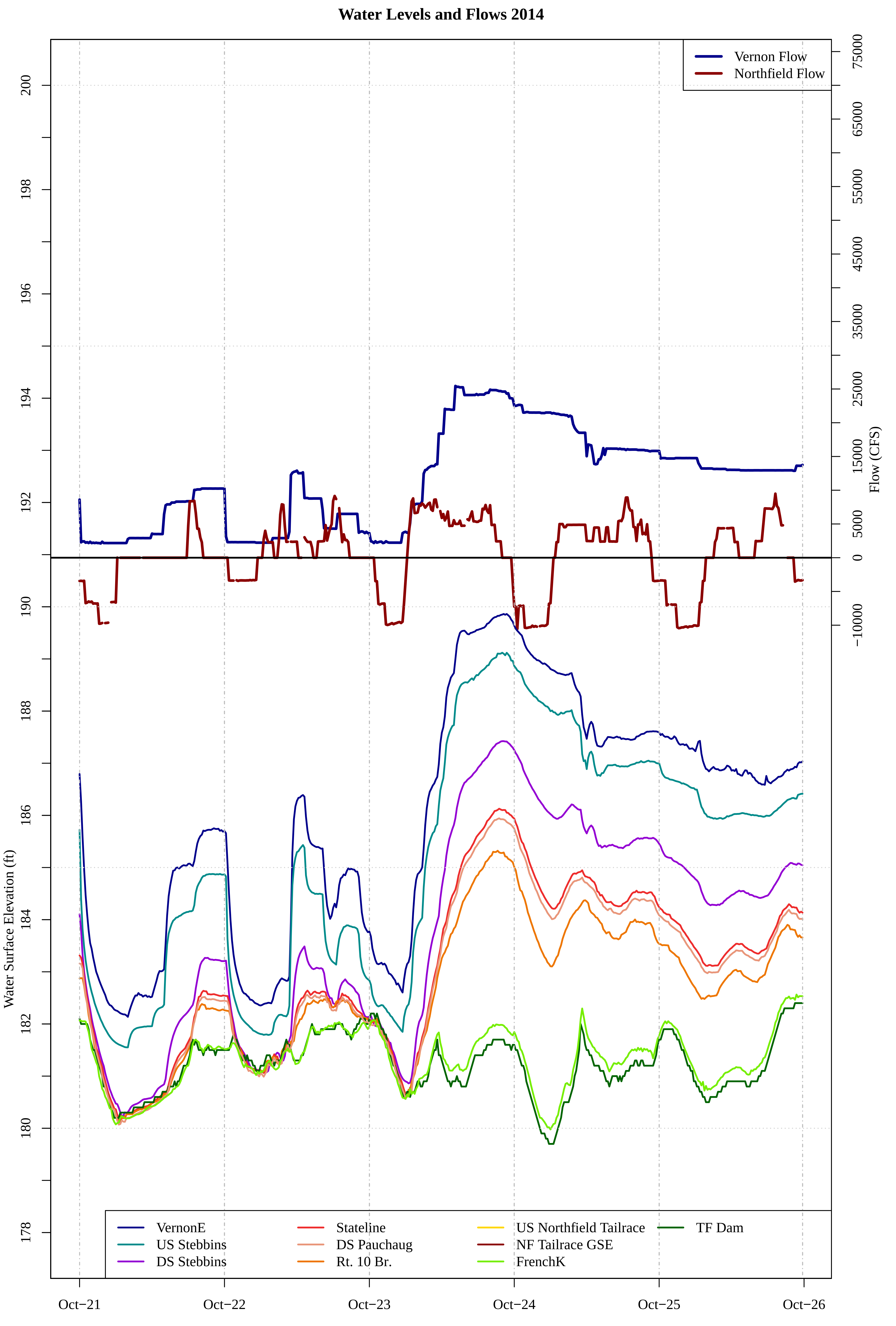
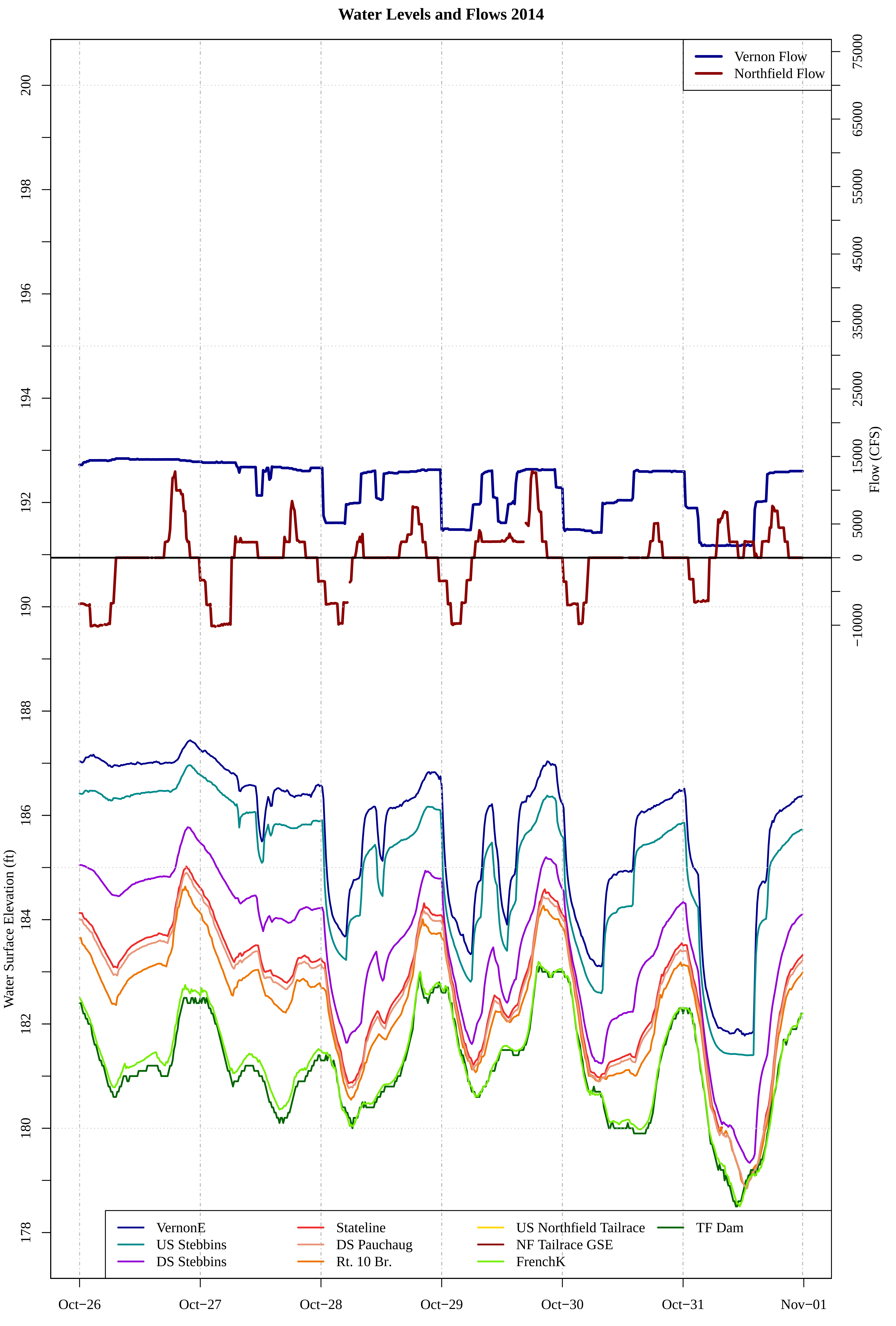
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam


Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam
Oct−21
Oct−22
Oct−23
Oct−24
Oct−25
Oct−26



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam
Oct−26
Oct−27
Oct−28
Oct−29
Oct−30
Oct−31
Nov−01
178
180
182
184
186
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192
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198
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−10000
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35000
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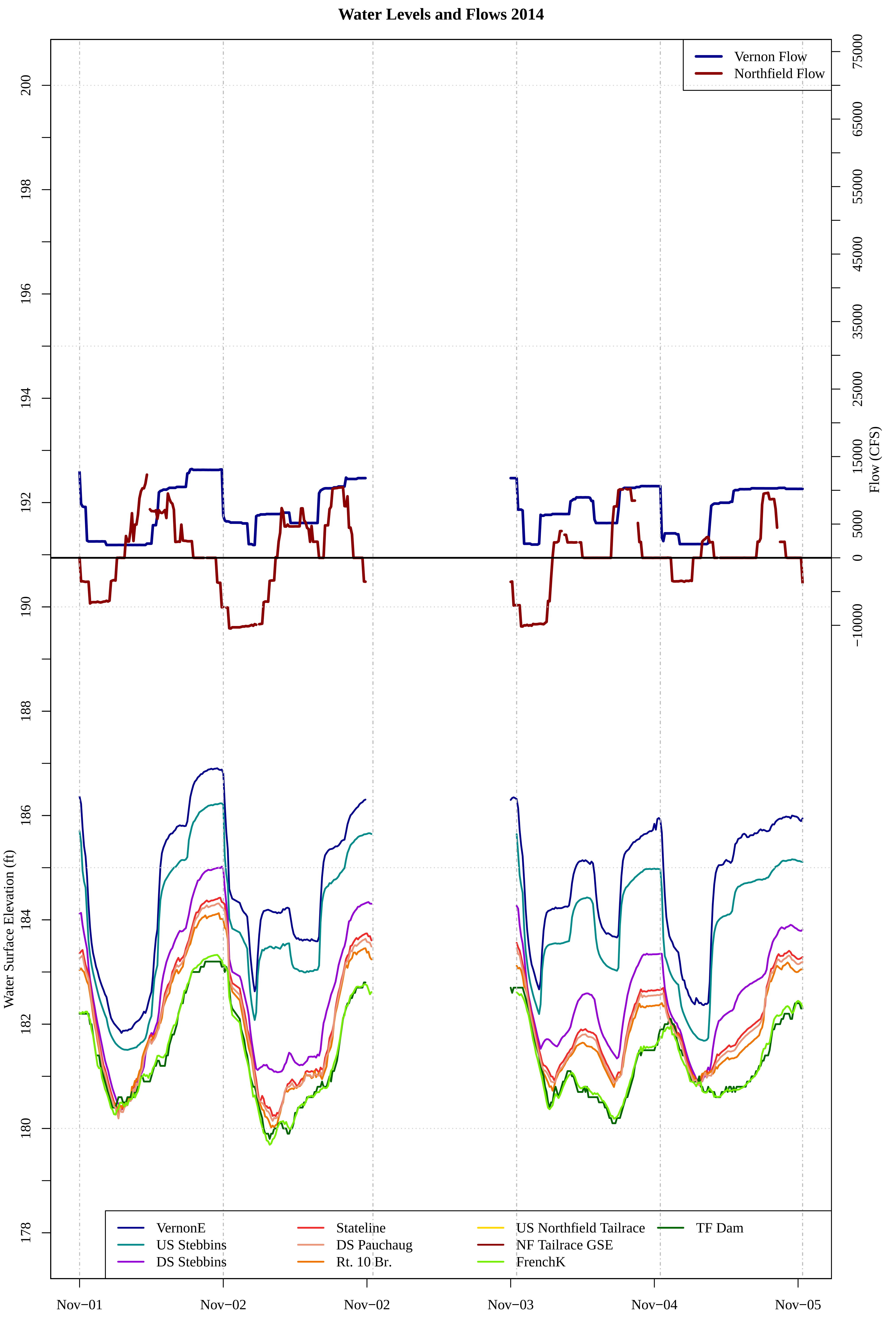
65000
75000



Water Levels and Flows 2014
Vernon Flow
Northfield Flow
Water Surface Elevation (ft)
Flow (CFS)
178
180
182
184
186
188
190
192
194
196
198
200
−10000
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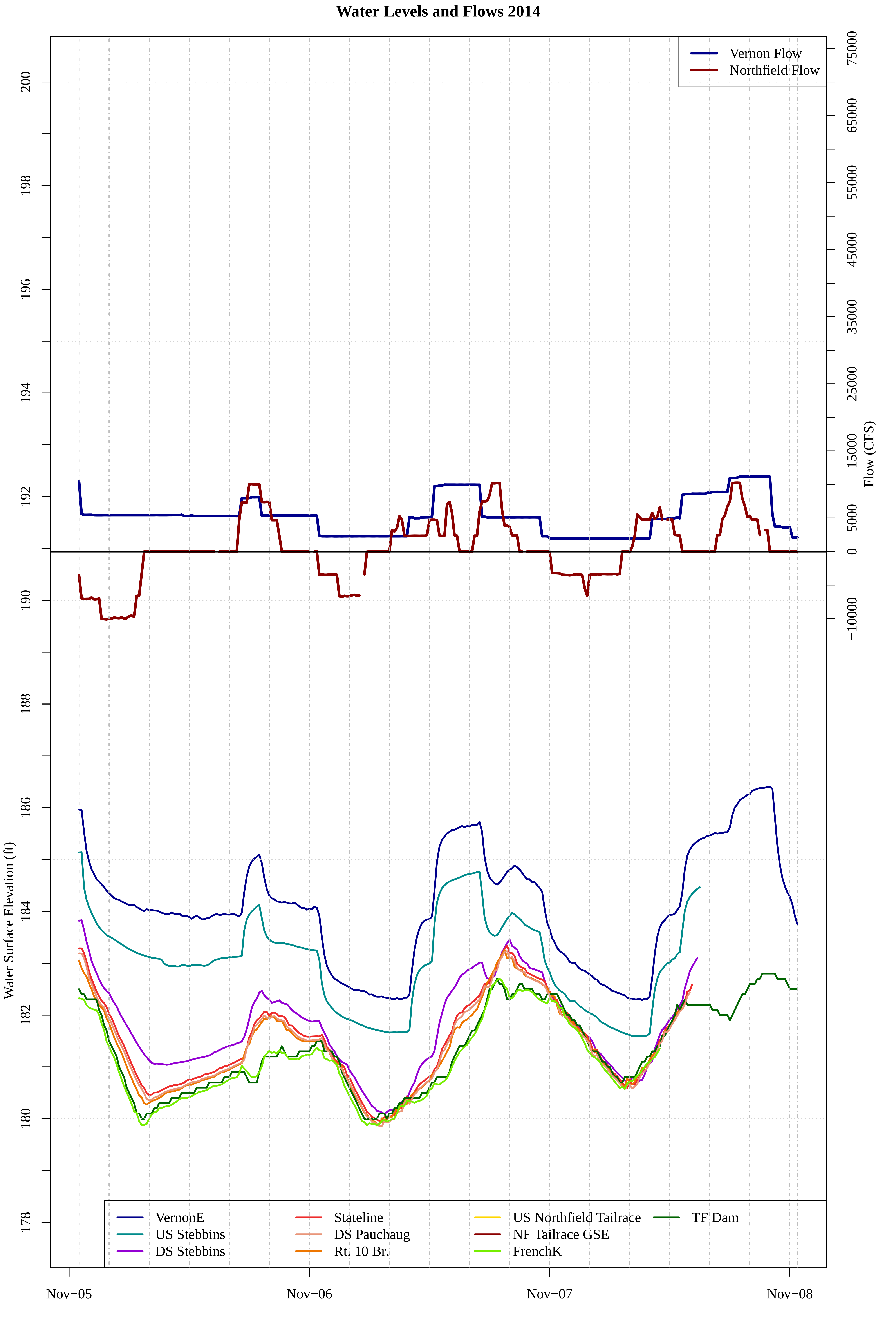
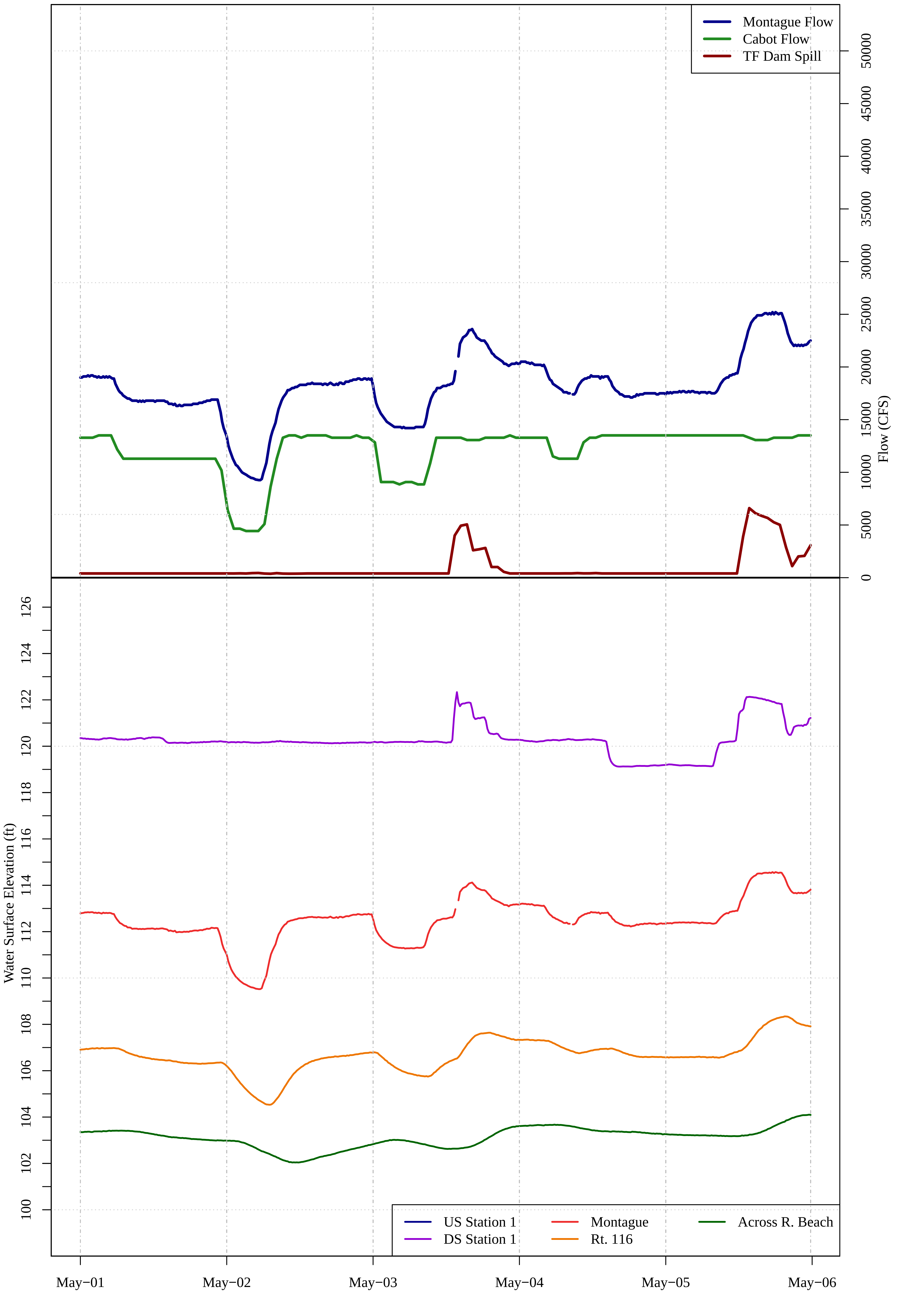
5000
15000
25000
35000
45000
55000
65000
75000
Nov−01
Nov−02
Nov−02
Nov−03
Nov−04
Nov−05
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam

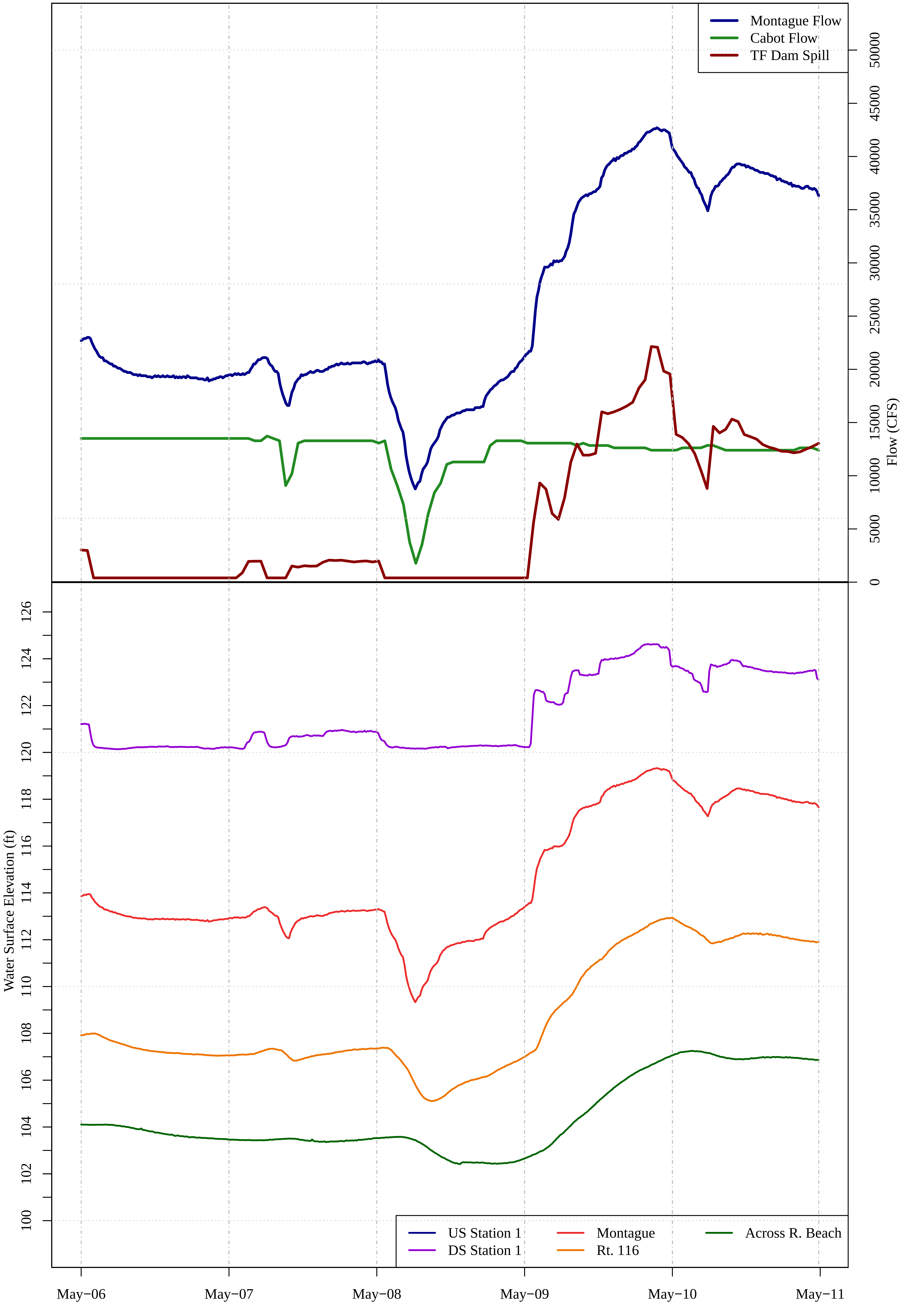

Water Levels and Flows 2014
Water Surface Elevation (ft)
Flow (CFS)
Vernon Flow
Northfield Flow
VernonE
US Stebbins
DS Stebbins
Stateline
DS Pauchaug
Rt. 10 Br.
US Northfield Tailrace
NF Tailrace GSE
FrenchK
TF Dam
Nov−05
Nov−06
Nov−07
Nov−08

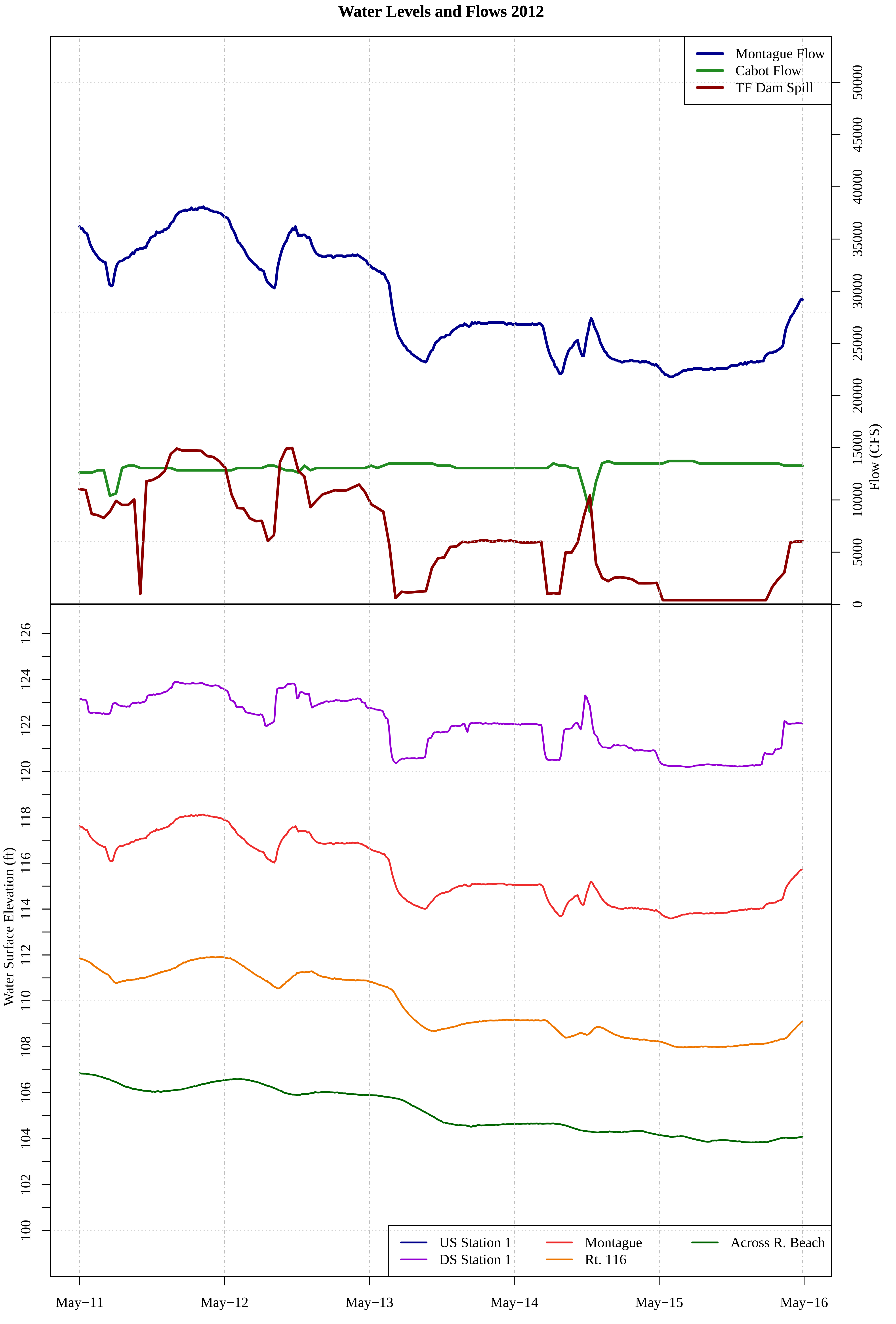
APPENDIX C- MONTAGUE USGS GAGE TO HOLYOKE DAM REACH: 2012 DATA

Water Levels and Flows 2012



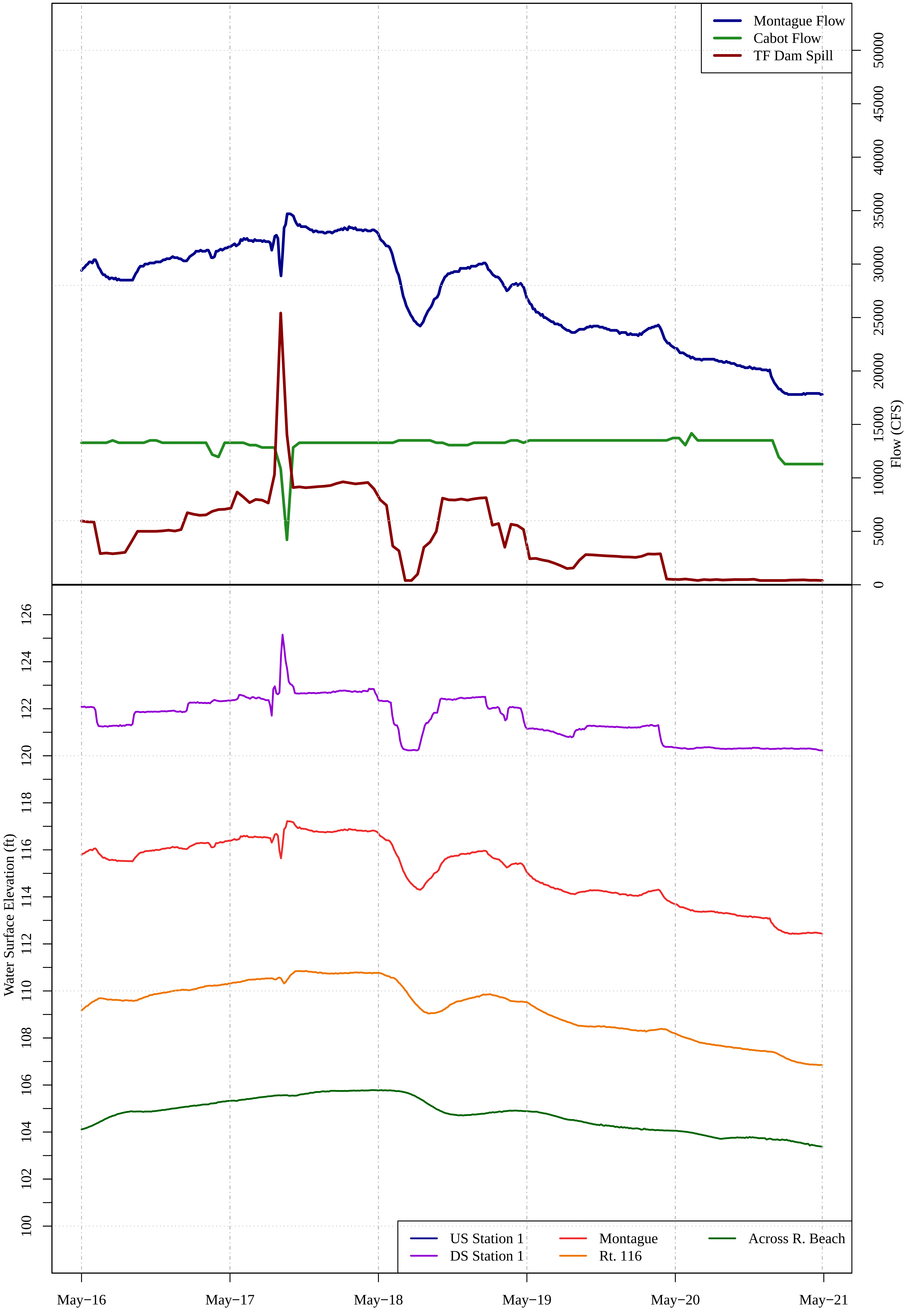
Water Levels and Flows 2012

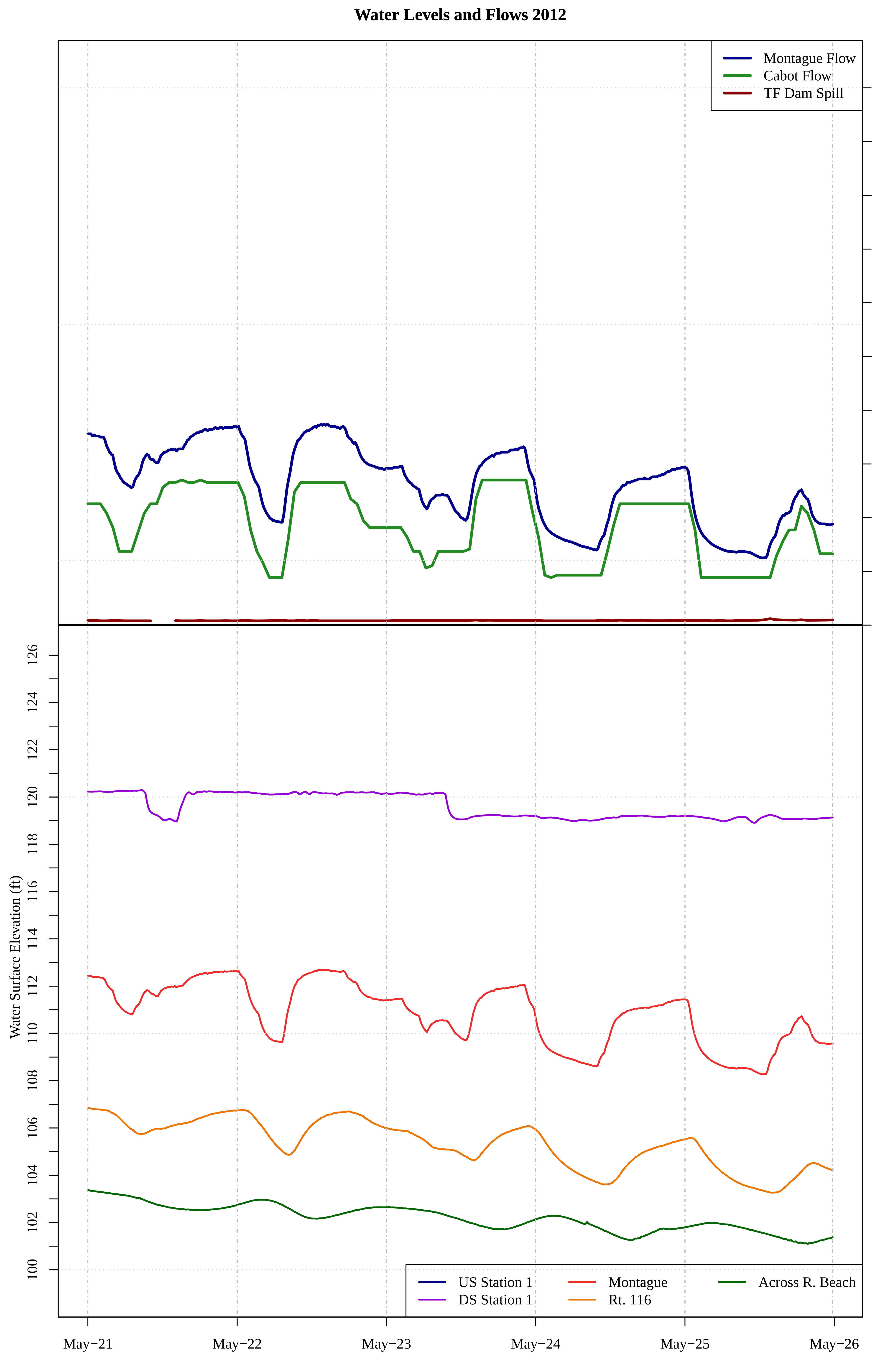




Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Water Surface Elevation (ft)
100
102
104
106
108
110
112
114
116
118
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
May−11
May−12
May−13
May−14
May−15
May−16

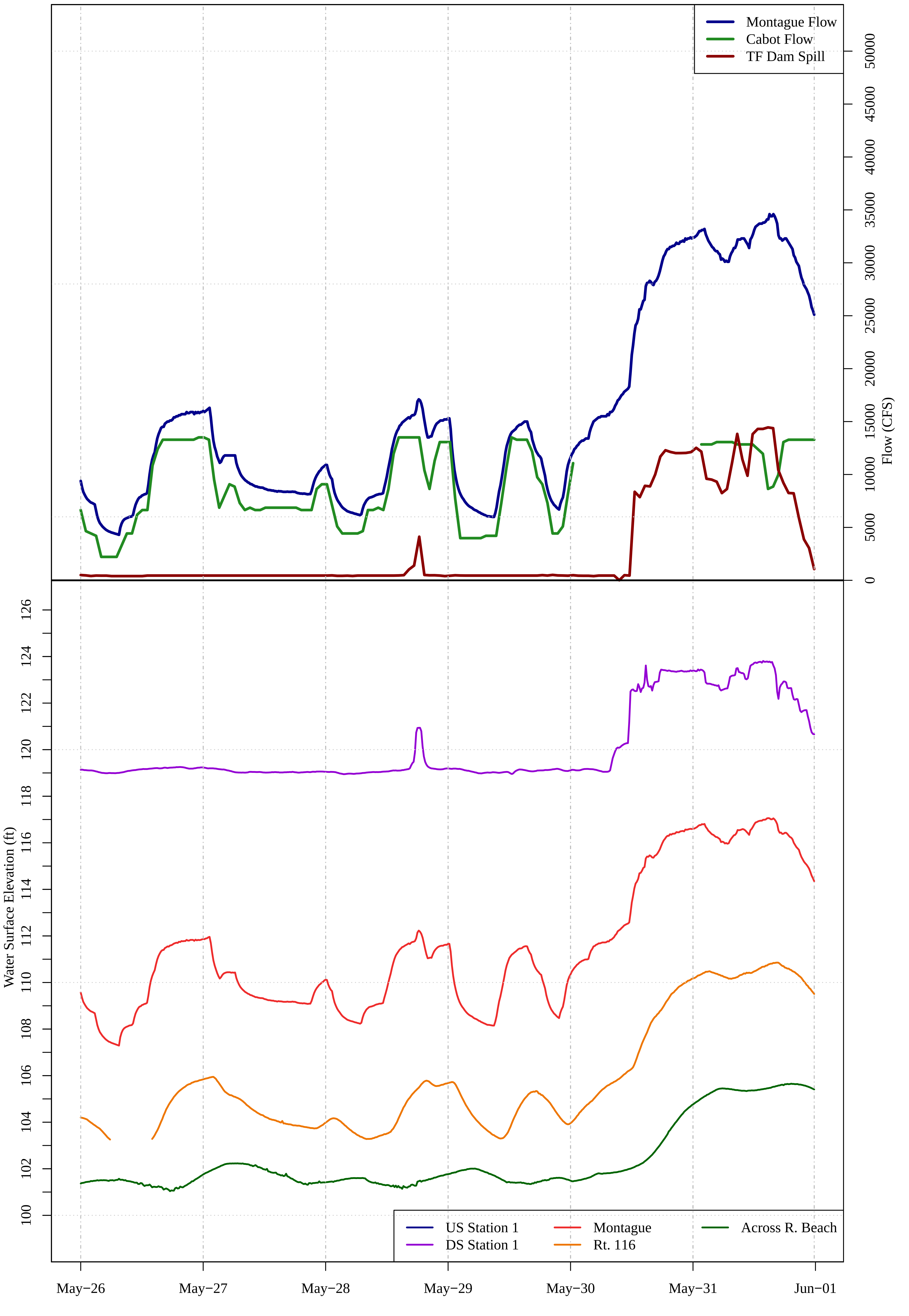
Water Levels and Flows 2012

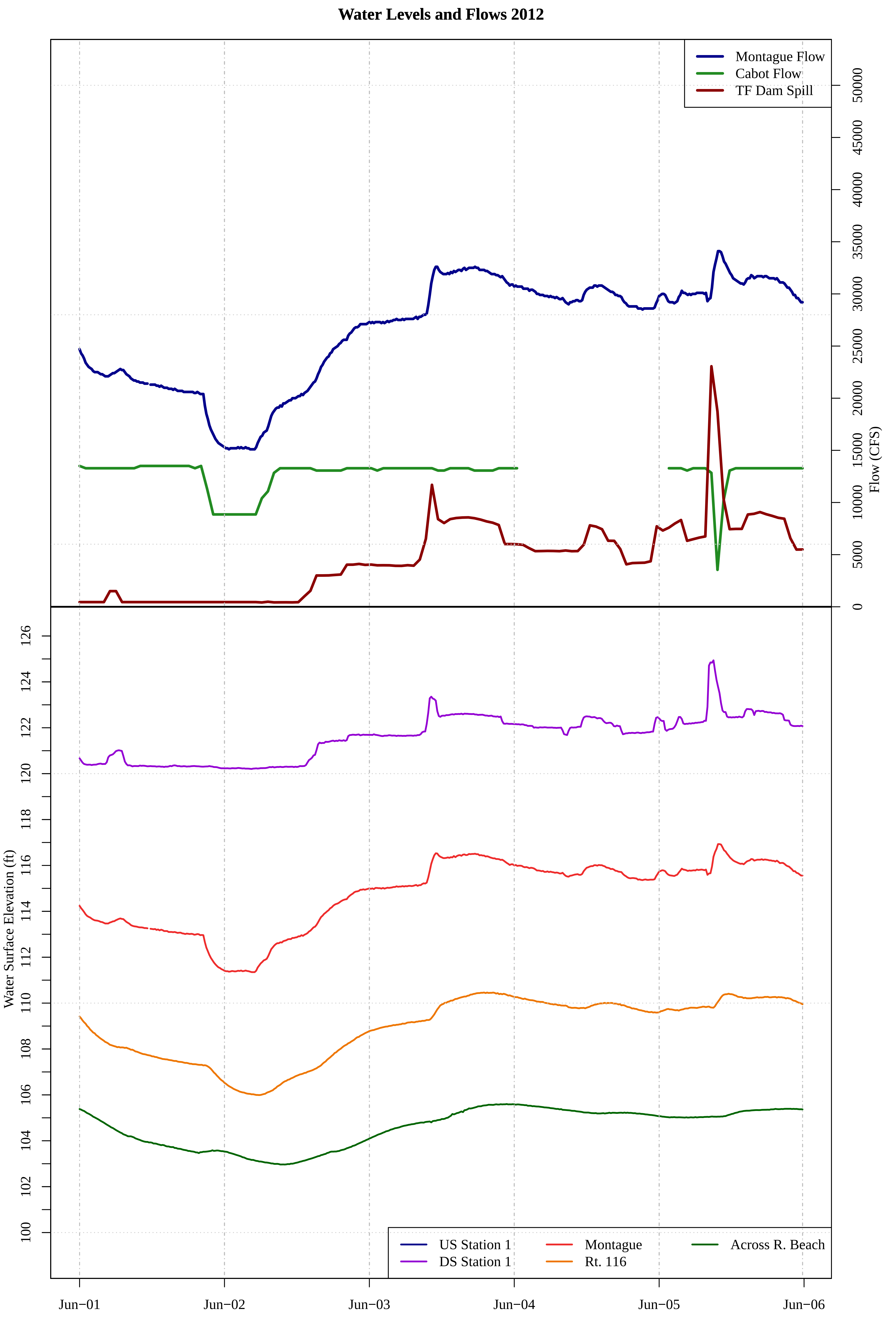




Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Water Surface Elevation (ft)
100
102
104
106
108
110
112
114
116
118
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
May−21
May−22
May−23
May−24
May−25
May−26

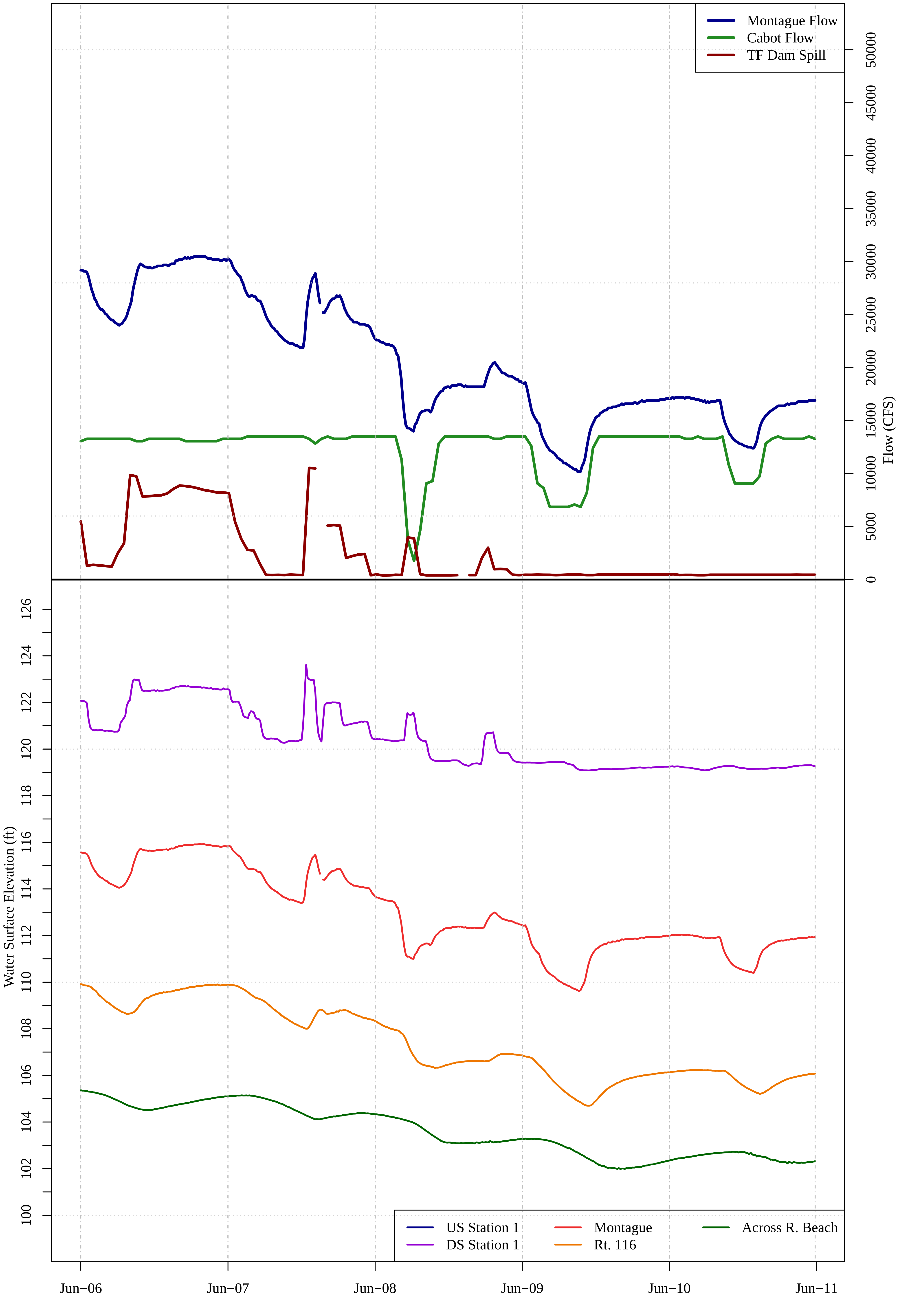
Water Levels and Flows 2012



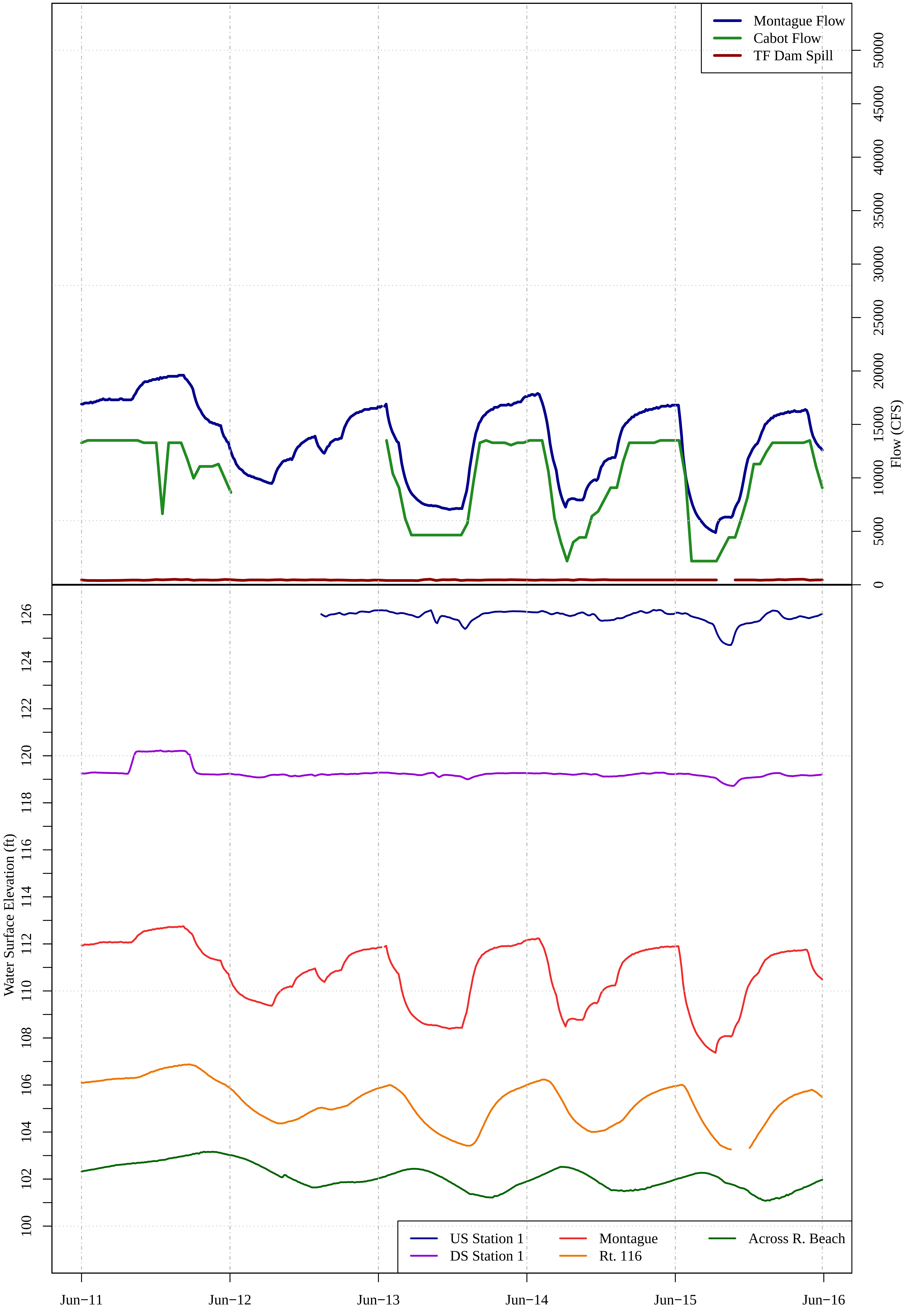


Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Water Surface Elevation (ft)
100
102
104
106
108
110
112
114
116
118
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Jun−01
Jun−02
Jun−03
Jun−04
Jun−05
Jun−06

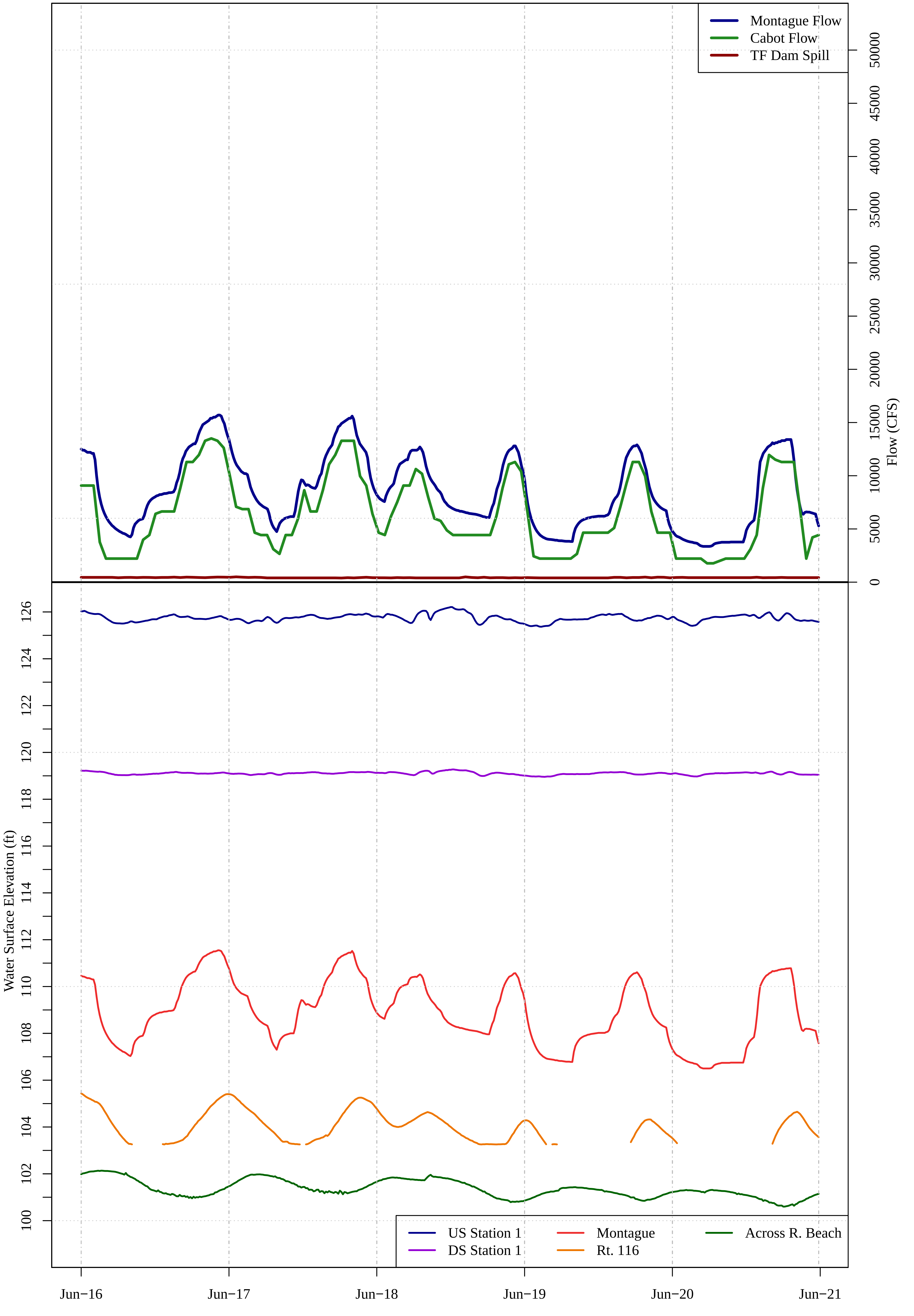
Water Levels and Flows 2012

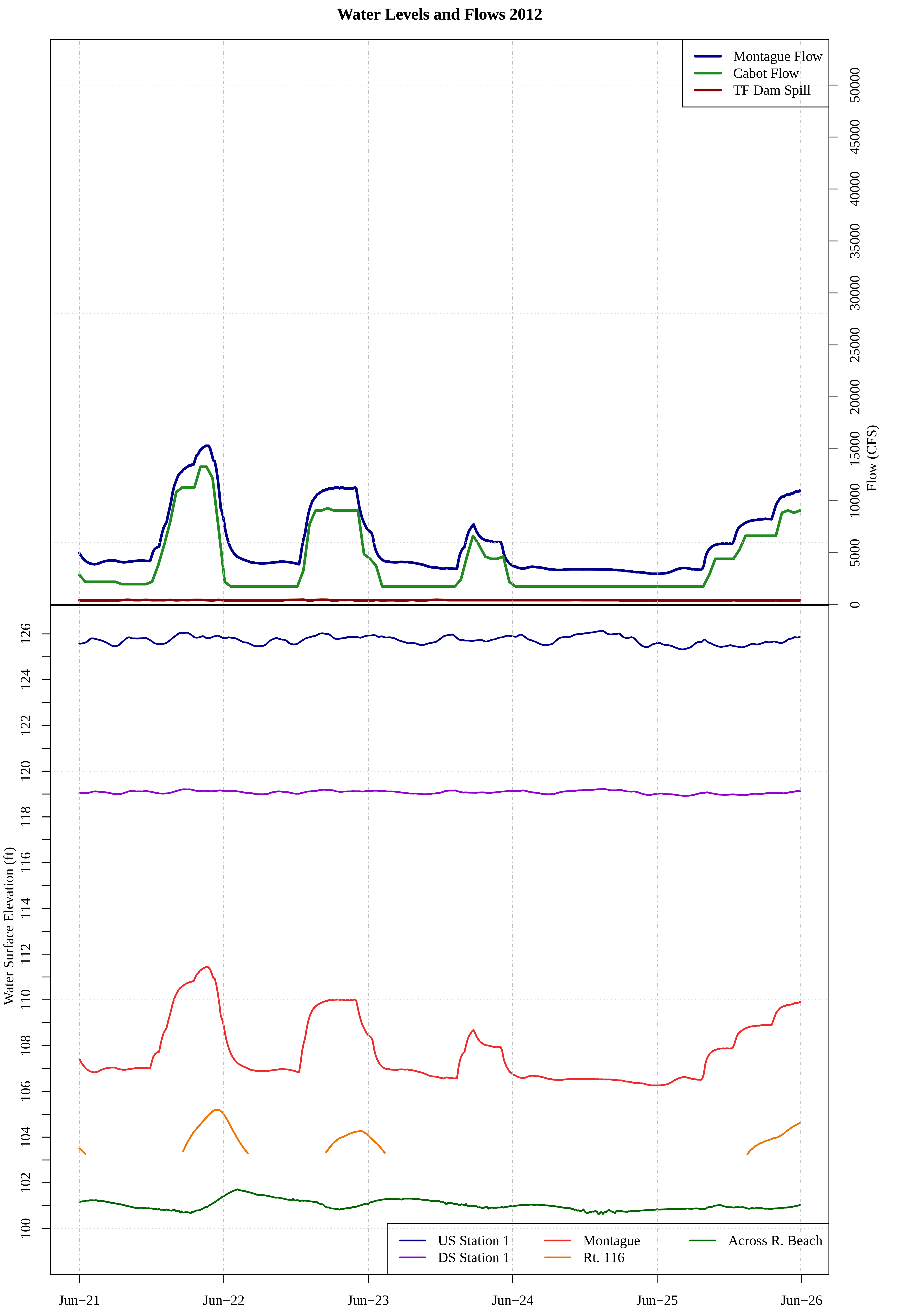


Water Levels and Flows 2012



Water Levels and Flows 2012




Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
0
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50000
Water Surface Elevation (ft)
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102
104
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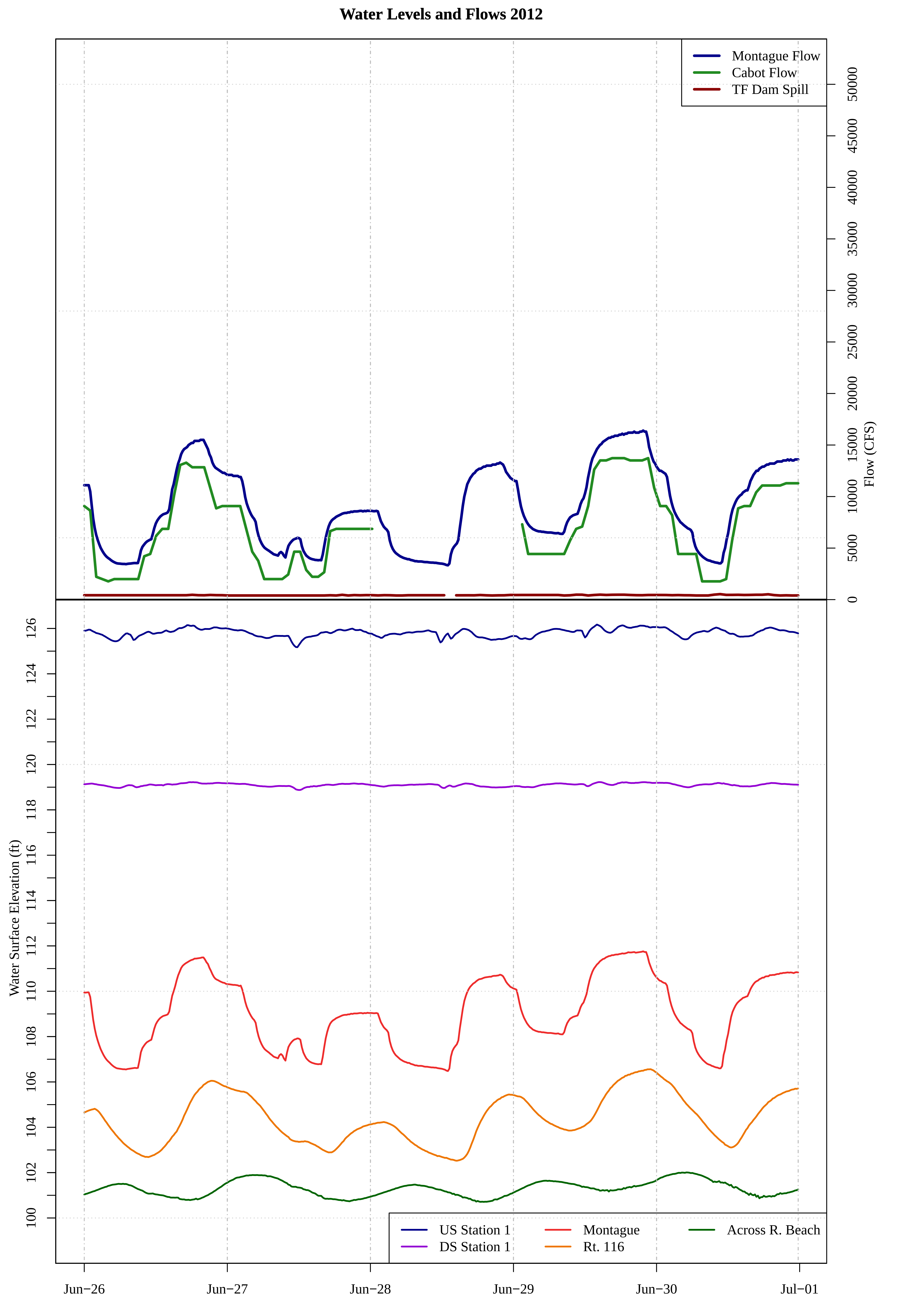
112
114
116
118
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Jun−21
Jun−22
Jun−23
Jun−24
Jun−25
Jun−26



Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
0
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40000
45000
50000
Water Surface Elevation (ft)
100
102
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108
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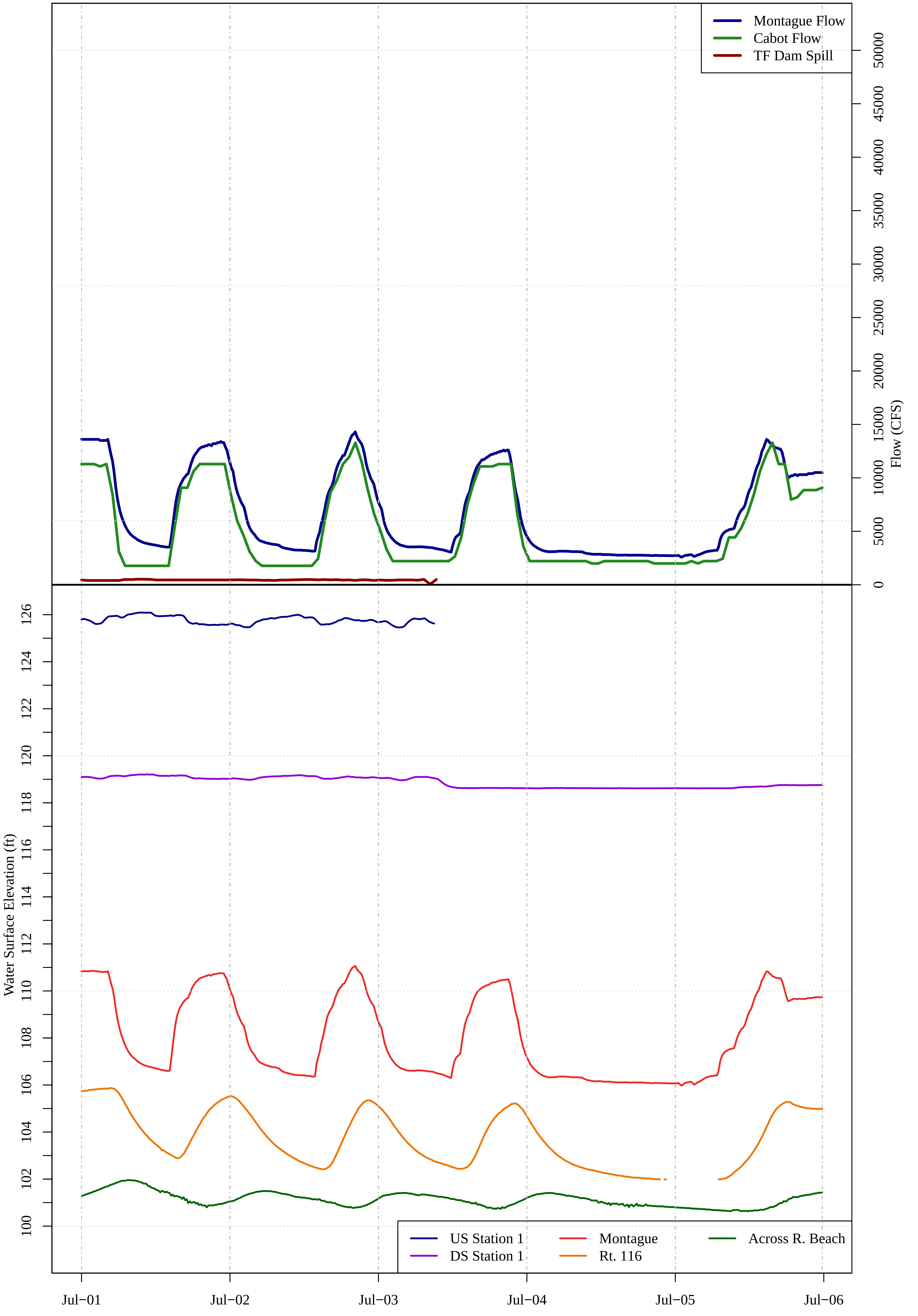
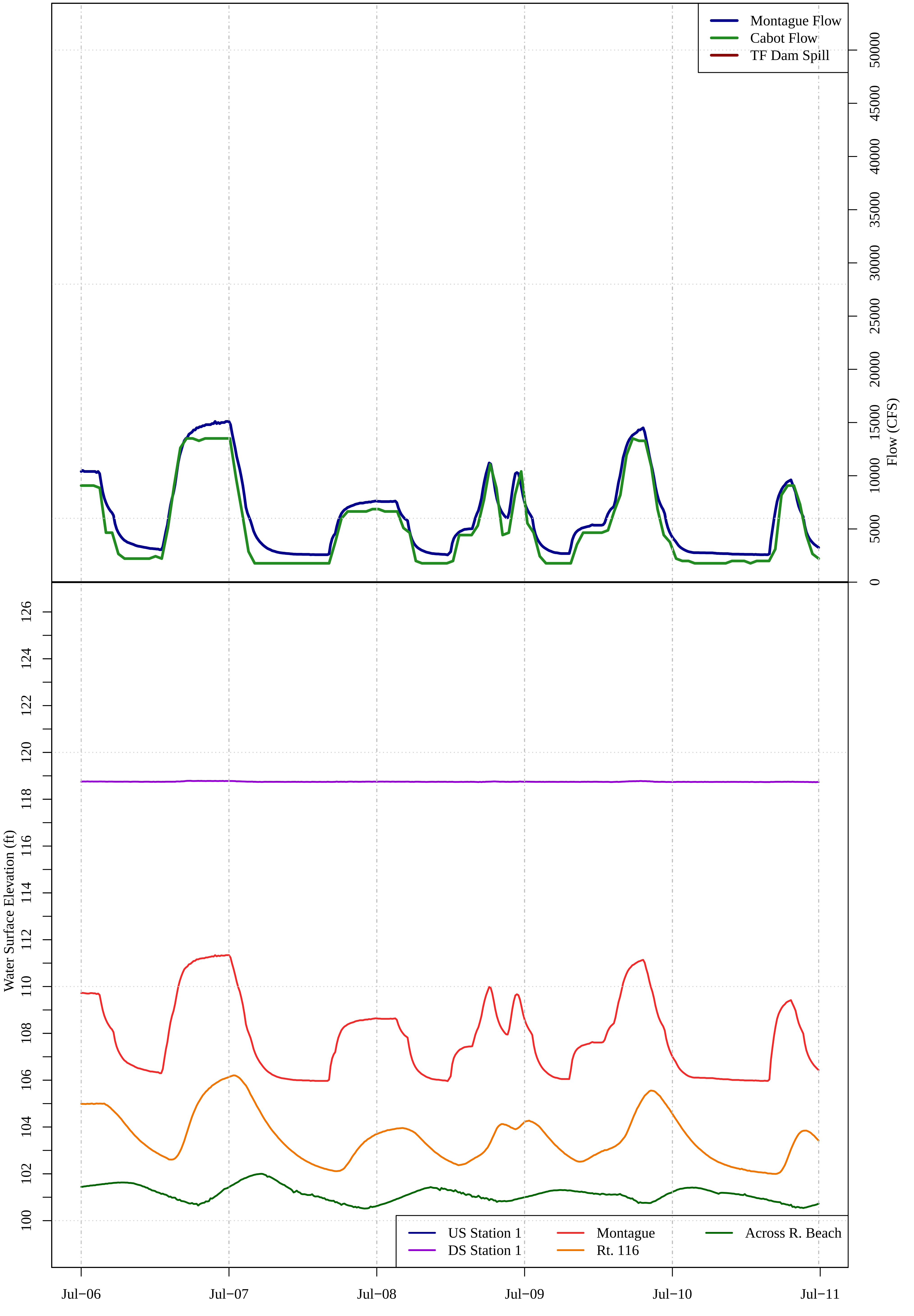
112
114
116
118
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Jun−26
Jun−27
Jun−28
Jun−29
Jun−30
Jul−01

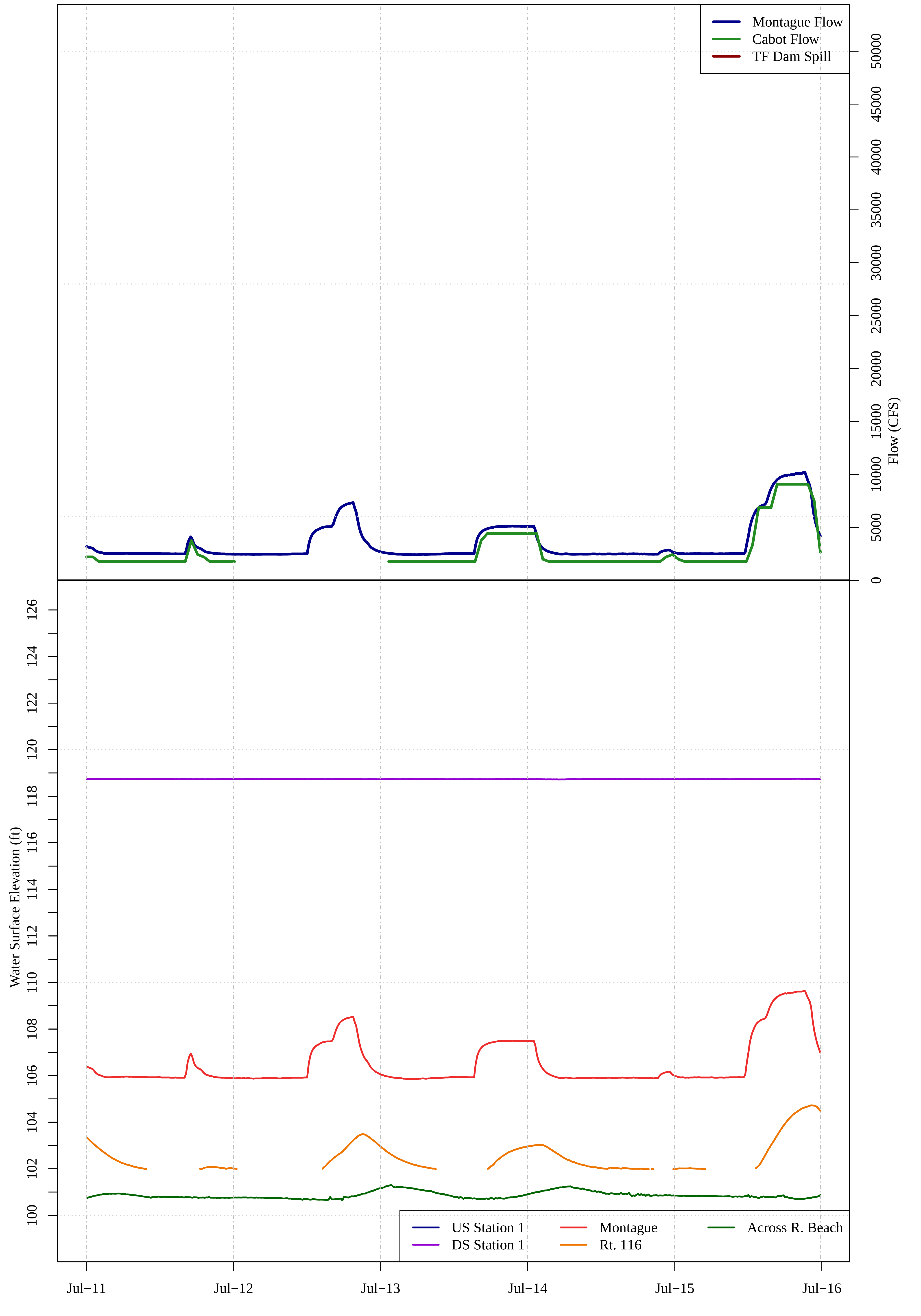
Water Levels and Flows 2012

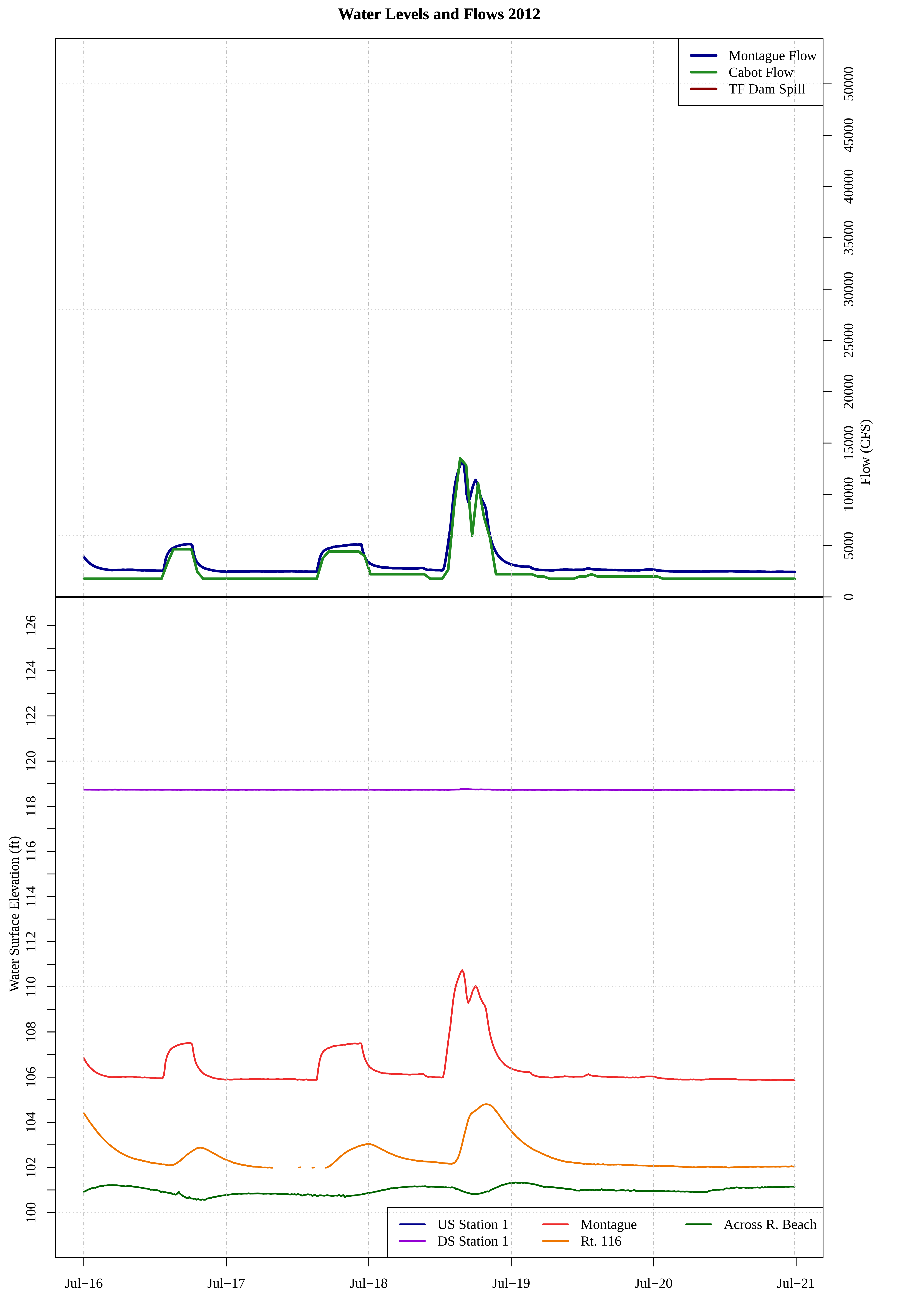


Water Levels and Flows 2012



Water Levels and Flows 2012





Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
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10000
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20000
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40000
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50000
Water Surface Elevation (ft)
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102
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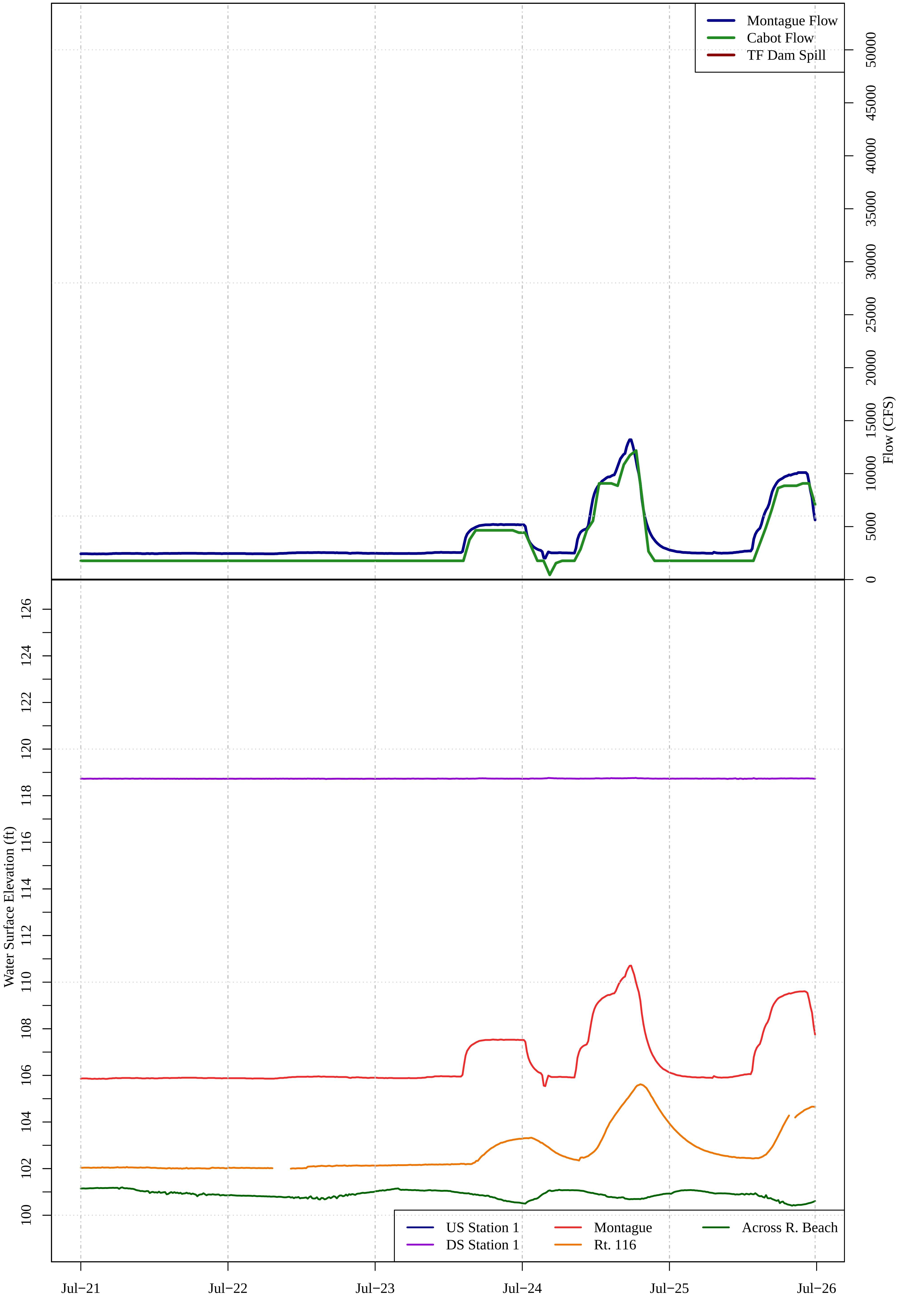
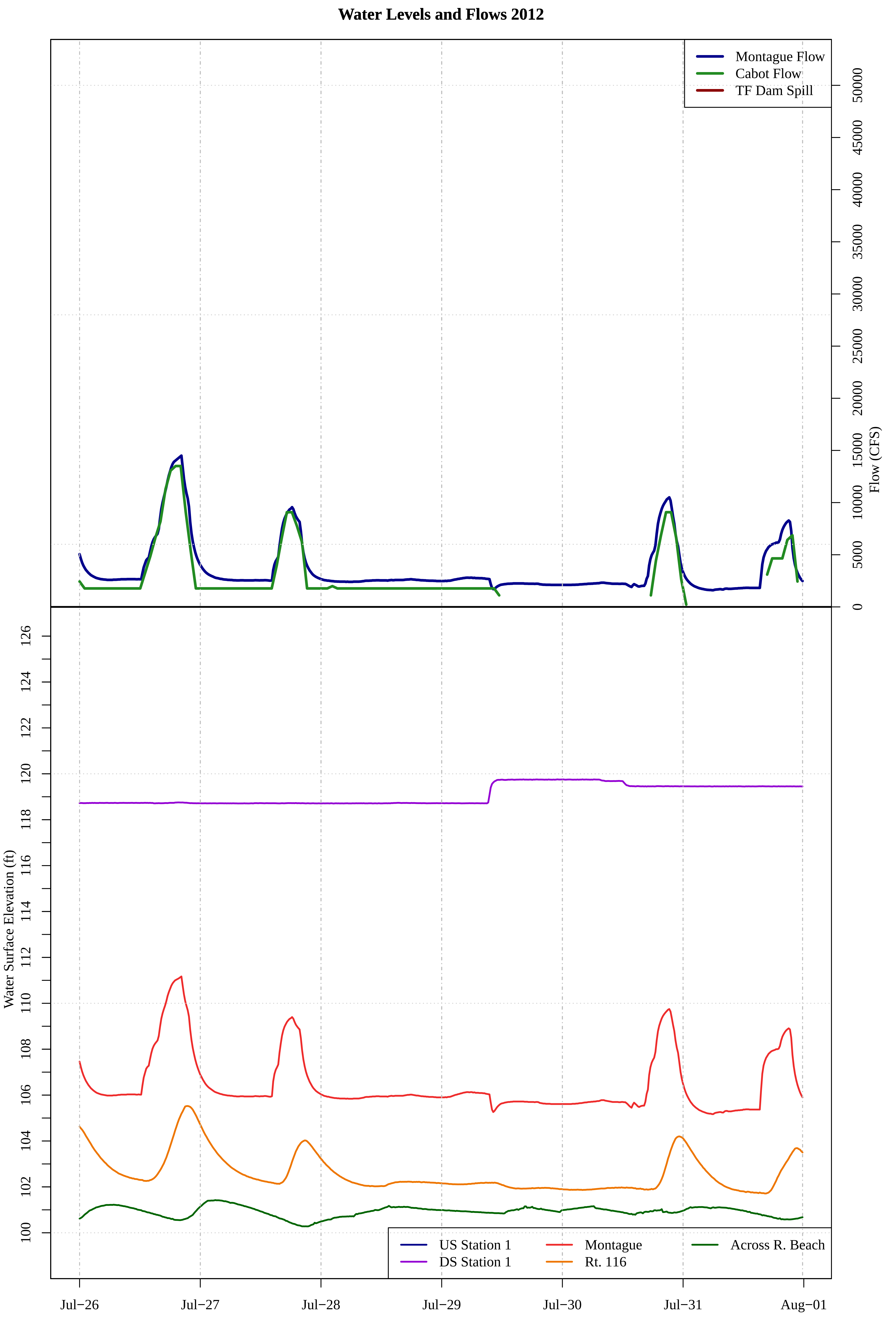
112
114
116
118
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Jul−16
Jul−17
Jul−18
Jul−19
Jul−20
Jul−21

Water Levels and Flows 2012





Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
0
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50000
Water Surface Elevation (ft)
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102
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108
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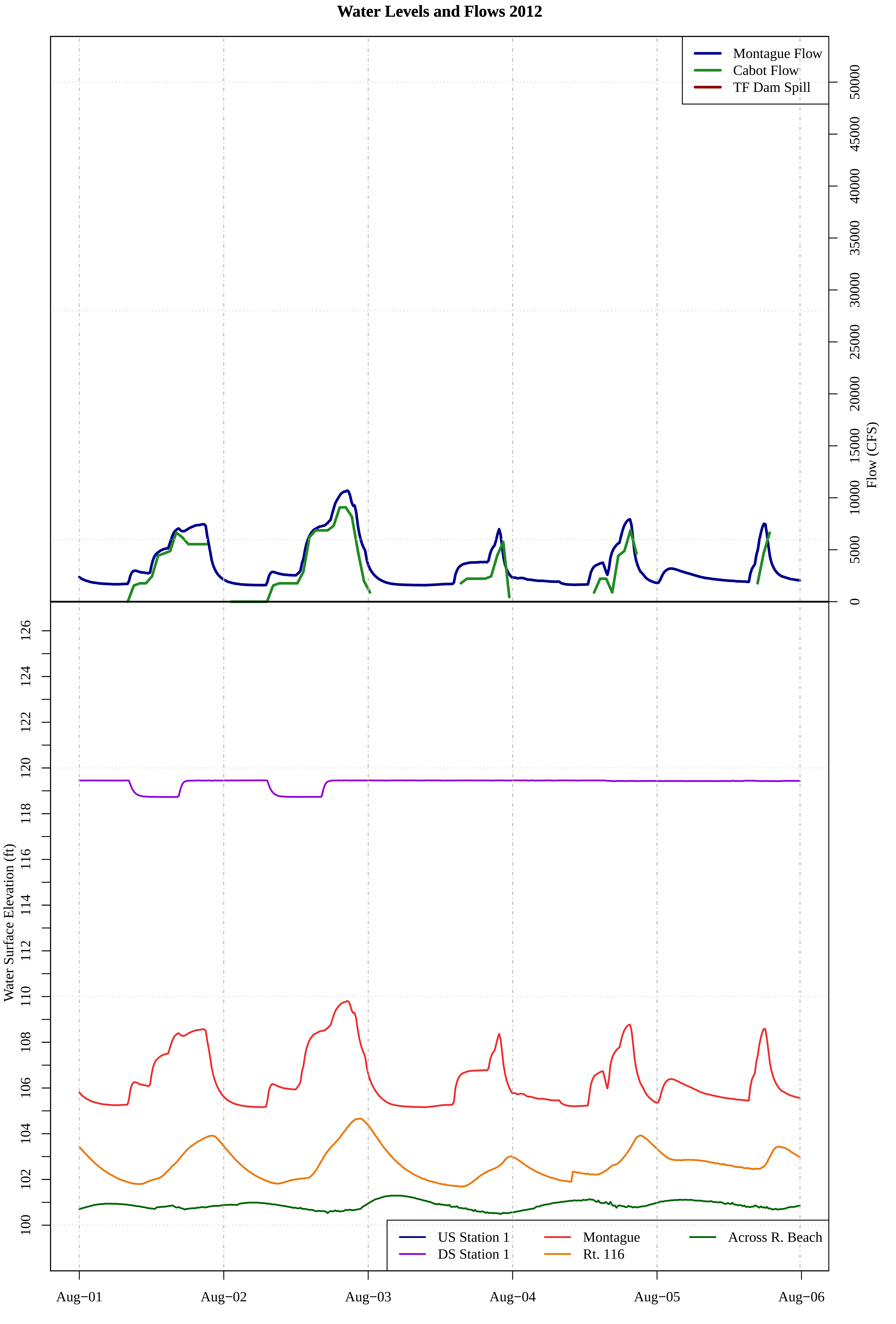
112
114
116
118
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Jul−26
Jul−27
Jul−28
Jul−29
Jul−30
Jul−31
Aug−01



Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
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40000
45000
50000
Water Surface Elevation (ft)
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116
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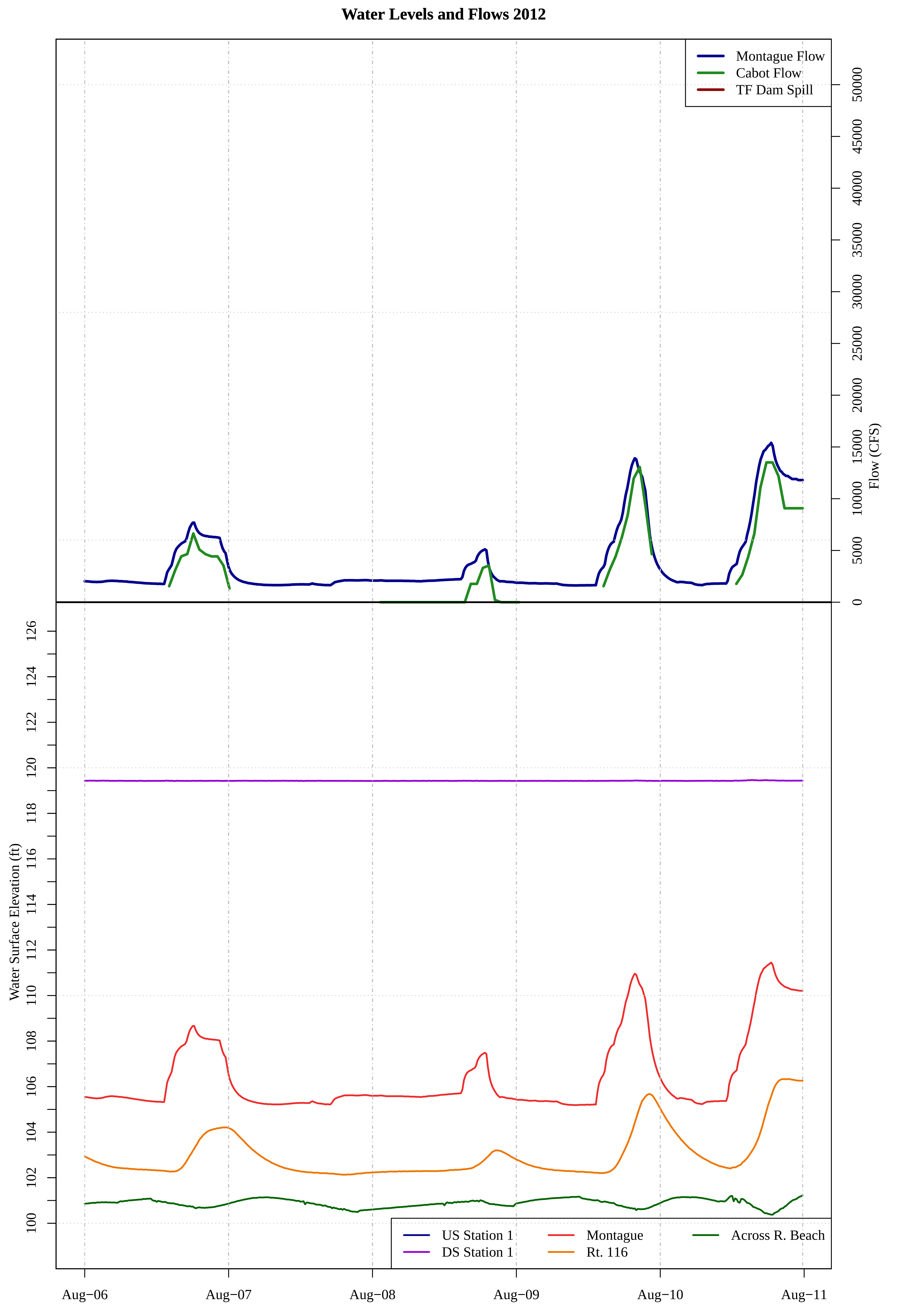
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Aug−01
Aug−02
Aug−03
Aug−04
Aug−05
Aug−06



Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
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40000
45000
50000
Water Surface Elevation (ft)
100
102
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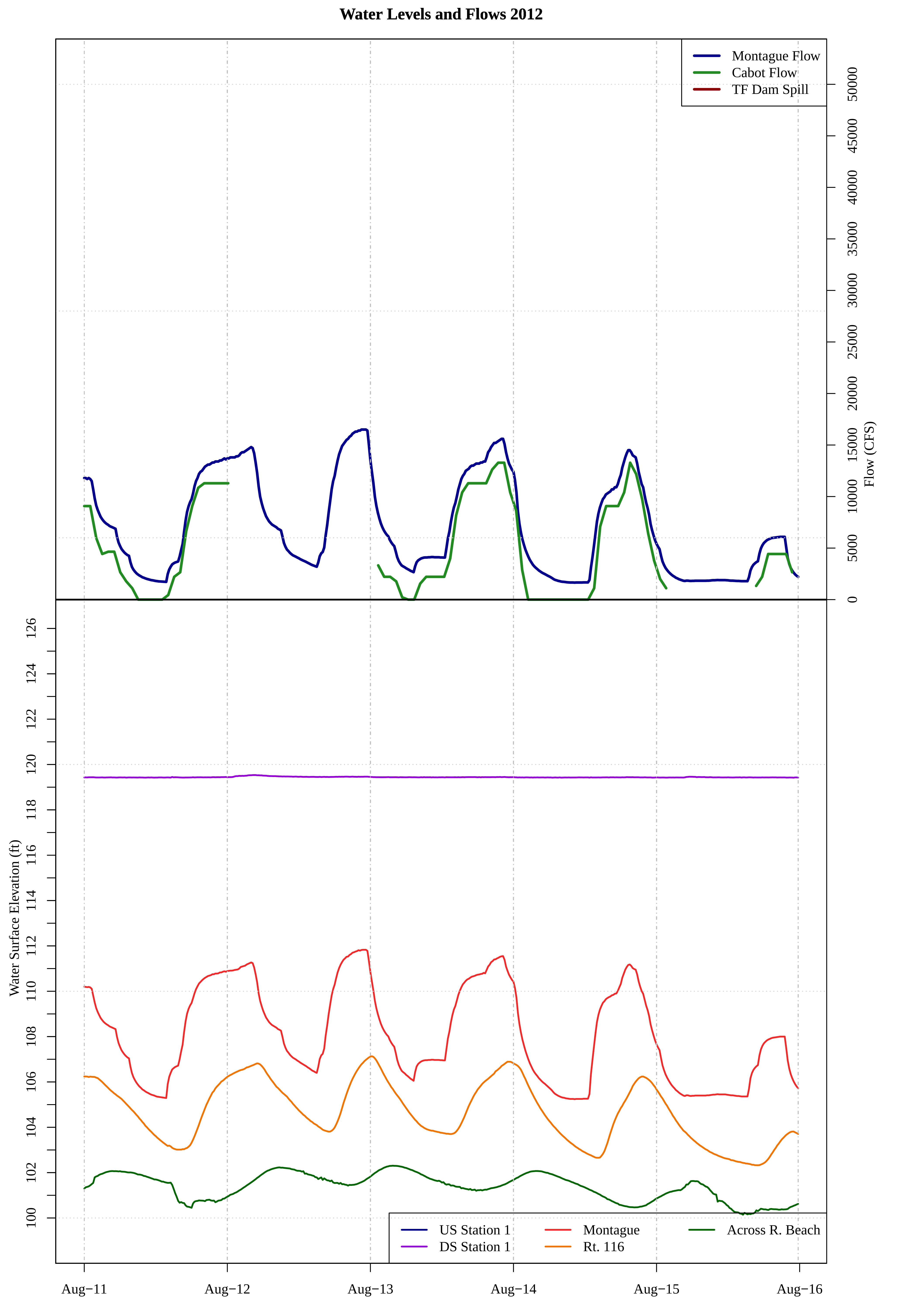
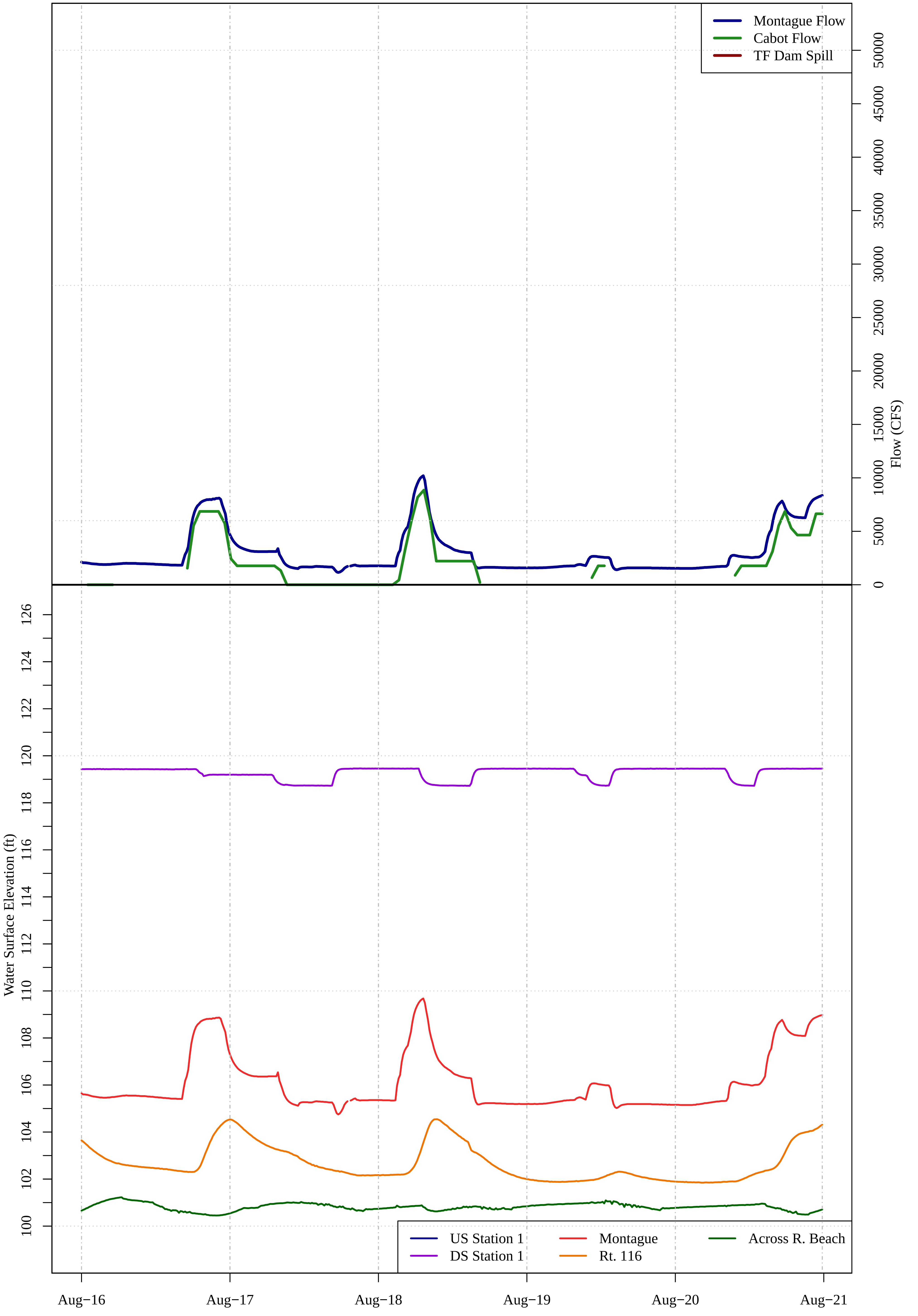
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Aug−06
Aug−07
Aug−08
Aug−09
Aug−10
Aug−11

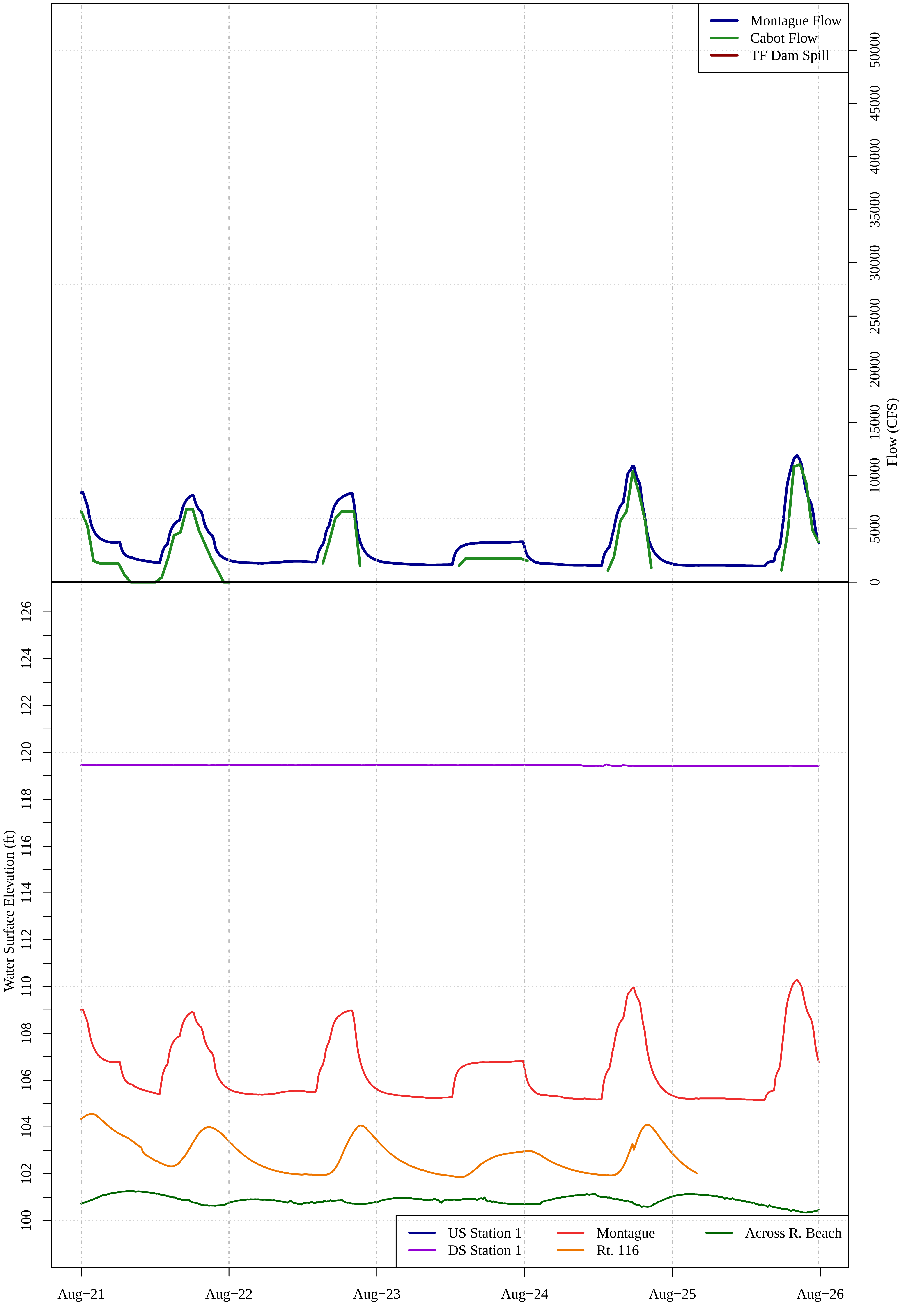


Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Water Surface Elevation (ft)
100
102
104
106
108
110
112
114
116
118
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Aug−11
Aug−12
Aug−13
Aug−14
Aug−15
Aug−16

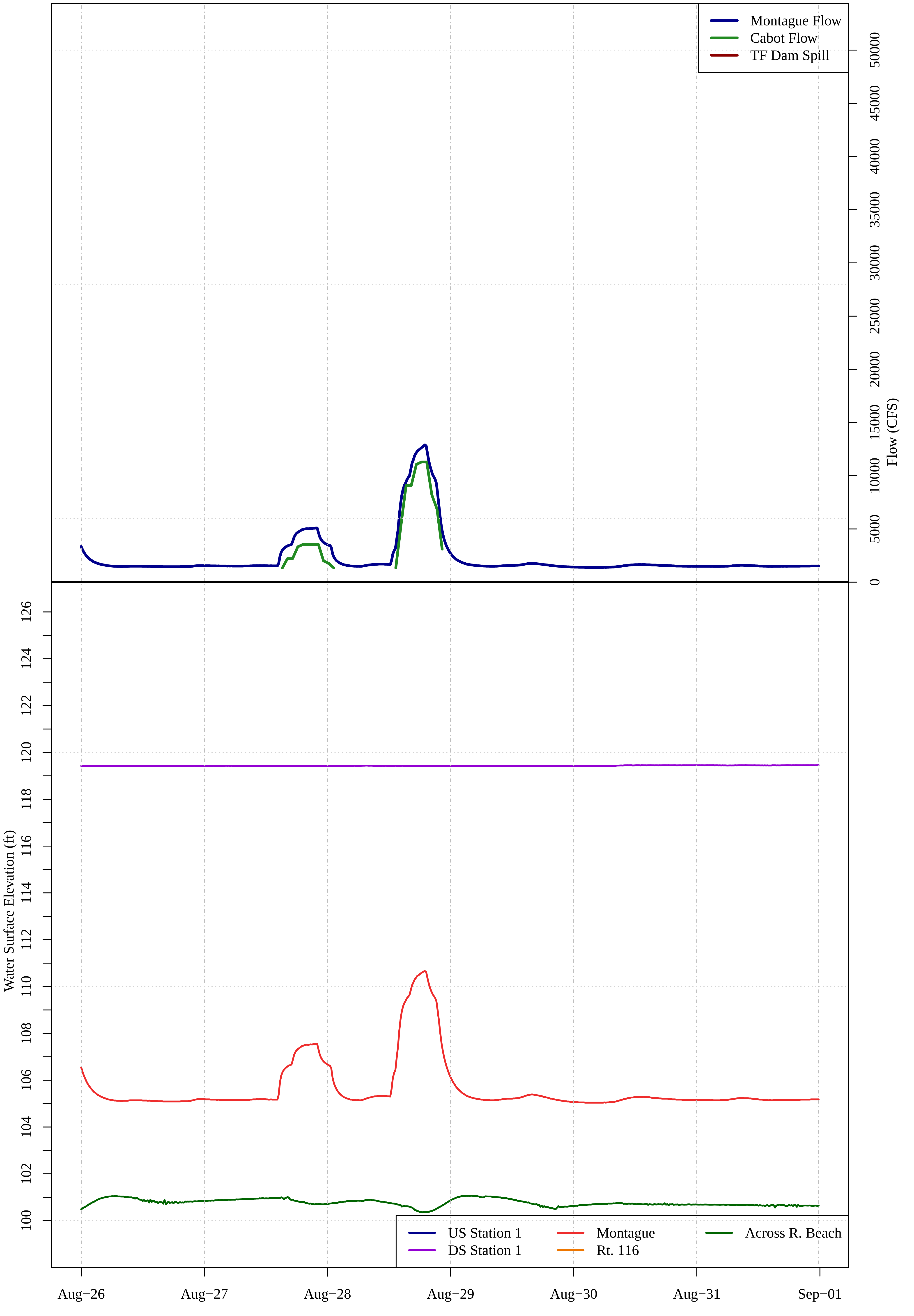
Water Levels and Flows 2012

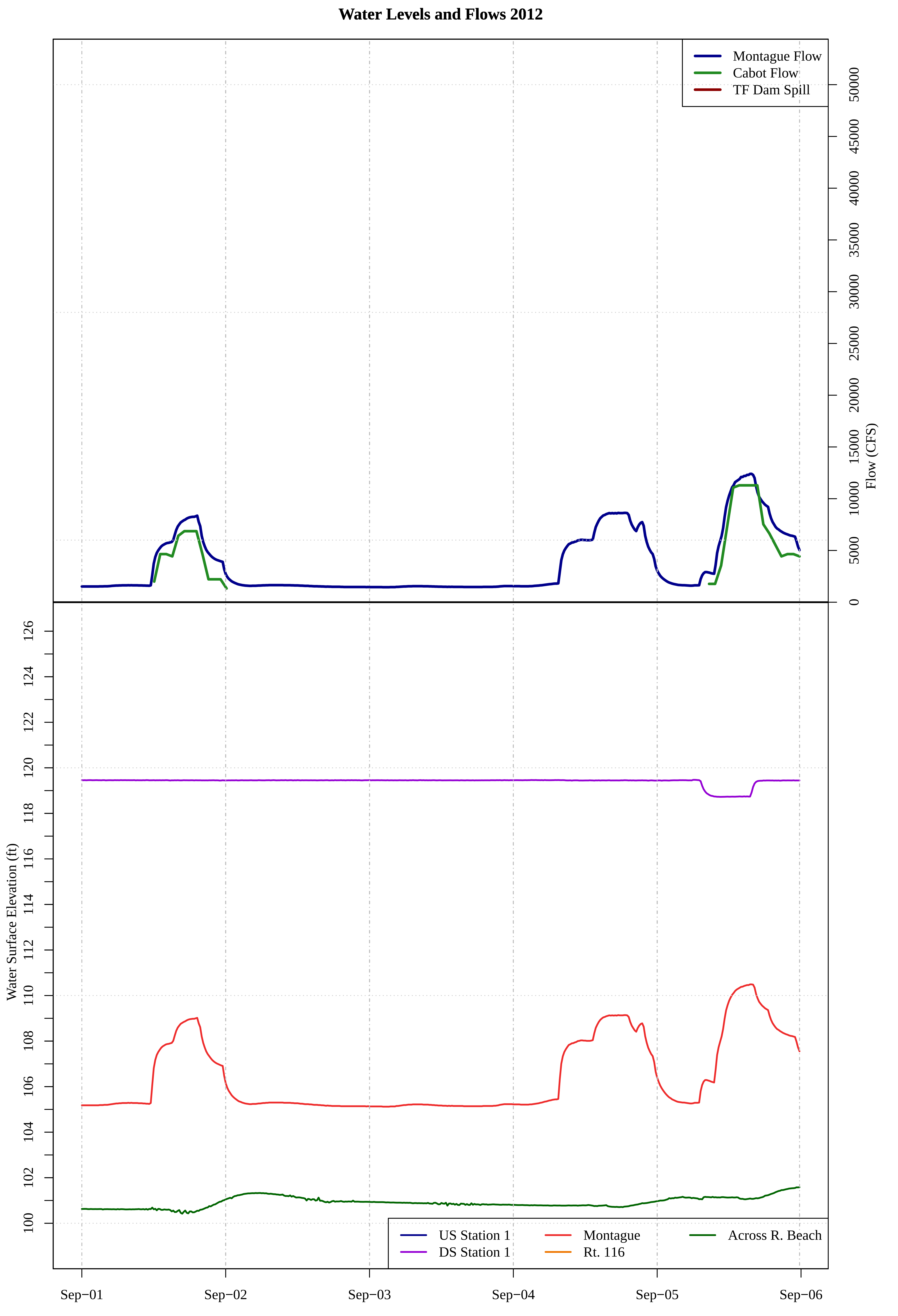


Water Levels and Flows 2012



Water Levels and Flows 2012





Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
0
5000
10000
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20000
25000
30000
35000
40000
45000
50000
Water Surface Elevation (ft)
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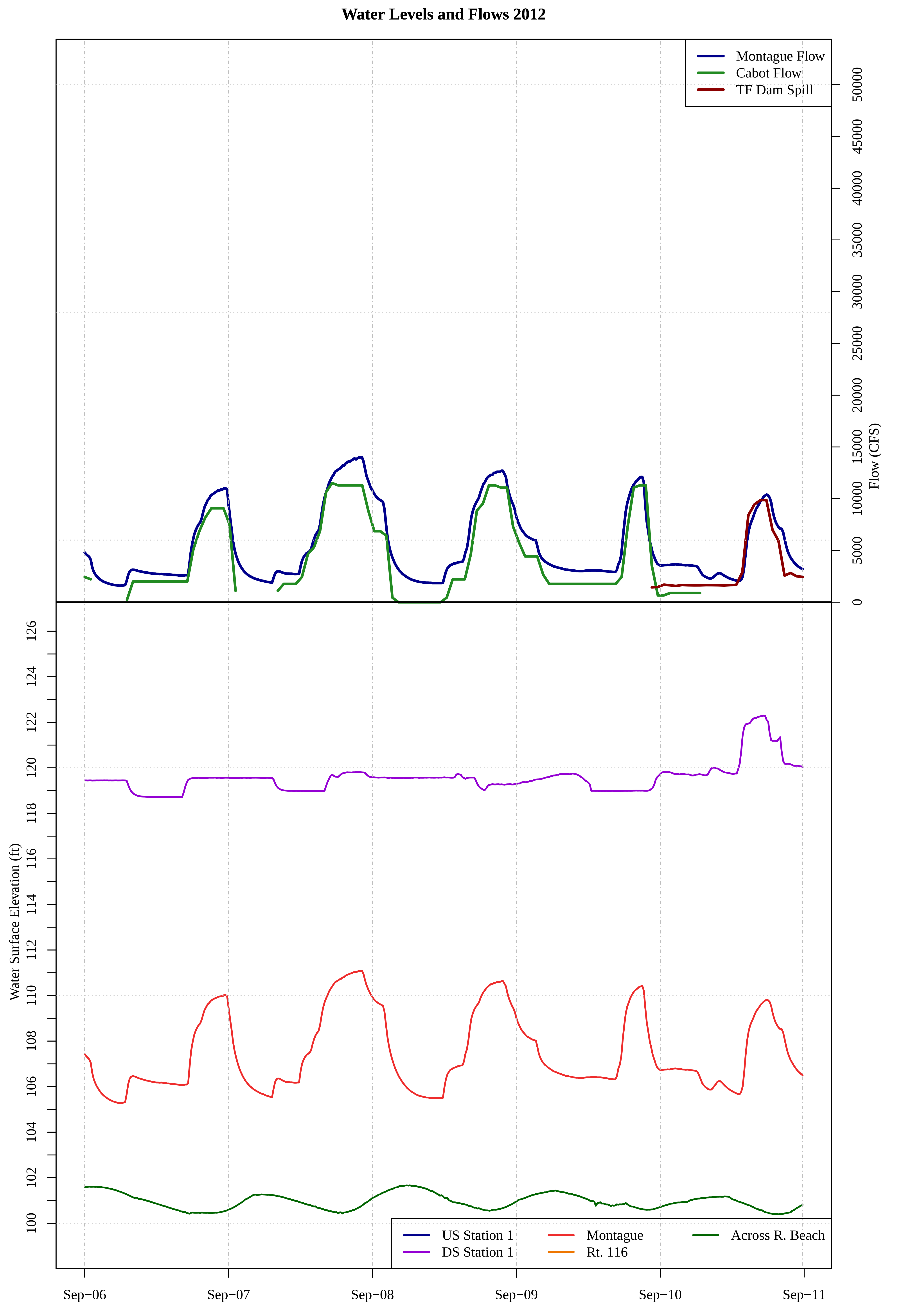
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Sep−01
Sep−02
Sep−03
Sep−04
Sep−05
Sep−06


Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
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10000
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45000
50000
Water Surface Elevation (ft)
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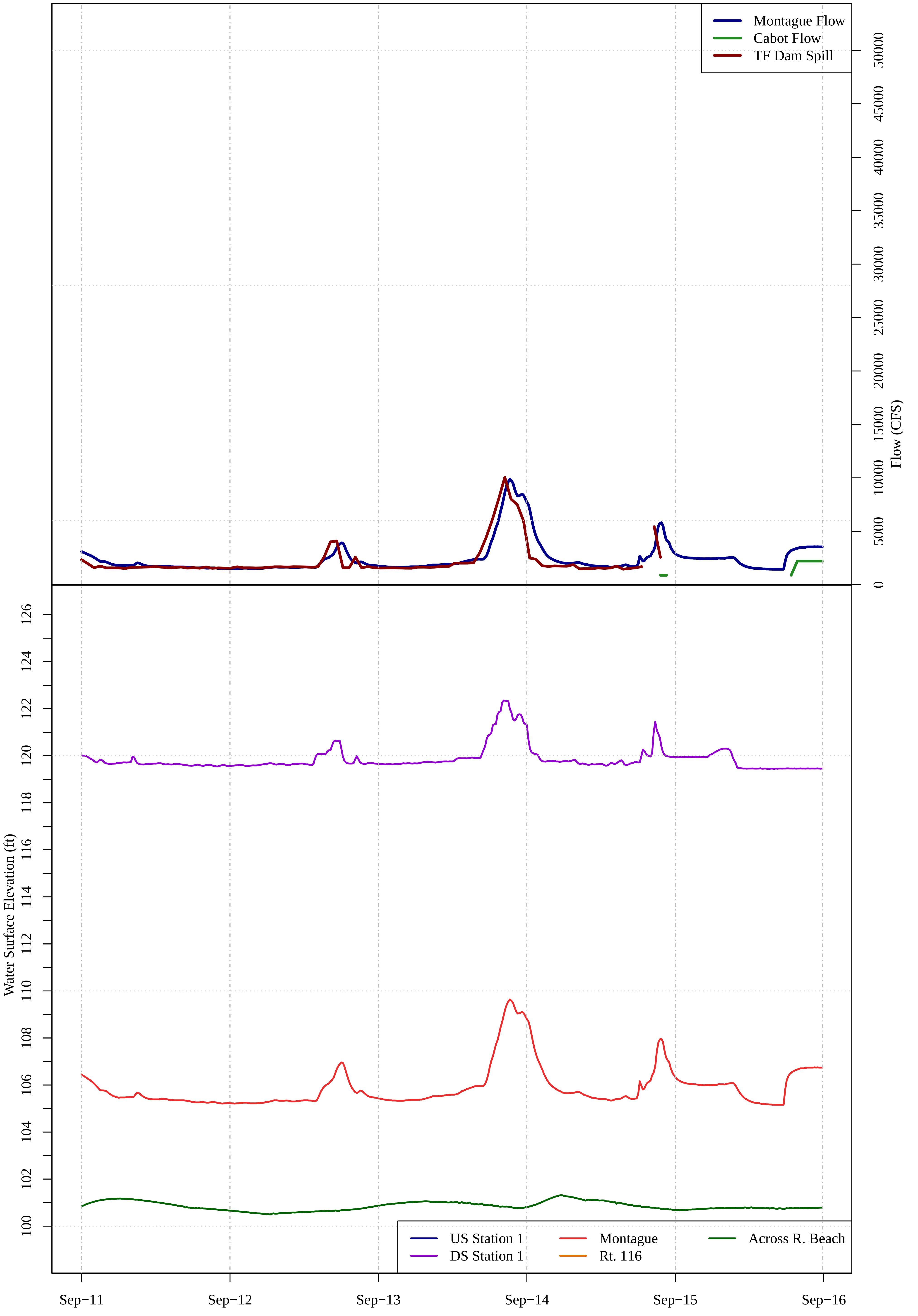
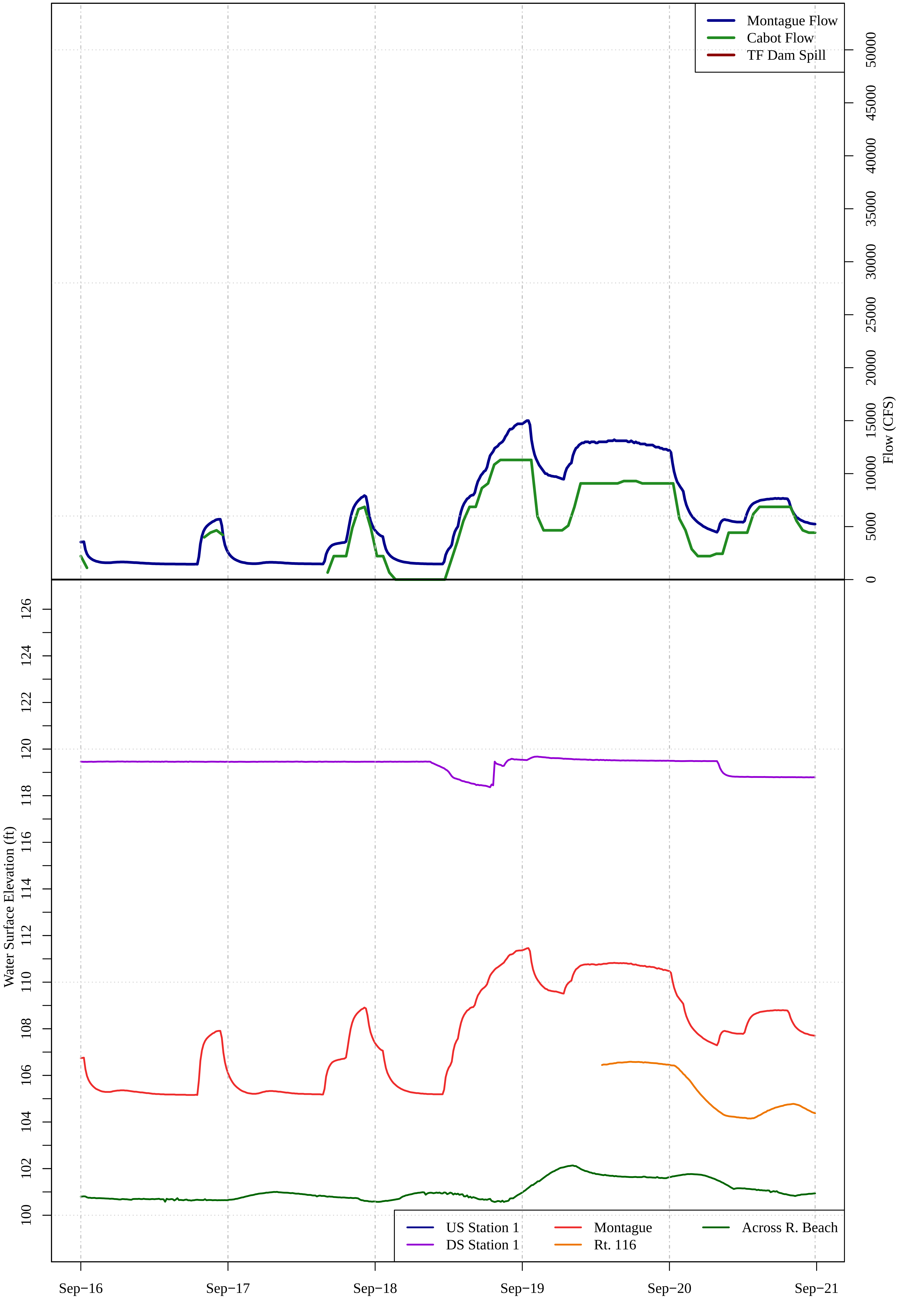
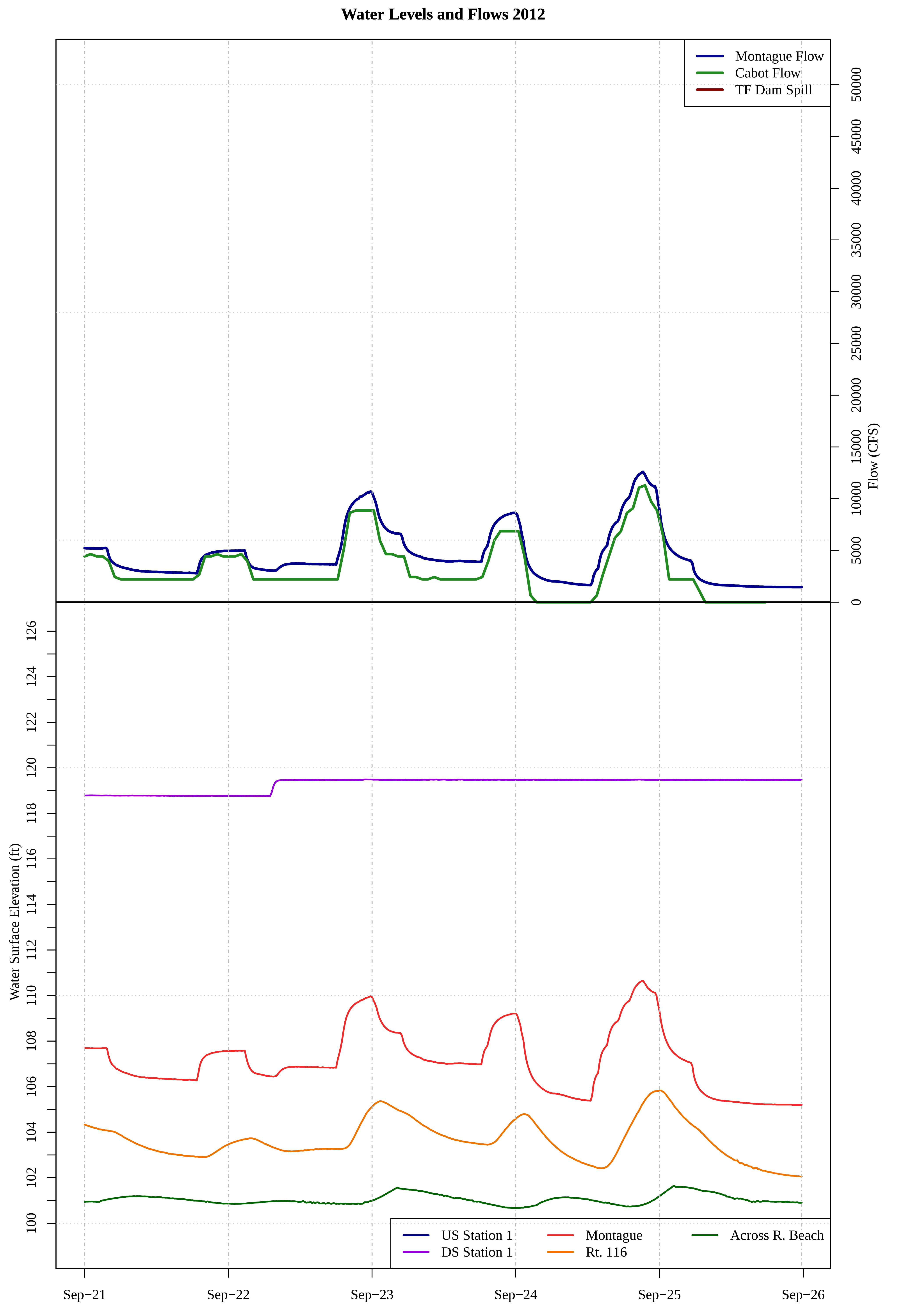
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Sep−06
Sep−07
Sep−08
Sep−09
Sep−10
Sep−11

Water Levels and Flows 2012



Water Levels and Flows 2012




Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
0
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10000
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35000
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45000
50000
Water Surface Elevation (ft)
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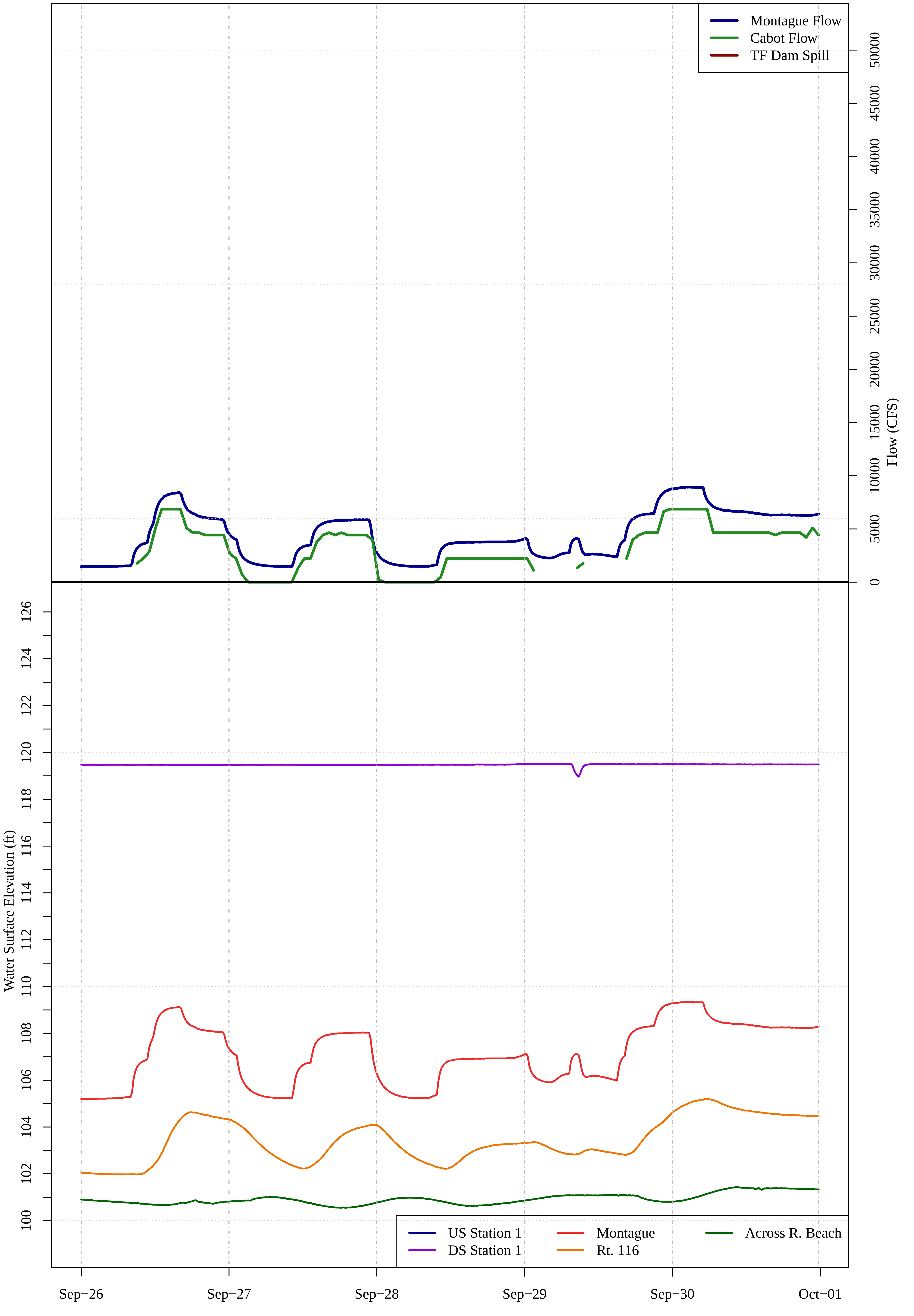
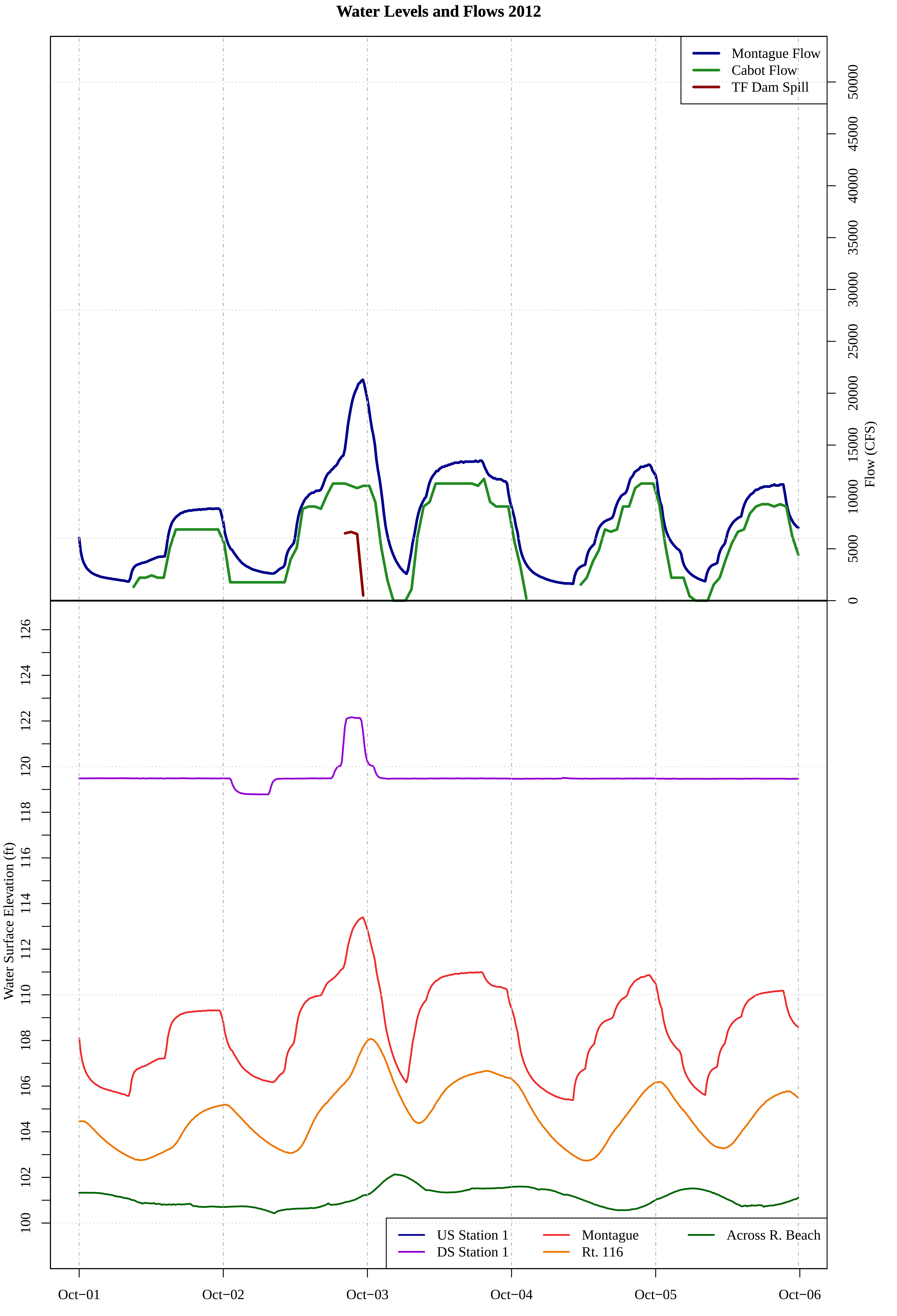
120
122
124
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Sep−21
Sep−22
Sep−23
Sep−24
Sep−25
Sep−26

Water Levels and Flows 2012





Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
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10000
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35000
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45000
50000
Water Surface Elevation (ft)
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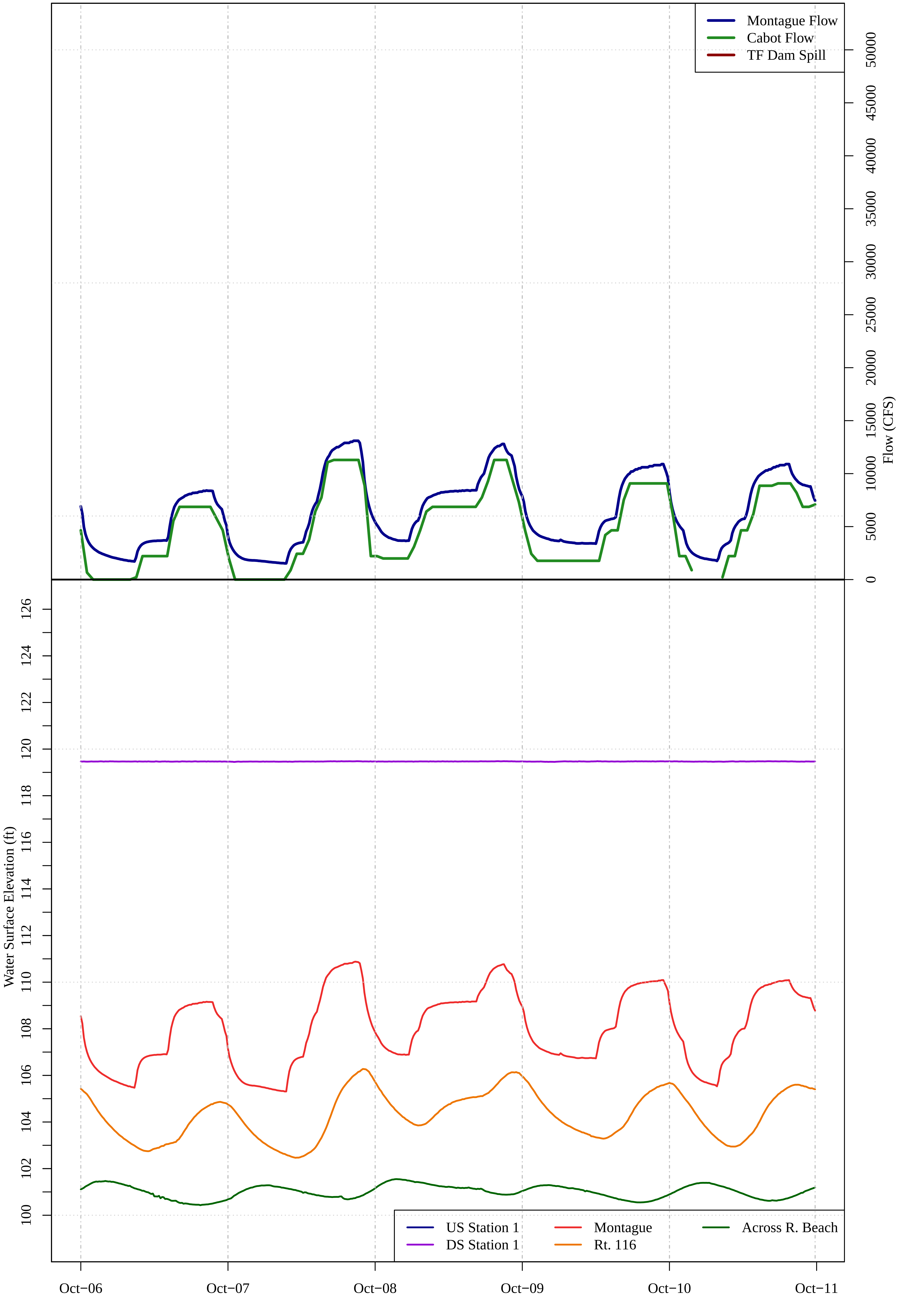
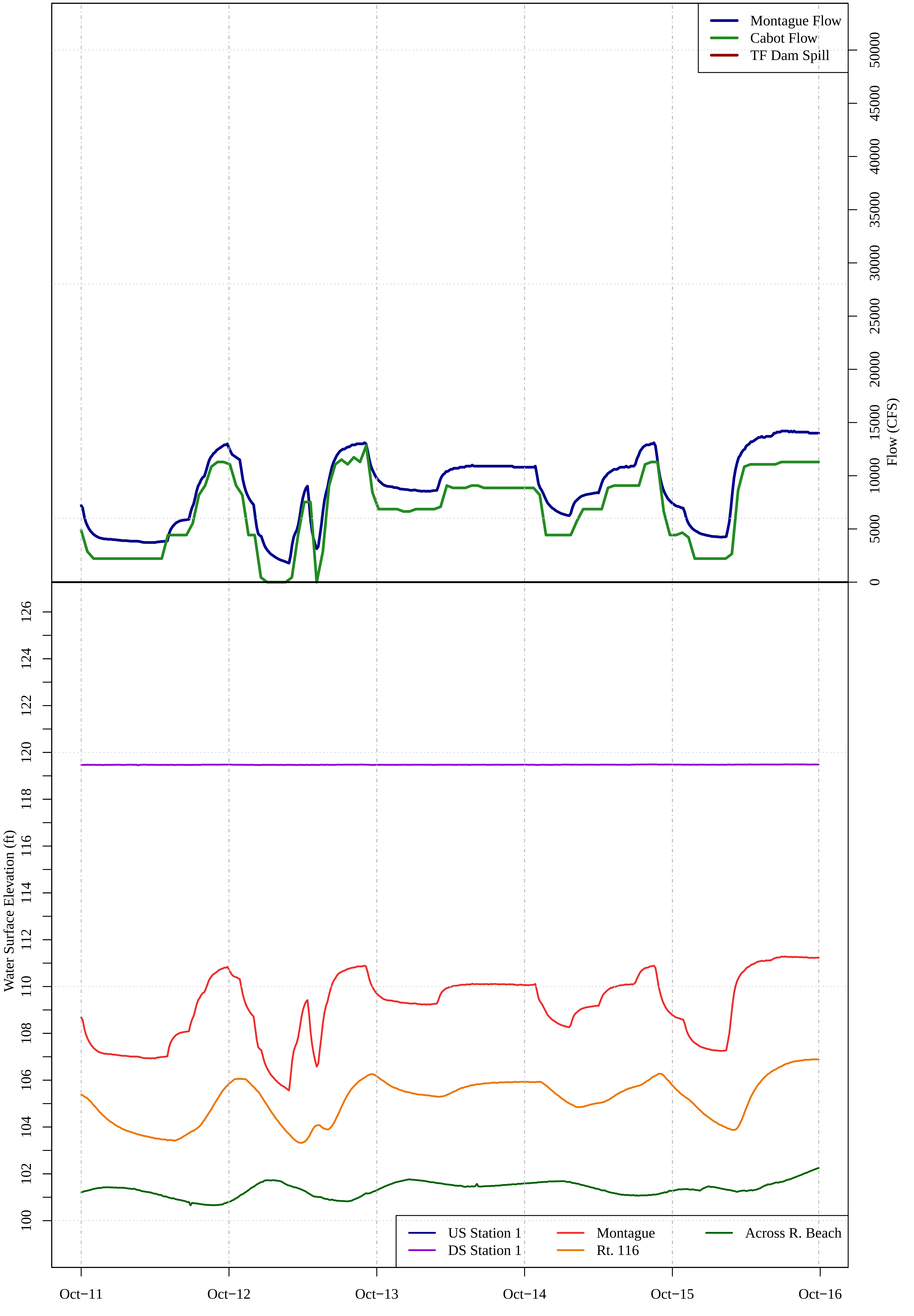
126
US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Oct−01
Oct−02
Oct−03
Oct−04
Oct−05
Oct−06

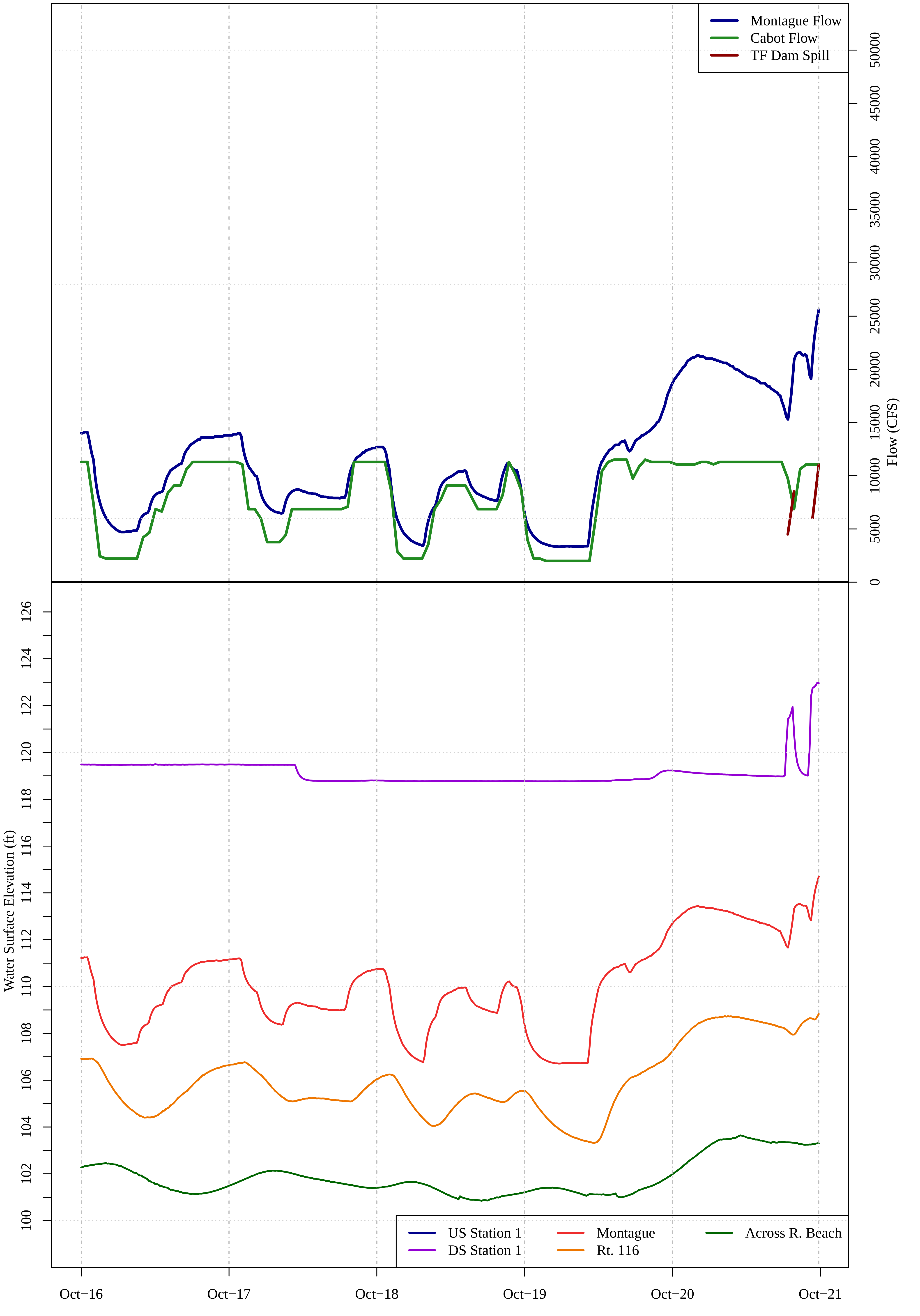
Water Levels and Flows 2012

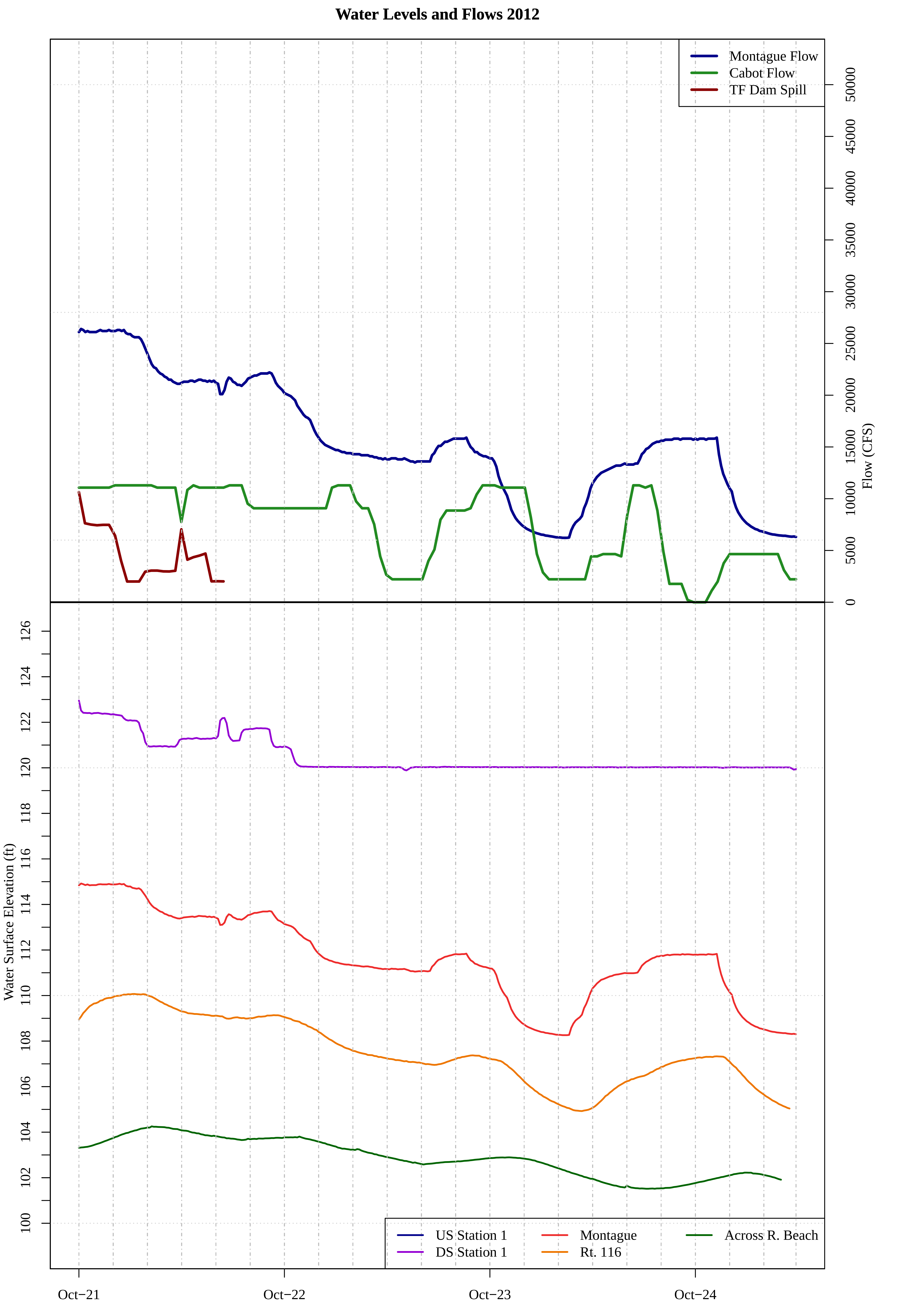


Water Levels and Flows 2012



Water Levels and Flows 2012




Water Levels and Flows 2012
Montague Flow
Cabot Flow
TF Dam Spill
Flow (CFS)
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10000
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45000
50000
Water Surface Elevation (ft)
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US Station 1
DS Station 1
Montague
Rt. 116
Across R. Beach
Oct−21
Oct−22
Oct−23
Oct−24