2012 Baseline Water Quality Study

Wilder Hydroelectric Project No.1892
Bellows Falls Hydroelectric Project No.1855
Vernon Hydroelectric Project No.1904

Wilder Impoundment

Agency Draft Report

Prepared For:
TransCanada Hydro Northeast Inc.
4 Park Street, Suite 402
Concord, NH 03301

Submitted On:
February 8, 2013

Prepared By:
Normandeau Associates, Inc.
25 Nashua Road
Bedford, NH 03110

www.normandeau.com

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Prepared for
TransCanada Hydro Northeast Inc.
4 Park Street, Suite 402
Concord, NH 03301

Prepared by
Normandeau Associates, Inc.
917 Route 12, #1
Westmoreland, NH 03467

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EXECUTIVE SUMMARY

This report presents the results of a comprehensive baseline water quality study conducted in support of Federal Energy Regulatory Commission (FERC) relicensing efforts by TransCanada Hydro Northeast Inc. (TransCanada) for three existing hydroelectric projects: Wilder Hydroelectric Project (FERC No. 1892), Bellows Falls Hydroelectric Project (FERC No. 1855), and Vernon Hydroelectric Project (FERC No. 1904) (Projects), located on the Connecticut River in Vermont and New Hampshire. Project licenses will expire in April 2018 and TransCanada is using the Integrated Licensing Process (ILP) for relicensing of these Projects. The water quality study presented herein was designed and revised with stakeholder feedback to satisfy state water quality certification criteria as well as to satisfy the seven ILP study criteria outlined in 18 CFR Section 5.9(b), and is presented as a fully supporting study for the FERC relicensing efforts.

Specific goals for the water quality study were to monitor basic water quality parameters including dissolved oxygen, temperature, specific conductance, and pH in areas of the Connecticut River affected by Project operations. Monitoring stations were established above and below each Project to characterize water quality conditions throughout each respective impoundment as well as tailrace areas below each facility. Utilizing a combination of fixed and mobile monitoring equipment, we collected a continuous data record at multiple stations combined with recurring spot measurements and supplemented with laboratory analysis of water samples. The study took place from June through September 2012 and was conducted under a wide range of flow and operating conditions including an extensive period of low flow/high temperature conditions which were specifically targeted as periods of critical importance due to the potential for low oxygen levels under those conditions.

The data show that under ordinary hydroelectric operating conditions during summer high temperature/low flow periods, basic water quality parameters were typical of a large New England river and generally met applicable state standards. Minor deviations from state water quality standards were infrequent, short-lived, and spatially limited and were not specifically attributable to Project operations. Stratification effects in impoundments were generally minor and hypoxic conditions were non-existent. These data show that irrespective of the effects of Project operations, water quality in Project waters supported all designated uses and met applicable criteria for the overwhelming majority of the study period throughout the entire study area. The complete water quality dataset is summarized and discussed in this report and included in its entirety as Appendix A.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

1.0 INTRODUCTION

This report presents the results of a comprehensive study of baseline water quality that was conducted on the Connecticut River in support of Federal Energy Regulatory Commission (FERC) relicensing efforts by TransCanada Hydro Northeast Inc. (TransCanada). The relicensing process applies to three existing hydroelectric projects (Projects): Wilder (FERC No. 1892), Bellows Falls (FERC No. 1855) and Vernon (FERC No. 1904) on the Connecticut River in Vermont and New Hampshire, whose current operating licenses will expire in April 2018. TransCanada is using the Integrated Licensing Process (ILP, 18 CFR Part 5) for relicensing.

In recognition of the fact that there were very little facility-specific water quality data available, TransCanada proactively decided to undertake a comprehensive pre-licensing baseline water quality study prior to submittal of Notices of Intent (NOIs) and Preliminary Application Documents (PADs) for each Project. This decision was made to:

- Help inform the development of the PADs;
- Fill important water quality data gaps related to the Projects;
- Resolve potential questions about the effects of the Projects on water quality; and
- Alleviate the need for agencies to formally request a water quality study during the ILP study phase of relicensing.

The study was conducted during the pre-licensing phase, but was designed to meet the seven FERC ILP study criteria as described in the rest of this Section and in Section 2.0 below. The study was designed to assess whether Project waters, defined as those waters both upstream (i.e., impounded areas) and immediately downstream (i.e., tailrace areas) of the dams that are potentially influenced by the Projects, met applicable water quality standards for the parameters of concern during a complete summer, high temperature/low flow season. Additionally, we sought to determine whether passage of water through the generating facilities had any effect on water quality in the tailrace areas below each dam, especially with respect to dissolved oxygen (DO).

ILP Study Request Criteria 18 CFR § 5.9(b)

1. Describe the goals and objectives of each study proposal and the information to be obtained.

The goal of the water quality study was to document definitively the existing water quality of Projects waters during critical conditions of high temperature/low flow; determine whether Project waters complied with applicable state water quality standards; and determine to what extent, if any, Projects operations affected water quality. During study plan development and review by New Hampshire Department of Environmental Services and Vermont Department of Environmental Conservation, DO was identified as the primary parameter of concern because that parameter is most typically affected by hydroelectric operations and also plays an overriding role in supporting other aquatic resources. In addition, the agencies requested that weekly sampling for nutrients and chlorophyll-*a* be part of the sampling program. Accordingly, the final study plan required the collection of project-specific DO, temperature, pH, and conductivity as well as laboratory analysis of nitrate/nitrite, total nitrogen, total phosphorus, total Kjeldahl nitrogen, and Chlorophyll-*a* in sufficient detail and during important low flow/high temperature time frames to determine the impact of each Project, if any, on water quality in the study area. The methodology approved by the agencies and used in the study is described in Section 2 below.

Specific objectives included:

a. Continuous monitoring of DO, temperature, pH, and conductivity in the impoundment and the tailrace area of each of the three Projects from mid-June through mid-September 2012. At impoundment sites, measurements were to take place at ~25% of the total depth of the water column. Additional continuous monitoring was also conducted to characterize the bypass reach at the Bellows Falls Project.

b. Weekly profile measurements in each of the three impoundments to characterize DO, temperature, pH, and conductivity with depth from the water surface to near the channel bottom. Three stations were to be established in each dam's impoundment at the lower, middle, and upper extents of each respective impounded area as previously delineated by TransCanada.

c. Weekly water samples were to be taken in the impoundment of each Project and would be a composite of the full water column at each site. Samples would then be analyzed for nitrate/nitrite, total nitrogen, total phosphorus, total Kjeldahl nitrogen, and Chlorophyll-*a*.

2. If applicable, explain the relevant resource management goals of the agencies or Indian tribes with jurisdiction over the resource to be studied.

The Clean Water Act directs the states to develop water quality standards for the nation's waters. Because waters potentially affected by these Projects are regulated by two states, (New Hampshire and Vermont), water quality standards for both states define the resource management goals for water quality. Specific water quality standard relevant to these Projects are presented in Section 3.2.

3. If the requester is not a resource agency, explain any relevant public interest considerations in regard to the proposed study.

The study was requested and designed in consultation with state agencies.

4. Describe existing information concerning the subject of the study proposal, and the need for additional information.

Relevant existing water quality data is limited in scope for the study area and includes:

- A 2004 study led by the New Hampshire Department of Environmental Services (New Hampshire DES) and assisted by the US Environmental Protection Agency (EPA) (CRJC, 2009);
- A 2008-2009 joint study between the University of Massachusetts Water Resources Research Center and the Targeted Watershed Initiative (TWI, 2010);
- Periodic historic water quality data, 2005-2007, from the US Geological Survey National Water Information System (USGS, 2012) at several maintained Connecticut River gaging stations (North Walpole, NH; West Lebanon, NH; Ryegate, VT);
- 2011-2012 dissolved oxygen and temperature study (preliminary data) performed by Normandeau Associates, Inc. in support of 401 Water Quality Certification by the New Hampshire DES for Vernon dam. The study consisted of recurring water column profile measurements at a location above the Vernon dam during the summer seasons of 2011 & 2012, and mid-water measurements at two additional locations below the dam in the summer season of 2011.

Summaries of existing data were included in Section 3.5.5 of the PAD for each Project. A review of the historical data indicated no water quality standards violations for dissolved oxygen within the study area. The historical data did show some instances of elevated bacteria counts and elevated nutrient concentrations, primarily nitrogen, within the study area which are likely attributable to non-point source runoff events and/or point source discharges from combined sewer overflows from municipalities within the watershed. Project operations are unlikely to contribute to elevated bacteria or nutrient levels within the project areas.

The primary limitation of the existing water quality data was the lack of a continuous record across a range of temperature and flow conditions in the study area. This limitation underscored the need for a comprehensive location-specific study to characterize multiple water quality parameters within the Projects and lasting a full summer season.

5. Explain any nexus between project operations and effects (direct, indirect, and/or cumulative) on the resources to be studied, and how the study results would inform the development of license requirements.

The Wilder, Bellows Falls and Vernon Hydroelectric Projects (Projects) are existing conventional hydroelectric projects located on the Connecticut River in Vermont and New Hampshire. Each Project includes an existing dam, storage reservoir (impoundment) and powerhouse. The Wilder Project is located in the towns of Wilder, VT and Lebanon, NH. The Bellows Falls Project is located in the towns of Rockingham, VT and Walpole, NH approximately 44 miles downstream of Wilder dam. The Vernon Project spans the Connecticut River between the towns of Vernon, VT and Hinsdale, NH near the Massachusetts border, approximately 32 miles downstream of the Bellows Falls Project.

Operation of the Projects is conducted in a coordinated manner in response to flows from upstream hydroelectric projects and inflows from tributaries. Hydroelectric operations have the potential to affect water quality directly and indirectly through hydroelectric generation, impoundment of water in Project reservoirs, and the timing and extent of flow management. Effects could occur locally at each Project, as well as cumulatively in the river from the upstream end of the Wilder impoundment to the area downstream of Vernon dam. TransCanada is not proposing a change in operations of the Projects, so this water quality study provides a comprehensive evaluation of water quality conditions relative to existing and future Project operations.

6. Explain how any proposed study methodology (including any preferred data collection and analysis techniques, or objectively quantified information, and a schedule including appropriate field season(s) and the duration) is consistent with generally accepted practice in the scientific community or, as appropriate, considers relevant tribal values and knowledge.

The methods of water quality data collection (described above and in Section 2.0) were included in the formal study plan that was prepared and submitted for review and comment to the New Hampshire DES and the Vermont Department of Environmental Conservation (Vermont DEC). Agency staff reviewed and commented on the study plan scope and methodology. The plan was subsequently revised to incorporate comments and recommendations from both agencies. The final study plan was approved by the agencies, and was designed to simultaneously satisfy requirements for:

a. An accepted ILP study under the FERC relicensing process;
b. State requirements in support of 401 Water Quality Certification (Section 401 of the Clean Water Act); and
c. Compliance of each Project with applicable state water quality standards.

7. Describe considerations of level of effort and cost, as applicable, and why any proposed alternative studies would not be sufficient to meet the stated information needs.

Projects waters include approximately 97 miles of impoundments and additional unimpounded tailwaters. Study plans were prepared and subsequently reviewed, modified and approved by the resource agencies, the goal of which was to definitively document water quality within Projects waters during critical high temperature/low flow conditions. Reductions in the geographic coverage, study duration or water quality parameters investigated would have potentially compromised the study goal of definitive evaluation of compliance of existing water quality with applicable state water quality standards. Study scope and associated costs were considered by TransCanada and found to be acceptable.

2.0 STUDY METHODS

2.1 Geographic Scope

The baseline water quality study was conducted on the Connecticut River covering an area from approximately River Mile 259.3 at the upper end of the Wilder impoundment near Newbury, VT and Haverhill NH, to River Mile 141.9 immediately below Vernon Dam near Vernon, VT and Hinsdale, NH (Figure 2.1-1). Thirteen water quality stations were established in the study area and included stations below each dam in the tailrace, and above each dam in the impounded areas. The dam impoundment boundaries were determined from Project boundary maps provided by TransCanada. Based on the Project maps, we identified preliminary station locations to be located immediately above each dam, at the midpoint of each impoundment, and at the upper reach of each impoundment.

Final station locations were determined based on field logistics. It was necessary to move the upper impoundment stations downstream from the planned locations due to periodic low water conditions which made boat travel to access the monitors difficult or impossible. The stations located mid-impoundment were then likewise moved downriver from the planned locations so that they were located at approximately the mid-point between the lower and upper impoundment stations. Below each dam, a station was established in each Project's tailrace and was located close enough to represent waters passing through the generating units but also far enough downstream to ensure that the equipment would not be damaged by high flow conditions. Figures 2.1-2 through 2.1-4 and Table 2.1-1 summarize the final station locations.

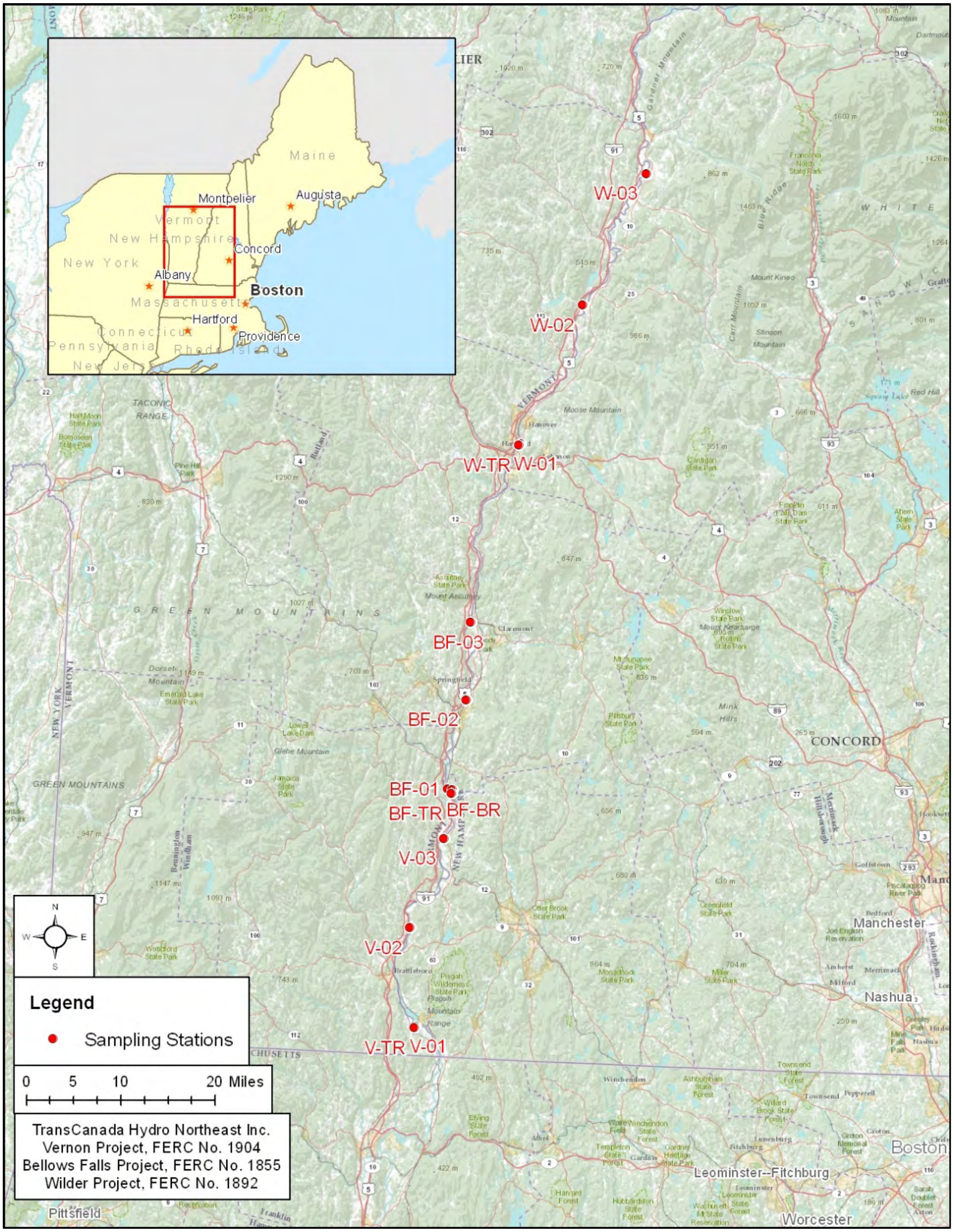

Figure 2.1-1. Location map showing all sampling stations in the study area.

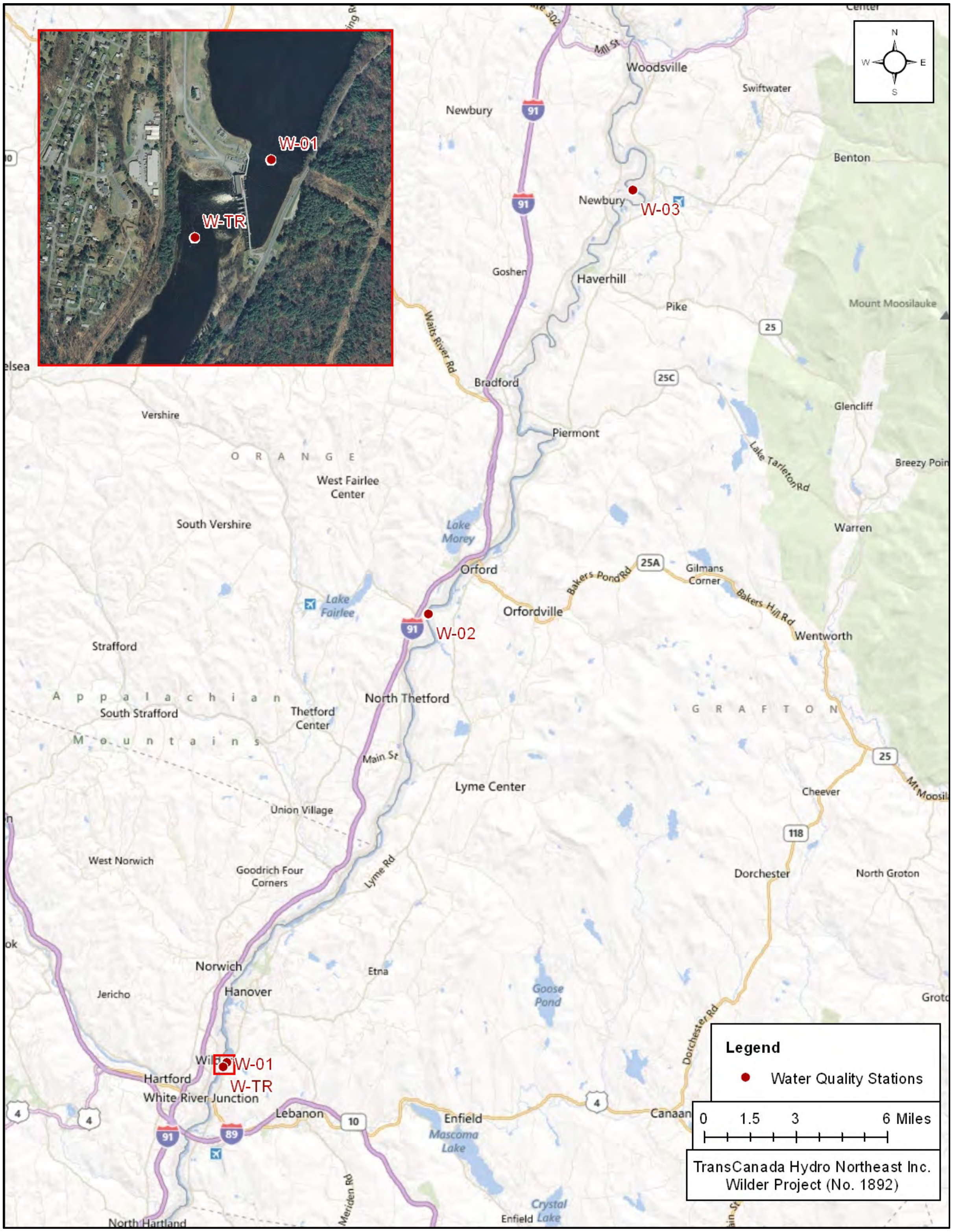

Figure 2.1-2. Location map showing sampling stations in the Wilder Project.

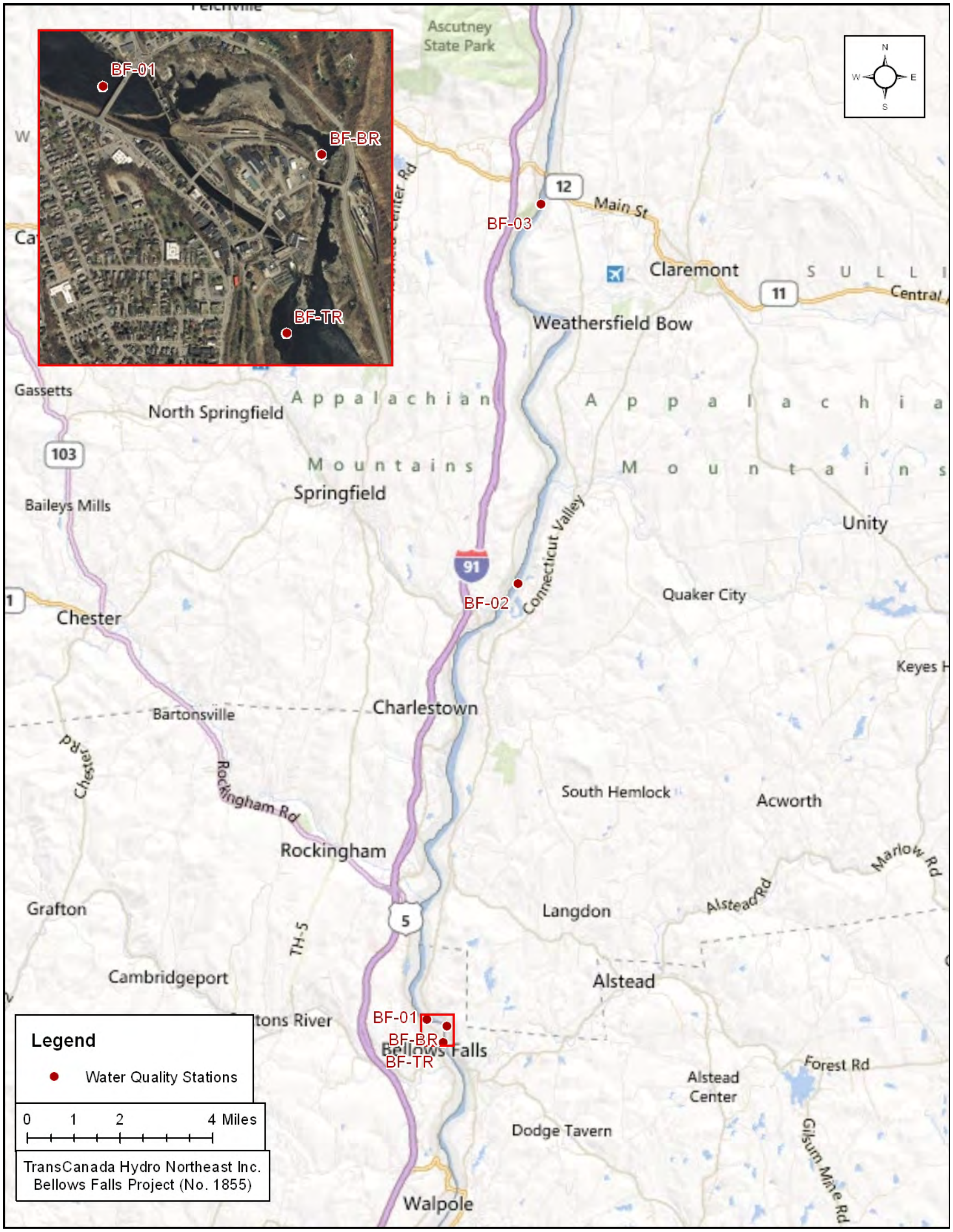

Figure 2.1-3. Location map showing sampling stations in the Bellows Falls Project.

Figure 2.1-4. Location map showing sampling stations in the Vernon Project.

Table 2.1-1. Summary of sampling stations.

Station ID	Description	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
W-03	Wilder upper-impoundment at RM 259.0	44.10057	-72.04336
W-02	Wilder mid-impoundment at RM 236.0	43.88204	-72.17256
W-01	Wilder forebay – at RM 217.5	43.66877	-72.30223
W-TR	Wilder tailrace – below dam and powerhouse at RM 217.3	43.66618	-72.30520
BF-03	Bellows Falls upper-impoundment at RM 194.5	43.45599	-72.39025
BF-02	Bellows Falls mid-impoundment at RM 184.4	43.29502	-72.40262
BF-01	Bellows Falls forebay - at RM 173.8	43.13808	-72.44861
BF-BR	Bellows Falls bypass reach – approximately 2,100 feet below dam in bypass reach	43.13620	-72.44040
BF-TR	Bellows Falls tailrace – below dam and powerhouse at RM 172.9	43.13156	-72.44179
V-03	Vernon upper-impoundment at RM 167.4	43.07041	-72.44458
V-02	Vernon mid-impoundment at RM 154.1	42.92997	-72.52601
V-01	Vernon forebay – at RM 142.0	42.77271	-72.51082
V-TR	Vernon tailrace – below dam and powerhouse at RM 141.8	42.76932	-72.51408

2.2 Study Plan

To achieve the water quality study objectives outlined in Section 1.1, we utilized a combination of continuous monitoring equipment deployed at 7 stations along with recurring spot measurements at 9 stations, supplemented with weekly sample collection at 3 stations. Sampling activities are summarized in Table 2.2-1.

2.2.1 Continuous Monitoring with Multiparameter Datasondes

Continuous monitoring water quality datasondes (YSI 6920 V2 and YSI 600 XLM instruments) were utilized to measure DO, temperature, conductivity, and pH in the forebay area of each impoundment (stations W-01, BF-01, and V-01) as well as at each of the tailrace stations (W-TR, BF-TR, and V-TR). The location of the instruments immediately above and below each dam was intended to characterize the effects of the impoundment on water quality as well as the effects of passage of water through the generating units on water quality in the tailrace areas below. An additional continuous monitor was installed in the Bellow Falls bypass reach (BF-BR) to characterize water quality in the bypass. Flow in the bypass results primarily from leakage at the dam and is not influenced by flow through the generating units. The instruments installed in the tailrace areas below each of the powerhouses were deployed during the week of June 17, 2012 while the impoundment and bypass reach monitors were deployed during the week of July 8, 2012. The reason for the discrepancy in initial deployment times was due to changes in the study plan requested by New Hampshire DES and Vermont DEC, and agreed to by TransCanada.

Table 2.2-1. Summary of water quality monitoring activities.

Task	Locations	Description	Sampling Frequency	Start Date	End Date
Continuous Monitoring with Multiparameter Datasondes	W-01, W-TR, BF-TR, BF-BR, BF-01, V-TR, V-01,	Monitoring of DO, temperature, conductivity, and pH via deployed datasonde with automatic logging	Every 15 minutes	06/19/2012	09/13/2012
Instantaneous Measurements with Multiparameter Datasonde	W-01, W-02, W-03, BF-01, BF-02, BF-03, V-01, V-02, V-03,	Monitoring of DO, temperature, conductivity, and pH via mobile datasonde. Measurements taken as profile at 1 m increments from water surface to channel bottom	Once per week	06/19/2012	09/13/2012
Water Sample Collection and Laboratory Analysis	W-01, BF-01, and V-01	Water samples collected as water column core from water surface to channel bottom. Laboratory analysis of nitrate/nitrite, total nitrogen, total phosphorus, total Kjeldahl nitrogen, and Chlorophyll-*a*	Once per week	07/10/2012	09/13/2012

At impoundment stations, the instruments were deployed at a depth equivalent to ~25% of the total water depth to compensate for stratification effects near the water surface. The equipment was deployed using an anchor and buoy system where an anchor was fixed to the channel substrate with a line of steel rope run to a buoy at the water surface. The instruments were attached to the buoy with a weighted dropper line to ensure a consistent recording depth. Instruments deployed in the tailrace areas utilized a modified version of this setup and did not have a dropper line attached to the buoy but rather were fixed directly to the main line run up from the anchor. While the recording depths were more variable with this setup (typically measuring 1-2 meters below the water surface), it was not a concern for the study as tailrace areas are well mixed due to turbulence and this more robust setup was more desirable to accommodate high flow conditions. All datasondes were programmed to log at 15-minute intervals to ensure high temporal resolution to the dataset while still conserving enough data logger memory and battery power to allow for extended unattended operation. All stations were visited by boat and a two man crew (with the exception of Bellows Falls bypass reach (BF-BR) which was accessed by foot from 8/10/12 through the end of the study) for the initial deployment and for recurring weekly site visits to download data and calibrate/maintain the instruments.

2.2.2 Instantaneous Measurements with Multiparameter Datasonde

Spot measurements were taken in the impounded areas above each dam once per week for the duration of the study, beginning the week of June 17, 2012. We accessed the stations by boat and used the same type of instrumentation as was used for continuous monitoring;

however, the instrument was treated as a mobile unit and real time readings of DO, temperature, conductivity, and pH were manually recorded on field data sheets. Measurements were taken as a profile through the water column, from the surface to the channel bottom at 1-meter increments, to characterize water quality with depth during the recurring spot measurements. Profile measurements were taken at the 9 stations located in the Project impoundments (W-01, W-02, W-03, BF-01, BF-02, BF-03, V-01, V-02, and V-03). During profiles, the boat was allowed to drift with the river current to control the depth of the instrument and to represent the same parcel of water moving downstream. The datasonde was lowered through the water via the instrument cable; with each change in instrument depth, we allowed the live readings to stabilize before recording values on the data sheets. Stations located at mid-impoundment and upper impoundment sites were marked initially and relocated at each sampling visit with a handheld GPS to maintain the sampling site location. Stations located immediately above each dam were identified by the deployed datasonde buoy.

2.2.3 Water Sample Collection and Laboratory Analysis

Water samples were collected from the forebay stations (V-01, BF-01, and W-01) on a weekly basis beginning the week of July 8, 2012, and were analyzed for nitrate/nitrite, total nitrogen, total phosphorus, total Kjeldahl nitrogen, and Chlorophyll-*a*. Samples were collected for ten consecutive weeks. To address the potential effects of stratification in the relatively deep impoundments (maximum depth is 46 feet at Wilder, 43 feet at Bellows Falls, and 56 feet at Vernon), we collected water samples as a core composite which represented the column average analyte concentrations from the surface to near the channel bottom. This was accomplished by lowering a length of weighted plastic tubing through the water column, capping the vented end to prevent the sample from flowing out of the tubing, extracting the tubing, and transferring the sample to a container. The sample was then mixed and poured off into the appropriate sample jars and chilled on ice to await transport to the lab. Chlorophyll-*a* samples were filtered at the end of the field day through a 0.45 μm cellulose filter, then frozen until transferring to the lab. We contracted with Eastern Analytical Labs, Inc. of Concord, NH to perform the laboratory analyses.

2.2.4 Variances from the Study Plan

There were several incidents that caused variances from the study plan, primarily in the form of small data gaps from the continuous monitor datasondes; however, variances did not have a significant impact on the conclusions drawn from the study.

- DO data are missing for the first week from the Wilder tailrace (station W-TR, 6/20/12 through 6/26/12) due to an oxygen sensor failure.

- At the Bellows Falls tailrace (station BF-TR) the wire rope from which the datasonde was deployed failed and the instrument settled at the bottom of the channel in the vicinity of the deployment setup. A replacement datasonde was deployed two days after the original sonde broke free. The original sonde was later recovered and as a result, two days of data in the final record (7/10/12 through 7/11/12) represent readings from the channel bottom rather than the near surface. We believe this does not affect the results as the current was very strong and turbulent in this area, creating well mixed conditions.
- Data are missing from the Vernon tailrace (station V-TR) for the four day period 7/2/12 through 7/6/12 due to a battery failure in the instrument. At the same station, the pH sensor failed early in the study and pH data are missing from 7/2/12 through 7/12/12.

Another slight variance from the study plan resulted from being unable to access the Bellows Falls bypass reach station (BF-BR) for a two week period from 7/25/12 through 8/10/12 due to low water conditions making boat access impossible. Posted property prevented immediate foot access until permission to access by foot was granted by the land owner beginning 8/10/12. Although the protocol was to visit each station weekly to check the instruments, download data, and re-calibrate, the quality assurance checks conducted on 8/10/12 were acceptable, leading us to conclude that the data were not compromised by the two-week unattended deployment. Outside of these exceptions, the final continuous monitor dataset represents a nearly contiguous record for the duration of the study period. There were no incidents that compromised any of the data from the recurring profile measurements or the water sample collection/laboratory analysis.

2.3 Quality Assurance Protocols

2.3.1 Data Quality Objectives

Table 2.3-1 includes a description of data quality objectives utilized in this study. These objectives applied to instrumentation used for continuous monitoring, as well as the mobile instruments used for recurring profile measurements. Laboratory analyses were performed by Eastern Analytical Labs, Inc. of Concord, NH, an EPA certified laboratory, and data quality objectives for that lab adhere to EPA standards.

Table 2.3-1. Data quality objectives.

Parameter	Condition	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	Frequency
Temperature (*YSI 6920 V2 or YSI 600 XLM* Multiparameter Datasonde)	Precision	Relative Percent Difference (RPD) ≤ 10 %	Field replicate (pre- and post-deployment)	Weekly (continuous monitor datasondes) Daily (mobile datasondes)
	Accuracy	RPD ≤ 10 %	Field replicate (pre- and post-deployment) side-by-side with calibrated instrument (*YSI 6920 V2 or YSI 600 XLM* Multiparameter Datasonde)	
	Sensitivity	Project Quantitation Limit NA	NA	
	Completeness	80% of planned measurements must be collected and pass the QA/QC process.	Data completeness check by Project Manager	
Dissolved Oxygen (*YSI 6920 V2 or YSI 600 XLM* Multiparameter Datasonde)	Precision	RPD ≤ 10 %	Field replicate (pre- and post-deployment)	Weekly (continuous monitor datasondes) Daily (mobile datasondes)
	Accuracy	RPD ≤ 10 %	Field calibration check using saturated air method (pre- and post-deployment) Field replicate (pre- and post-deployment) side-by-side with calibrated instrument (*YSI 6920 V2 or YSI 600 XLM* Multiparameter Datasonde)	
	Sensitivity	Project Quantitation Limit NA	NA	
	Completeness	80% of planned measurements must be collected and pass the QA/QC process.	Data completeness check by Project Manager	
Conductivity (*YSI 6920 V2 or YSI 600 XLM* Multiparameter Datasonde)	Precision	RPD ≤ 10 %	Field replicate (pre- and post-deployment)	Weekly (continuous monitor datasondes) Daily (mobile datasondes)
	Accuracy	RPD ≤ 10 %	Field calibration check with known standards (pre- and post-deployment) Field replicate (pre- and post-deployment) side-by-side with calibrated instrument (*YSI 6920 V2 or YSI 600 XLM* Multiparameter Datasonde)	
	Sensitivity	Project Quantitation Limit NA	NA	
	Completeness	80% of planned measurements must be collected and pass the QA/QC process.	Data completeness check by QA Officer	
pH (*YSI 6920 V2 or YSI 600 XLM* Multiparameter Datasonde)	Precision	RPD ≤ 10 %	Field replicate (pre- and post-deployment)	Weekly (continuous monitor datasondes) Daily (mobile datasondes)
	Accuracy	RPD ≤ 10 %	Field calibration check with known standards (pre- and post-deployment) Field replicate (pre- and post-deployment) side-by-side with calibrated instrument (*YSI 6920 V2 or YSI 600 XLM* Multiparameter Datasonde)	
	Sensitivity	Project Quantitation Limit ≤ 4.0	pH 4.0 reading with known standard	
	Completeness	80% of planned measurements must be collected and pass the QA/QC process.	Data completeness check by QA Officer	

2.3.2 Instrument Testing, Inspection, Maintenance

The inspection, testing, and maintenance of multiparameter datasondes were performed in accordance with the manufacturer's recommendations and the schedule included in Table 2.3-1. Datasondes deployed for continuous monitoring were inspected for debris or fouling, cleaned as necessary during weekly retrieval/redeployment, and tested through the quality assurance (QA) process outlined in Table 2.3-1. Mobile datasondes used for profile measurements were inspected and tested before and after each field day as outlined in Table 2.3-1. Sensors which failed the QA and calibration process described in Section 2.3.3 were replaced or repaired (e.g. replacement of DO sensor membrane).

2.3.3 Instrument Calibration and Frequency

The continuous monitor multiparameter datasondes were calibrated and tested (as per manufacturer's recommendations and outlined in Table 2.3-1) prior to initial deployment and the mobile datasondes were calibrated and tested prior to the start of each field day. The continuous monitor datasondes were then recalibrated and tested during the weekly site visits concurrently with data downloads. An additional quality assurance measure conducted during each site visit was to take field replicate samples where the continuous monitor datasondes were tested upon retrieval side-by-side with the calibrated mobile datasonde and then retested in the same way after calibration. Calibration techniques and standard solutions were in compliance with manufacturer recommendations and standard protocols. All calibration data, field replicate data, and other testing/maintenance information was documented in field notebooks. Calibration procedures are summarized in Table 2.3-2.

Table 2.3-2. Instrument calibration and frequency.

Instrument/Equipment	Calibration Method	Calibration Frequency
Water Temperature	Default Factory Calibration will be used	Not Applicable
Dissolved Oxygen	Saturated Air Method	Calibrate at start of sampling day (mobile datasonde) or at time of data download (continuous monitor datasondes). Check calibration at end of sampling day (mobile datasonde) and as needed.
Specific Conductivity	One Point calibration Method	Calibrate at start of sampling day (mobile datasonde) or at time of data download (continuous monitor datasondes). Check calibration at end of sampling day (mobile datasonde) and as needed.
pH	Two Point Calibration Method	Calibrate at start of sampling day (mobile datasonde) or at time of data download (continuous monitor datasondes). Check calibration at end of sampling day (mobile datasonde) and as needed.
Depth	One Point calibration Method	Calibrate prior to vertical profile or deployment.

2.4 Quality Control Protocols

2.4.1 Data Synthesis

All data from the continuous monitor datasondes were downloaded to a handheld device (YSI 650 MDS) during the weekly site visits. Data from the recurring profile measurements using a mobile datasonde were manually recorded on field datasheets. Laboratory data were provided in an electronic format from the lab. Data were then transferred to a spreadsheet database either directly from a file transfer (i.e., from the logged data on a YSI 650 MDS) or via manual data entry from the field datasheets to a SAS® Software database then exported to spreadsheet format. The compiled dataset was then reviewed and quality controlled based on the study field notes and calibration logs.

2.4.2 Data Censorship

There were two separate instances where it was determined that data logged by a water quality sonde was compromised and could not be corrected using the data correction measures discussed in Section 2.4.3 below, thus necessitating removal from the final dataset. The datasonde in the Wilder tailrace (W-TR) was discovered to have a torn membrane on the DO sensor upon retrieval in the second week of the study. The data record showed highly anomalous DO values from the initial deployment, leading us to conclude that the sensor membrane failed at the time of initial deployment. It was therefore necessary to remove DO data from the final dataset for the period from initial deployment through sonde retrieval (6/20/12 – 6/26/12).

A second incident occurred with a pH sensor that failed on the datasonde in the Vernon tailrace (V-TR) on the third through fourth weeks of the study. Although the sensor was functional, there were anomalously high values and the instrument failed the QA checks at the time of calibration on 7/6/12. A replacement sensor was immediately ordered and was deployed with the datasonde the following week on 7/12/12. Unfortunately, we determined it was not possible to correct the data with any certainty and the anomalous pH data for the period 7/2/12 – 7/12/12, were removed from the final dataset.

All other continuous monitor data were included in the final dataset pending data correction discussed in Section 2.4.3.

2.4.3 Data Correction

The continuous monitor dataset was reviewed and in some instances a correction factor was applied to the data to adjust for instrument drift and fouling effects on sensor readings. We determined whether to apply any correction to the data based on the criteria discussed in the US Geological Survey (USGS)'s publication "Guidelines and Standard Procedures for Continuous Water Quality Monitors: Station Operation, Record Computation, and Data Reporting" (USGS, 2006) and summarized in Table 2.4-1. The method described by USGS

(2006) utilizes the field replicate differential (pre- and post-instrument cleaning) as well as the instrument calibration offsets to determine fouling and calibration drift errors for a given period of instrument deployment. If the combined instrument error exceeded the criteria outlined in Table 2.4-1, a weighted linear correction was applied to the dataset for the deployed period. The first datapoint in such a period would have no correction while the last datapoint would be corrected to the same percent difference as the total fouling and calibration drift error. The final dataset represents the reported dataset with corrections applied.

Table 2.4-1. Data correction criteria.

Field Parameter	Data-correction criteria (apply correction when the sum of the absolute values for fouling and calibration drift error exceeds the value listed)
Temperature (may affect other field parameters)	± 0.2 ºC
Specific conductance	± 5 µS/cm or ± 3% of the measured value, whichever is greater
Dissolved oxygen	± 0.3 mg/L
pH	± 0.2 pH unit

(Source: USGS, 2006)

It was not necessary to apply instrument error corrections to data from the mobile datasondes used for profile measurements. Due to the short period of exposure to the aquatic environment and the daily calibration and field replicate checks, we determined the mobile datasondes to be reading accurately throughout the study period.

We determined it was necessary to apply an adjustment to the reported DO percent saturation values for both the continuous monitor data and the water quality profile data. The water quality datasondes used for this study measure dissolved oxygen as a percent of saturation at mean sea level pressure. To adjust for the effects of elevation, we corrected the percent saturation values to the mean atmospheric pressure at the local elevation for each of the stations. This was accomplished by determining the DO concentration at 100% saturation from the reported DO concentration and reported saturation value then applying a proportional correction based on mean barometric pressure at a given elevation (barometric pressure/mean sea level pressure). The elevation corrected percent saturation values are reported in the final quality controlled dataset discussed in this report and included in Appendix A. An excellent discussion of dissolved oxygen saturation and justification for the barometric pressure correction at low elevations can be found in Chapter 3 of EPA’s publication “Rates, Constants and Kinetics Formulations in Surface Water Quality Modeling” (EPA, 1985).

3.0 ANALYSIS AND RESULTS

3.1 Temporal Patterns of Water Quality

We reviewed the continuous monitor data to determine seasonal trends in water quality as shown in the time series plots in Figures 3.1-1 through 3.1-7. Time series plots are also presented for water quality profiles in the impoundments in Figures 3.1-8 through 3.1-10 as well as water chemistry in Figure 3.1-11.

Due to the complexity of presenting the profile data in a concise and meaningful way, we present the mean value for a single profile in the time series plots in Figures 3.1-8 through 3.1-11. This facilitates comparison of profile data through time while compensating for variations with depth, particularly at the deeper stations where some stratification was observed. Section 3.3 presents a more detailed discussion of the effects of stratification in the impoundments.

3.1.1 Seasonal Trends in Water Quality

Over the study period we saw significant short term variability in all water quality parameters and more subtle longer term trends as shown in Figures 3.1-1 through 3.1-11. As would be expected, water temperatures generally warmed from the beginning of the study to a peak in early August at all sites, and then began a cooling trend through the end of the study in mid-September. Temperatures were between 20-30 °C at all sites and had a seasonal range of approximately 5 - 8 °C. DO was highly variable and did not strongly correlate with other water quality parameters but was generally highest at the beginning and end of the study in the 9-10 mg/L range (100-120 % saturation) coincident with the coolest water temperatures. Specific conductivity was also variable, typically in the 80-175 µS/cm range, and was generally higher in the middle and latter half of the study versus the beginning. pH did not vary significantly throughout the study and was generally between pH 7 and 8 at all stations. The upper impoundment stations (W-03, BF-03, and V-03) did show occasional lower pH values between pH 6 and 7 (Figures 3.1-8 through 3.1-10).

Water chemistry generally did not show strong seasonal patterns in the forebay stations (W-01, BF-01, or V-01) as can be seen in Figure 3.1-11. Nitrate - nitrite (NO_3+NO_2) increased at all three sites from the start of sampling in July at ~ 0.16 mg/L to a peak in early or mid-August at over 0.20 mg/L then dropped and remained in the 0.15-0.20 mg/L range. Total nitrogen (TN) did not trend significantly during the study and varied between 0.5 and about 0.8 mg/L at all three stations. Likewise, total Kjeldahl nitrogen (TKN) did not show any seasonal patterns and varied from about 0.4-0.6 mg/L. Total phosphorus (TP) was also variable and was generally higher in the mid-summer ranging from 0.01-0.06 mg/L than

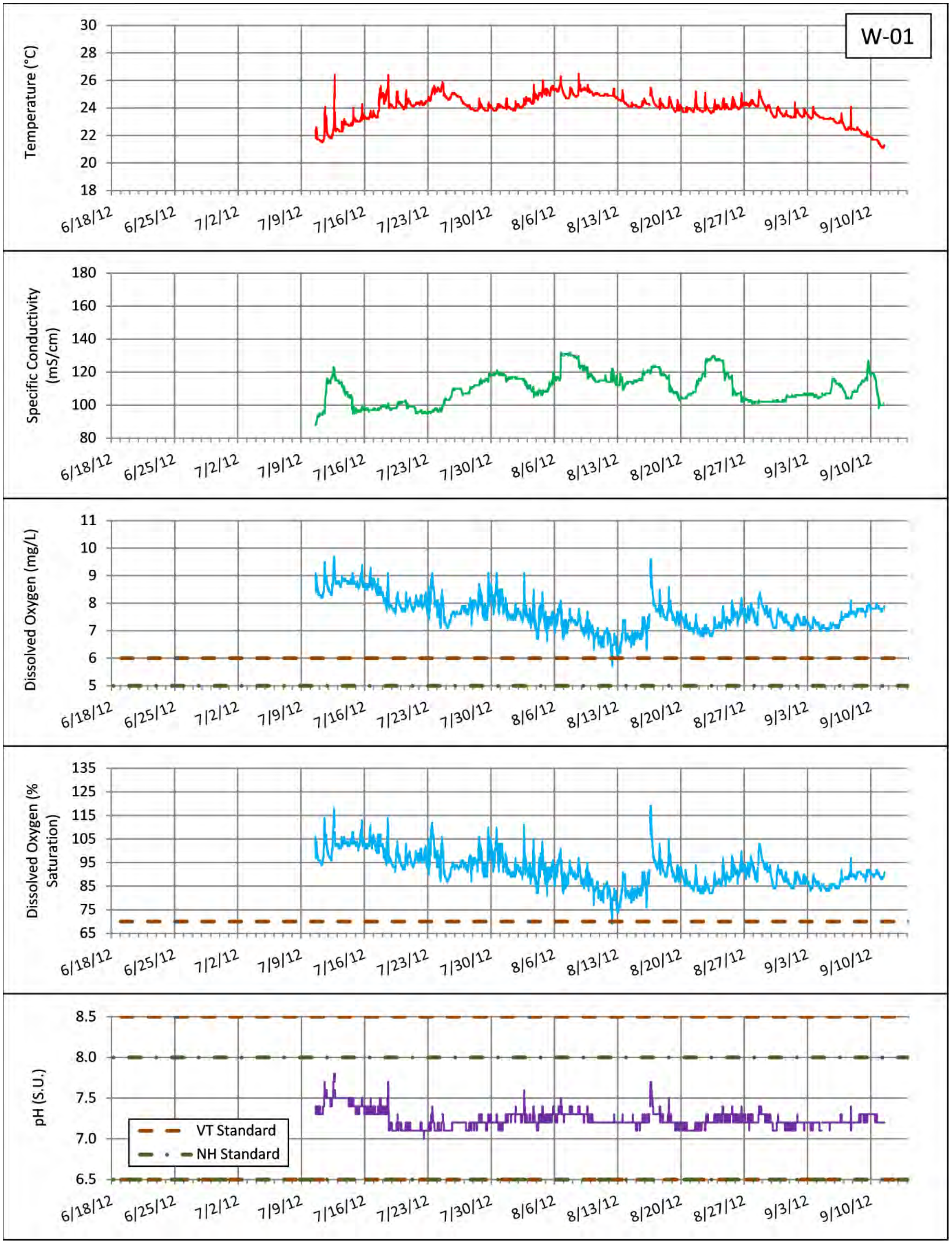

Figure 3.1-1. Time series plot of water quality parameters recorded in the Wilder impoundment forebay area (Station W-01).

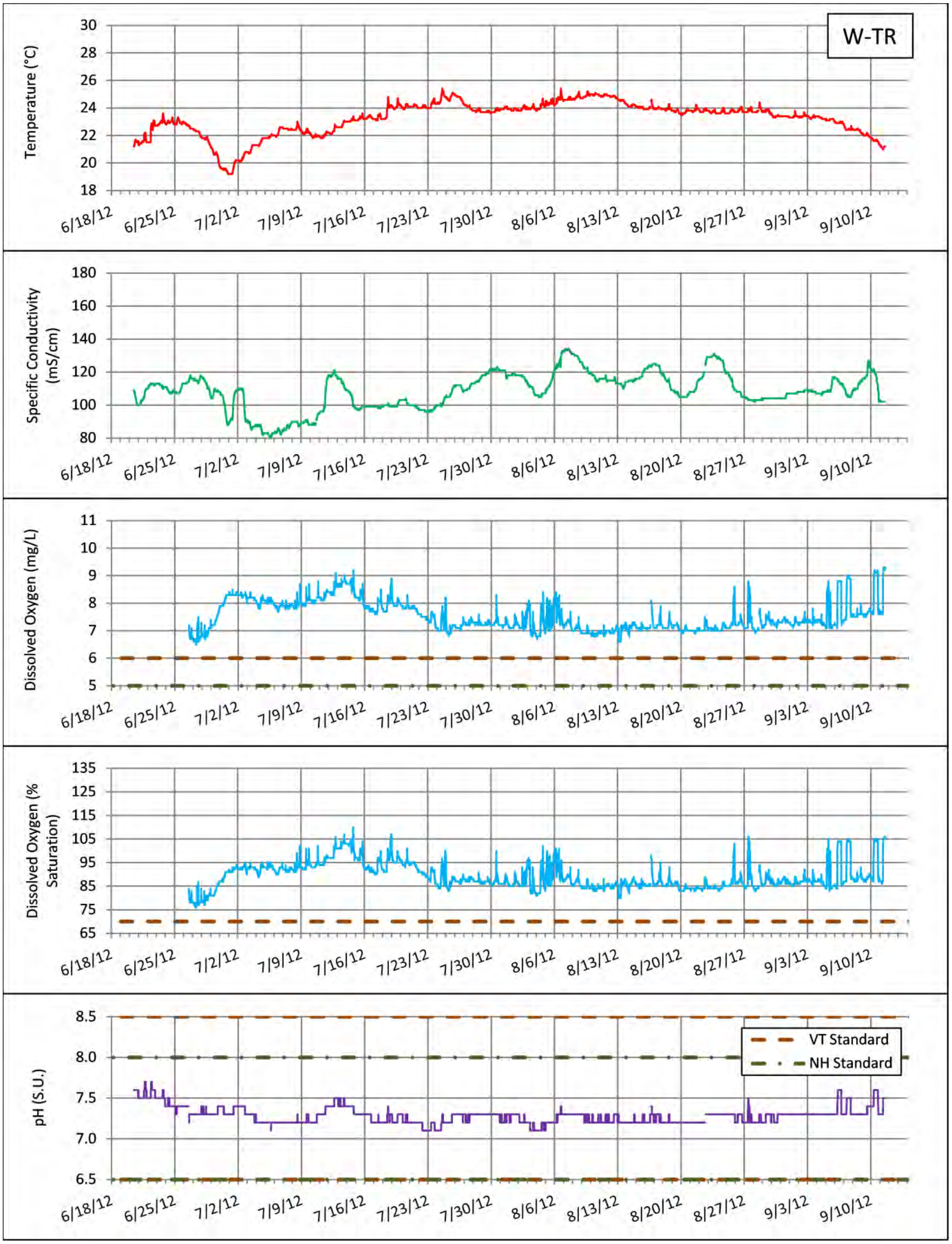

Figure 3.1-2. Time series plot of water quality parameters recorded in the Wilder tailrace (Station W-TR).

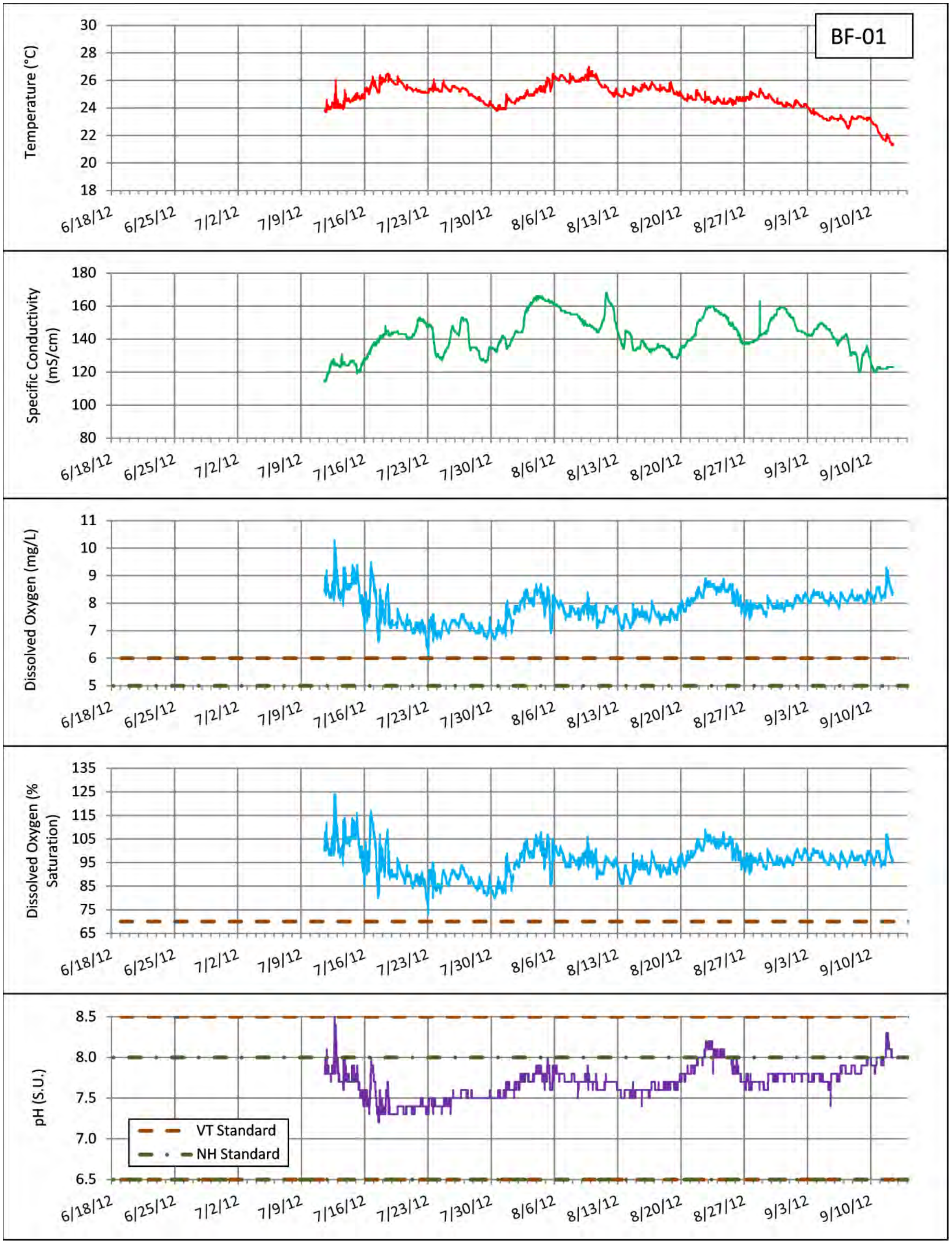

Figure 3.1-3. Time series plot of water quality parameters recorded in the Bellows Falls impoundment forebay area (Station BF-01).

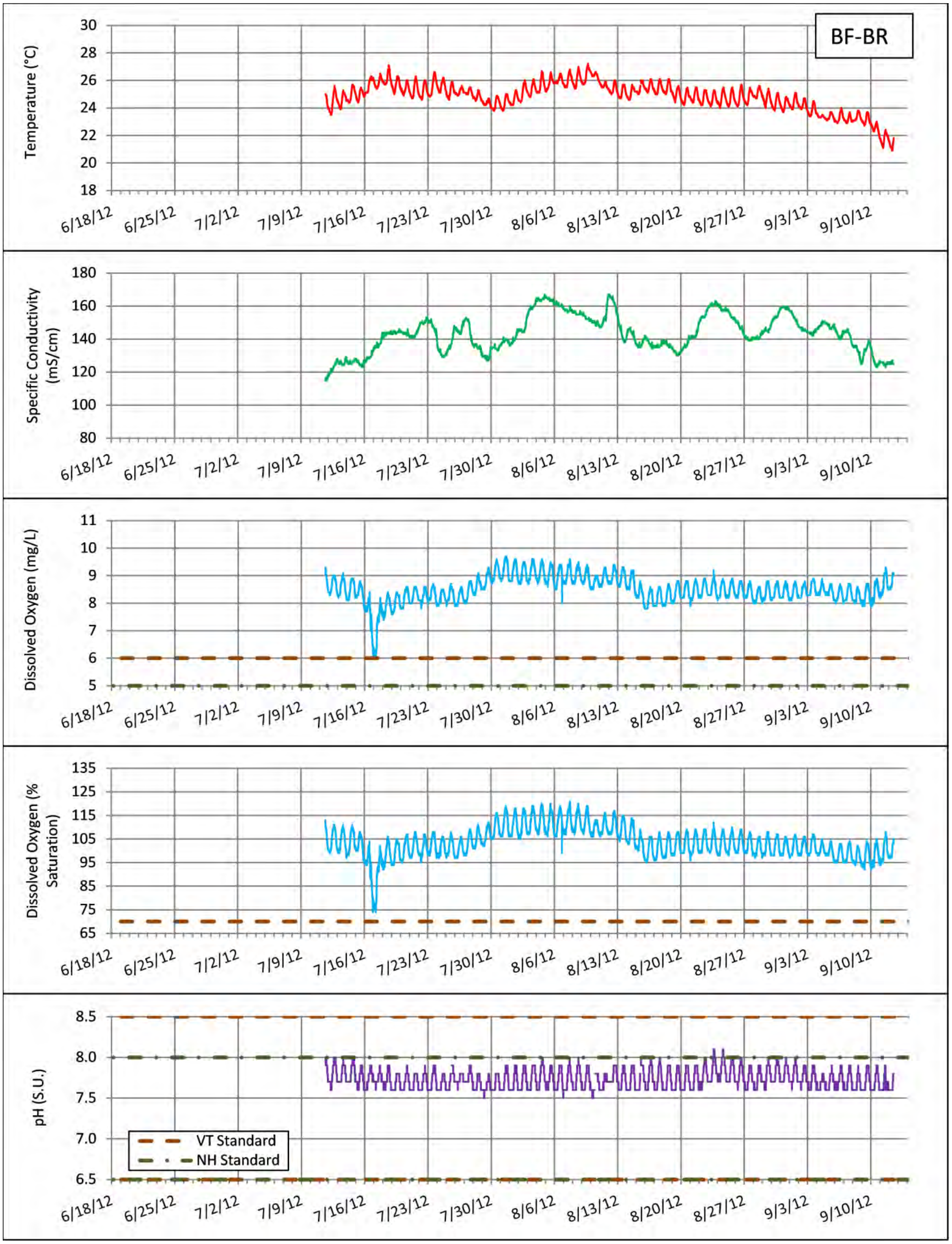

Figure 3.1-4. Time series plot of water quality parameters recorded in the Bellows Falls bypass reach (Station BF-BR).

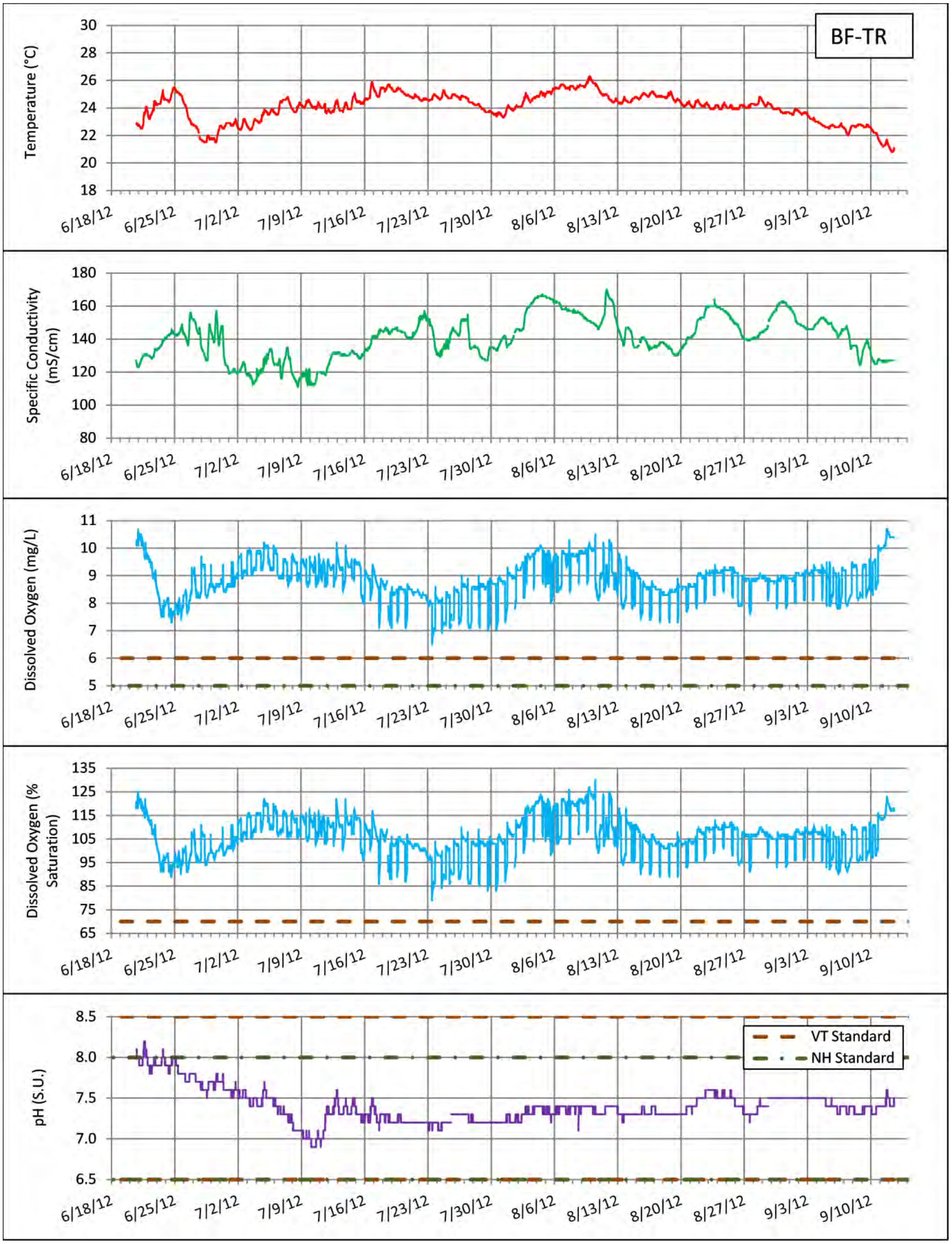

Figure 3.1-5. Time series plot of water quality parameters recorded in the Bellows Falls tailrace (Station BF-TR).

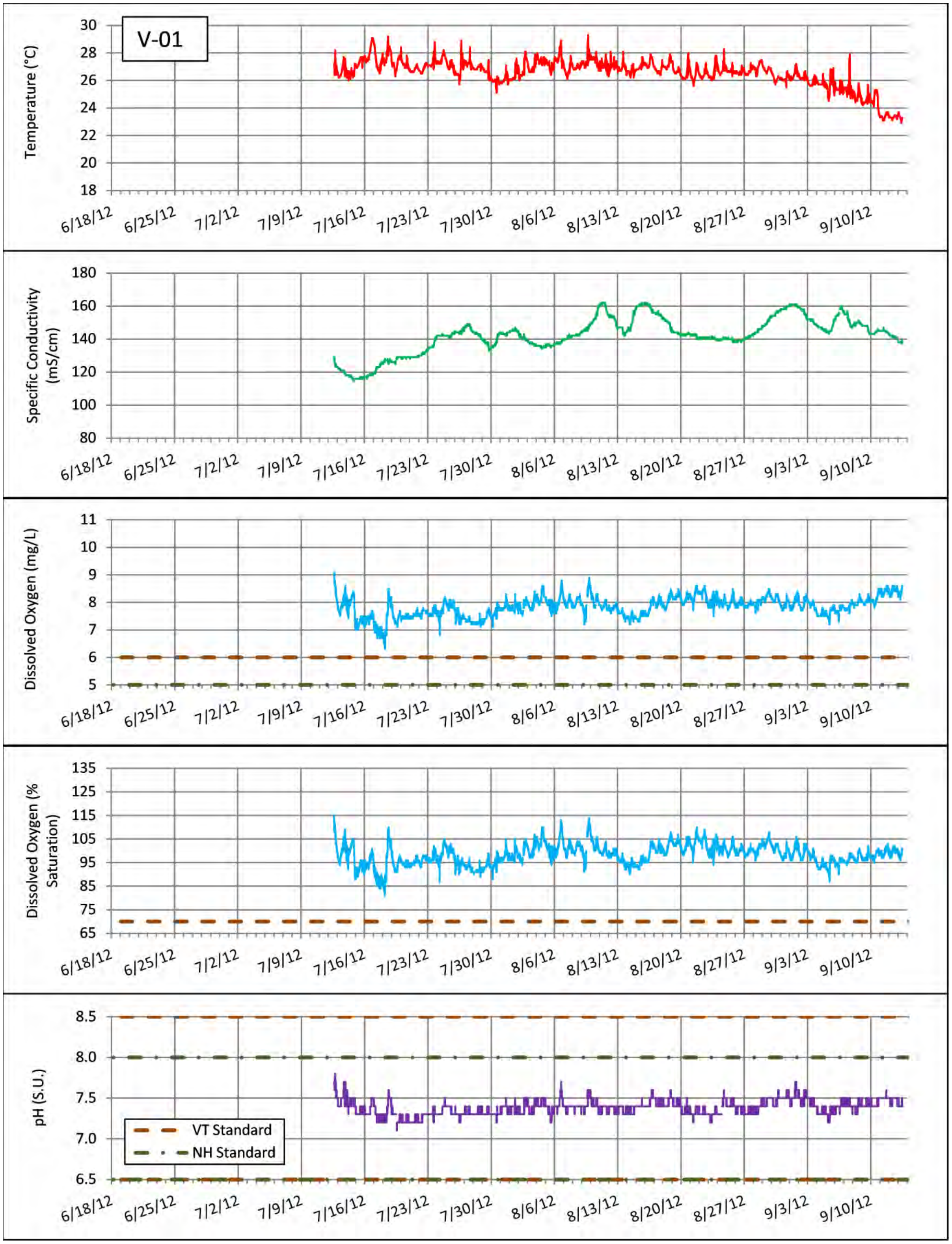

Figure 3.1-6. Time series plot of water quality parameters recorded in the Vernon impoundment near the dam (Station V-01).

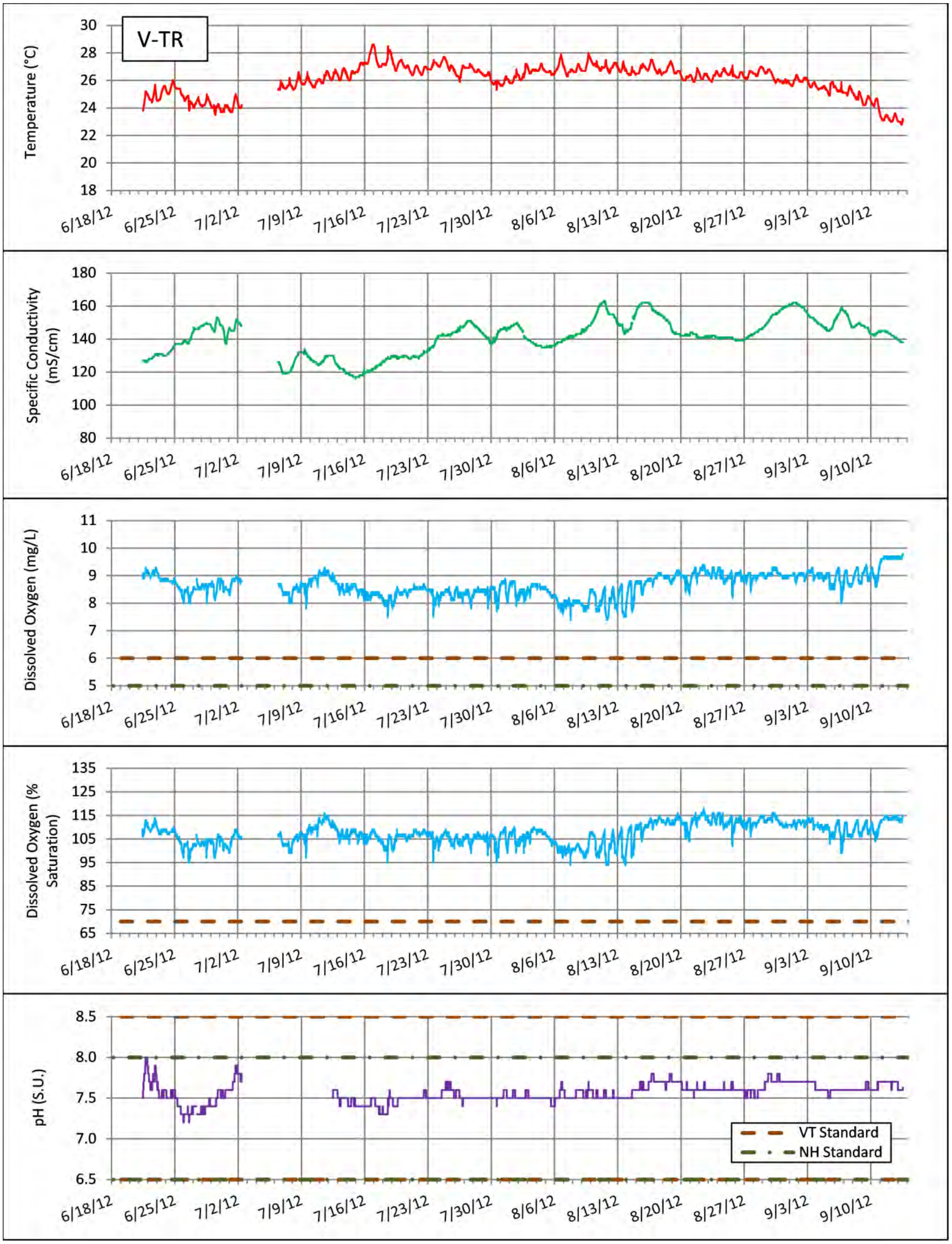

Figure 3.1-7. Time series plot of water quality parameters recorded in the Vernon tailrace (Station V-TR).

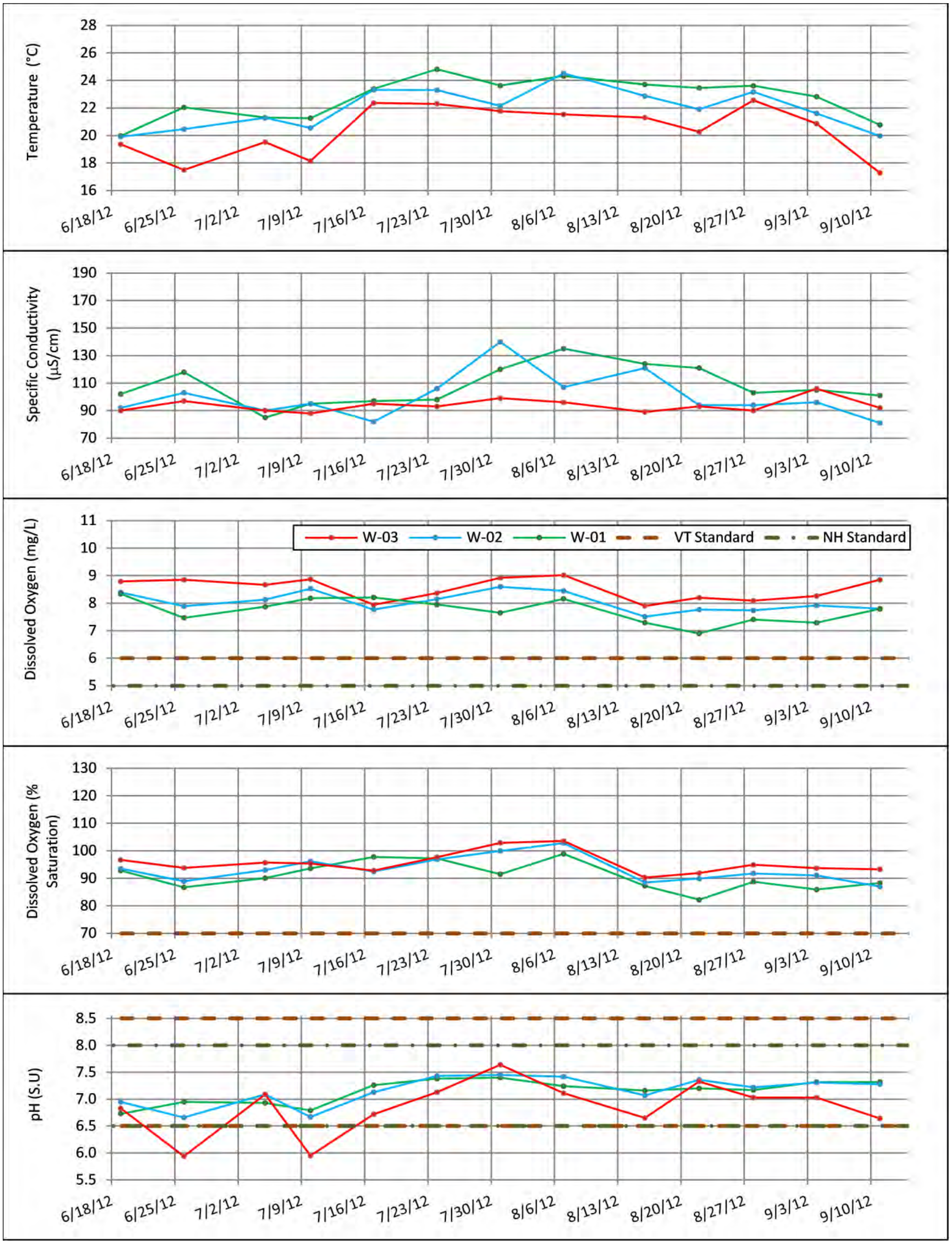

Figure 3.1-8. Time series plot of water quality profile data (global mean of all depths in a profile) at three stations in the Wilder impoundment.

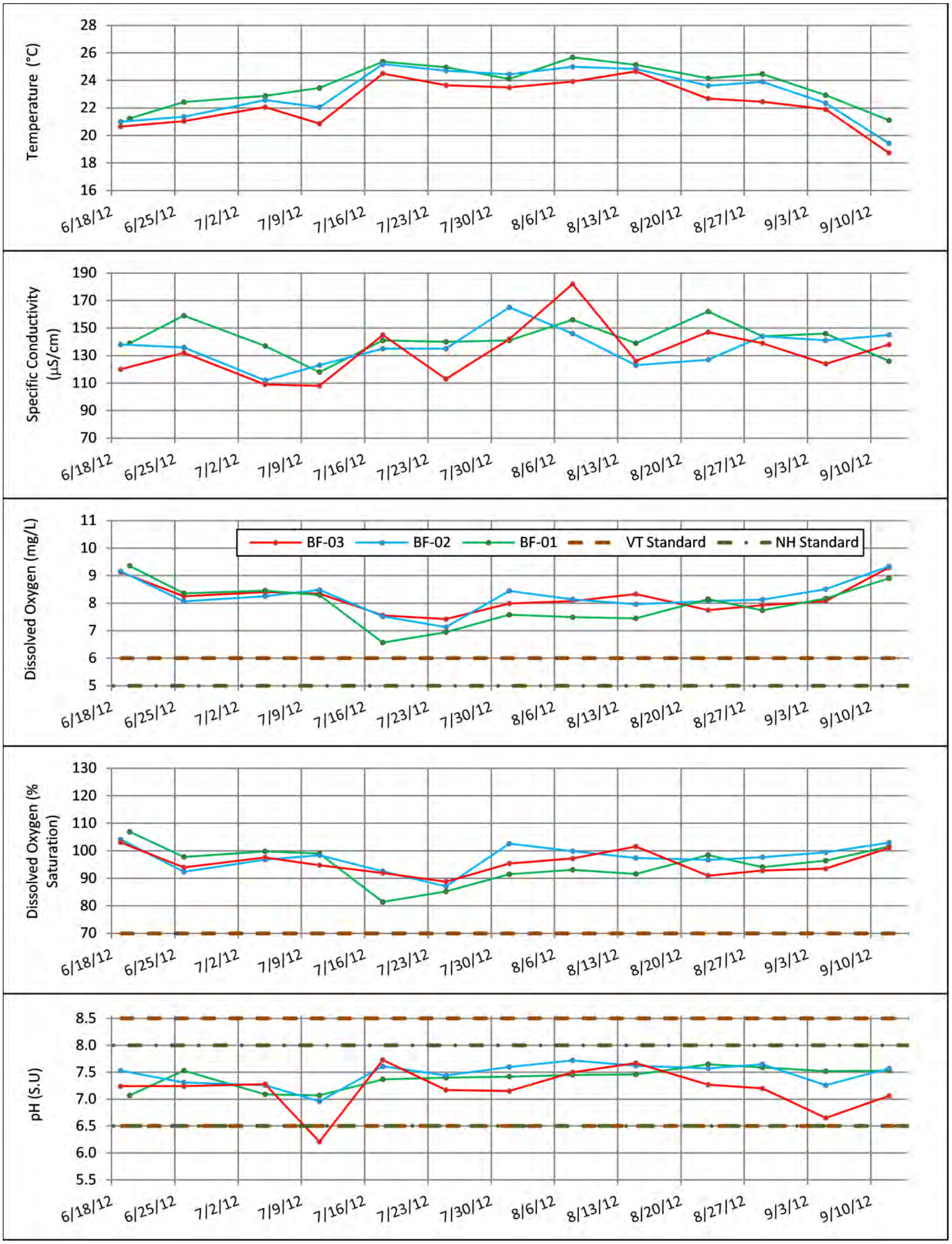

Figure 3.1-9. Time series plot of water quality profile data (global mean of all depths in a profile) at three stations in the Bellows Falls impoundment.

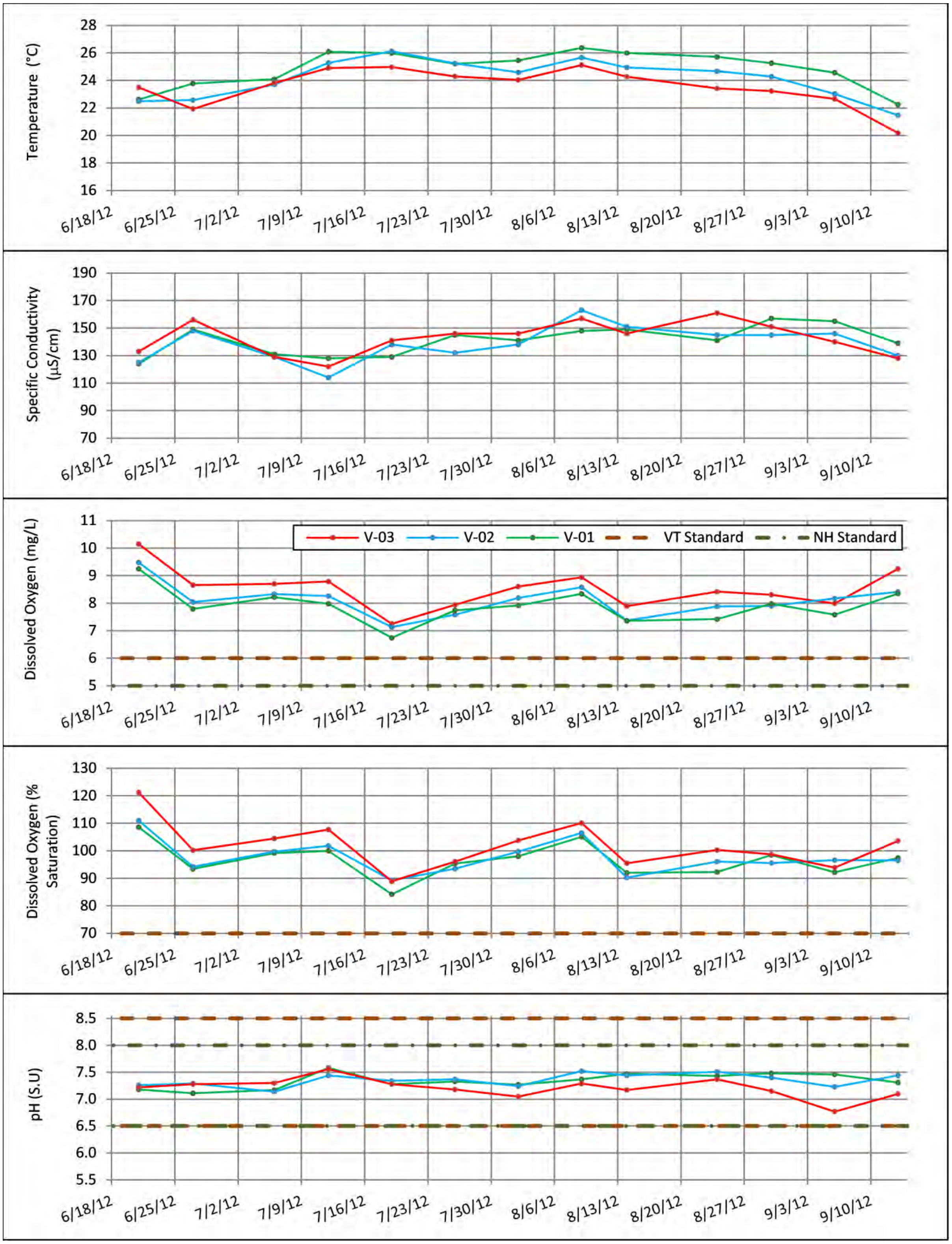

Figure 3.1-10. Time series plot of water quality profile data (global mean of all depths in a profile) at three stations in the Vernon impoundment.

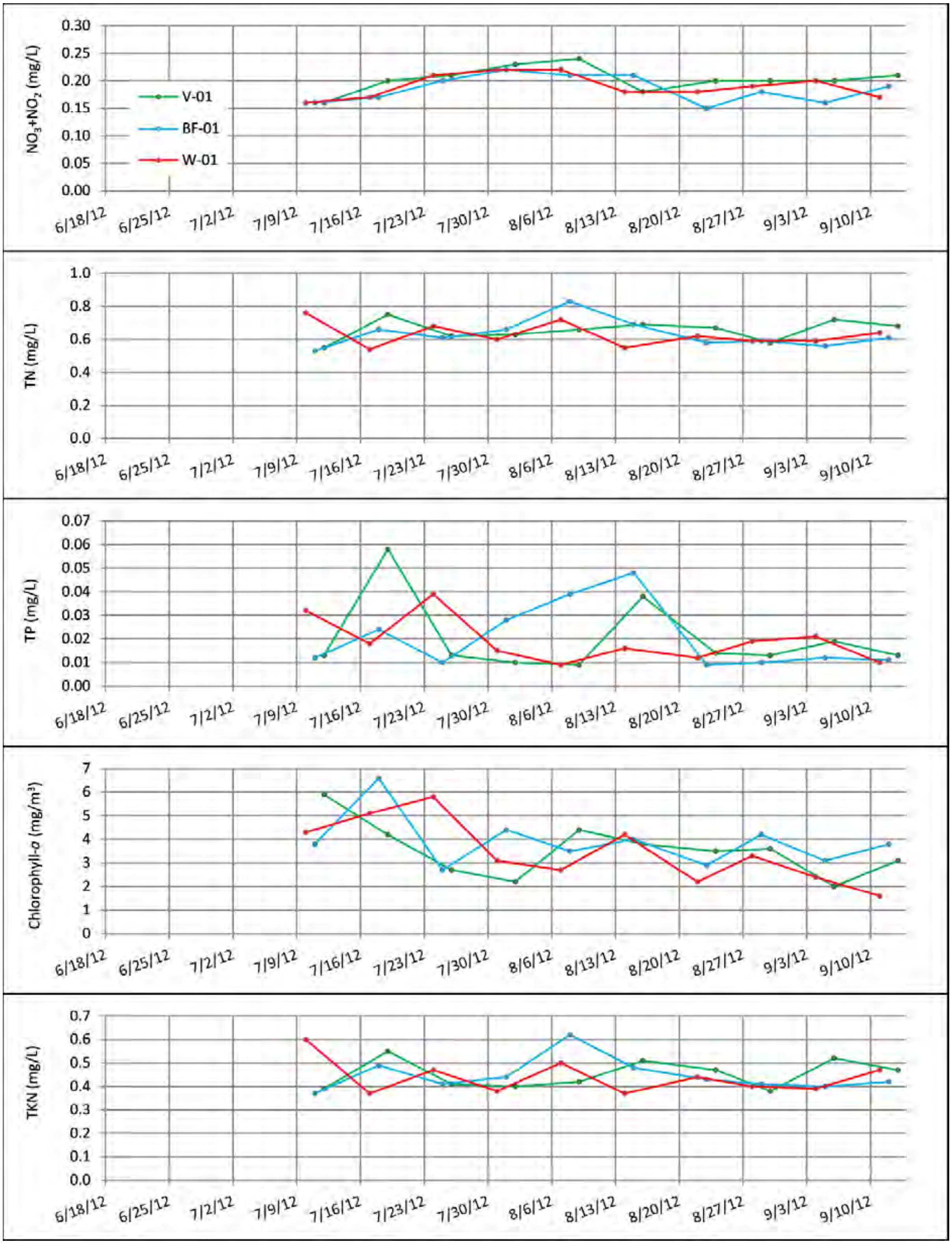

Figure 3.1-11. Time series plot of laboratory analyses of water chemistry for samples collected near the dam in each impoundment.

during the final four weeks of the study when values were about 0.01-0.02 mg/L. Chlorophyll-*a* demonstrated a slight decreasing trend from the start of sampling in mid-July with values ranging from about 4-7 mg/m^3 to values of about 1-4 mg/m^3 during the middle and end of the study.

3.1.2 Short Term Patterns of Water Quality

Water quality parameters as measured by the 7 continuous monitor stations (Figures 3.1-1 through 3.1-7) showed some variability on short time scales, from hours to a few days. These trends appears to result from two types of drivers: 1) regional trends of weather (warming and cooling periods) and precipitation events (increased flow), resulting in water quality parameter changes over a period of several days, and 2) daily variations and cyclical patterns reflecting localized influences including periods of algal growth, diurnal heating and cooling, and changes in flow resulting from Project operations.

Daily temperature fluctuations were also documented at all of the stations. Diurnal temperature changes of 1°C or more were common and are typical of large, riverine and impounded environments in New England. Temperature changes are driven entirely by meteorological conditions, although daily differences are typically smaller in impoundments than free flowing rivers because of greater volume and reduced atmospheric exposure in riverine impoundments. Similarly dissolved oxygen demonstrated strong patterns of daily variation of ~0.5-1.0+ mg/L (~5-15% saturation) at all stations throughout the study period, largely in response to temperature changes (temperature and DO are inversely related), but also at times apparently related to algal growth, especially in the Bellows Falls impoundment and especially earlier in the study. DO variation was typical of daily cycles expected in a large, moderately nutrient-enriched river in northern New England. Generally the daily variations in DO at the continuous monitor stations were gradual and parallel with temperature changes; however, the DO values at the Bellows Falls tailrace station (BF-TR) commonly exhibited a strong binary pattern with a step decrease of ~1.0+ mg/L (see Figure 3.1-5, generally occurring within a fifteen minute interval between datasonde readings). This was generally followed by a corresponding step increase 3-12+ hours later by a similar amount. The step changes in DO concentration occurred during daytime and appeared to be synchronized with similar step changes in river flow (see Section 3.5 for further discussion of this phenomenon). Periodic step changes in DO concentration were also measured in the Wilder tailrace (W-TR) and were particularly pronounced during the last week of the study (see Figure 3.1-2). pH also varied on a daily cycle, however the variations were generally on the order of 0.1-0.2 s.u. The bypass reach at Bellows Falls (BF-BR) demonstrated repeated daily variations in temperature, DO, and pH that were unique from the other sites in the consistency of the pattern over time (see Figure 3.1-4). We attribute these trends to a steady and reduced flow regime resulting from leakage flow only. Reduced flows and shallower depths allow water to respond more quickly and with greater magnitude to atmospheric and solar insolation conditions.

3.2 State Water Quality Standards

The state boundary between New Hampshire and Vermont is the low-water mark on the western side of the Connecticut River as it existed before the creation of reservoirs on the river. Because discharges from Project facilities occur in both states, the Projects are subject to the water quality standards of both states.

In 1972, the Federal Water Pollution Control Act Amendments established the Clean Water Act as the foundation of modern surface water quality protection in the United States. Sections 303 and 305 of the Act guide the national program on water quality. Four subparts of Section 303 are relevant to this water quality discussion – Sections 303(a-c), which discuss the process by which all states are to adopt and periodically review water quality standards, and Section 303(d) which directs the states to identify waters of the state that do not meet water quality standards and to develop plans (Total Maximum Daily Loads or TMDLs) to bring those waters into compliance. Section 305(b) directs the states to periodically prepare a report that assesses the quality of surface and ground waters in the state.

3.2.1 Vermont Water Quality Standards

Vermont water quality standards serve as the foundation for protecting Vermont's surface waters. The current standards became effective December 30, 2011 (Vermont DEC, 2011). Surface waters in Vermont are presently classified as Class A(1), Class A(2), or Class B based on numerical or narrative criteria intended to protect the designated uses for each class. Waters designated as Class A(1) are designated as Ecological Waters that are managed to maintain an essentially natural condition. Class A(2) waters are designated as Public Water Supply waters that are managed for the natural condition with the exception of withdrawals for public water supplies. Class B waters are managed to achieve and maintain a level of quality that fully supports multiple designated uses. Currently the Connecticut River is designated as Class B water in Vermont and as a coldwater fish habitat. Applicable water quality standards and the associated designated uses for Class B waters in Vermont are shown in Table 3.2-1.

3.2.2 New Hampshire Water Quality Standards

NH-Env-Wq 1700 Surface Water Quality Regulations, readopted with amendments in 2008, fulfill the Section 303 requirements of the federal Clean Water Act. Standards consist of three parts: designated uses, such as fishing or swimming; numerical or narrative criteria to protect the designated uses, and an antidegradation policy which maintains existing high quality water that exceed the criteria. Criteria are established by statute and by administrative rules (Env-Wq 1700).

Table 3.2-1. Vermont water quality standards applicable to Project waters.

Class	Designated Uses	Dissolved Oxygen (DO)	pH	Nutrients
B	Aquatic biota, wildlife and aquatic habitat, aesthetics, public water supply with filtration and disinfection, irrigation of crops, primary contact recreation, boating, fishing, other recreation.	For cold water fish habitat waters, not less than 6 mg/L and 70% saturation	Between 6.5 and 8.5	Total phosphorus loadings limited so as to not accelerate eutrophication or the stimulation of the growth of aquatic biota in a manner that prevents full support of uses; nitrates not to exceed 5.0 mg/L as NO_3-N at flows exceeding low median monthly flows.

(Source: Vermont DEC, 2011)

Surface waters in New Hampshire are classified as Class A or Class B. Class A waters are of the highest quality and are managed to be potentially acceptable for water supply uses after adequate treatment. Class B waters are of the second highest quality and are managed to achieve and maintain certain designated uses. The Connecticut River has been designated a Class B water by the New Hampshire General Court. Applicable water quality standards and the designated uses for Class B waters in New Hampshire are listed in Table 3.2-2.

Table 3.2-2. New Hampshire water quality standards applicable to Project waters.

Class	Designated Uses	Dissolved Oxygen (DO)	pH	Nutrients
B	Acceptable for fishing, swimming, other recreation, and water supply use after adequate treatment.	At least 75% saturation, based on a daily average; instantaneous minimum of 5.0 mg/l	6.5 to 8 unless due to natural causes	No phosphorus or nitrogen in such concentrations that would impair any existing or designated uses, unless naturally occurring.

(Source: Chapter 485:A, Water Pollution and Waste Disposal, Classification of Waters and Env-Wq 1700 Surface Water Quality Regulations)

3.2.3 Compliance with State Water Quality Standards

The water quality data generated in this study were within a range that is typical of large, good quality riverine systems in northern New England. Most DO and pH levels met state standards for Vermont and New Hampshire, with a few isolated exceptions that were very limited in extent and duration and were generally minor deviations from the applicable standards. There are no specified state standards for temperature and specific conductivity, but both parameters reflect typical natural variations and seasonality. Water quality data for the continuous monitor stations are summarized in Table 3.2-3 and the impoundment profile data are summarized in Tables 3.2.4 and 3.2-5. Water chemistry data from laboratory analyses for the forebay stations (W-01, BF-01, and V-01) are summarized in Tables 3.4-1 through 3.4-3 in Section 3.4 below.

The weekly water samples did not exceed nutrient criteria for either state, although at this time Vermont is the only state that provides numeric criteria, while New Hampshire only notes that phosphorus or nitrogen levels should not impair any existing or designated uses, unless naturally occurring. We note that there are sources of nutrient loading from wastewater treatment plant discharges upstream of all the Projects, but nutrient concentrations were not high enough to cause measurable impairment.

3.2.3.1 Wilder Project

At the Wilder water quality stations (W-TR, W-01, W-02 and W-03), values for the water quality parameters of concern were generally within the acceptable range determined by state standards and guidelines. However, there were some instances of non-compliance with state standards for DO and pH (Tables 3.2-4 and 3.2-5). The Vermont and New Hampshire minimum pH standard is 6.5. On three occasions, we recorded pH values below the standard in the Wilder impoundment. Two events occurred on 6/26/12, one in the upper impoundment (stations W-03, pH 5.7) and one at mid-impoundment (station W-02, pH 6.4). The other violation occurred in the upper impoundment (Station W-03) on 7/10/12, (pH 5.8). These minimum values were recorded on a single day for each observation, and data from the preceding and subsequent site visits were above the state standards. The station where two of these measurements were recorded was located in the upper-most reaches of the impoundment and may be a reflection of proximity to headwater/high elevation streams in the White Mountains and associated episodic occurrences of lower pH due to atmospheric deposition (e.g. Likens and Bormann, 1995). Wilder "Lake" is listed by New Hampshire DES as non-attainment for pH in the 2010 and 2012 303 (d) reports, so occasional low pH values were not unexpected.

On one occasion DO fell below the Vermont standard of 6 mg/L. On 8/12/12 a DO level of 5.7 mg/L was recorded at the continuous monitoring station in the forebay (W-01), (Table 3.2-3). The corresponding DO % saturation value at the time of this measurement was 69 %, which also fell below the DO state standard for Vermont of 70 %. However, the instantaneous values and the minimum daily average (Table 3.2-3) were never lower than the New Hampshire compliance standards of 5.0 mg/L and 75 % saturation, respectively, at any time during the study. These values reflect a decline in DO levels recorded during a seven-day period from 8/6/12 through 8/13/12 before rising again and reaching a sharp peak on 8/16/12 (see Figure 3.1-1); this time period corresponded to a period of low flow, high temperature and slightly elevated primary productivity as seen in the Chlorophyll-*a* data and coinciding with slightly elevated total phosphorus values (Table 3.4-1).

3.2.3.2 Bellows Falls Project

At the Bellows Falls water quality stations (BF-TR, BF-BR, BF-01, BF-02 and BF-03), values for the water quality parameters of concern were generally within the acceptable range determined by state standards and guidelines. However, there were some instances of non-compliance with state standards for pH and DO. Table 3.2-5 shows that pH was slightly below the New Hampshire and Vermont minimum standard of 6.5 on 7/11/12 and 9/5/12 in the upper impoundment (station BF-03, pH 6.1 and 6.4 respectively). These minimum values were recorded on a single day for each observation, and data from the preceding and subsequent site visits were above the state standards. Two of these samples were measured in the upper-most half of the impoundment and likely reflect episodic occurrences of lower pH associated with acidic atmospheric deposition (e.g. Likens and Bormann, 1995). The Bellows Falls impoundment is listed as impaired for pH by New Hampshire DES, so occasional low pH values were not unexpected.

The New Hampshire pH water quality standard of 8.0 was exceeded at the three continuous monitor stations in the Bellows Falls project. In the forebay (station BF-01) multiple readings were above pH 8.0 for the periods 7/11/12 through 7/12/12 (up to pH 8.5), 8/21/12 through 8/25/12 (up to pH 8.2), and 9/9/12 through 9/12/12 (up to pH 8.3). In the bypass reach (station BF-BR), readings above pH 8.0 (up to pH 8.1) occurred during the period 8/23/12 through 8/24/12, coincident with high pH readings in the forebay. In the tailrace (station BF-TR), we recorded multiple readings above pH 8.0 (up to pH 8.2) during the period 6/20/12 through 6/23/12. No pH values above 8.0 were recorded during the recurring water quality profile measurements in the Bellows Falls impoundment. There were no exceedances of Vermont pH standards (maximum of 8.5).

The lowest DO level recorded during the study was 3.3 mg/L in the Bellows Falls forebay (station BF-01), on 7/18/12. DO fell below the state standards of 6.0 mg/L for Vermont and 5.0 mg/L for New Hampshire, with the concurrent DO % saturation value at 39 %, which also fell below the state standard for Vermont (70 %). Because the sample was an instantaneous spot measurement, compliance with New Hampshire standards for DO saturation (daily average of 75% saturation) could not be determined. It is unclear what the significance of this low DO reading was; however, it is clear that it was a real event in that DO values were depressed throughout the middle and lower portions of the water column and QA protocols including field replicates of surface readings at ~100+ % saturation indicated that the instrument was performing adequately.

One additional low DO reading was documented by the continuous monitor datasondes at Bellows Falls in the forebay on 7/23/12 of 5.9 mg/L (73 % saturation). This reading fell slightly below the Vermont standard of 6.0mg/L but above the New Hampshire standard of

5.0 mg/L. The 24-hour rolling average DO saturation values for this station was never less than 75 % so DO saturation was compliant with New Hampshire water quality standards. The continuous monitors in the bypass reach (station BF-BR) and the tailrace (station BF-TR) did not record any violations of state standards for any parameters of concern during this study.

3.2.3.3 Vernon Project

At the Vernon water quality stations (V-TR, V-01, V-02 and V-03), values for the water quality parameters of concern were within the acceptable range determined by state standards and guidelines. We did not record any values for any parameter of concern via continuous monitoring, spot field measurements, or laboratory analysis of water chemistry that did not meet applicable state standards in either Vermont or New Hampshire.

3.3 Stratification Effects in Impoundments

One of the typical effects of dams on impounded waters is stratification with depth, particularly in the deeper areas where currents may have difficulty mixing the entire water column under high temperature/low flow conditions. To investigate the changes in water quality with depth throughout each of the three Project impoundments, we performed weekly profile measurements of water quality using a mobile datasonde. The entire water quality profile dataset is included in Appendix A.

Due to the large amount of data and the complexity in displaying it in a concise and meaningful way, the results of the profile data in Figures 3.1-8 through 3.1-10 in Section 3.1 above are presented as the global mean for each profile at each station. Below, data is presented as the standard deviation for each profile and station, in Figures 3.3-1 through 3.3-3, as a metric for describing variation in parameter values through the water column. A lower standard deviation value would indicate uniformity through the water column while a higher standard deviation would indicate greater variation and can be used as a proxy for stratification.

The data show that temperature was typically most variable in the forebay stations (W-01, BF-01, and V-01) and least variable in the stations at the top of the impoundments (W-03, BF-03 and V-03). In a few circumstances temperatures were more variable at the mid-impoundment stations (W-02, BF-02 and V-02) than the forebay stations, but this was less common as can be seen in Figures 3.3-1 through 3.3-3.

Table 3.2-3. Statistical summary of continuous monitor water quality data.

	Temperature (°C)	Specific Conductivity (µS/cm)	Dissolved Oxygen (% saturation)	Rolling 24 hr. Avg. DO (% saturation)	Dissolved Oxygen (mg/L)	pH (s.u.)
	W-01					
Max	26.5	132	119	104	9.7	7.8
Min	21.1	88	69	78	5.7	7.0
Median	24.1	109	91	91	7.6	7.2
Mean	24.0	110	92	92	7.6	7.2
	W-TR					
Max	25.4	134	110	103	9.3	7.7
Min	19.2	80	76	79	6.5	7.1
Median	23.6	109	87	88	7.3	7.3
Mean	23.2	109	89	89	7.5	7.3
	BF-01					
Max	27.0	168	124	108	10.3	8.5
Min	21.3	114	73	83	5.9	7.2
Median	24.9	142	96	96	7.9	7.7
Mean	24.7	142	95	95	7.8	7.7
	BF-BR					
Max	27.2	167	121	113	9.7	8.1
Min	20.9	115	74	84	6.0	7.5
Median	25.0	144	103	102	8.5	7.7
Mean	24.8	143	104	104	8.5	7.7
	BF-TR					
Max	26.3	170	130	122	10.7	8.2
Min	20.8	111	79	93	6.5	6.9
Median	24.2	141	106	105	8.9	7.4
Mean	24.0	141	106	106	8.8	7.4
	V-01					
Max	29.3	162	115	106	9.1	7.8
Min	22.9	115	81	87	6.3	7.1
Median	26.7	143	98	99	7.9	7.4
Mean	26.6	142	98	98	7.8	7.4
	V-TR					
Max	28.6	163	118	115	9.8	8.0
Min	22.8	116	94	100	7.4	7.2
Median	26.4	142	107	107	8.7	7.6
Mean	26.1	141	108	108	8.7	7.6

This result was expected since the deeper water at the forebay stations, immediately above the dams, was more likely to show stratification effects than the shallow and well mixed waters at the top of the impoundments.

Table 3.2-4. Statistical summary of water quality profile data in impoundments.

	Specific Conductivity (µS/cm)			pH (s.u.)			Temperature (°C)		
	W-03	**W-02**	**W-01**	**W-03**	**W-02**	**W-01**	**W-03**	**W-02**	**W-01**
Max	106	141	137	7.7	7.6	7.5	22.6	25.1	26.0
Min	88	81	85	5.7	6.4	6.6	17.3	19.8	19.8
Median	93	95	103	7.0	7.2	7.2	20.9	21.9	23.4
Mean	94	100	108	6.9	7.2	7.1	20.4	21.9	22.7
	BF-03	**BF-02**	**BF-01**	**BF-03**	**BF-02**	**BF-01**	**BF-03**	**BF-02**	**BF-01**
Max	183	165	162	7.8	7.8	7.7	24.7	25.6	26.5
Min	107	111	118	6.1	6.9	6.5	18.7	19.4	21.0
Median	132	136	141	7.2	7.6	7.5	22.5	23.6	24.1
Mean	133	136	142	7.2	7.5	7.4	22.4	23.1	23.7
	V-03	**V-02**	**V-01**	**V-03**	**V-02**	**V-01**	**V-03**	**V-02**	**V-01**
Max	161	164	158	7.6	7.6	7.9	25.1	27.4	28.3
Min	122	113	123	6.6	7.1	6.7	20.2	21.4	21.7
Median	146	138	141	7.2	7.4	7.3	23.8	24.6	25.3
Mean	143	139	141	7.2	7.4	7.3	23.6	24.2	24.9

Table 3.2-5. Statistical summary of dissolved oxygen profile data in impoundments.

	Dissolved Oxygen (mg/L)			Dissolved Oxygen (% saturation)		
	W-03	**W-02**	**W-01**	**W-03**	**W-02**	**W-01**
Max	9.1	8.8	9.0	104	104	109
Min	7.9	7.4	6.0	90	87	72
Median	8.7	7.9	7.8	95	93	90
Mean	8.5	8.1	7.7	96	93	91
	BF-03	**BF-02**	**BF-01**	**BF-03**	**BF-02**	**BF-01**
Max	9.3	9.4	10.6	103	105	122
Min	7.4	7.1	3.3	89	87	40
Median	8.1	8.1	8.2	95	98	96
Mean	8.2	8.3	8.0	96	98	95
	V-03	**V-02**	**V-01**	**V-03**	**V-02**	**V-01**
Max	10.2	9.8	9.6	121	116	117
Min	7.2	7.0	6.4	89	87	80
Median	8.6	8.2	7.9	100	97	97
Mean	8.5	8.1	7.9	102	98	97

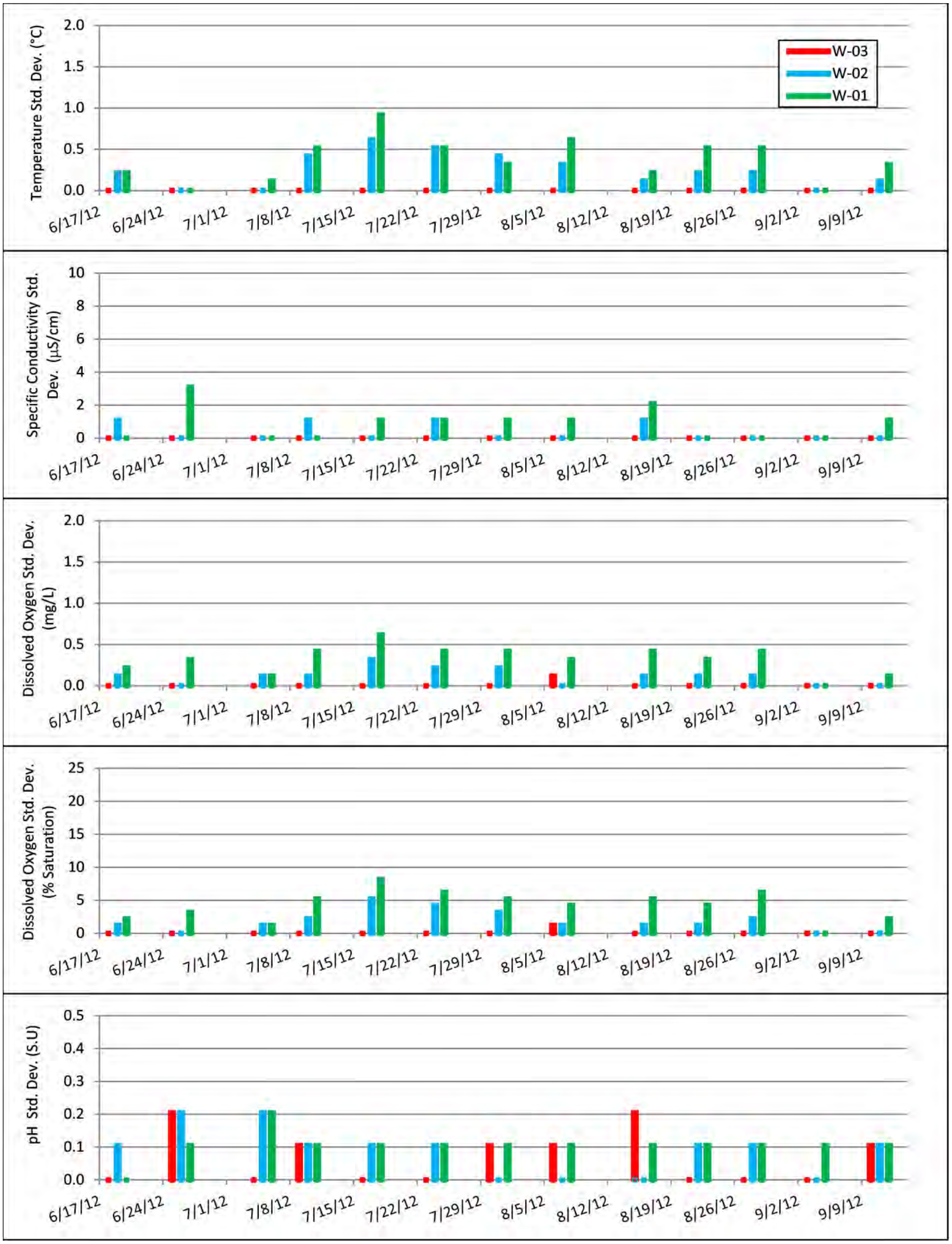

Figure 3.3-1. Plot of standard deviation by station and parameter for water quality profiles at the Wilder impoundment.

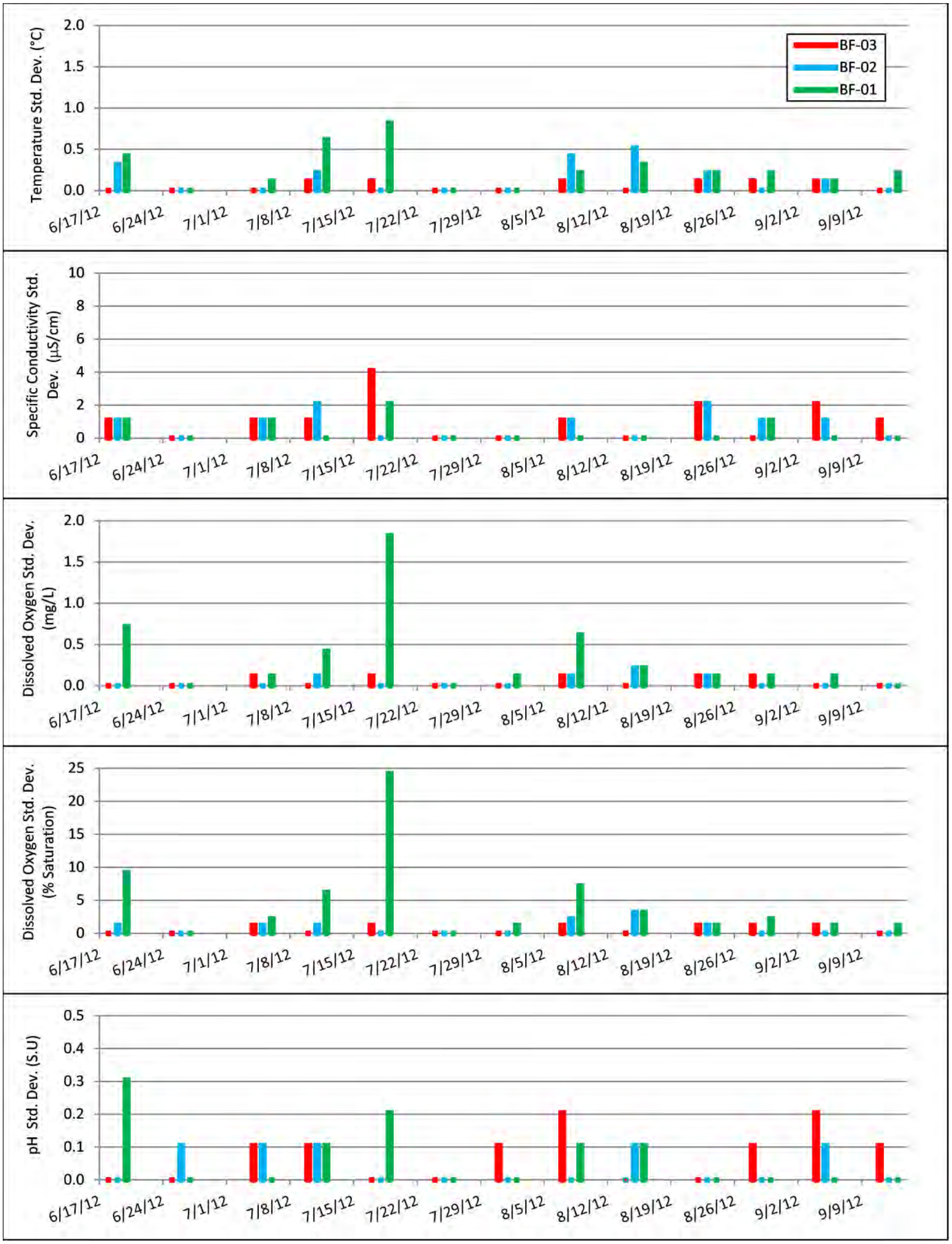

Figure 3.3-2. Plot of standard deviation by station and parameter for water quality profiles at the Bellows Falls impoundment.

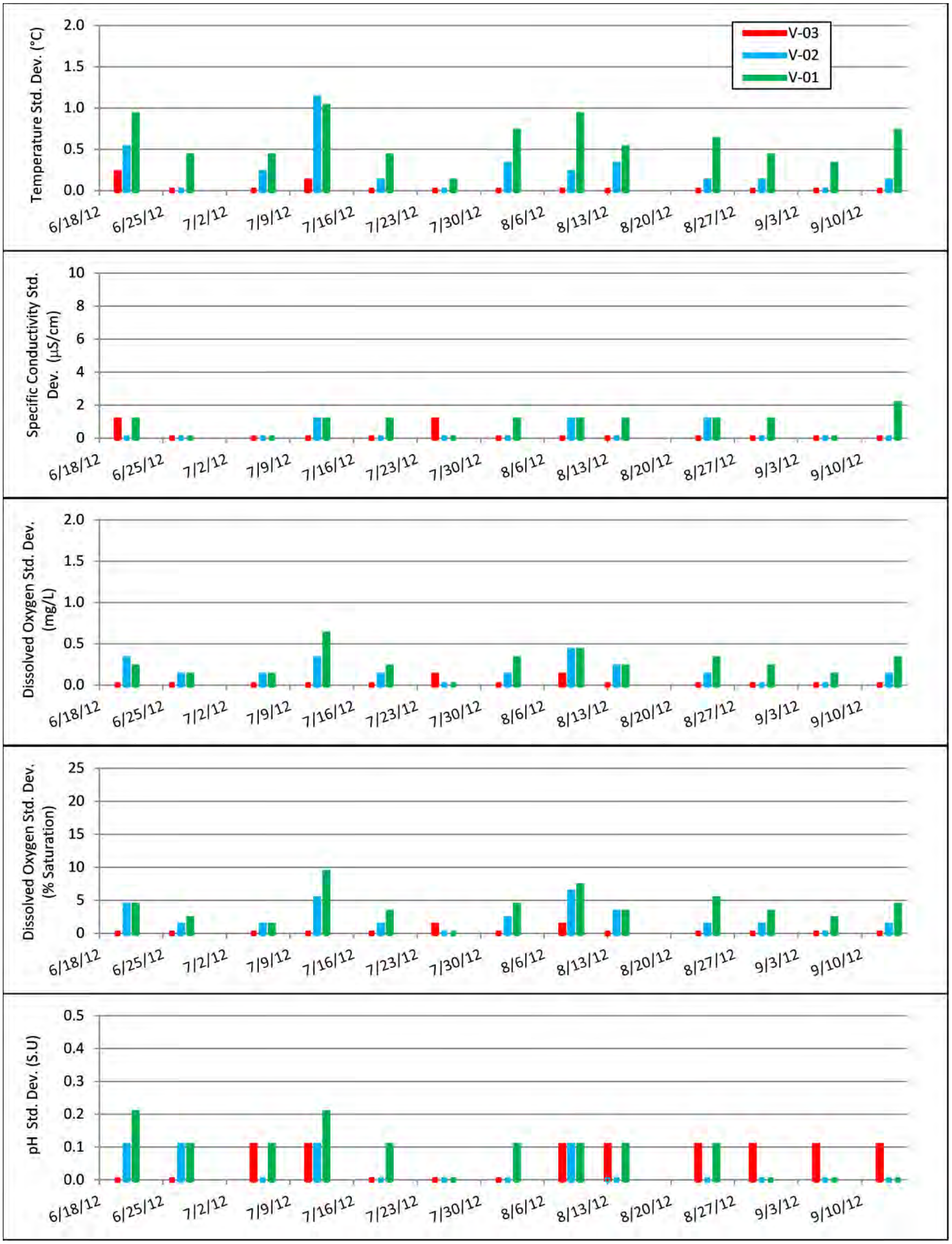

Figure 3.3-3. Plot of standard deviation by station and parameter for water quality profiles at the Vernon impoundment.

It should be noted that the sequence of visiting each station for data collection typically went from upstream to downstream and therefore the upper impoundment stations were normally visited early in the morning while the lower impoundment stations were typically visited mid-day and diurnal heating could account for some of the observed variability at those stations. The continuous monitor data reinforce this point as shown in Figures 3.1-1, 3.1-3, and 3.1-6 where a diurnal warming pattern occurred in each of the forebay stations.

The data show similarity between the patterns of DO variability, as measured by the standard deviation of a profile, and temperature variability. The greatest standard deviations in DO were consistently at the forebay stations while the lowest standard deviations were consistently in the upper-impoundment stations, with DO variability at mid-impoundment stations typically falling in between. These patterns were strongest at the Vernon and Wilder monitoring stations and slightly more variable at the Bellows Falls monitoring stations. As with the temperature data, these results were expected due to the greater water depth at the forebay stations, and the associated reduced mixing compared to shallower stations with stronger currents. Again, we emphasize that the forebay stations were typically visited mid-day for water quality profiles while the upper impoundment stations were typically visited early morning and this could affect the results due to the effects of diurnal heating, diel algal production and respiration and the associated influence of both on DO (and on pH with algal growth).

The most significant stratification episode observed during this study (previously highlighted in Section 3.2.3) occurred in the Bellows Falls forebay (station BF-01) on 7/18/12 and can be seen in Figure 3.3-2. The data show that during that event there was increased variability across depth with DO, pH, and temperature as indicated by markedly higher value ranges and standard deviations compared to the other profile measurements at that station. Due to the high variability in pH, DO, and temperature and the positive correlation between each parameter, this event may have been an isolated episode of temporary thermal stratification combined with algal decay leading to depressed DO through the middle and lower portions of the water column.

pH variability by profile was inconsistent between the sites and from one week to the next. We could not infer any emergent patterns from the pH dataset, and profile pH ranges and standard deviations were highly variable within and between the three impoundments, suggesting pH variability in the water column was somewhat random and not associated with total water depth or position within the impoundment. While some profile measurements showed correlation between pH and other parameters, as highlighted above for the thermal/DO stratification event on 7/18/12 at station BF-01, other profile measurements with minor stratification indicated little or no change in pH through the water column. Likewise, specific conductivity did not vary significantly with depth at any of the stations and no strong or consistent patterns of conductivity variability by monitoring station and profile were apparent in the dataset (Figures 3.3-1 through 3.3-3). These results were expected as we would not anticipate a pH or conductivity response under typical thermal stratification conditions in a riverine impoundment.

It should be noted that while the above standard deviation evaluation appears to indicate a certain amount of stratification, especially at the forebay station in each impoundment, the absolute levels of stratification are in fact quite small, and could only be interpreted as minor and temporary at best. Still, the analysis provides evidence of the expected daily cycle of temperature and DO response found in most riverine impoundments where depth is not sufficient to maintain more permanent seasonal stratification.

3.4 Spatial Patterns in Water Quality

We reviewed the dataset to determine whether there were any patterns of changing water quality with geographical position in the river, such as whether there was an improvement or degradation in water quality from upstream to downstream. Tables 3.2-3 through 3.2-5 and Tables 3.4-1 through 3.4-3 facilitate the comparisons of water quality parameters between stations while Figures 3.1-1 through 3.1-7, Figure 3.1-11 and Figures 3.3-1 through 3.3-3 display these data graphically.

The data show that DO was generally highest in concentration and percent saturation at the Vernon stations and lowest at the Wilder stations, evident in both the recurring profile measurements and the continuous monitor data, as can be seen in Tables 3.2-3 through 3.2-5. The highest overall average DO levels from a single station occurred in the Bellows Falls tailrace (station BF-TR) and the lowest average DO levels were recorded in the Wilder tailrace (station W-TR). At the Vernon and Wilder impoundments, the recurring profile data show that DO generally decreased from upstream to downstream, from the stations in the upper impoundment areas to the stations in the lower impoundment areas (see Tables 3.2-4 and 3.2-5).

At the Bellows Falls impoundment DO levels were highest in the middle of the impoundment (station BF-02) and lowest in the forebay area (station BF-01). The minor changes in upstream to downstream values of study parameters within an impoundment may reflect the impacts of impounded riverine waters, with increased time-of-travel and water column algal activity from upstream to downstream. However, as noted above, the profile measurements at a given impoundment generally went in an upstream to downstream sequence such that the monitoring stations at the top of the impoundments were generally sampled in the early morning and the forebay stations were generally sampled mid-day and could therefore have also been affected by diurnal heating and biological activity.

Temperature consistently increased from upstream to downstream monitoring stations both within each of the three impoundments and between the three impoundments as can be seen in Tables 3.2-3 through 3.2-5. This result was not surprising considering the increased time of travel from upstream to downstream stations and the associated heat gain which would result and widely observed increase in water temperature with decreasing latitude and elevation.

pH values were generally lowest in the Wilder impoundment stations and highest in the Bellows Falls impoundment stations as is reflected in both the profile data and the continuous monitor data shown in Tables 3.2-3 through 3.2-5. The highest average pH data from the continuous monitor stations were recorded in the Bellows Falls bypass reach (BF-BR) and were comparable to values measured in the forebay (BF-01), while the lowest average pH levels within the continuous monitor dataset were recorded in the Wilder forebay (W-01). Within the impoundments, the recurring water quality profile data show that the lowest pH levels were consistently recorded at the head of an impoundment with comparable pH values recorded in the middle and lower impoundment stations. This pattern was most pronounced at the Wilder impoundment and least pronounced at the Vernon impoundment. We suspect this pattern to be an effect of time of travel and algal influences through the impoundment.

Specific conductivity values typically increased from upstream to downstream within the Wilder impoundment but were quite comparable between all the stations in the Bellows Falls and Vernon impoundments and tailraces as was reflected in the profile data and the continuous monitor data shown in Tables 3.2-3 and 3.2-4. This result may suggest that the greatest sources of solute loading were within and immediately below the Wilder impoundment.

There were no strong or consistent patterns in the spatial distribution of the water chemistry parameters of nitrate/nitrite, total nitrogen, total phosphorus, total Kjeldahl nitrogen, and Chlorophyll-*a* as presented in Figure 3.1-11 in Section 3.1 and Tables 3.4-1 through 3.4-3 below. While these parameters were somewhat variable in time, the global station averages and standard deviations were comparable among the three sampling locations.

Table 3.4-1. Summary of water chemistry data at W-01.

Date	$NO_{3+}NO_2$ (mg/L)	TN (mg/L)	TP (mg/L)	Chlorophyll-a (mg/m^3)	TKN (mg/L)
7/10/2012	0.16	0.76	0.032	4.3	0.60
7/17/2012	0.17	0.54	0.018	5.1	0.37
7/24/2012	0.21	0.68	0.039	5.8	0.47
7/31/2012	0.22	0.60	0.015	3.1	0.38
8/7/2012	0.22	0.72	0.009	2.7	0.50
8/14/2012	0.18	0.55	0.016	4.2	0.37
8/22/2012	0.18	0.62	0.012	2.2	0.44
8/28/2012	0.19	0.59	0.019	3.3	0.40
9/4/2012	0.20	0.59	0.021	2.4	0.39
9/11/2012	0.17	0.64	0.010	1.6	0.47
Mean	0.19	0.63	0.019	3.5	0.44

Table 3.4-2. Summary of water chemistry data at BF-01.

Date	$NO_{3+}NO_2$ (mg/L)	TN (mg/L)	TP (mg/L)	Chlorophyll-a (mg/m^3)	TKN (mg/L)
7/11/2012	0.16	0.53	0.012	3.8	0.37
7/18/2012	0.17	0.66	0.024	6.6	0.49
7/25/2012	0.20	0.61	0.010	2.7	0.41
8/1/2012	0.22	0.66	0.028	4.4	0.44
8/8/2012	0.21	0.83	0.039	3.5	0.62
8/15/2012	0.21	0.69	0.048	4.0	0.48
8/23/2012	0.15	0.58	0.009	2.9	0.43
8/29/2012	0.18	0.59	0.010	4.2	0.41
9/5/2012	0.16	0.56	0.012	3.1	0.40
9/12/2012	0.19	0.61	0.011	3.8	0.42
Mean	0.19	0.63	0.020	3.9	0.45

Table 3.4-3. Summary of water chemistry data at V-01.

Date	$NO_{3+}NO_2$ (mg/L)	TN (mg/L)	TP (mg/L)	Chlorophyll-a (mg/m^3)	TKN (mg/L)
7/12/2012	0.16	0.55	0.013	5.9	0.39
7/19/2012	0.20	0.75	0.058	4.2	0.55
7/26/2012	0.21	0.62	0.013	2.7	0.41
8/2/2012	0.23	0.63	0.010	2.2	0.4
8/9/2012	0.24	0.66	0.009	4.4	0.42
8/16/2012	0.18	0.69	0.038	3.8	0.51
8/24/2012	0.20	0.67	0.014	3.5	0.47
8/30/2012	0.20	0.58	0.013	3.6	0.38
9/6/2012	0.20	0.72	0.019	2.0	0.52
9/13/2012	0.21	0.68	0.013	3.1	0.47
Mean	0.20	0.66	0.020	3.5	0.45

3.5 Effects of Hydroelectric Operations on Water Quality

The continuous monitoring equipment was installed at locations above and below each of the three Project dams as a means of assessing the effects on water quality from Project operations. These data are summarized in Table 3.2-3 and shown in Figures 3.1-1 through 3.1-7.

The data show that at Wilder dam on average, DO was comparable but slightly lower at the tailrace station (W-TR) than at the forebay station above the dam (W-01) with an average difference of only 0.1 mg/L. Conversely, at the Bellows Falls and Vernon continuous monitoring stations, DO was consistently slightly higher at the below-dam stations (BF-TR, V-TR) versus the above-dam stations (BF-01, V-01), with an average difference of approximately 0.8 mg/L at Vernon and 1.0 mg/L at Bellows Falls.

Temperatures were consistently comparable, but slightly lower at all of the tailrace stations versus the forebay stations (by ~0.5-0.7 °C) and likely were influenced by the measurement depths in the forebay continuous monitors which were at ~2.4m (W-01), ~3.7m (BF-01) and ~3.3m (V-01), and therefore may have been warmer than the column average.

pH was, on average, marginally lower in the Bellows Falls tailrace (BF-TR) versus the forebay (BF-01, by 0.3 s.u.), slightly higher in Vernon tailrace (V-TR) versus the forebay (V-01, by 0.2 s.u.), and comparable between the Wilder tailrace (W-TR) and forebay (W-01, 0.1 s.u. difference).

Specific conductivity values did not vary significantly between above-dam and below-dam stations at any of the three Projects. The minor changes in above-dam to below-dam values of study parameters may reflect the differences between a whole-water column value, as would be found in the completely mixed environment in the tailrace area (during generating periods), versus a single point of measurement in the upper 25% of the water column as measured at the forebay continuous monitors. There were also variations with depth in temperature, DO, and, to a lesser extent, pH at the forebay and middle impoundment stations (see Section 3.3), which further supports this explanation of water quality differences between above-dam and below-dam stations.

As discussed in Section 3.1.2, a recurring pattern of abrupt step changes in dissolved oxygen were documented at each of the tailrace stations (W-TR, BF-TR, V-TR) and were most pronounced and consistent in the Bellows Falls tailrace (BF-TR). The pattern showed a decrease in dissolved oxygen that was timed closely with an increase in streamflow on the Connecticut River and generally occurred mid-afternoon through early evening, coincident with the Projects' summer operating schedules. An example of this pattern is shown in Figure 3.5-1 below for each of the three tailrace stations including the period 8/10/12

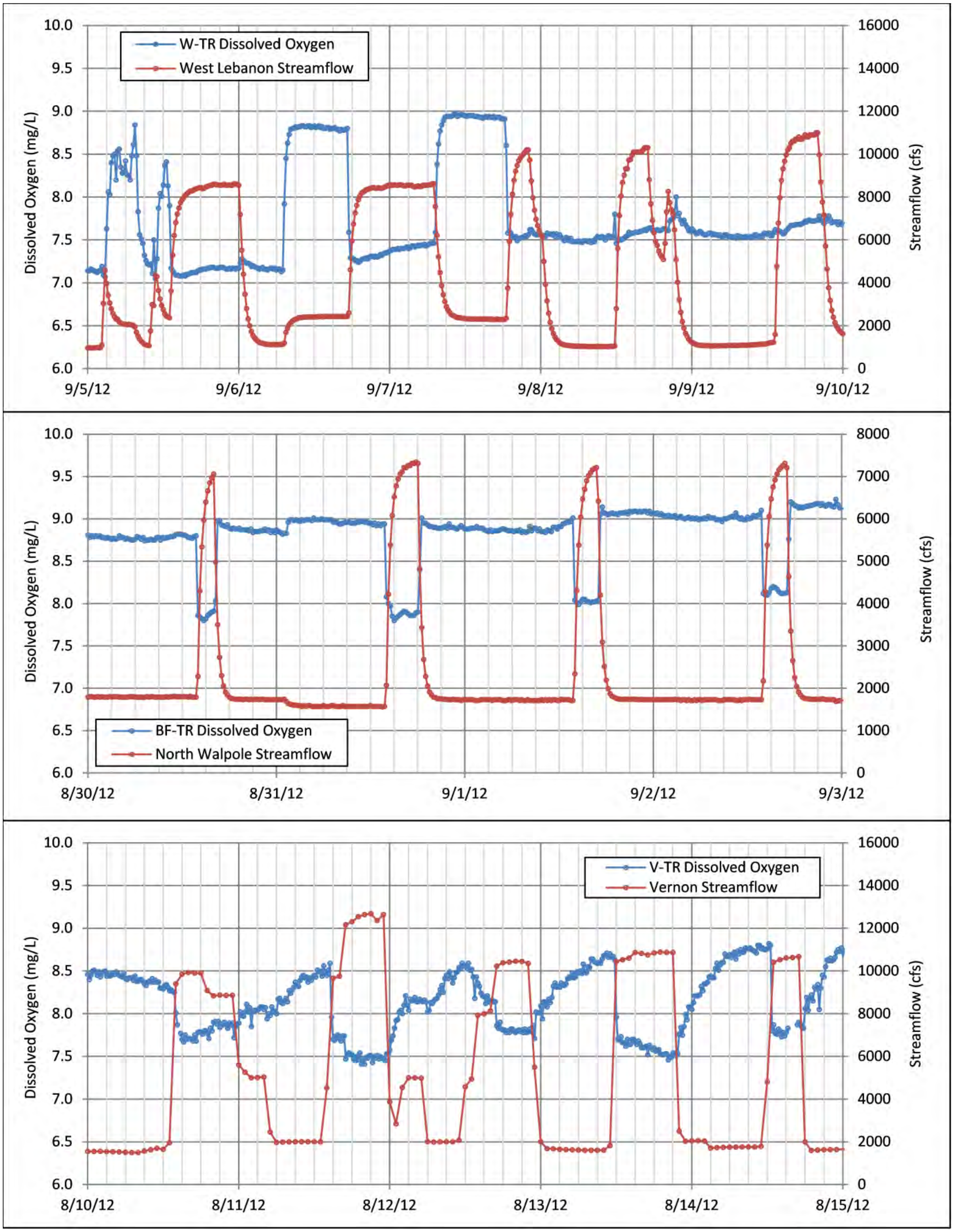

Figure 3.5-1. Time series plot of dissolved oxygen at tailrace stations and streamflow.

through 8/15/12 at Vernon tailrace (V-TR) in the bottom panel of the Figure; the period 8/30/12 – 9/03/12 at Bellows Falls tailrace (BF-TR) in the middle panel; and the period 9/05/12 through 9/10/12 at Wilder tailrace (W-TR) in the top panel. Figure 3.5-1 plots also include preliminary streamflow for the USGS Connecticut River Gage at North Walpole, NH[1] which is located immediately below Bellows Falls tailrace (BF-TR) as well as preliminary streamflow for the USGS Connecticut River Gage at West Lebanon, NH[2] which is located below Wilder tailrace (W-TR) as well as streamflow data provided by TransCanada for Vernon dam.

As can be seen in Figure 3.5-1, changes in streamflow and DO were highly synchronized at all tailrace stations. At Bellows Falls tailrace (BF-TR), abrupt increases in streamflow of ~5,500 cfs were correlated with abrupt decreases in DO of ~1 mg/L for the time period presented. Likewise, abrupt decreases in streamflow of comparable magnitude were correlated with an increase in DO of ~1 mg/L. A similar pattern, although less consistent through the study period (see Figure 3.1-2), was seen at Wilder tailrace (W-TR) where changes in DO of up to 1.5 mg/L coincided with changes in streamflow at the West Lebanon gage. Periodic changes in DO at Vernon tailrace (V-TR) also coincided to some degree with changes in streamflow at the North Walpole gage, although the pattern was not consistent in frequency or magnitude of DO changes. The distance from the North Walpole gage to the Vernon tailrace station was greater than 30 miles so we elected to use streamflow data for Vernon dam as provided by TransCanada rather than a USGS Connecticut River gage.

The synchronous patterns of streamflow and DO strongly suggest that Project hydroelectric operations, which were largely responsible for daily streamflow fluctuations seen in this section of the Connecticut River, had a pronounced effect on DO concentration in the tailrace area of Bellows Falls, and to a lesser extent on the DO concentrations in the Wilder and Vernon tailrace areas. We suspect that the cause of the changes in DO were the result of changes in the specific strata of forebay water being conveyed through the turbines to the tailrace areas under different operating regimes (i.e., minimum flow generation versus maximum generation) rather than a direct physical effect of the hydroelectric operations (such as off-gassing) on waters passing through the turbines.

This assertion is supported by the continuous monitor DO data at the forebay stations (W-01, BF-01, and V-01) above the dams which were similar to the DO concentrations at the respective tailrace sites during maximum generating periods, while the minimum flow periods in the tailraces were characterized by DO concentrations much higher in the

[1] USGS gage no. 01154500 accessed via National Water Information System: Web Interface on 11/12/12.
[2] USGS gage no. 01144500 accessed via National Water Information System: Web Interface on 11/12/12.

tailraces than at the forebay monitoring stations. Our profile measurements in the dam forebays typically showed elevated DO near the water surface versus the middle and lower depths, including the 3-4 m depth where the continuous monitors were deployed.

It is important to note that while Project operations appeared to have some effect on DO concentrations in the tailrace areas, DO levels in the tailraces of each Project were always in compliance with DO standards for both Vermont and New Hampshire. Thus, there was no indication that Project operations negatively affected attainment and maintenance of compliance with applicable water quality standards even under relatively low flow/high temperature conditions that prevailed during the summertime study period.

4.0 REFERENCES

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APPENDIX A

Temperature, DO, pH, and conductivity data for seven continuous monitor stations (V-TR; V-01; BF-TR; BF-BR; BF-01; W-TR; W-01)

Temperature, DO, pH, and conductivity water column profile data for nine sampling stations (V-01; V-02; V-03; BF-01; BF-02; BF-03; W-01; W-02; W-03)

Nitrate/nitrite, total nitrogen, total phosphorus, total Kjeldahl nitrogen, and Chlorophyll-a data for three sampling stations (V-01; BF-01; W-01)

File: Appendix A_TransCanada Baseline WQ Data 2012.xlsx
Source: Normandeau Associates, Inc.