Boundary Hydroelectric Project (FERC No. 2144)

Study No. 6
Evaluation of the Relationship of pH and Dissolved Oxygen to Macrophytes in Boundary Reservoir
Final Report

Prepared for
Seattle City Light

Prepared by
Darlene Siegel, Shannon Brattebo, Rob Plotnikoff, Harry Gibbons, Toni Pennington, Adam Baines, and Kari Kimura
Tetra Tech

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1 INTRODUCTION

Study No. 6, Evaluation of the Relationship of pH and Dissolved Oxygen (DO) to Macrophytes in Boundary Reservoir, was conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP; SCL 2007) submitted by Seattle City Light (SCL) on February 14, 2007, and approved by FERC in its Study Plan Determination letter dated March 15, 2007. This is the final report describing the field efforts, analyses, and determination of Project effects and represents the completion of the study.

High pH levels have been documented throughout the Pend Oreille River and in Boundary Reservoir (Ecology 2005; SCL 2006). The specific cause of these high pH levels has not been investigated prior to this study, but both background geologic conditions and the growth of macrophytes have been suggested as contributing factors. The geochemical makeup of the Pend Oreille River basin, and specifically within the reservoir wetted area of Boundary Reservoir, includes exposed deposits of limestone and other calcium carbonate-bearing rock, which tends to buffer the acidity of the water toward an alkaline condition. This results in a lower hydrogen ion activity as indicated by pH values greater than neutrality of 7.0. In other similar geochemical regions in North America, the observed pH of river systems ranges from 7.6 to 8.6, very similar to the values observed in the Pend Oreille River.

Invasive macrophytes in Boundary Reservoir, such as Eurasian watermilfoil (*Myriophyllum spicatum*) and curly pondweed (*Potamogeton crispus*), also have the potential to affect water chemistry when macrophyte bed densities are high. Both pH and DO can be altered through the processes of photosynthesis, respiration, and senescence. Dense macrophyte growth can increase pH through the uptake of carbon dioxide during photosynthesis. Alternatively, with either nighttime respiration or senescence, DO levels can be reduced by plant and microbial consumption of oxygen. The goal of this study is to explore the relationship of pH and DO to macrophytes in Boundary Reservoir to learn whether macrophytes are contributing to high pH readings during periods of rapid photosynthesis and, if so, to explore the indirect effect of the Project on pH and DO in the reservoir via its influence on macrophyte distribution and growth.

2 STUDY OBJECTIVES

The goals of this study were: 1) to assess whether macrophytes are contributing to high pH and low DO readings in Boundary Reservoir and 2) to investigate potential indirect effects of Project operations on pH and DO via macrophytes. To achieve these goals, the following three objectives were addressed:

- *Objective 1*: Document and determine the magnitude of the impact macrophyte respiration/photosynthesis and senescence have on pH and DO levels in Boundary Reservoir.
- *Objective 2*: Assess the effect of varying densities of macrophyte beds on changes in pH and DO in support of the fish habitat analysis.
- *Objective 3*: Assess the effect of Project operations, specifically inundation and frequency of dewatering, on changes in pH and DO in macrophyte beds. This objective is important because it addresses whether reservoir operations influence the physiology of macrophytes and, hence, water chemistry.

The methodologies for achieving these objectives are described in Section 4, and the results are presented in Section 5.

3 STUDY AREA

The study area encompassed Boundary Reservoir, including side channels off the main river, as shown in the map provided in Section 4 Figure 4.0-1. Eurasian watermilfoil, curly pondweed, and other macrophytes are found in shallow coves and bays of Boundary Reservoir. Dense mats of macrophytes have been found in side channels upstream of Pewee Creek near Project river mile (PRM) 17.9, upstream of Metaline Falls between PRM 26.8 and 28.2, and between Metaline Falls and the U.S. Geological Survey (USGS) gaging station (PRM 30.3 to 33.3).

4 METHODS

To address differences in reservoir morphology and habitat types, data were collected within two reaches, upstream and downstream of Metaline Falls. Water quality data collected in each macrophyte bed were used to satisfy one or more objectives depending on site conditions.

Macrophyte study sites are shown in Figure 4.0-1. Figure 4.0-2 shows general sampling locations (upstream, in bed, and downstream) within each sampling site. For a more detailed layout of sampling locations within macrophyte beds please refer to the Study 6 Quality Assurance Project Plan (QAPP) included in Appendix 1. The sampling locations were initially selected as part of a site review using aerial photography (DeGross 2005) and confirmed based on site visits during July and August 2007. The RSP (SCL 2007) indicated that there would be six potential macrophyte monitoring locations (M1 to M6). After the site visit in July 2007, it was determined that macrophyte growth in lower Boundary Reservoir was limited and site M3 was not to be included in the sampling efforts. Following the site visit in August 2007, sites M1 and M2 were relocated to areas of sufficient macrophyte growth. Table 4.0-1 highlights the sampling design and locations based on each objective.

Table 4.0-1. Macrophyte water quality sampling design.

Objective Description	Sampling Method	No. and Location of Sampling Stations	Corresponding Macrophyte Beds	No. of Sampling Sites per Station	Sampling Schedule	Sampling Duration Interval
1. Assess pH/DO within and apart from macrophyte beds	Remote WQ Buoys	1 (upstream of Metaline Falls)	M6	3 (1 upstream, 1 within, and 1 downstream of the macrophyte bed)	June–October 2007 July–October 2008	Every 15 mins.
	Profile	5 (3 above Metaline Falls and 2 below Metaline Falls)	M1, M2, M4, M5, M6	9 (3 upstream, 3 within, and 3 downstream of the macrophyte bed)	July–August 2007 (M4, M5, M6) August 2007 (M1, M2)	24 hrs, 4-6 hrs 72 hrs, 4-6 hrs (M4, M5, M6)
2. Assess pH/DO at different densities of macrophytes	Profile	5 (3 above Metaline Falls and 2 below Metaline Falls)	M1, M2, M4, M5, M6	9 (3 high, 3 medium, and 3 low density sites)[1]	July–August 2007 (M4, M5, M6) August 2007 (M1, M2)	24 hrs, 4-6 hrs 72 hrs, 4-6 hrs (M4, M5, M6)
3. Assess pH/DO at sites experiencing different degrees of inundation and drawdown	Profile	5 (3 above Metaline Falls and 2 below Metaline Falls)	M1, M2, M4, M5, M6	6 (3 continuously inundated, 4-6 hours exposure, and 3 8-12 hours exposure)	July–August 2007 (M4, M5, M6) August 2007 (M1, M2)	24 hrs, 4-6 hrs 72 hrs, 4-6 hrs (M4, M5, M6)

Notes:
1 At macrophyte sites M1 only high and medium densities were monitored, no low density area could be found. At macrophyte site M2 only a medium density area was monitored.
DO – dissolved oxygen

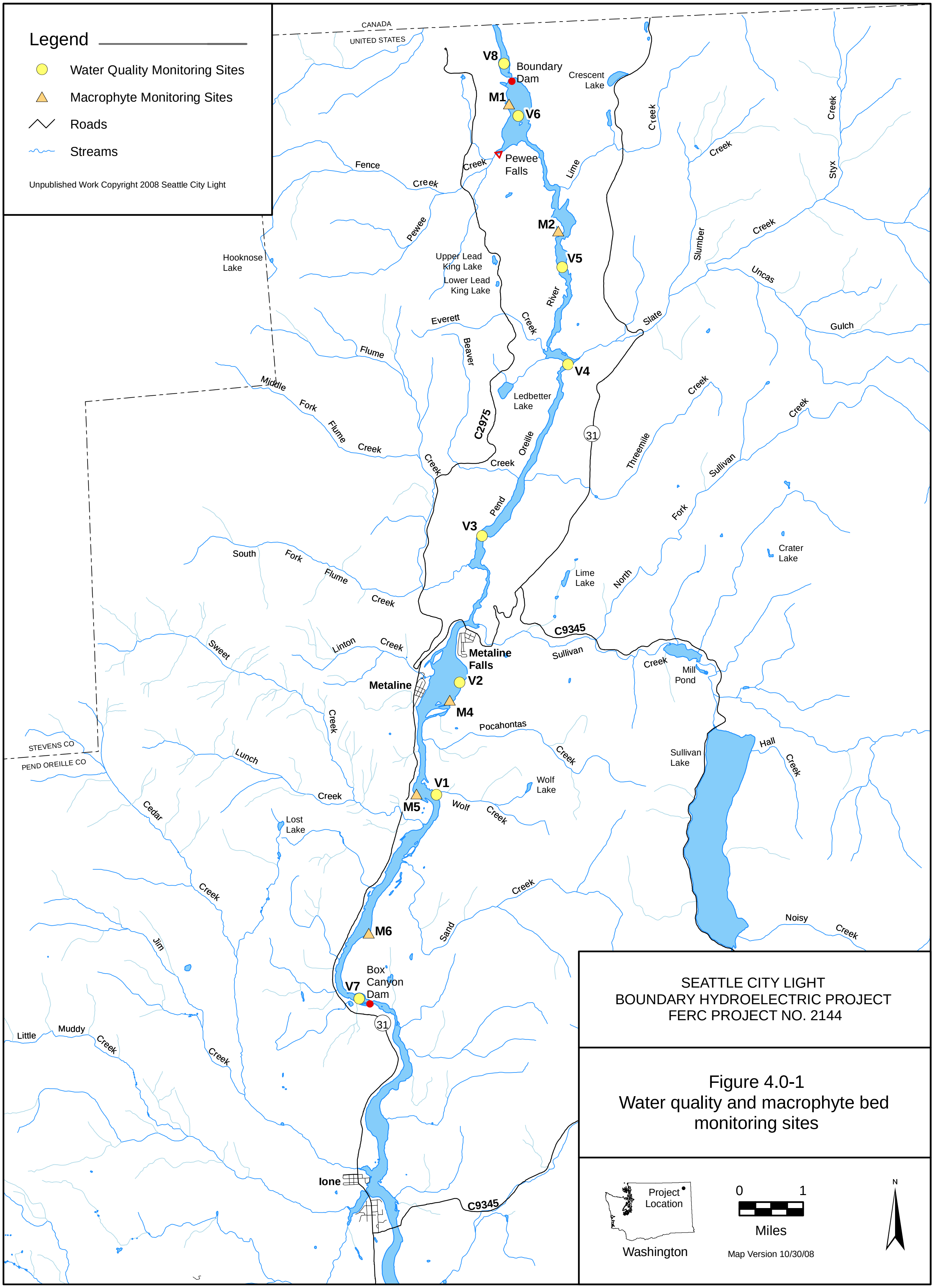

Figure 4.0-1
Water quality and macrophyte bed monitoring sites

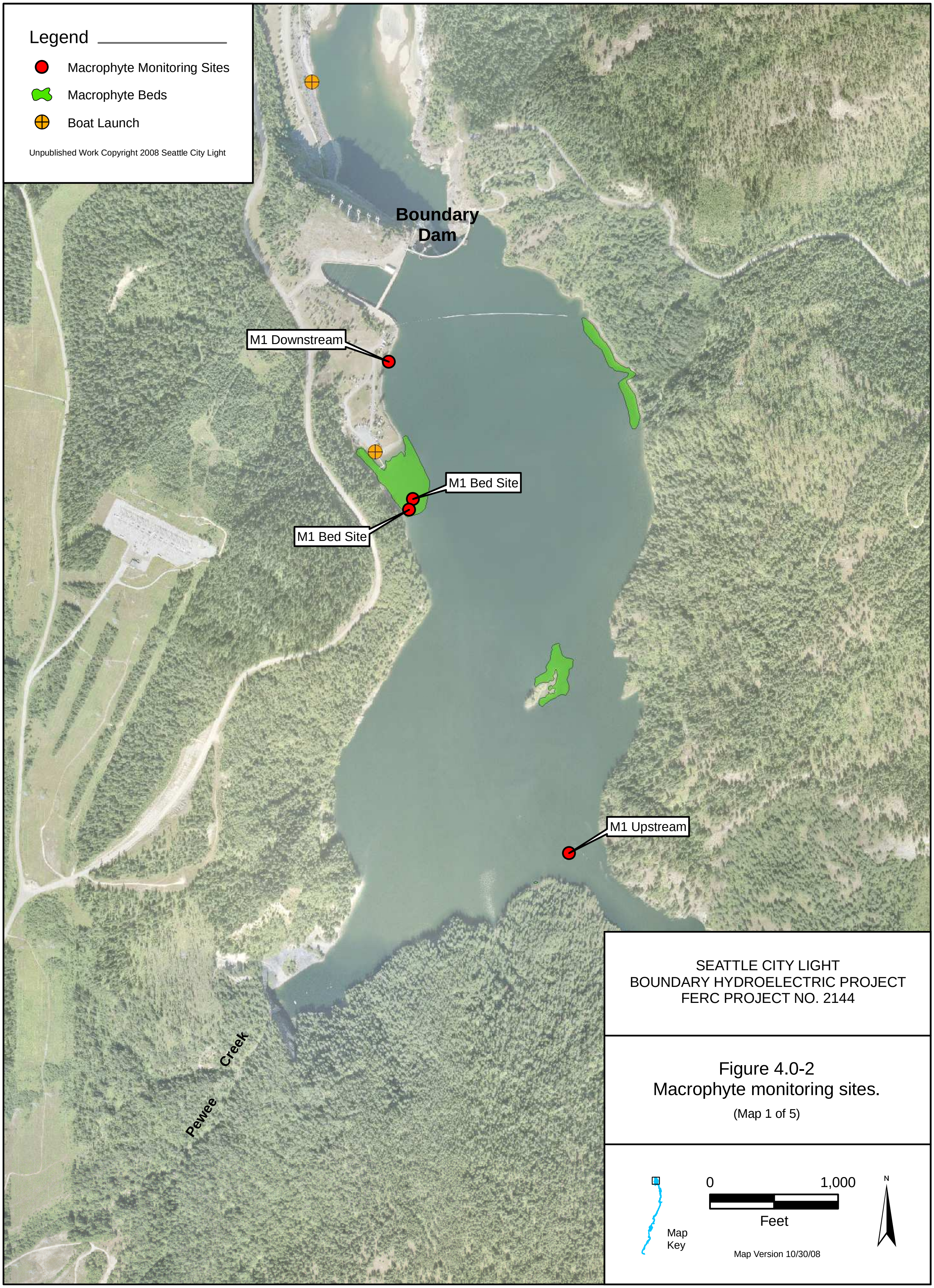

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Figure 4.0-2
Macrophyte monitoring sites.
(Map 1 of 5)

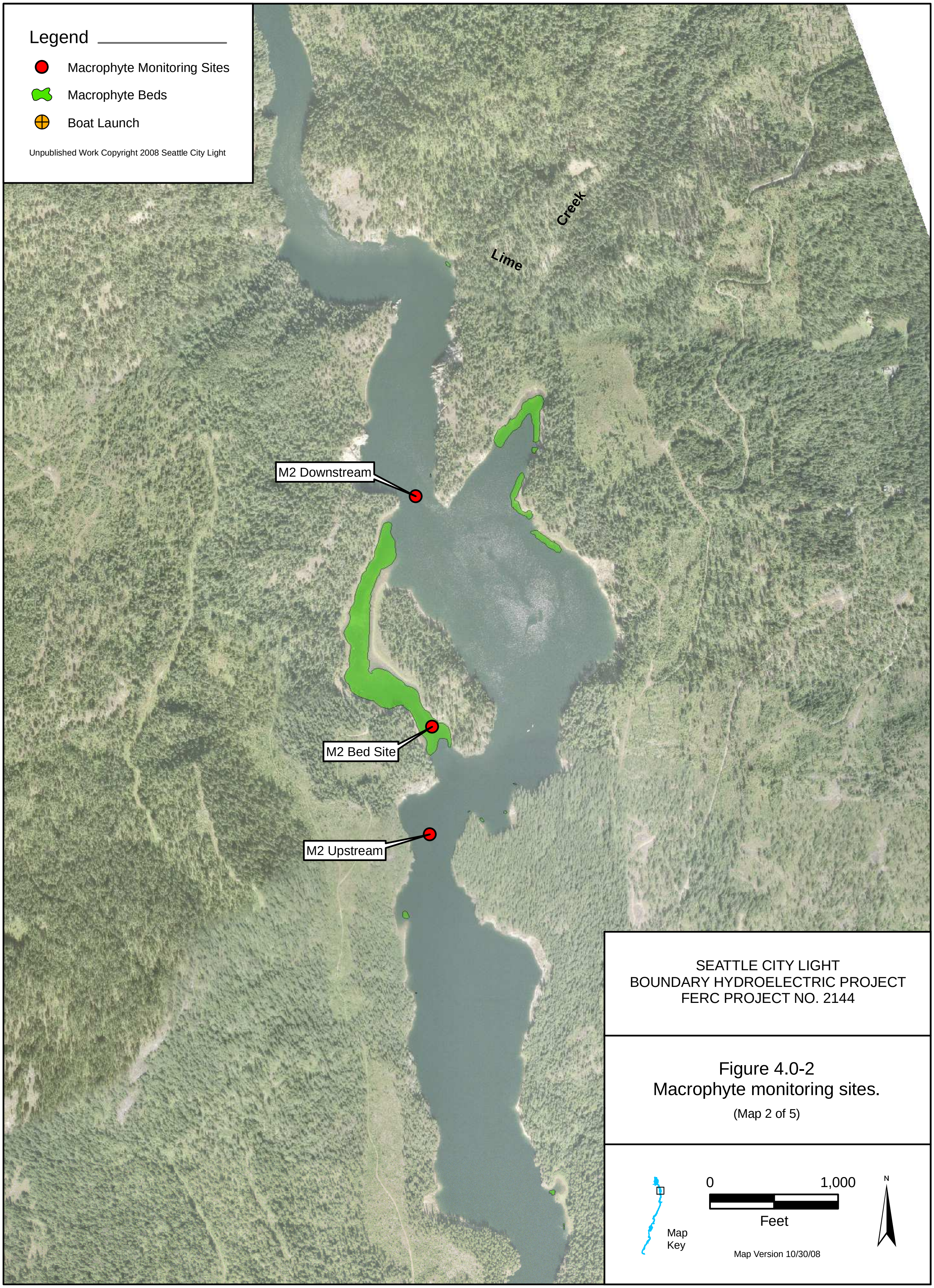

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Figure 4.0-2
Macrophyte monitoring sites.
(Map 2 of 5)

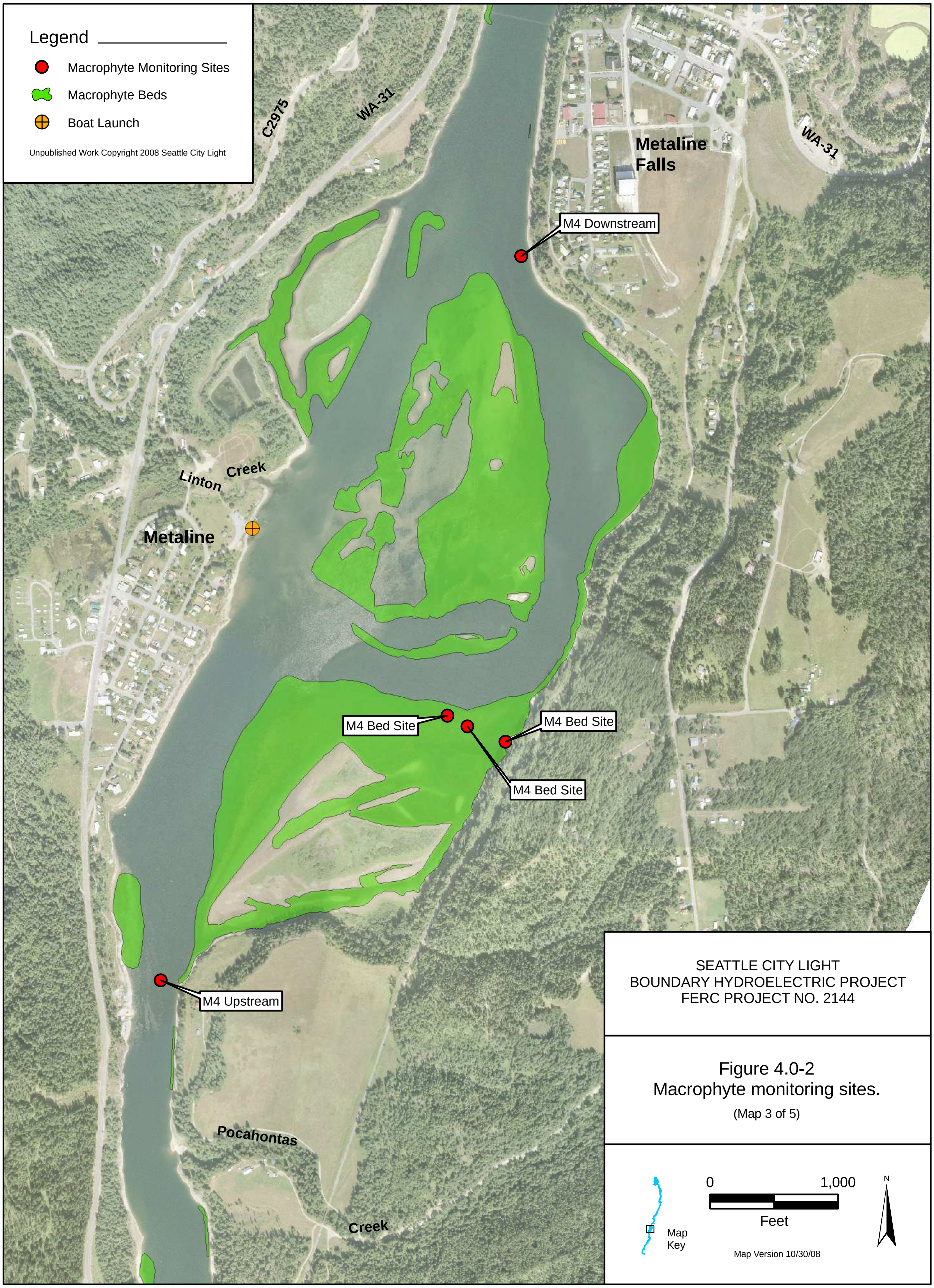

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Figure 4.0-2
Macrophyte monitoring sites.
(Map 3 of 5)

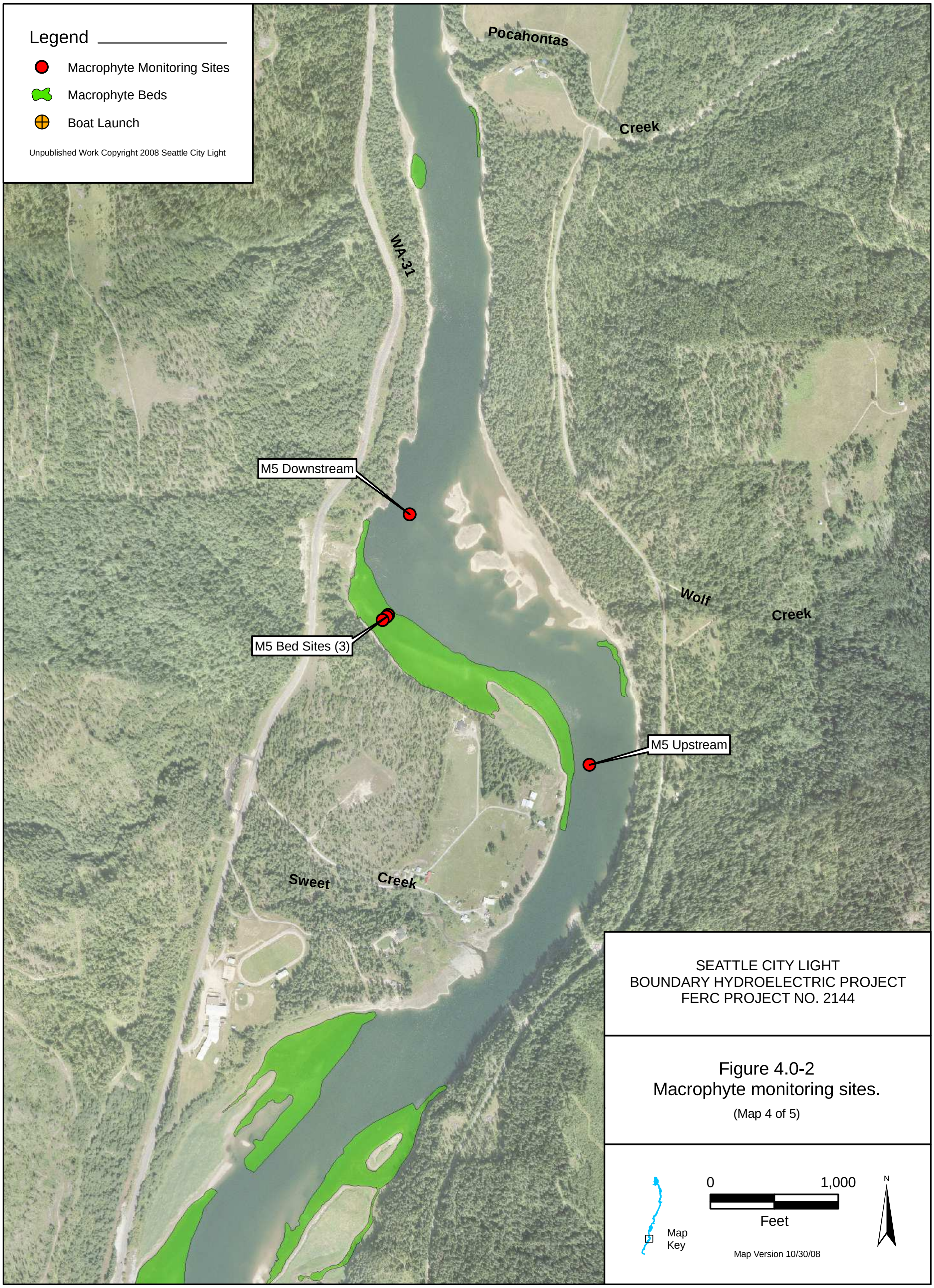

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Figure 4.0-2
Macrophyte monitoring sites.
(Map 4 of 5)

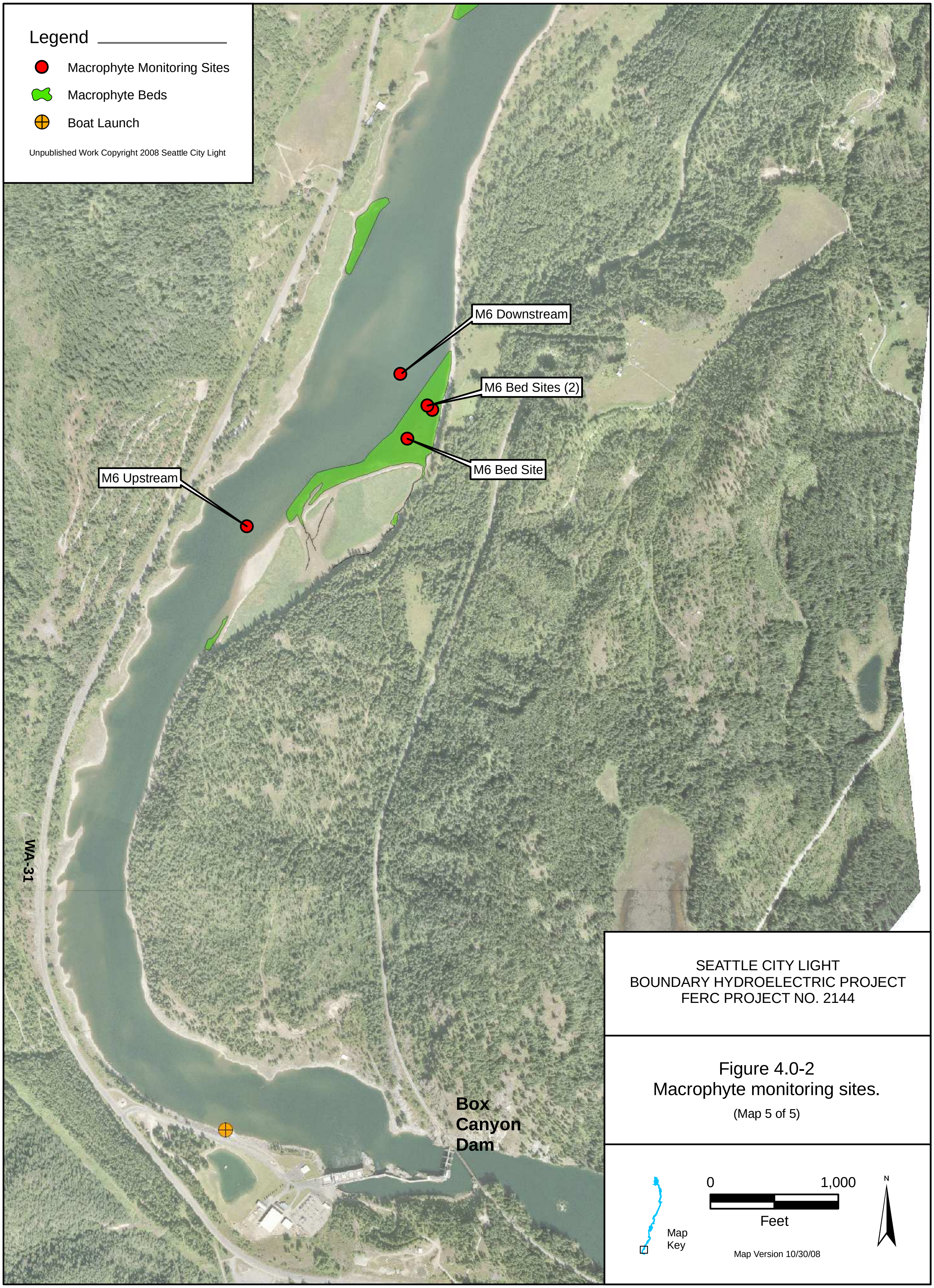

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Figure 4.0-2
Macrophyte monitoring sites.
(Map 5 of 5)

4.1. In Situ Profile Data Collection

In situ data for vertical profiles of temperature, pH, DO, and conductivity were collected using a Hydrolab® MS5, a multiprobe water quality sampling instrument. Calibration and sampling were performed per manufacturer's specifications. Field technicians were trained for sampling and calibrating instrumentation, and a copy of the Hydrolab manual was kept with the field crew during sampling. The Hydrolab MS5 multiprobe was lowered through the water column by the data cable. An eight-pound weight was attached to the bottom of the Hydrolab to ensure the instrument remained vertical in the water column as it was lowered. Measurement depths were determined by depth demarcations on the Hydrolab data cable in addition to the depth probe included in the Hydrolab sensors bundle. Water quality measurements were taken at depth intervals from the surface to the bottom of the reservoir; the depth of each interval was dependent on the total depth at each site. The exceptions to this process were the upstream and downstream locations of sites M1 and M2 where the reservoir was too deep to collect measurements without the use of a cable winch system. In situ vertical profile measurements were taken at predetermined positions within the five macrophyte monitoring sites and positions upstream and downstream of each monitoring site. In situ vertical profiles were taken in replicates of three at each position.

There were locations where a single sample represented multiple sampling objectives. For instance, there were positions within the macrophyte sites where a single sampling location met both Objective 2 (low macrophyte density) and Objective 3 (continuously inundated macrophytes). Due to sampling locations meeting duplicate monitoring objectives, a total of 15 vertical profiles were taken at the macrophyte monitoring sites (M1, M2, and M4 to M6).

Several of the monitoring objectives use macrophyte density as a criterion for locating a sample. Macrophyte density was quantified by field crews with a visual estimation sampling technique. Field crews used a viewing scope to count the number of macrophyte stems per square meter at various locations within each monitoring bed. The following are the macrophyte density criteria used for delineating low, medium, and high density of macrophytes in the field:

- Low macrophyte density: fewer than 3 stems per square meter
- Medium macrophyte density: 4 to 6 stems per square meter
- High macrophyte density: 7 or more stems per square meter

4.2. Continuous Remote Monitoring

Continuous water quality monitoring occurred at site M6, approximately 0.75 mile upstream from Lost Creek on the east bank. A Hydrolab MS5 was attached 1 meter beneath a buoy containing a radio telemetry system at three locations of site M6, upstream, downstream, and within the macrophyte bed (Figure 4.0-2, Map 5). Calibration and sampling were performed per manufacturer's specifications and distributor configuration. In situ water quality data (temperature, pH, DO, and conductivity) were measured every 15 minutes through the data collection period of June through October 2007 and again from July through October 2008. Telemetry readings were checked every week during the monitoring periods to ensure the sampling instrument was functioning properly. If water quality data signals were lost, in error, or were not identified due to environmental conditions, fouling of equipment, or vandalism, monitoring operators visited the site and attempted to repair equipment within 48 hours of identification of a problem. The continuous monitoring stations were checked for maintenance at a minimum of every 30 days.

5 RESULTS

This section presents analysis of the water quality data (e.g., DO and pH) collected for Study 6 from June 22, 2007 to October 24, 2007 and late July 31, 2008 to October 21, 2008. The data were evaluated to address the objectives of the study and are described from sites throughout the Boundary Reservoir. Data are sorted by objective and site, and each parameter is analyzed separately and together to identify potential interrelationships between parameters.

5.1. Document and Determine the Magnitude of the Impact Macrophyte Respiration/Photosynthesis and Senescence Have on pH and DO Levels in Boundary Reservoir

Data were analyzed to determine whether pH and DO were similar among sites located inside and outside of macrophyte beds, in regard to both macrophyte density and location. The analysis also attempted to quantify the magnitude of such differences. In addition, the data were assessed for the potential effect upon pH and DO from Project operations and the influence of pool level fluctuations on macrophyte beds.

5.1.1. Macrophyte Influence on pH or DO

To identify whether the presence of macrophytes influences pH or DO inside the macrophyte bed and within the mainstem river (meaning outside the macrophyte bed), both the remote and vertical profile data were evaluated. A time-series graph was developed to compare the within-bed, upstream, and downstream remote data. From this, the effect of macrophytes on pH and DO was quantified by comparing peak and average differences among sites.

Vertical profiles for DO and pH were collected from locations in macrophyte beds of varying densities as well as from sites upstream and downstream of these locations. In general, there was limited variation in DO and pH at most sites over time. Two time intervals were measured—24 hours (July 2007) and 72 hours (August 2007)—during which field water chemistry was recorded every 4 to 6 hours in macrophyte beds and at a control (upstream) and downstream location.

During the 24-hour vertical profile monitoring effort, DO and pH were measured at sites M1, M2, M4, M5, and M6. In general, DO and pH did not differ among the macrophyte bed density categories (i.e., low density, medium density, and high density) in the 24-hour study, nor did levels in beds differ substantially from those at control sites upstream and downstream of macrophyte beds (Figures 5.1-1 through 5.1-5). The only exception was that the average pH value was greater in the high density macrophyte bed at site M1 (Figure 5.1-1). All other sites showed no differences in average pH or DO concentrations among macrophyte density categories. The uncorrelated pattern of DO and pH variation among bed density categories during the same 24-hour sampling period suggest factors other than Project operations were responsible for the broader range of observations, since pool elevation levels at each site were synchronous. These measurements were likely affected by convergent factors that promote larger diel shifts such as photosynthetic rate affected by substrata nutrient levels and light availability (e.g., cloud cover and water clarity).

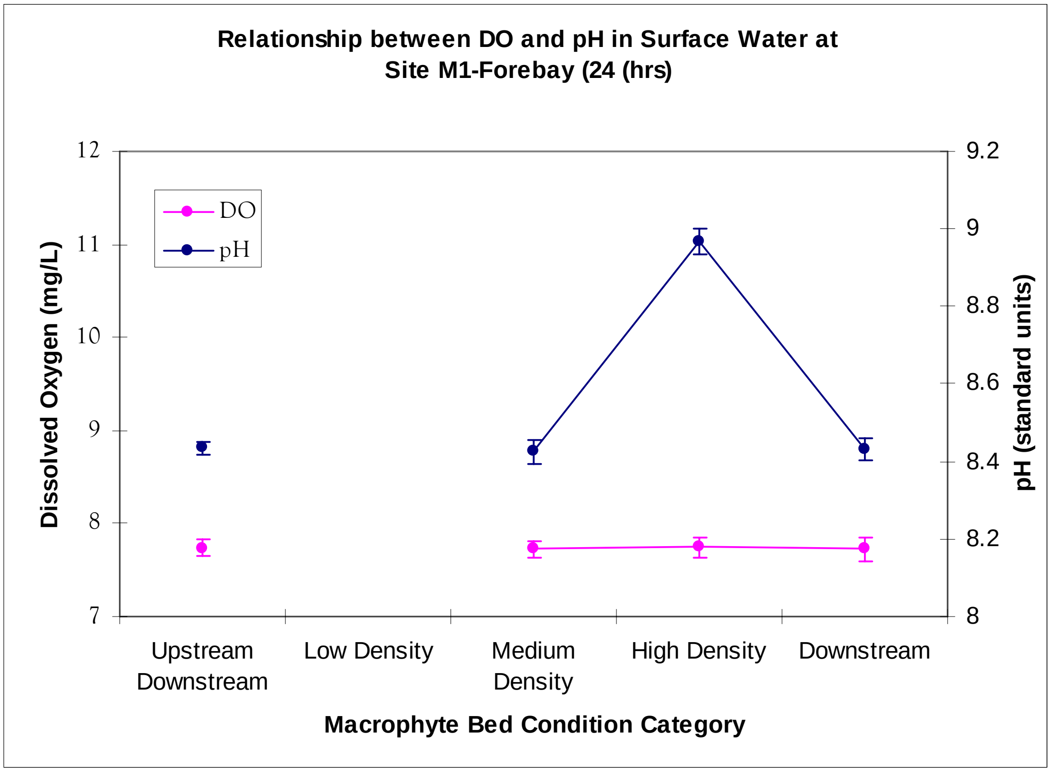

Figure 5.1-1. Means of DO and pH (±1 SD) in macrophyte beds at site M1 (24-hour event).

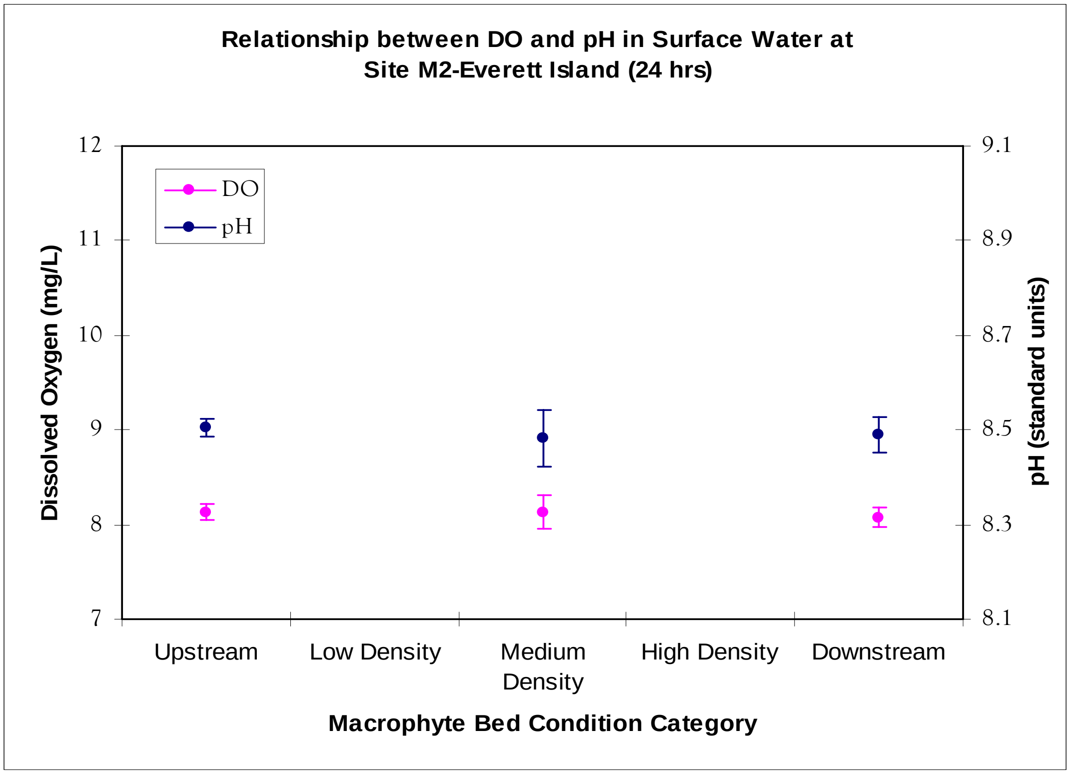

Figure 5.1-2. Means of DO and pH (±1 SD) in macrophyte beds at site M2 (24-hour event).

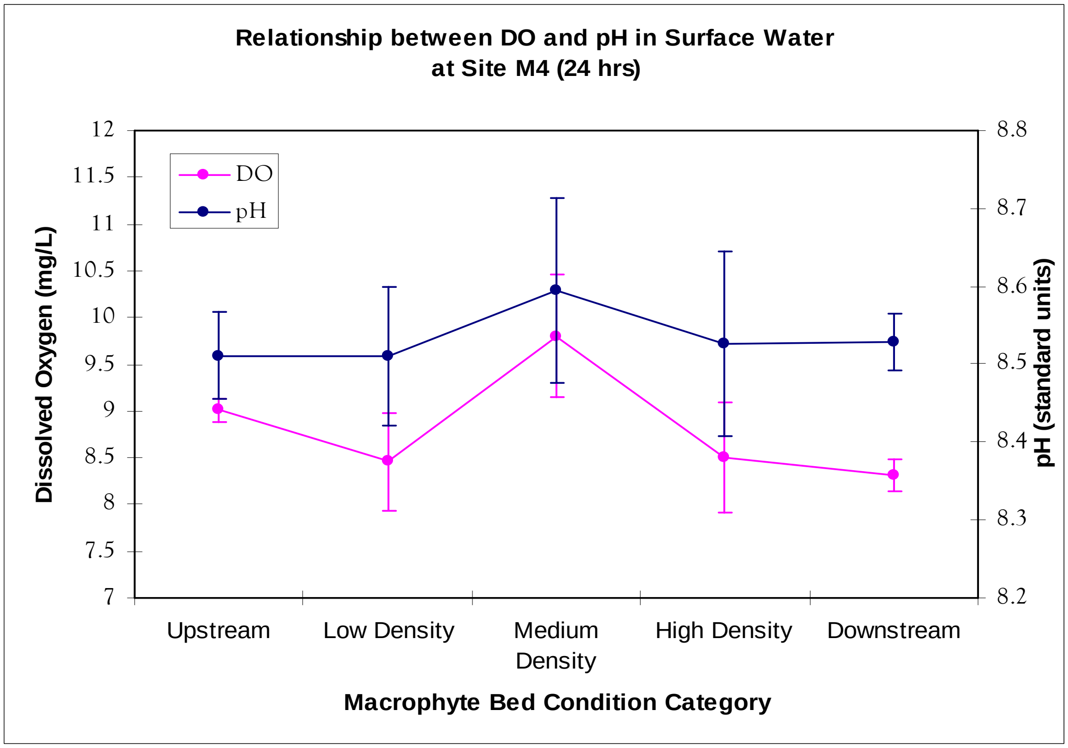

Figure 5.1-3. Means of DO and pH (±1 SD) in macrophyte beds at site M4 (24-hour event).

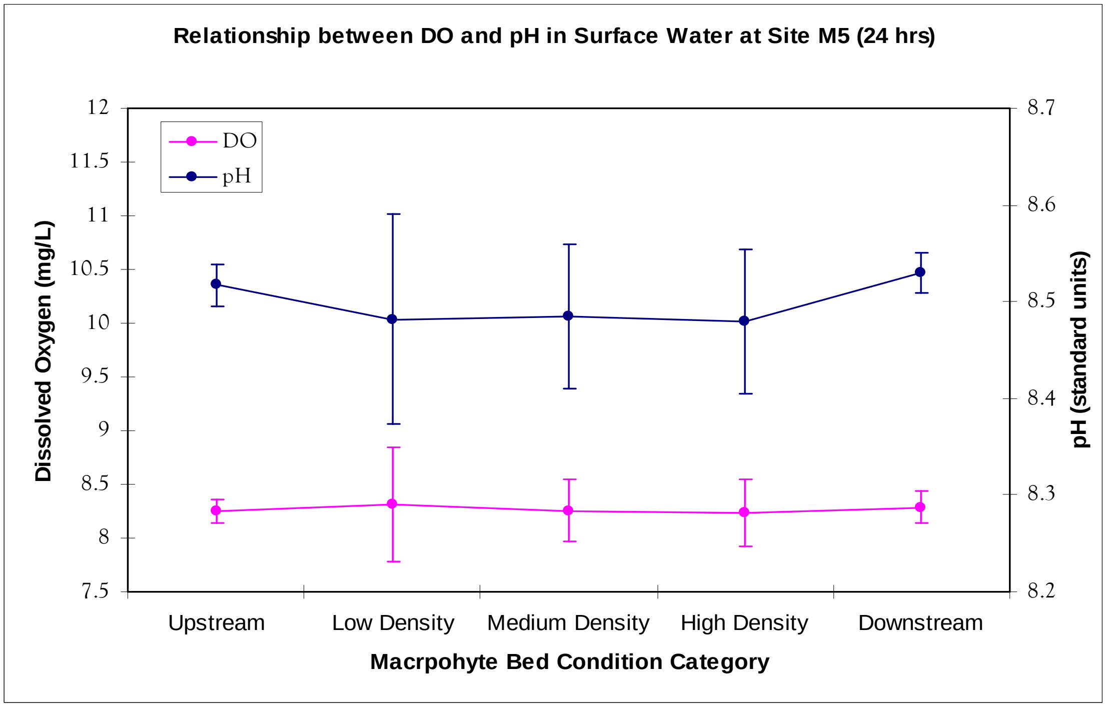

Figure 5.1-4. Means of DO and pH (±1 SD) in macrophyte beds at site M5 (24-hour event).

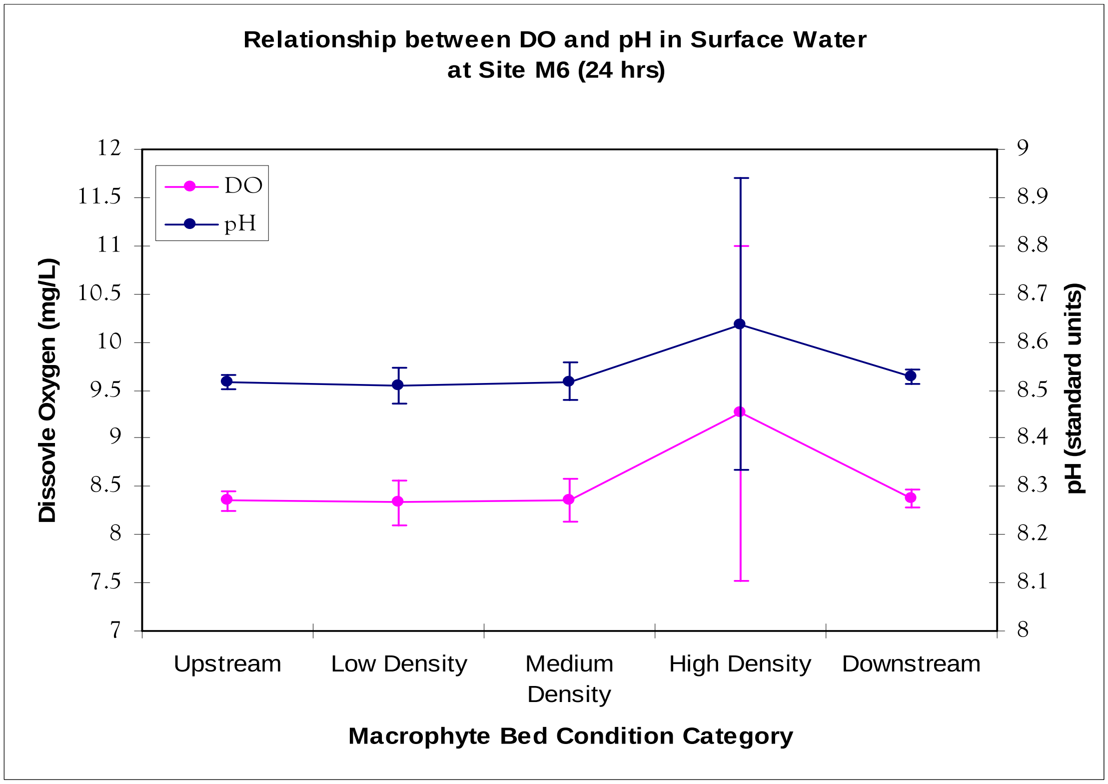

Figure 5.1-5. Means of DO and pH (±1 SD) in macrophyte beds at site M6 (24-hour event).

During the 72-hour vertical profile monitoring effort, DO and pH were measured at sites M4, M5, and M6 (Figures 5.1-6 through 5.1-8). Slightly larger ranges occurred in high density macrophyte beds at site M4 (Figure 5.1-6) and at site M6 (Figure 5.1-8). The high density bed at site M6 responded similarly to environmental factors during the August 2007 (72-hour) sampling event as was recorded in the shorter duration event from July 2007 (24-hour). The high density macrophyte bed at site M4 had a larger range of DO and pH, which differed from the July 2007 sampling event in which the medium density bed recorded the larger constituent ranges at this site. The shift in larger diel ranges from one bed density category to another during different sampling events may indicate that localized conditions have an effect on macrophytes.

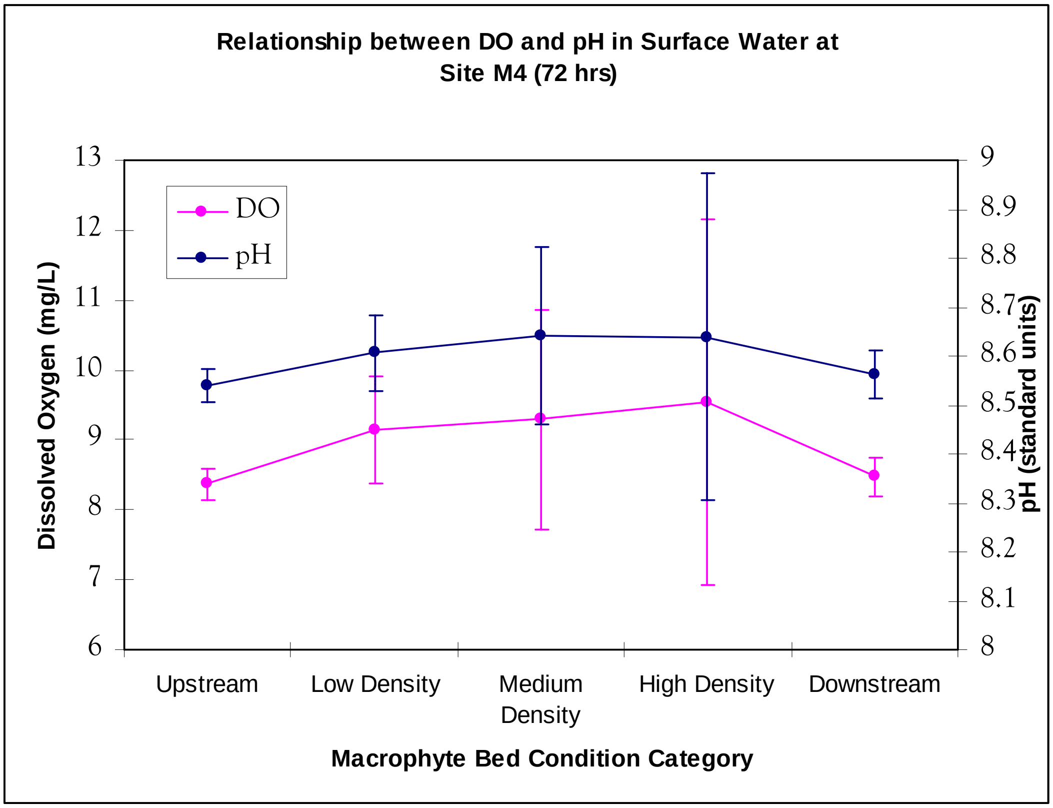

Figure 5.1-6. Means of DO and pH (±1 SD) in macrophyte beds at site M4 (72-hour event).

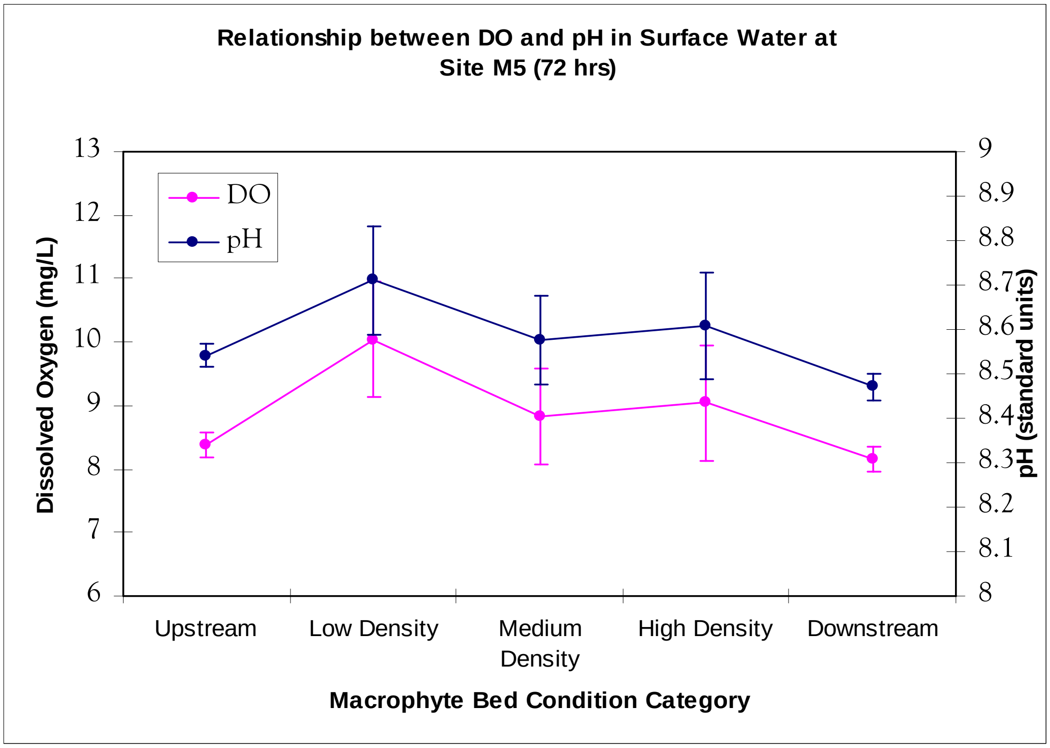

Figure 5.1-7. Means of DO and pH (±1 SD) in macrophyte beds at site M5 (72-hour event).

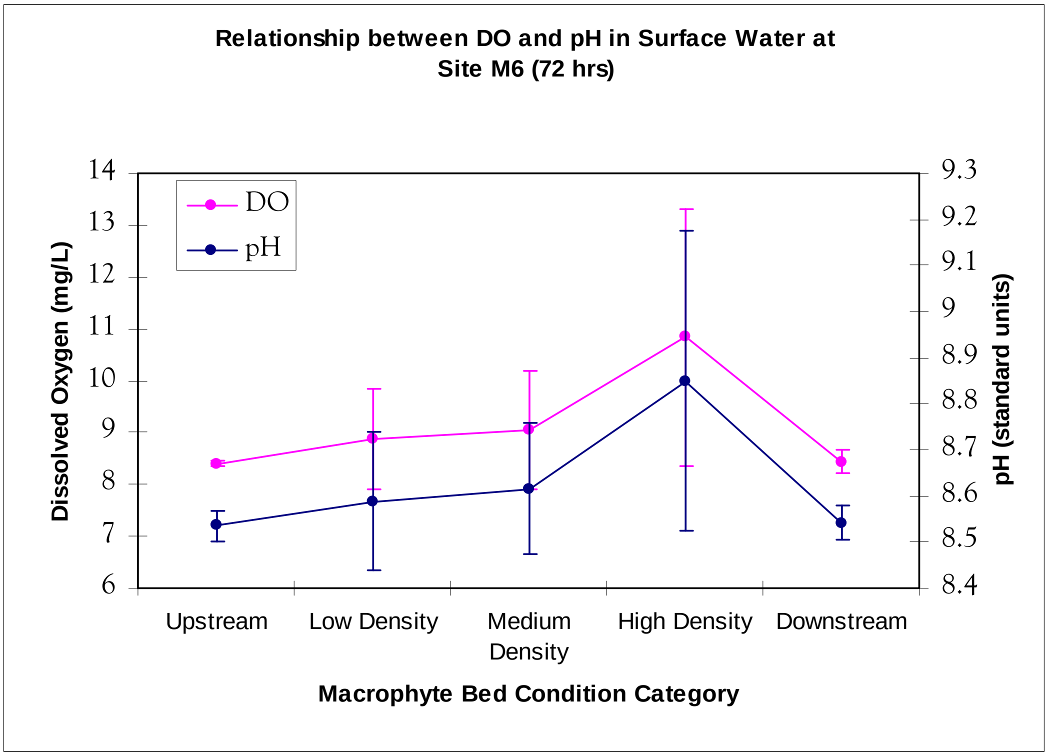

Figure 5.1-8. Means of DO and pH (±1 SD) in macrophyte beds at site M6 (72-hour event).

5.1.2. Macrophyte Influence on pH and DO Over Time

DO concentrations and pH levels were continuously monitored at fixed depth in the open water column associated with macrophyte site M6 (June 22 to October 24, 2007, and again from July 31 through October 21, 2008). Continuously gathered data provided the opportunity to observe subtle changes in the water quality of macrophyte beds. Three Hydrolabs were anchored, one each at locations upstream of (Buoy 1), downstream of (Buoy 3), and within (Buoy 2) an extensive macrophyte bed near site M6. These locations were chosen to isolate the effects of macrophyte bed respiration, photosynthesis, and senescence on DO concentrations and pH conditions. Other downstream locations were not selected due to the potential for other non-point pollution factors to influence water quality.

In 2007, average DO concentrations for Buoy 1 and Buoy 3 were almost identical, and variances indicate overlapping confidence intervals between the two data sets (Table 5.1-1). Differences in DO concentrations were small enough to be accounted for by factors such as field measurement error (0.2 milligram per liter [mg/L]). In 2008, the average DO concentration was slightly higher at Buoy 1 compared to Buoy 3; however, confidence intervals overlapped between the two data sets (Table 5.1-1). The DO concentration for Buoy 2 was at levels between those at Buoy 1 and Buoy 3 with overlapping confidence intervals between the three data sets.

Table 5.1-1. Summary statistics for DO concentrations at Buoys 1, 2, and 3 at macrophyte site M6.

Groups	No. of Observations	Average (mg/L)	Standard Deviation
2007 Monitoring			
Buoy 1	11,463	9.10	0.54
Buoy 2	8,391	9.44	0.83
Buoy 3	11,950	9.19	0.36
2008 Monitoring			
Buoy 1	7,968	9.21	0.36
Buoy 2	7,966	9.02	0.52
Buoy 3	7,968	8.86	0.36

Note:
mg/L – milligram per liter

In 2007, average pH levels for Buoy 1 and Buoy 3 were almost identical, and variances indicate overlapping confidence intervals between the two data sets (Table 5.1-2). Field measurement error for the probes used to measure pH at each of the buoys was 0.1 mg/L. The variances calculated for each of the data sets generated at the buoys were much smaller than detectable changes by the pH probe. The data did not indicate that macrophyte beds (Buoy 2) influence pH levels at a downstream location (Buoy 3). In 2008, average pH levels for Buoy 1 and Buoy 3 were similar, and variances indicate overlapping confidence intervals between the two data sets (Table 5.1-2). In contrast, average pH levels for Buoy 2 were higher than Buoy 1 and Buoy 3; but confidence intervals overlapped between the three data set and within the error of instrumentation measurements therefore no real difference.

Table 5.1-2. Summary statistics for pH conditions at Buoys 1, 2, and 3 at macrophyte site M6.

Groups	No. of Observations	Average	Standard Deviation
2007 Monitoring			
Buoy 1	11,463	8.59	0.18
Buoy 2	8,391	8.61	0.21
Buoy 3	11,950	8.58	0.11
2008 Monitoring			
Buoy 1	7,968	8.49	0.18
Buoy 2	7,966	8.66	0.08
Buoy 3	7,968	8.55	0.09

Data collected June 22 to October 24, 2007 from remote water quality buoys (Buoy 1 (upstream), Buoy 2 (macrophyte bed), and Buoy 3 (downstream) at monitoring site M6 were compared on a weekly basis. The purpose of this comparison was to determine how the presence of macrophytes influenced pH and DO over the sampling season and when the largest impact occurred. Figures 5.1-9 through 5.1-14 show the weekly average, maximum, and minimum pH and DO values recorded. Table 5.1-3 and Table 5.1-4 summarize the weekly statistics for pH and DO measured at the three buoys for 2007 and 2008.

There was little fluctuation in pH or DO throughout the sampling period (June–October 2007) at Buoy 1 (Figures 5.1-9 and Figure 5.1-10) and Buoy 3 (Figure 5.1-13 and Figure 5.1-14). The range of weekly pH values from June through October was 8.79 to 8.20 at Buoy 1 and 8.78 to 8.20 at Buoy 3. The range of weekly DO values from June through October was 8.12 to 11.45 mg/L at Buoy 1 and 8.41 to 11.07 mg/L at Buoy 3. DO values at both Buoy 1 and Buoy 3 decreased as the summer progressed. The decrease in DO values at both Buoy 1 and Buoy 3 corresponds to increasing water temperatures and DO concentrations of water entering Boundary Reservoir from Box Canyon Dam. At the beginning of the sampling season water temperatures at Buoy 1 and Buoy 3 were approximately 17°C. In August, water temperatures at Buoy 1 and Buoy 3 had increased to approximately 23°C (for more detailed information about water temperatures during the sampling season, refer to Appendix 2 and the continuous monitoring data set available in electronic form).

DO and pH values at Buoy 2 ranged from 5.38 to 15.39 mg/L and 6.37 to 11.30, respectively, throughout the 2007 sampling period (Figures 5.1-11 and 5.1-12). Weekly average pH and DO values at Buoy 2 remained fairly consistent through the sampling period, with a slight increase in pH at the end of August and a slight increase in DO at the beginning of October, but the range of pH and DO values varied greatly. The largest range of maximum and minimum pH and DO values at Buoy 2 occurred during the week of August 3–9, 2007 during the peak macrophyte growing season. During the same week, pH and DO values measured at Buoy 1 and Buoy 3 were not significantly different from each other. The large variations in pH and DO at Buoy 2 are attributable to diurnal change in photosynthetic activity and respiration within the macrophyte bed. Measurements of pH and DO at Buoy 2 were affected by grounding of the sampling instrument during extremely low pool levels. With fluctuating water levels, Buoy 2 would sometimes become grounded (in very shallow water) in the evenings and through the night until reservoir levels increased during refill. During the dates August 24–30, 2007, Buoy 2 was completely dry and the Hydrolab was removed from the buoy to prevent damage to the sampling instrument. These times of extreme low pool occurred through September 2007 with drawdowns of the reservoir related to other study efforts. The intermittent drawdowns through September 13, 2007, dried the beds. These drawdowns that occurred during the sampling season were extreme and the pH and DO data collected did not convey what would have happened at this location under a more normal range of Project operations; therefore, no data were collected for Buoy 2 during this period. The Hydrolab was replaced in Buoy 2 on September 17, 2007, after the bed had been re-wetted for a few days, and data logging resumed.

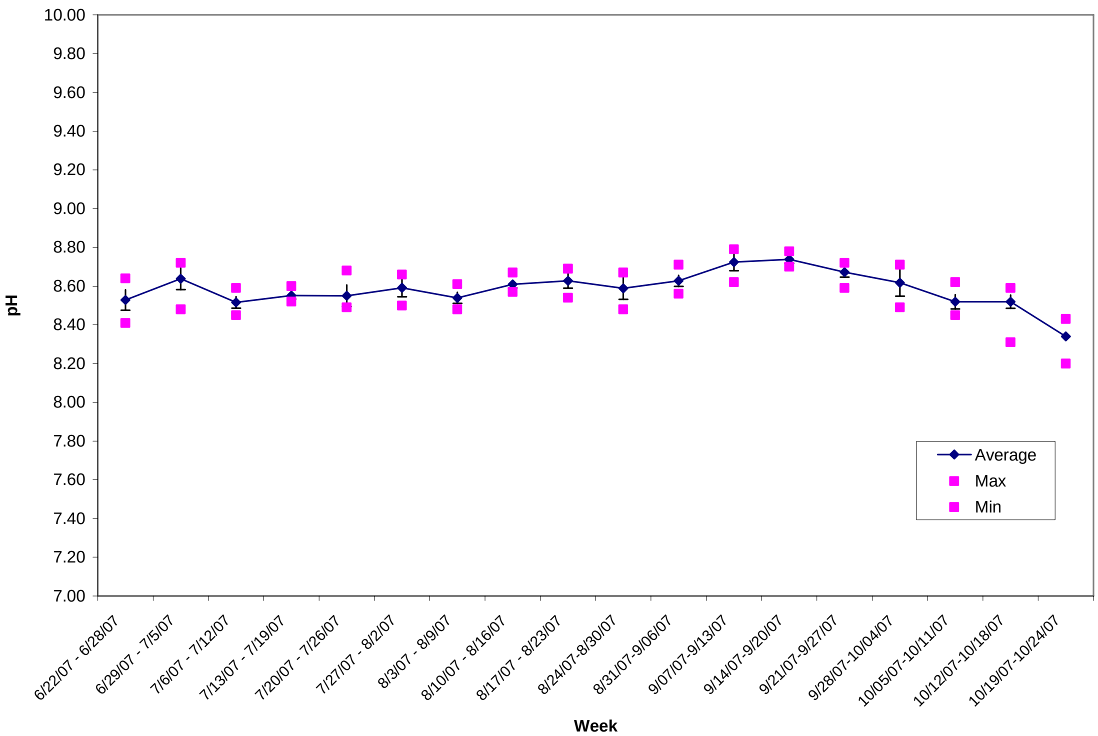

Figure 5.1-9. Buoy 1 (upstream) weekly pH values from 6/22/07 to 10/24/07 at site M6.

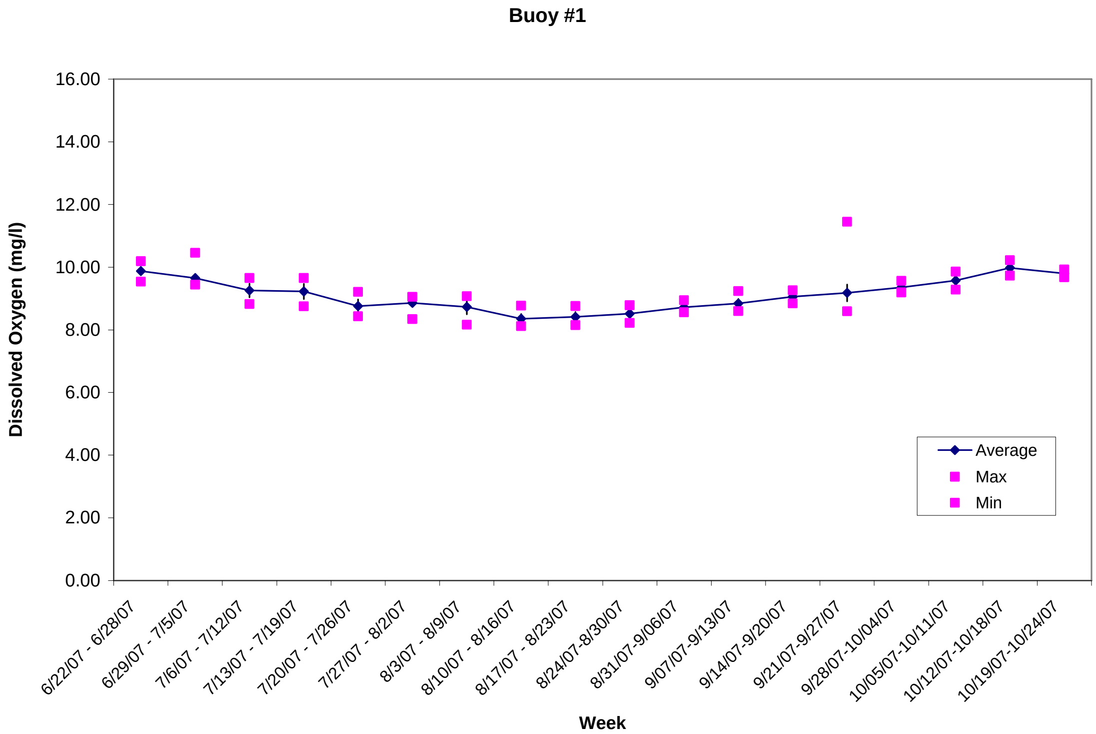

Figure 5.1-10. Buoy 1 (upstream) weekly DO values from 6/22/07 to 10/24/07 at site M6.

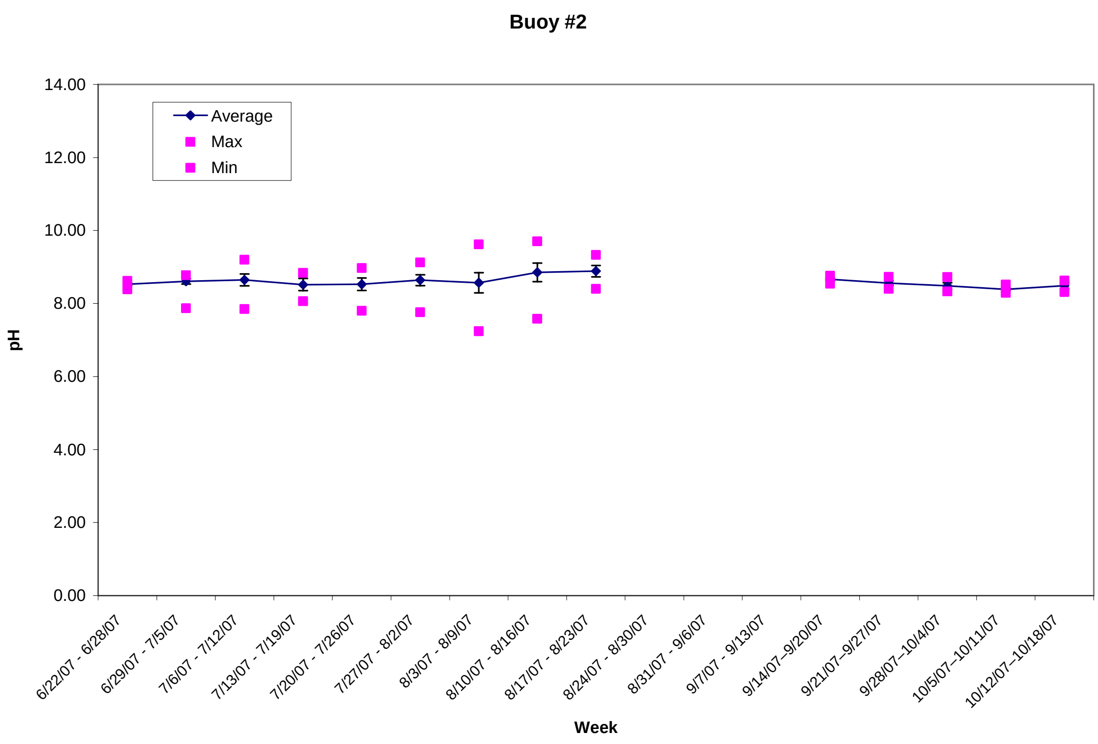

Figure 5.1-11. Buoy 2 (macrophyte bed) weekly pH values from 6/22/07 to 10/24/07 at site M6.

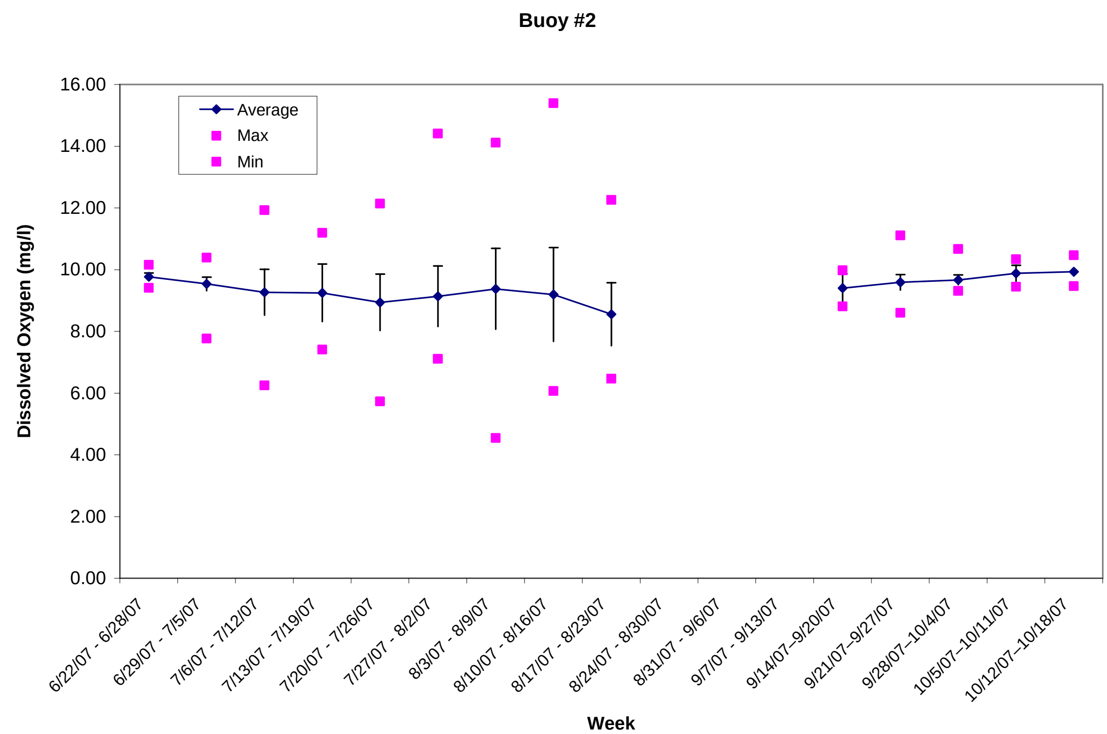

Figure 5.1-12. Buoy 2 (macrophyte bed) weekly DO values from 6/22/07 to 10/24/07 at site M6.

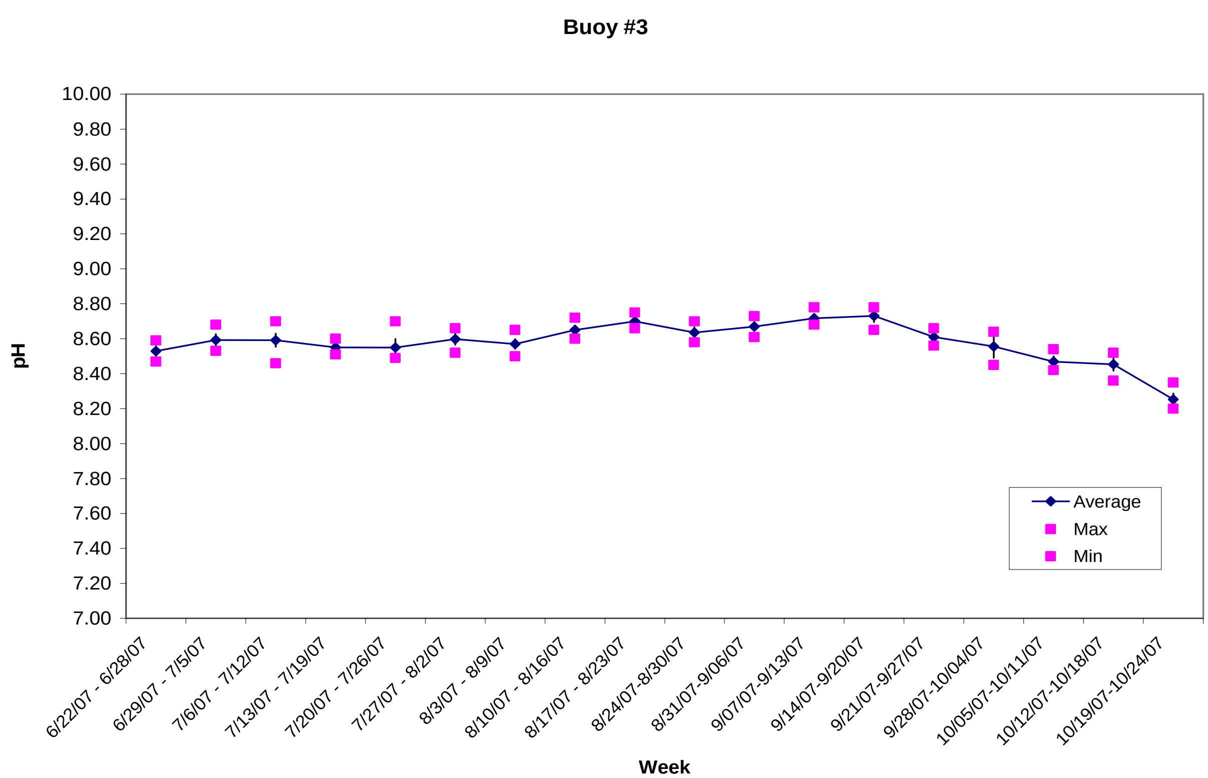

Figure 5.1-13. Buoy 3 (downstream) weekly pH values from 6/22/07 to 10/24/07 at site M6.

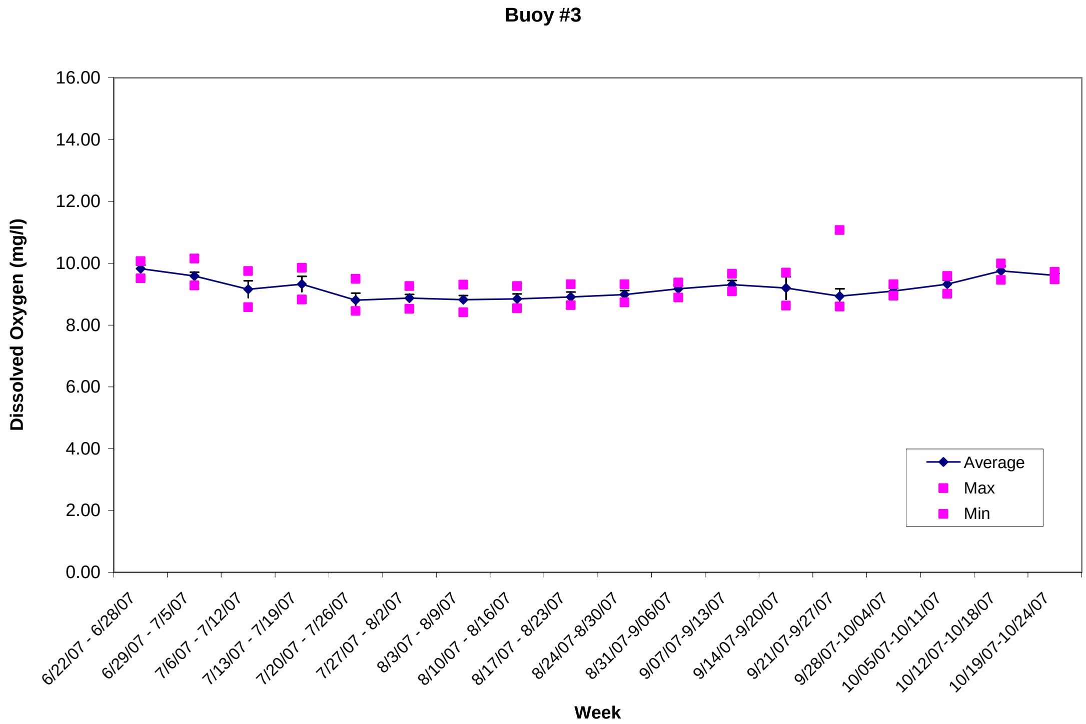

Figure 5.1-14. Buoy 3 (downstream) weekly DO values from 6/22/07 to 10/24/07 at site M6.

Table 5.1-3. Summary of 2007 weekly pH and DO statistics for Buoys 1, 2, and 3 located at site M6.

Week	Average pH	Max pH	Min pH	pH STDEV	Average DO (mg/L)	Max DO (mg/L)	Min DO (mg/L)	DO STDEV	n
Buoy 1									
6/22/07–6/28/07	8.53	8.64	8.41	0.05	9.88	10.19	9.54	0.13	672
6/29/07–7/5/07	8.64	8.72	8.48	0.06	9.65	10.46	9.44	0.10	672
7/6/07–7/12/07	8.52	8.59	8.45	0.03	9.25	9.65	8.82	0.22	672
7/13/07–7/19/07	8.55	8.60	8.52	0.02	9.22	9.65	8.75	0.24	672
7/20/07–7/26/07	8.55	8.68	8.49	0.06	8.75	9.21	8.43	0.21	672
7/27/07–8/2/07	8.59	8.66	8.50	0.05	8.86	9.05	8.34	0.10	672
8/3/07–8/9/07	8.54	8.61	8.48	0.03	8.73	9.07	8.16	0.24	672
8/10/07–8/16/07	8.61	8.67	8.57	0.02	8.36	8.77	8.12	0.15	672
8/17/07–8/23/07	8.63	8.69	8.54	0.04	8.41	8.76	8.15	0.16	672
8/24/07–8/30/07	8.59	8.67	8.48	0.06	8.52	8.78	8.22	0.15	672
8/31/07–9/6/07	8.63	8.71	8.56	0.03	8.72	8.94	8.56	0.08	672
9/7/07–9/13/07	8.72	8.79	8.62	0.04	8.84	9.24	8.60	0.15	672
9/14/07–9/20/07	8.74	8.78	8.70	0.02	9.06	9.26	8.84	0.09	425
9/21/07–9/27/07	8.67	8.72	8.59	0.03	9.18	11.45	8.59	0.27	672
9/28/07–10/4/07	8.62	8.71	8.49	0.07	9.35	9.56	9.19	0.09	672
10/5/07–10/11/07	8.52	8.62	8.45	0.04	9.58	9.86	9.28	0.12	672
10/12/07–10/18/07	8.52	8.59	8.31	0.03	9.98	10.22	9.73	0.15	576
10/19/07–10/24/07	8.34	8.43	8.20	0.04	9.80	9.93	9.68	0.07	382
Buoy 2									
6/22/07–6/28/07	8.52	8.62	8.39	0.04	9.77	10.16	9.41	0.12	672
6/29/07–7/5/07	8.61	8.77	7.87	0.08	9.54	10.39	7.77	0.22	672
7/6/07–7/12/07	8.65	9.20	7.85	0.16	9.26	11.93	6.25	0.74	465
7/13/07–7/19/07	8.52	8.84	8.06	0.17	9.25	11.19	7.41	0.93	153
7/20/07–7/26/07	8.53	8.97	7.80	0.17	8.94	12.14	5.73	0.92	652
7/27/07–8/2/07	8.64	9.12	7.76	0.15	9.14	14.41	7.11	0.98	648
8/3/07–8/9/07	8.57	9.62	7.24	0.28	9.41	14.11	5.38	1.26	610
8/10/07–8/16/07	8.85	9.70	7.58	0.25	9.19	15.39	5.44	1.52	618
8/17/07–8/23/07	8.89	9.33	8.40	0.16	8.55	12.26	6.47	1.02	410
8/24/07–8/30/07[1]	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
8/31/07–9/6/07[1]	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
9/7/07–9/13/07[1]	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
9/14/07–9/20/07	8.66	8.76	8.54	0.04	9.40	9.98	8.81	0.26	299
9/21/07–9/27/07	8.56	8.73	8.4	0.06	9.59	11.11	8.60	0.46	609
9/28/07–10/4/07	8.48	8.72	8.33	0.09	9.67	10.67	9.31	0.25	672
10/5/07–10/11/07	8.39	8.52	8.29	0.04	9.89	10.34	9.45	0.16	672
10/12/07–10/18/07	8.49	8.63	8.31	0.09	9.93	10.47	9.47	0.26	672
10/19/07–10/24/07	8.43	8.53	8.36	0.04	9.44	9.84	9.25	0.11	567

Table 5.1-3, continued…

Week	Average pH	Max pH	Min pH	pH STDEV	Average DO (mg/L)	Max DO (mg/L)	Min DO (mg/L)	DO STDEV	n
Buoy 3									
6/22/07–6/28/07	8.53	8.59	8.47	0.03	9.83	10.07	9.51	0.11	672
6/29/07–7/5/07	8.59	8.68	8.53	0.03	9.59	10.15	9.28	0.12	672
7/6/07–7/12/07	8.59	8.70	8.46	0.04	9.16	9.75	8.58	0.27	672
7/13/07–7/19/07	8.55	8.60	8.51	0.02	9.33	9.85	8.83	0.25	672
7/20/07–7/26/07	8.55	8.70	8.49	0.05	8.81	9.49	8.46	0.22	672
7/27/07–8/2/07	8.60	8.66	8.52	0.03	8.88	9.26	8.53	0.12	672
8/3/07–8/9/07	8.57	8.65	8.50	0.03	8.82	9.31	8.41	0.13	672
8/10/07–8/16/07	8.65	8.72	8.60	0.02	8.85	9.26	8.54	0.16	672
8/17/07–8/23/07	8.70	8.75	8.66	0.02	8.91	9.32	8.64	0.16	672
8/24/07–8/30/07	8.64	8.70	8.58	0.03	8.99	9.32	8.73	0.12	672
8/31/07–9/6/07	8.67	8.73	8.61	0.03	9.17	9.38	8.89	0.10	672
9/7/07–9/13/07	8.72	8.78	8.68	0.02	9.31	9.66	9.09	0.13	672
9/14/07–9/20/07	8.73	8.78	8.65	0.04	9.20	9.70	8.63	0.36	672
9/21/07–9/27/07	8.61	8.66	8.56	0.02	8.93	11.07	8.60	0.24	672
9/28/07–10/4/07	8.56	8.64	8.45	0.06	9.10	9.32	8.95	0.09	668
10/5/07–10/11/07	8.47	8.54	8.42	0.03	9.32	9.59	9.01	0.12	672
10/12/07–10/18/07	8.45	8.52	8.36	0.04	9.75	9.99	9.46	0.16	672
10/19/07–10/24/07	8.25	8.35	8.20	0.04	9.61	9.72	9.48	0.06	530

Notes:
1 Experimental drawdown of the reservoir during this week resulted in loss of water quality readings at Buoy 2 when the multiprobe meter was stranded on a dry macrophyte bed.
DO – dissolved oxygen
mg/L – milligram per liter
n – number of observations
STDEV – standard deviation

Table 5.1-4. Summary of 2008 weekly pH and DO statistics for Buoys 1, 2, and 3 located at site M6.

Week	Average pH	Max pH	Min pH	pH STDEV	Average DO (mg/L)	Max DO (mg/L)	Min DO (mg/L)	DO STDEV	n
Buoy 1									
7/31/08–8/7/08	8.63	8.72	8.56	0.03	9.09	9.41	8.79	0.16	768
8/8/08–8/14/08	8.61	8.65	8.49	0.02	9.09	10.36	8.16	0.28	672
8/15/08–8/21/08	8.61	8.68	8.50	0.05	8.97	9.33	8.19	0.26	672
8/22/08–8/28/08	8.57	8.69	8.44	0.08	8.69	9.04	8.17	0.23	672
8/29/08–9/4/08	8.57	8.62	8.53	0.02	9.02	9.49	8.67	0.21	672
9/5/0/8–9/11/08	8.54	8.59	8.49	0.03	9.57	9.79	8.65	0.14	672
9/12/08–9/18/08	8.56	8.63	8.51	0.02	9.52	10.01	8.98	0.23	672

Table 5.1-4, continued…

Week	Average pH	Max pH	Min pH	pH STDEV	Average DO (mg/L)	Max DO (mg/L)	Min DO (mg/L)	DO STDEV	n
9/19/08–9/25/08	8.58	8.64	8.51	0.03	9.09	9.95	8.70	0.23	672
9/26/08–10/2/08	8.60	8.66	8.53	0.03	9.29	9.49	9.07	0.11	672
10/3/08–10/9/08	8.39	8.57	8.29	0.09	9.00	9.35	8.70	0.17	672
10/10/08–10/16/08	8.18	8.32	8.07	0.07	9.57	9.89	9.17	0.19	672
10/17/08–10/21/08	8.04	8.10	7.97	0.04	9.79	9.92	9.69	0.04	480
Buoy 2									
7/31/08–8/7/08	8.63	8.69	8.59	0.02	8.95	9.42	8.55	0.18	766
8/8/08–8/14/08	8.63	8.74	8.54	0.05	8.74	9.96	8.29	0.30	672
8/15/08–8/21/08	8.69	8.91	8.49	0.07	8.58	10.14	7.48	0.40	672
8/22/08–8/28/08	8.61	8.76	8.40	0.08	8.28	8.75	6.46	0.35	672
8/29/08–9/4/08	8.65	8.87	8.45	0.07	8.60	9.40	7.82	0.32	672
9/5/0/8–9/11/08	8.71	9.03	8.54	0.07	9.21	11.35	8.55	0.39	672
9/12/08–9/18/08	8.76	9.19	8.50	0.09	9.25	12.21	8.19	0.48	672
9/19/08–9/25/08	8.69	8.88	8.56	0.05	8.86	9.77	8.30	0.22	672
9/26/08–10/2/08	8.75	8.92	8.62	0.04	9.35	9.98	8.86	0.17	672
10/3/08–10/9/08	8.63	8.74	8.55	0.05	9.08	9.43	8.77	0.17	672
10/10/08–10/16/08	8.64	8.69	8.58	0.02	9.63	9.98	9.19	0.18	672
10/17/08–10/21/08	8.60	8.71	8.54	0.03	9.87	9.98	9.74	0.04	480
Buoy 3									
7/31/08–8/7/08	8.60	8.66	8.55	0.02	9.12	9.47	8.81	0.16	768
8/8/08–8/14/08	8.63	8.75	8.57	0.04	8.96	10.26	8.27	0.37	672
8/15/08–8/21/08	8.67	8.78	8.48	0.07	8.56	8.91	7.80	0.26	672
8/22/08–8/28/08	8.51	8.61	8.40	0.06	8.28	8.65	7.80	0.22	672
8/29/08–9/4/08	8.57	8.65	8.45	0.05	8.58	9.04	8.26	0.22	672
9/5/0/8–9/11/08	8.62	8.66	8.58	0.01	9.13	9.31	8.72	0.14	672
9/12/08–9/18/08	8.59	8.64	8.54	0.02	9.03	9.50	8.59	0.23	672
9/19/08–9/25/08	8.56	8.66	8.47	0.05	8.64	10.04	8.32	0.18	672
9/26/08–10/2/08	8.58	8.64	8.53	0.03	8.92	9.13	8.71	0.10	672
10/3/08–10/9/08	8.41	8.53	8.33	0.06	8.65	9.00	8.36	0.17	672
10/10/08–10/16/08	8.44	8.49	8.41	0.02	9.18	9.51	8.80	0.18	672
10/17/08–10/21/08	8.39	8.45	8.33	0.04	9.39	9.52	9.29	0.04	480

Notes:

1 Experimental drawdown of the reservoir during this week resulted in loss of water quality readings at Buoy 2 when the multiprobe meter was stranded on a dry macrophyte bed.

DO –dissolved oxygen

mg/L – milligram per liter

n – number of observations

STDEV – standard deviation

Continuous DO concentration data collected from June 22 to October 24, 2007, from Buoy 1 (upstream), Buoy 2 (within macrophyte bed), and Buoy 3 (downstream) are presented in Figure 5.1-15 to further illustrate previously described data.

Continuous DO concentration data collected from July 31 to October 21, 2008, from Buoy 1, Buoy 2, and Buoy 3 are presented in Figure 5.1-16. Overall, changes in DO concentration followed similar patterns at each site. DO concentrations at Buoy 2 exhibited greater variations, likely due to diel changes in photosynthesis and respiration. Drawdowns occurring in August 2008 resulted in a slight DO depression followed by a rapid recovery at all three buoys.

Continuous pH levels collected from June 22 to October 24, 2007, from Buoy 1 (upstream), Buoy 2 (within macrophyte bed), and Buoy 3 (downstream) are presented in Figure 5.1-17 to further illustrate previously described data.

Continuous pH levels collected from July 31 to October 21, 2008, from Buoy 1, Buoy 2, and Buoy 3 are presented in Figure 5.1-18. In general, pH was higher at Buoy 2 (within macrophyte bed) and, similar to DO, exhibited greater diel fluctuations; however, average pH levels for all three buoys had overlapping confidence intervals (Table 5.1-2). Patterns in pH fluctuations were similar between buoys until early October 2008 when levels declined at Buoy 1 and Buoy 3. The pH decline at Buoy 1 is likely due to reduced photosynthetic activity from Box Canyon Reservoir (upstream). The median pH level at Buoy 2 is likely due to photosynthetic activity (resulting in higher pH than Buoy 1) and dilution due to higher flows (resulting in lower pH than Buoy 3).

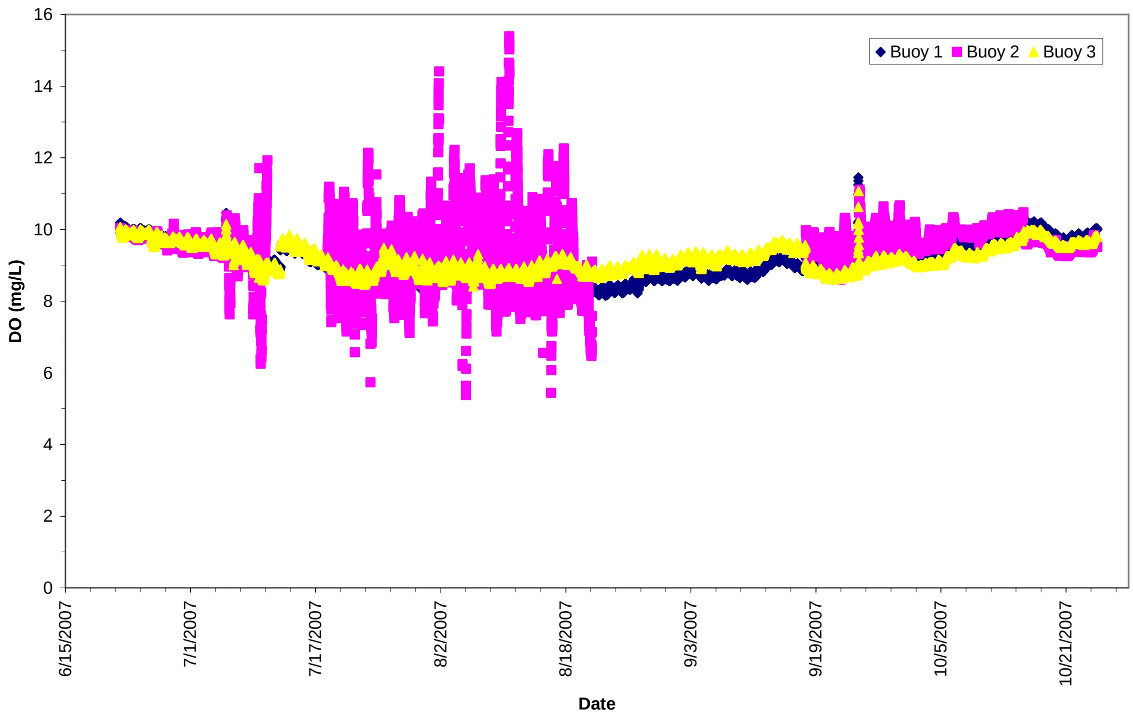

Figure 5.1-15. Continuous DO values from 6/22/07 to 10/24/07 at site M6.

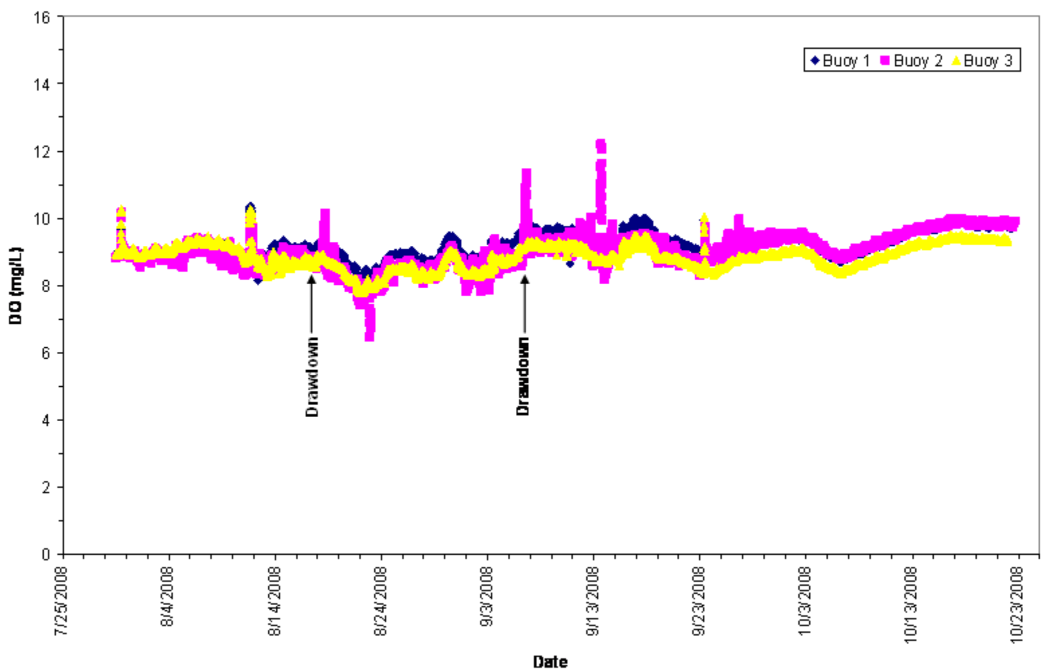

Figure 5.1-16. Continuous DO values from 7/31/08 to 10/21/08 at site M6.

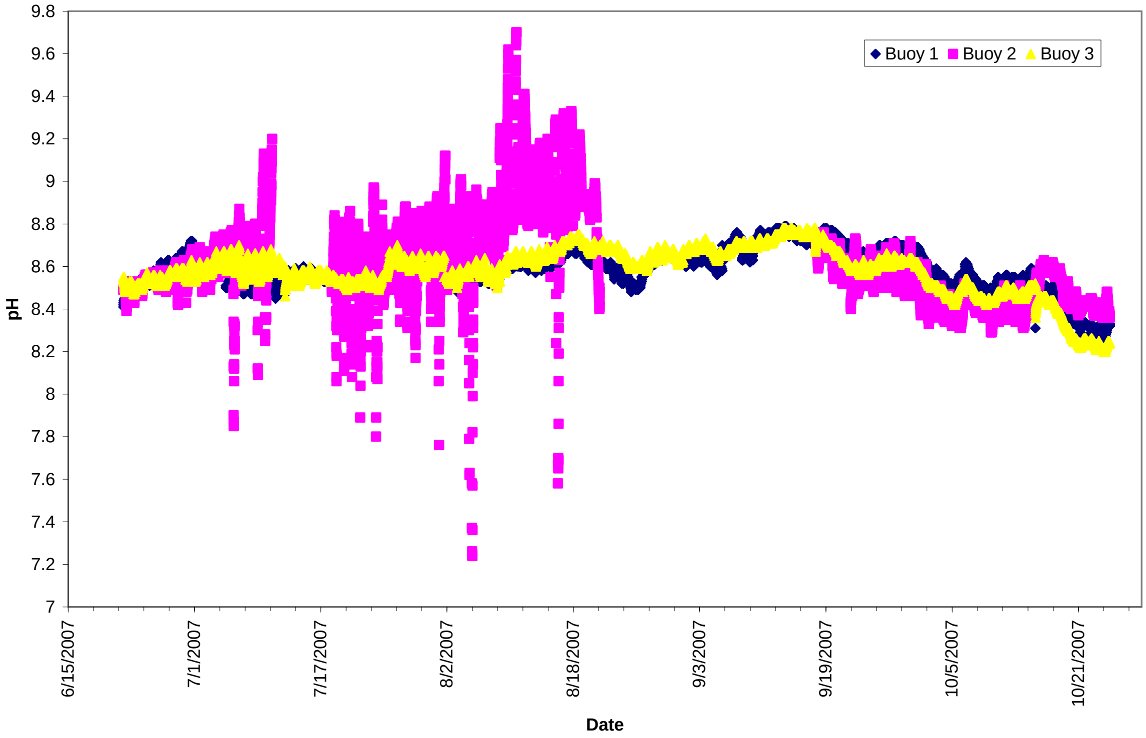

Figure 5.1-17. Continuous pH values from 6/22/07 to 10/24/07 at site M6.

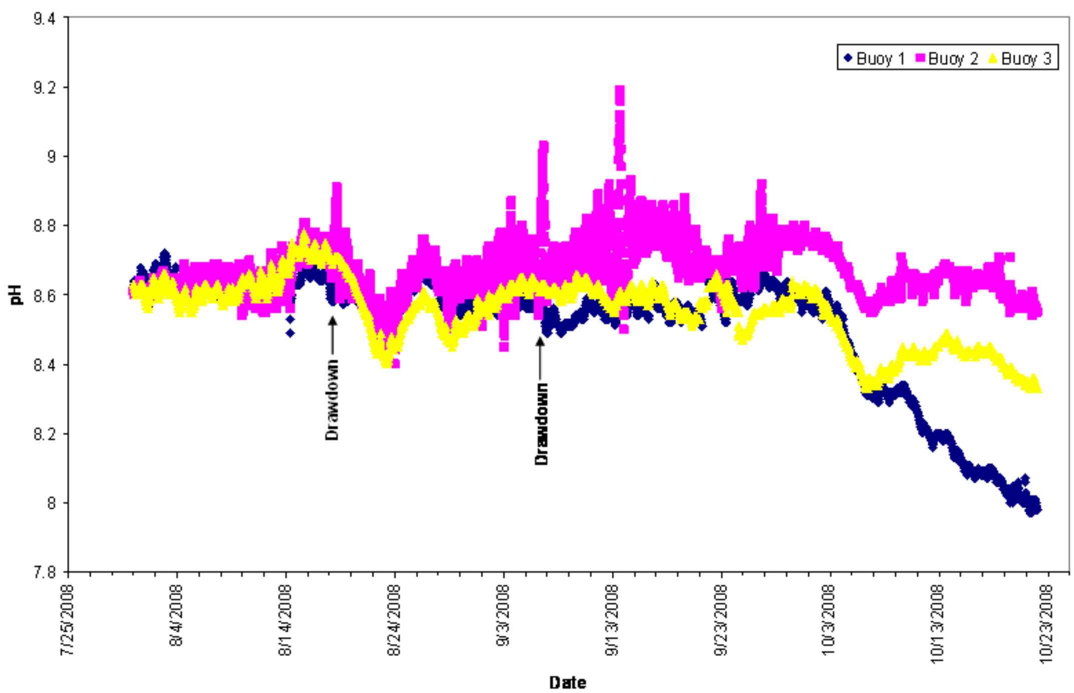

Figure 5.1-18. Continuous pH values from 7/31/08 to 10/21/08 at site M6.

It appears that the macrophyte bed in which Buoy 2 was located did not impact pH and DO values downstream (Buoy 3). Because the decrease in DO values towards the end of the summer is seen at both Buoy 1 and Buoy 3, it appears that increasing temperature and not macrophyte respiration is the factor influencing DO at these locations.

5.2. Assess the Effect of Varying Densities of Macrophyte Beds on Changes in pH and DO

Data from low, medium, and high macrophyte density sites were compared to evaluate how macrophyte abundance influenced changes in pH or DO within the macrophyte bed. Data analysis specifically identified whether macrophyte density influenced the maximum and minimum pH and DO measurements. Table 5.2-1 summarizes the maximum and minimum pH and DO values measured within low, medium, and high macrophyte density sites over a 72-hour period in August 2007. Figures 5.2-1 and 5.2-2 graphically present the maximum and minimum pH and DO values measured within low, medium, and high macrophyte density sites in Boundary Reservoir.

Table 5.2-1. Summary of pH and DO maximums and minimums for low, medium, and high density macrophyte beds over 72 hours in August 2007.

Site	Density	pH Maximum	pH Minimum	DO Maximum (mg/L)	DO Minimum (mg/L)
M4	Low	8.73	8.49	10.36	8.32
	Medium	9.09	8.25	13.53	7.90
	High	9.13	7.54	13.74	2.65
M5	Low	8.79	8.35	10.35	7.73
	Medium	8.77	8.41	10.11	8.02
	High	8.83	8.27	10.36	7.60
M6	Low	9.00	7.83	11.75	6.72
	Medium	8.99	8.41	12.07	8.00
	High	9.53	8.32	16.86	7.52

Notes:
DO – dissolved oxygen
mg/L – milligram per liter

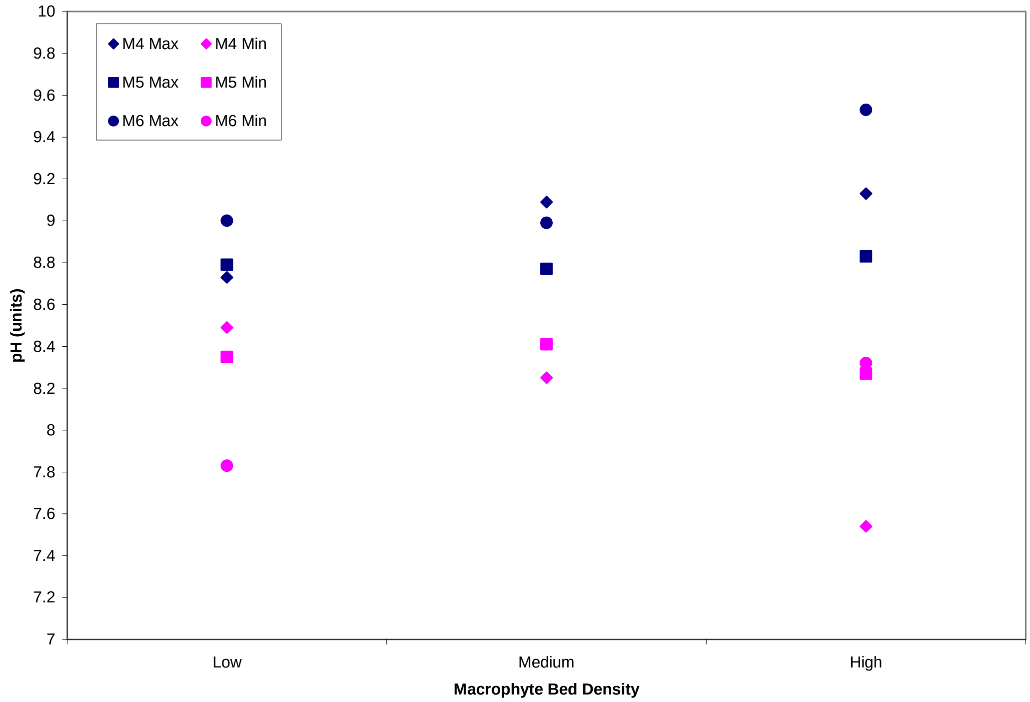

Figure 5.2-1. 72-hour pH maximums and minimums for low, medium, and high density macrophyte beds at sites M4, M5, and M6 collected in August 2007.

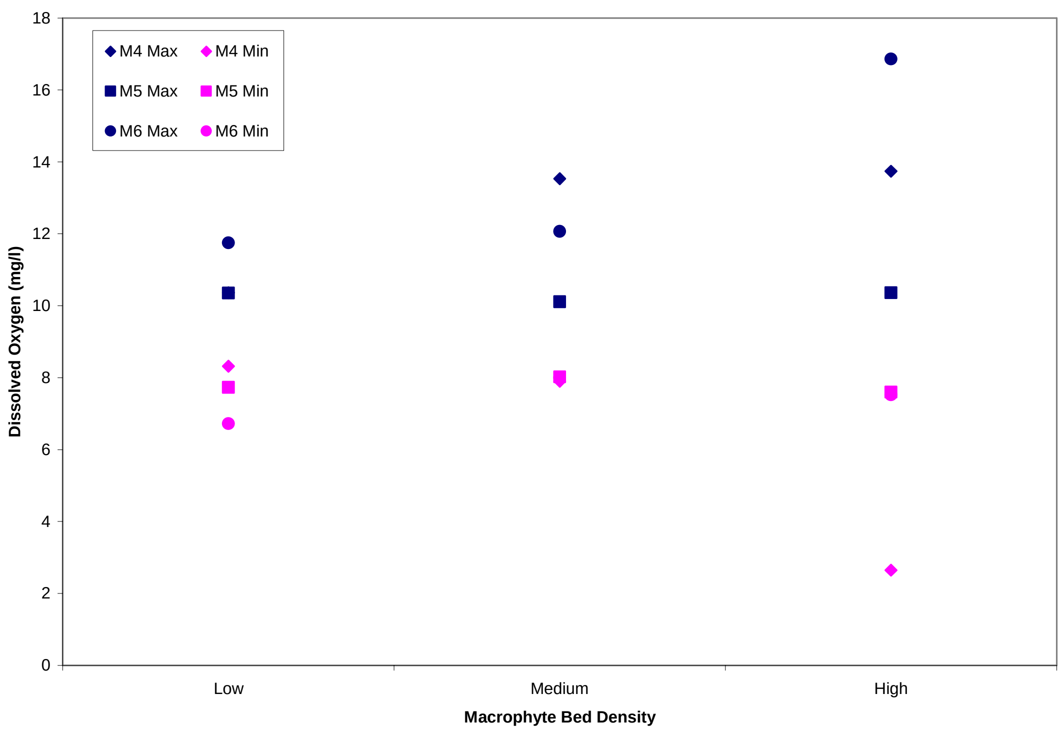

Figure 5.2-2. 72-hour DO maximums and minimums for low, medium, and high density macrophyte beds at sites M4, M5, and M6 collected in August 2007.

The pH and DO values of interest are maximum pH and minimum DO. During photosynthesis, macrophytes will consume carbon dioxide and produce DO, thereby increasing the DO concentration and pH in the water column. At night, macrophytes respire and release carbon dioxide and consume DO, lowering both pH and oxygen concentrations in the water column.

Sites M4 and M6 have macrophyte beds with the greatest range in density, and therefore the greatest difference between maximum and minimum pH and DO values. For example, at site M4 the maximum pH value for the low density site was 8.73 and for the high density site 9.13. For site M4, minimum DO values for the low and high density sites were 10.36 and 2.65 mg/L, respectively. At site M4 there also appears to be a slight difference between low and medium density sites, but the difference is not as large as that between the low and high density sites. The maximum and minimum pH and DO values observed at site M5 do not differ greatly between low, medium, and high densities of macrophytes.

Table 5.2-2 presents the daily range between pH and DO maximum and minimums within low, medium, and high density macrophyte sites over a 72-hour period in August 2007. The range presented in Table 5.2-2 was calculated by taking the difference between the daily maximum and daily minimum for both pH and DO. Tables 5.2-3 and 5.2-4 present the daily maximum and minimum pH and DO values used to calculate the daily ranges in Table 5.2-2.

Table 5.2-2. Daily range of pH and DO values for low, medium, and high density macrophyte sites in Boundary Reservoir during a 72-hour period in August 2007 (calculated as the difference between daily maximum and daily minimum).

Site	Date	pH Range			DO Range		
		Low Density	Medium Density	High Density	Low Density	Medium Density	High Density
M4	8/9/2007	0.24	0.61	1.58	2.03	5.63	11.09
	8/10/2007	0.08	0.74	0.83	1.04	4.40	6.04
	8/11/2007	0.18	0.59	0.68	0.90	4.99	5.69
M5	8/9/2007	0.37	0.25	0.31	2.59	1.71	2.00
	8/10/2007	0.38	0.35	0.37	2.59	1.86	2.32
	8/11/2007	0.34	0.29	0.51	2.43	2.01	2.76
M6	8/9/2007	1.09	0.41	1.16	4.79	2.63	9.34
	8/10/2007	0.32	0.34	0.93	1.86	2.29	6.12
	8/11/2007	0.49	0.55	1.08	3.62	4.07	7.93

Table 5.2-3. Daily pH maximums and minimums for low, medium, and high density macrophyte beds in Boundary Reservoir collected during a 72-hour period in August 2007.

Site	Date	pH Maximum (units)			pH Minimum (units)		
		Low Density	Medium Density	High Density	Low Density	Medium Density	High Density
M4	8/9/2007	8.73	9.08	9.12	8.49	8.47	7.54
	8/10/2007	8.58	8.99	9.07	8.50	8.25	8.24
	8/11/2007	8.68	9.09	9.13	8.50	8.50	8.45
M5	8/9/2007	8.72	8.66	8.73	8.35	8.41	8.42
	8/10/2007	8.78	8.77	8.83	8.40	8.42	8.46
	8/11/2007	8.79	8.77	8.78	8.45	8.48	8.27
M6	8/9/2007	8.92	8.82	9.48	7.83	8.41	8.32
	8/10/2007	8.80	8.83	9.53	8.48	8.49	8.60
	8/11/2007	9.00	8.99	9.53	8.51	8.44	8.45

Table 5.2-4. Daily DO maximums and minimums for low, medium, and high density macrophyte beds in Boundary Reservoir collected during a 72-hour period in August 2007.

Site	Date	DO Maximum (mg/L)			DO Minimum (mg/L)		
		Low Density	Medium Density	High Density	Low Density	Medium Density	High Density
M4	8/9/2007	10.36	13.53	13.74	8.33	7.90	2.65
	8/10/2007	9.36	12.44	13.40	8.32	8.04	7.36
	8/11/2007	9.28	13.03	13.45	8.38	8.04	7.76
M5	8/9/2007	10.32	9.73	9.90	7.73	8.02	7.90
	8/10/2007	10.33	9.98	10.31	7.74	8.12	7.99
	8/11/2007	10.35	10.11	10.36	7.92	8.10	7.60
M6	8/9/2007	11.51	10.65	16.86	6.72	8.02	7.52
	8/10/2007	10.09	10.40	15.03	8.23	8.11	8.91
	8/11/2007	11.75	12.07	15.93	8.13	8.00	8.00

Note:
mg/L – milligram per liter

At high macrophyte density sites the ranges of pH and DO values during a day were generally greater than daily ranges within low and medium macrophyte densities (Table 5.2-2). The exception to this occurred at site M5, where there was little difference among the ranges in daily pH and DO values at either low, medium, or high densities.

Other factors besides macrophyte density may have influenced pH and DO within macrophyte bed M5. For instance, bed M5 could have had greater flow and/or substrate influences than beds M4 and M6. Higher flows through the M5 bed, relative to M4 and M6, would reduce localized, macrophyte-induced fluctuations in pH and DO.

5.3. Assess the Effect of Project Operations, Specifically Inundation and Frequency of Dewatering, on Changes in pH and DO in Macrophyte Beds

The pH/DO data among macrophyte beds were compared with different lengths of exposure to air to assess the effect of dewatering on macrophyte growth and the corresponding effect on pH or DO. Hypotheses tested to answer this question were 1) extreme (maximum pH, minimum DO) values are the same in areas with varying levels of dewatering, and 2) the daily range in pH and DO is the same in areas with varying levels of dewatering.

Macrophyte distribution (and therefore the spatial extent of the macrophyte beds) in Boundary Reservoir was established early in the season (e.g., April or May) by extremes in water surface elevation and light limitation in the water column. Macrophyte beds establish themselves during this time of year in areas continuously inundated with water. The macrophyte beds sampled represent areas where beds are normally continuously covered by water, but are subject to water surface elevation changes due to Project operations. The following results incorporate effects from this water surface fluctuation and the influence of macrophyte beds on surface water pH and DO throughout a range of hydrologic conditions. Both short-term (24-hour) and longer term (72-hour) studies were completed in July 2007 and August 2007, respectively, to measure the influence of macrophyte beds on surface water quality. Data used for analysis of the effects of dewatering on DO and pH are available in electronic form upon request (due to the large volume of data).

Exposure of macrophyte root crowns to desiccation did not occur during the data collection period. Depth measurements collected during mid-season (July 16, 2007) from the shallowest edge of macrophyte beds at site M6 indicated the edge of the rooted macrophyte bed was at approximately 1,985.80 feet NAVD 88. Minimum daily pool elevations did not consistently fall below the edge of the rooted macrophyte bed until the last 2 days of the monitoring record (Figure 5.3-1).

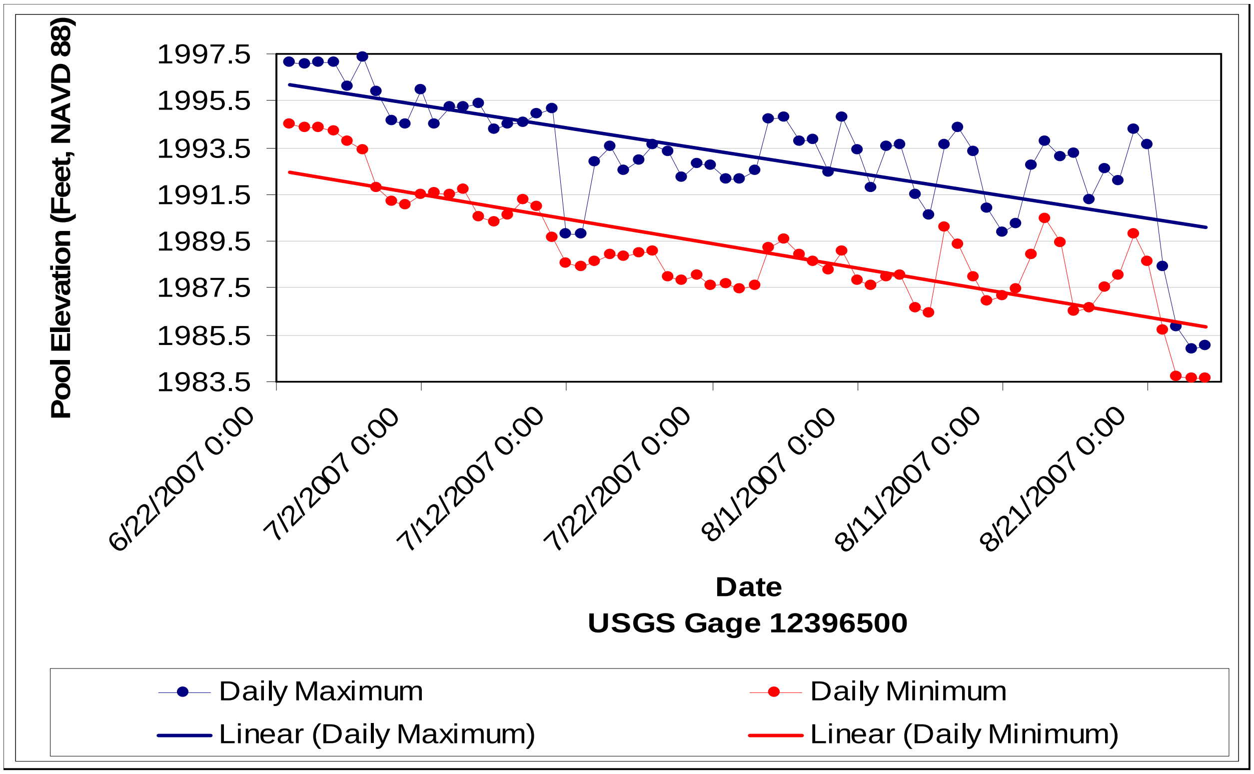

Figure 5.3-1. Pool elevation at site M6.

Comparisons were made between pool elevations (NAVD 88 datum) and DO in macrophyte beds at three densities: high, medium, and low. Measurements were made over a 72-hour period at each macrophyte bed density. Pool elevations were acquired from the USGS gage 12396500 (auxiliary gage) 1.2 miles downstream from the primary gage at Box Canyon Dam. All pool elevations recorded from this site were expressed in a NAVD 88 projection. Pool elevations were recorded hourly and those selected for comparison with DO were at the start of observation.

Pool elevation and DO concentrations were plotted using repeated observations from all depths during each sampling time interval to determine if a relationship existed. There was no significant relationship between pool elevation and DO concentration at high, medium, or low macrophyte density (Figures 5.3-2 to 5.3-4).

Comparisons were made between pool elevations (NAVD 88 datum) and pH in macrophyte beds from three density classes: high, medium, and low. Measurements were made over a 72-hour period at each macrophyte bed density class. Pool elevations were acquired from the USGS gage 12396500 (auxiliary gage) 1.2 miles from the primary gage at Box Canyon Dam.

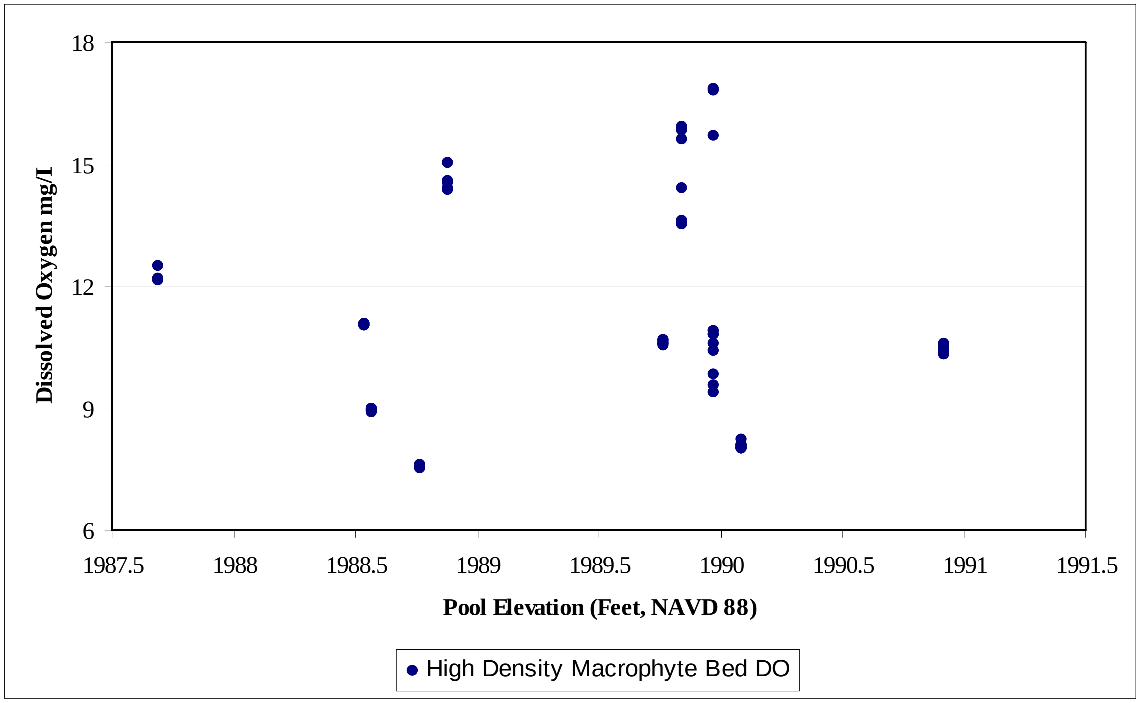

Figure 5.3-2. Relationship between DO concentrations (mg/L) and pool elevation (feet, NAVD 88) in a high density macrophyte bed at site M6.

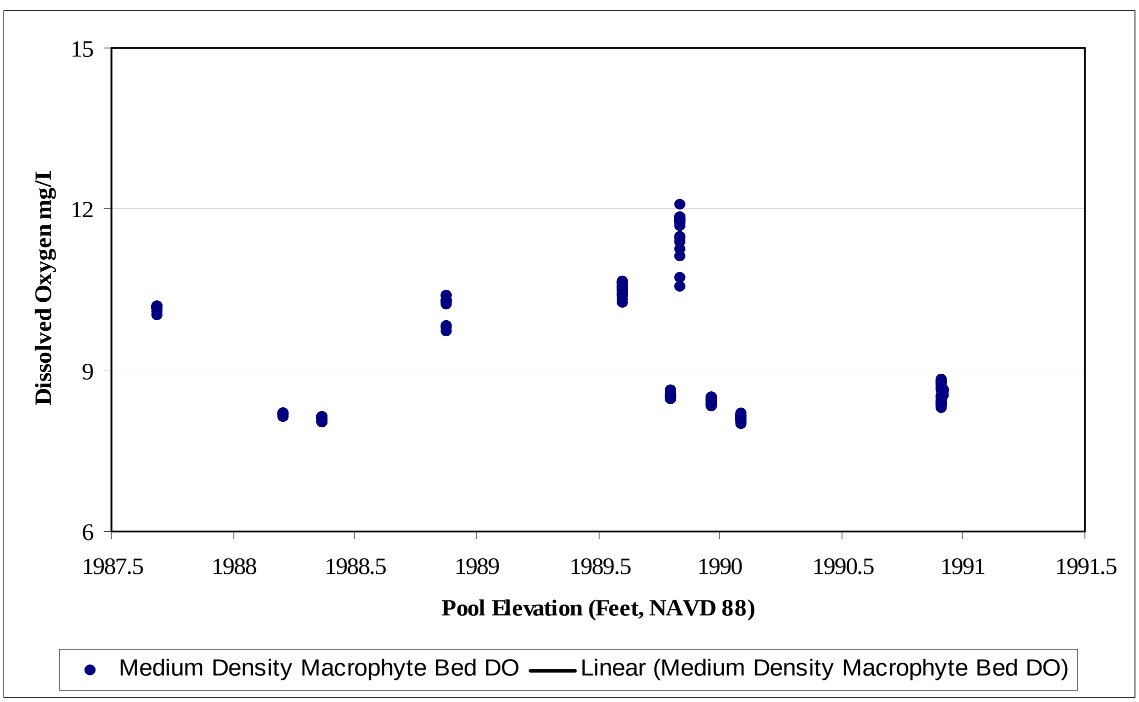

Figure 5.3-3. Relationship between DO concentrations (mg/L) and pool elevation (feet, NAVD 88) in a medium density macrophyte bed at site M6.

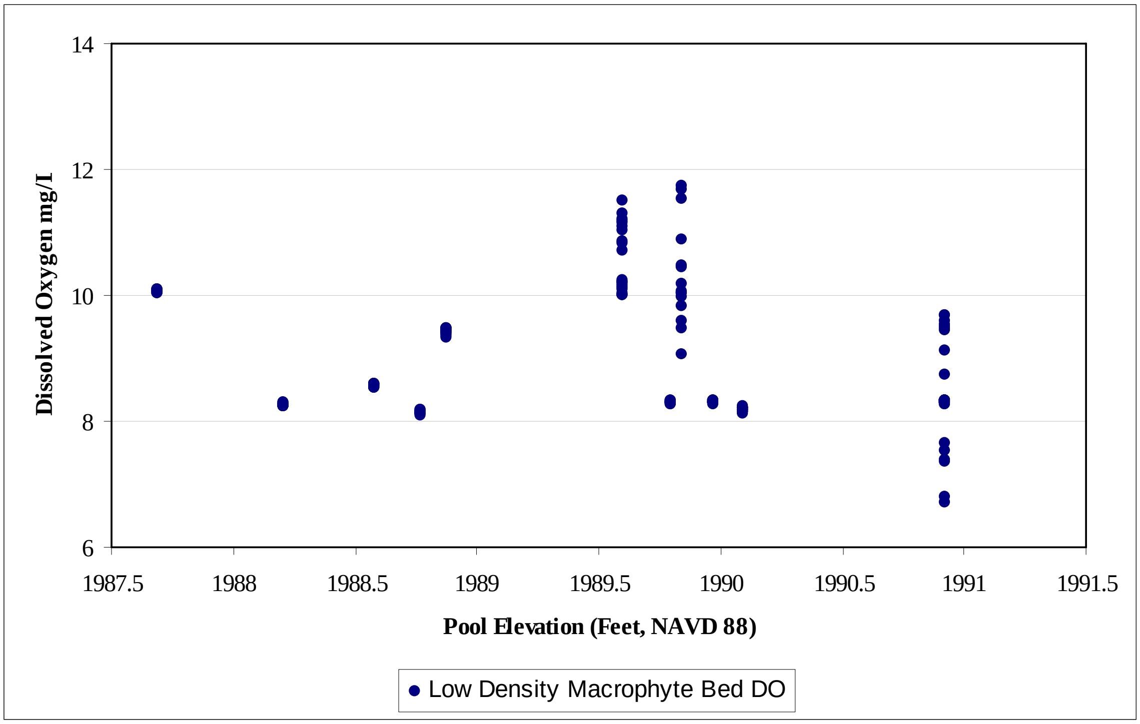

Figure 5.3-4. Relationship between DO concentrations (mg/L) and pool elevation (feet, NAVD 88) in a low density macrophyte bed at site M6.

All pool elevations recorded from this site were expressed in a NAVD 88 projection. Pool elevations were recorded hourly and those selected for comparison with pH were at the start of each observation.

Pool elevation and pH conditions were plotted using repeated observations from all depths during each sampling time interval to determine if a relationship existed. There was no significant relationship between pool elevation and pH at high, medium, and low macrophyte density (Figures 5.3-5 to 5.3-7).

Examination of extended flow records beyond the analysis period (August 24, 2007) indicated that reduction of pool elevation did not occur at levels below 1,985.8 feet NAVD 88, with the exception of the end of August and beginning of September 2007, and at that time inundation at the edge of the bed was regained in less than two days. This time was too short and infrequent for senescence to occur. Only the edge of the macrophyte bed was exposed and only for short periods, which were insufficient for senescence of macrophytes at a scale that might affect water quality.

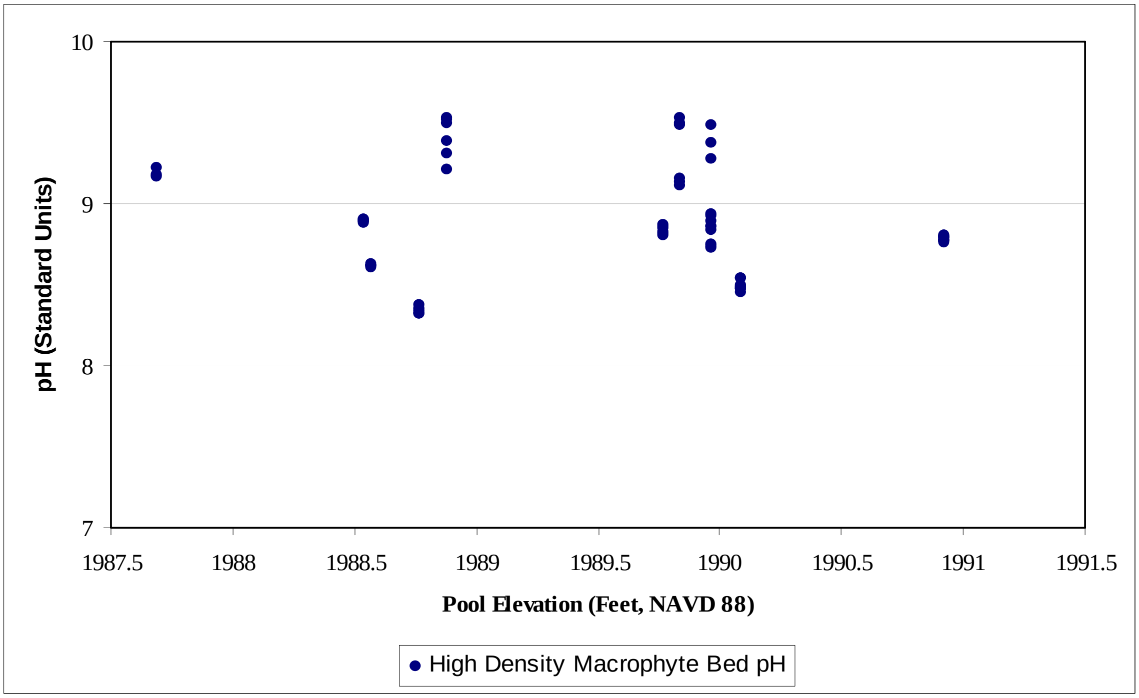

Figure 5.3-5. Relationship between pH (standard units) and pool elevation (feet, NAVD 88) in a high density macrophyte bed at site M6.

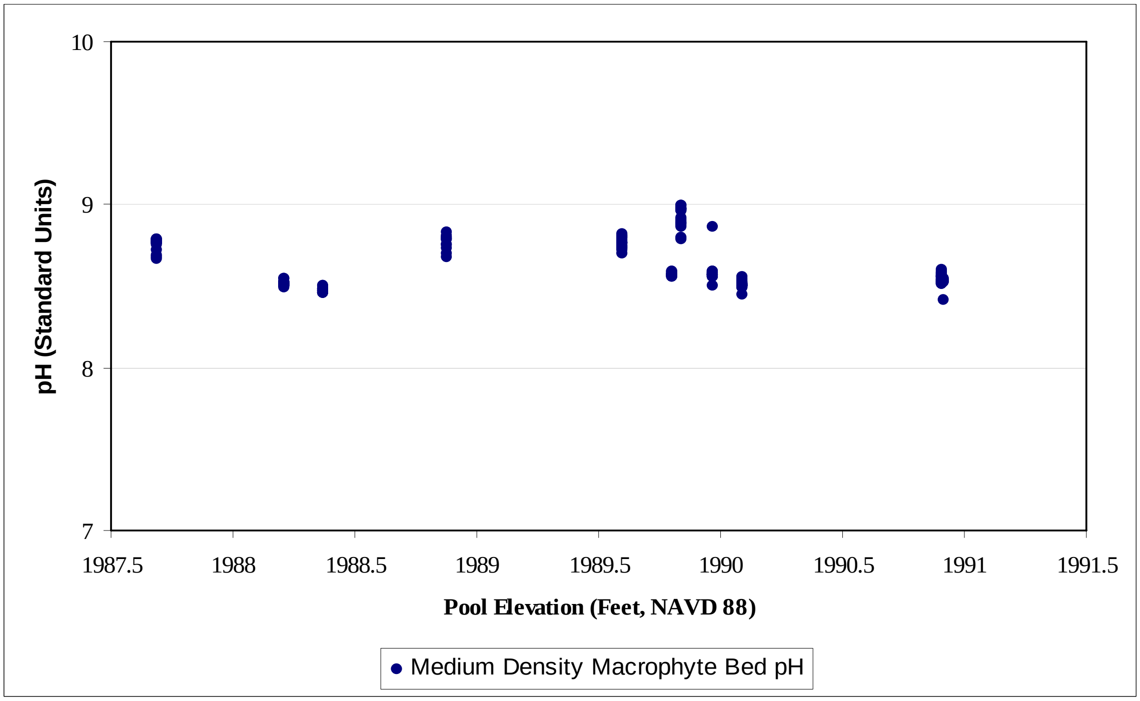

Figure 5.3-6. Relationship between pH (standard units) and pool elevation (feet, NAVD 88) in a medium density macrophyte bed at site M6.

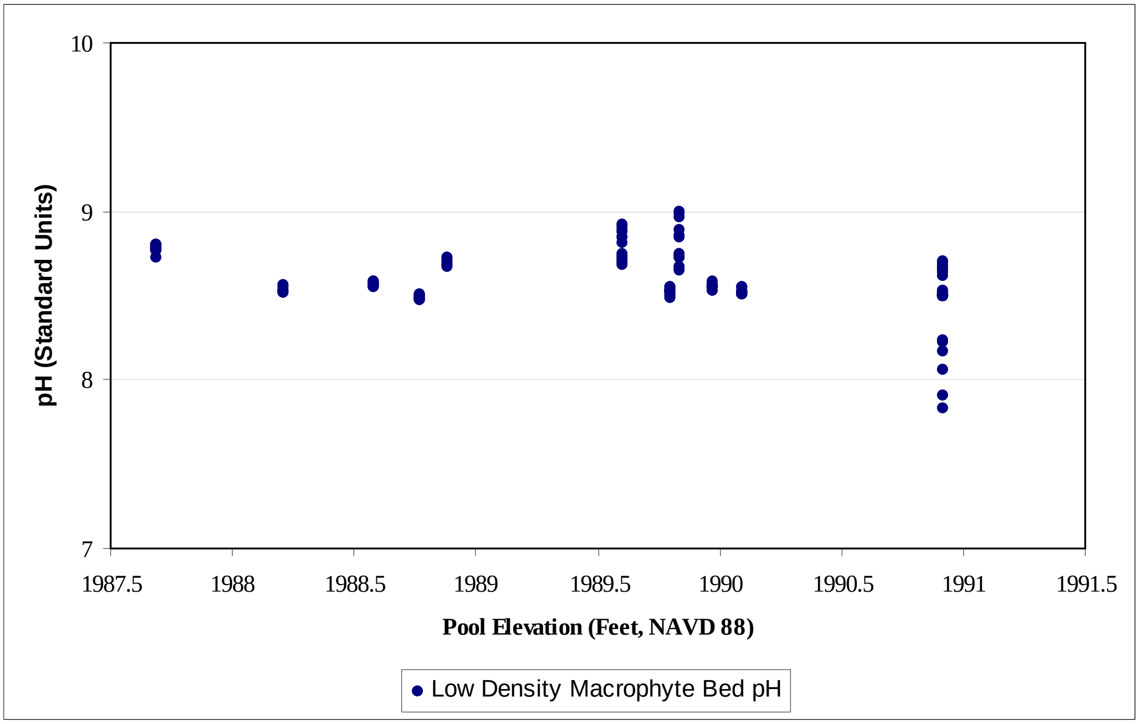

Figure 5.3-7. Relationship between pH (standard units) and pool elevation (feet, NAVD 88) in a low density macrophyte bed at site M6.

Appendix 3 presents figures comparing water surface elevation and flow with pH and DO concentrations at the buoy sites. Figures A.3-1 through A.3-12 in Appendix 3 show the daily average, with maximum and minimum, concentrations for DO and pH at the remote water quality buoys in 2007: Buoy 1 (upstream), Buoy 2 (macrophyte bed), and Buoy 3 (downstream). The remote water quality buoys were located at monitoring site M6.

There was little fluctuation in DO concentrations at Buoy 1 and Buoy 3 throughout the sampling period (June 29, 2007–October 9, 2007) despite the variation in daily average water surface elevations that occurred at these locations (Figures A.3-1 and A.3-3), suggesting that there is no relationship between DO and water surface fluctuation in the mainstem reservoir. DO concentrations at Buoy 2 were more variable than at Buoys 1 and 3, both daily as well as over the longer term (Figure A.3-2). The range of daily pH values from June through October was more stable at Buoy 1 and Buoy 3 than measurements made at Buoy 2 (Figure A.3-4 to Figure A.3-7), and there was no apparent relationship with water surface elevation.

Both DO concentrations and pH readings at Buoy 1 and Buoy 3 were stable throughout the monitoring period (June 29, 2007–October 9, 2007) with DO concentrations showing some relationship with flow (Figure A.3-7). The DO concentrations at Buoy 2 were much more variable (Figure A.3-8) during the deployment period than at Buoy 3 where DO concentrations were stable and unrelated to influence of the macrophyte bed (Figure A.3-9). The pH readings over the deployment period remained unchanged at Buoy 1 (Figure A.3-10) over time and on a daily basis. In contrast, minor fluctuations in pH were recorded at Buoy 2 (Figure A.3-11). The macrophyte bed did not appear to have any effect on pH downstream at Buoy 3 during the deployment period regardless of flow (Figure A.3-12).

Remote water quality buoys were located at monitoring site M6 and deployed from July 2008 through October 2008. Figures A.3-13 through A.3-24 in Appendix 3 show the daily average with maximum and minimum concentrations for DO and pH at the remote water quality buoys for 2008: Buoy 1 (upstream), Buoy 2 (macrophyte bed), and Buoy 3 (downstream). The purpose for re-deployment of the buoys at the same general locations used in 2007 was to confirm initial conclusions that DO concentrations and pH observations were not affected by macrophyte beds. Variation in daily DO concentrations and pH over the monitoring period was not correlated with either water surface elevation fluctuations or daily average flows.

5.4. Effects Assessment

The study results show that macrophytes do influence pH and DO levels within macrophyte beds through photosynthesis and respiration. Because less than 2 percent of the reservoir water volume is held within the macrophyte beds, and there is a large exchange of water (flow through) within the macrophyte beds from reservoir hydraulics, the effect of any localized impact on pH and DO is diluted. Daily drawdown and refill of the reservoir further enhance water exchange from the reservoir through macrophyte beds, lessening any potential impact of macrophytes on pH and DO levels within the mainstem reservoir, as well as levels within the macrophyte beds.

Analysis of the Project effects on macrophyte influence on pH and DO found that pH and DO levels fluctuated more on a diurnal basis within macrophyte beds. Throughout the observation period, however, no differences in pH or DO patterns were observed between the upstream or downstream buoy locations nor were there significant mean or median differences between the upstream, downstream, and within-bed locations. Upstream levels of pH and DO dominated mean observed levels within both the main reservoir and macrophyte beds. In addition, diurnal drawdown and refill of the reservoir enhanced water exchange from the reservoir through macrophyte beds, further reducing any potential impact of macrophytes on pH and DO.

The relative densities of macrophyte beds affecting pH and DO over time were evaluated in relation to Project operations. It was observed that the majority of macrophyte beds within Boundary Reservoir have high plant densities. Local and temporary disturbance resulting from boat traffic and/or animal activity result in low and medium bed densities and these isolated deviations from the normal high densities of the beds are not large enough to create a measurable difference in pH and DO. No identifiable trend for pH and DO levels due to plant density was observed within the macrophyte beds. Furthermore, no definable effects on macrophyte density or macrophyte influence on pH and DO were observed.

Project operations do not affect mainstem pH and DO under normal diurnal water surface elevation fluctuations. The pH and DO varied locally within macrophyte beds due to photosynthesis/respiration. There were no differences in pH or DO observed over the data logging period between upstream, downstream, or within-bed locations that were correlated with water surface elevation fluctuation. Weekly averages and range of pH and DO concentrations remained constant at Buoy 1 and Buoy 3 throughout the data logging period. Levels of pH and

DO within the mainstem of Boundary Reservoir appear to be dictated by the pH and DO levels of inflows from Box Canyon Reservoir (see Study 5, Water Quality Constituent and Productivity Monitoring Final Report [SCL 2009a]). However, photosynthesis and respiration impact mean levels and variation of pH and DO within macrophyte beds.

Project effects could occur if changes were made to Project operations for other purposes. For example, a decrease in diurnal reservoir water level fluctuation during low flow periods would likely result in increased DO and pH variation within macrophyte beds, potentially impacting habitat quality within beds. Reduced water volume exchange within the mainstem reservoir would likely confine any pH and DO impacts to localized areas immediately within beds. Alternatively, a decrease in diurnal reservoir water level fluctuation during high flow periods would increase water volume (reservoir flow), increase dilution, and limit any observable impact. Conversely, an increase in diurnal water level fluctuation from existing operations would increase water exchange between macrophyte beds and the mainstem reservoir, decreasing observable variation in pH and DO levels. With large, long duration vertical drawdowns, macrophyte coverage may be reduced.

6 CONCLUSIONS

Each of the macrophyte bed sampling locations was selected to represent a range of morphological conditions throughout Boundary Reservoir. Measuring the resulting water quality following passage through macrophyte beds of varying density and location in the reservoir provided insight into the effect of geochemical and morphological factors, as well as macrophyte metabolism, on ambient DO concentrations and pH. Additional details about species composition of macrophyte beds and areal extent can be found in the Study 7 Mainstem Aquatic Habitat Modeling Study Final Report (SCL 2009b) and the Study 11 Productivity Assessment Final Report (SCL 2009c).

Water quality data show that macrophytes have only minor and localized impact on reservoir pH and DO levels. This conclusion is supported by both 24-hour and 72-hour sampling events and continuous water quality monitoring with remote sensors. The data show large differences in pH and DO levels over a range of macrophyte density, but other factors, such as substrata, dilution, and water transparency, may have had some effect. Regardless, these large fluctuations within the macrophyte beds had no influence on pH and DO values downstream of the beds.

Analysis of available data from vertical profiles and remote monitoring indicated that the effect of macrophyte density on DO and pH levels was not influenced by Project operations. Medium and high density macrophyte beds appeared to have greater influence on DO and pH than did the influence from pool fluctuations and flow. Factors that may also influence the effect of macrophytes on pH and DO level include light limitation from high turbidity, flow patterns through and water residence time within macrophyte beds, and nutrient supply.

7 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

Variances from the RSP were as follows:

- The location of macrophyte bed M1 was moved from the original proposed position to the macrophyte bed located just off the forebay boat launch. The macrophyte bed off the forebay boat launch appeared to be much larger than the bed located in the original location of M1.
- Twenty-four-hour and 72-hour sampling events were conducted in macrophyte beds M1 and M2, but not in macrophyte bed M3. Water level fluctuations in the reservoir below Metaline Falls appeared to limit establishment of macrophyte beds that represent the three density classes and, therefore, bed M3 was dropped from further evaluation for both 2007 and 2008 studies following reconnaissance of the area. Based on field verification, bed M3 had sparse and intermittent growth of macrophytes and did not represent the three density classes necessary to continue using the original study design for this evaluation.
- In July 2007, no macrophyte beds were monitored in the lower reservoir because none could be found until water clarity improved in August. The 24-hour sampling event that was to take place in July was completed in August in place of the 72-hour event scheduled for that time. The 72-hour sampling event scheduled for August 2007 was not re-scheduled based on after-effects of the drawdown on macrophyte bed condition. The plants exposed during dewatering of some beds would be stressed from a limited quantity of desiccation and not produce comparable data to those beds continuously inundated during the drawdown period.
- The continuous water quality monitoring buoys were placed in the reservoir starting in June 2007 instead of May due to the lack of macrophyte growth in May.
- The RSP specified that a rake would be used to quantify differences in macrophyte densities among locations. This approach was abandoned in favor of stem counts conducted within a standard area of one square meter, which proved to be more effective and less difficult to conduct.
- The RSP included commitments to conducting a variety of statistical analyses. Only statistical analyses that were appropriate for the large number of data were conducted as part of this study.
- Remote water quality buoys were re-deployed between July and October of 2008 to provide data from conditions that are more representative of normal operations. In 2007, studies-related drawdowns were extreme in magnitude and duration and, therefore, not representative of normal conditions. The main reason for the redeployment of buoys was to capture the effect of senescence of macrophytes on DO concentrations and pH conditions that were missed during the 2007 sampling season due to extraordinary drawdowns in the reservoir.

8 REFERENCES

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SCL. 2009b. Study 7 – Mainstem Aquatic Habitat Modeling Study Final Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech, Thomas R. Payne and Associates, Golder Associates, and Terrapin Environmental. March 2009.

SCL. 2009c. Study 11 – Productivity Assessment Final Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech. March 2009.

Appendix 1: Study 6 Quality Assurance Project Plan

Boundary Hydroelectric Project
FERC No. 2144

Study 6

Evaluation of the Relationship of pH and DO to Macrophytes in Boundary Reservoir, Pend Oreille County, Washington

Quality Assurance Project Plan

Prepared for:
Seattle City Light

November 2007

Prepared by
Darlene Siegel, David Cline, Kari Kimura, Shannon Brattebo, and Harry Gibbons
Tetra Tech, Inc.

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Study No. 6: Evaluation of the Relationship of pH and Dissolved Oxygen to Macrophytes in Boundary Reservoir Quality Assurance Project Plan Boundary Hydroelectric Project (FERC No. 2144)

1 BACKGROUND

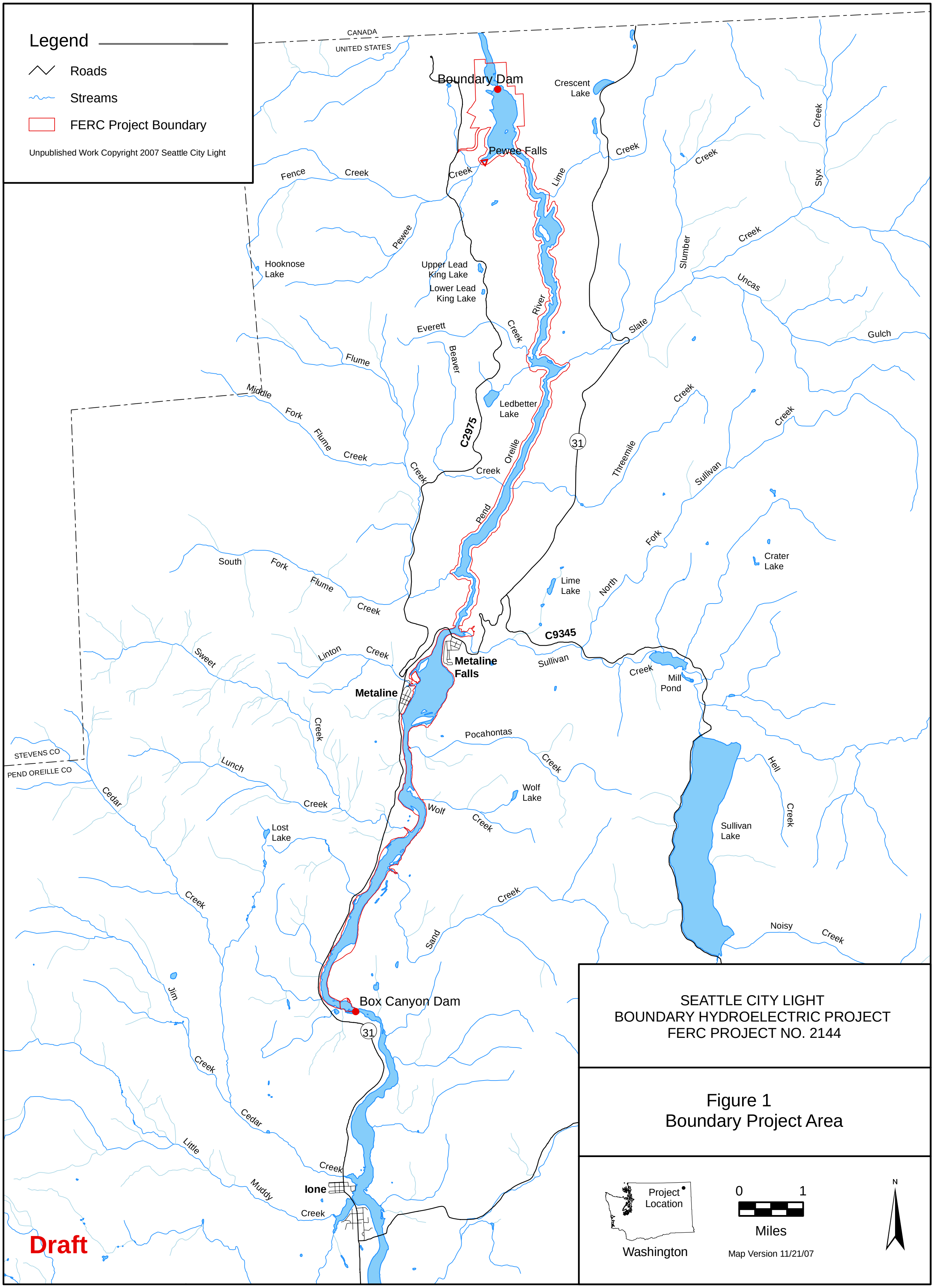
As part of the Federal Energy Regulatory Commission (FERC) relicensing requirements, Seattle City Light (SCL) is applying for certification under Section 401 of the Clean Water Act (CWA). The application for Section 401 certification requires characterization of existing water quality conditions within the Boundary Hydroelectric Project (Project) area (See Revised Study Plan, February 2007) and an assessment of whether water quality meets Washington Department of Ecology (Ecology) regulatory standards. As part of this relicensing and 401 certification process, SCL is exploring the relationship of pH and dissolved oxygen (DO) to macrophytes in the Boundary Reservoir to learn if macrophytes are contributing to high pH readings and, if so, to explore the effect of Project operations on pH and DO in the reservoir via its influence on macrophyte distribution and growth.

High daytime pH levels have been documented throughout the Pend Oreille River and in Boundary Reservoir (Ecology 2005, SCL 2007). The cause of these high pH levels is unknown, but background geochemical conditions appear to be the primary contributing factor, although it is unknown to what extent the growth of macrophytes may also contribute during periods of high photosynthesis. Invasive nonnative macrophytes in Boundary Reservoir, such as Eurasian watermilfoil (*Myriophyllum spicatum*) and curly pondweed (*Potamogeton crispus*), have the potential to affect water chemistry. Both pH and DO can be altered through the processes of photosynthesis, respiration, and senescence. During photosynthesis both pH and DO can increase. During periods of respiration (primarily at night) and senescence (primarily at the end of the growth season) within the macrophyte community, DO concentrations can be decreased due to oxygen consumption.

Reservoirs provide shallow, low-velocity conditions that are conducive to macrophyte growth. Operation of Boundary Dam affects the reservoir's water surface elevation and velocity, which can influence macrophyte growth. In turn, the growth of macrophytes can affect water quality conditions, especially pH and DO. The direct effect of Project operation on macrophyte distribution and abundance will be addressed as part of the Mainstem Aquatic Habitat Modeling Study 7.4.2 being conducted under the Fish and Aquatics resource investigations.

This quality assurance project plan (QAPP) was prepared to document the quality assurance and control (QA/QC) measures needed to ensure that the following objectives are met: data are consistent, correct, and complete, with no errors or omissions; QC sample results have been reviewed and are included; established criteria for QC results are met; measurement quality objectives have been met, or what data qualifiers are properly assigned where necessary; and data specified in the sampling process design are obtained. Data collection methods will follow established Ecology and U.S. Environmental Protection Agency (EPA) guidelines.

The Project is located on the Pend Oreille River in northeastern Washington, one of a total of eleven hydroelectric and storage projects within the Clark Fork - Pend Oreille River basin. The dam is located 1 mile south of the Canadian border, 16 miles west of the Idaho border, 107 miles north of Spokane, and 10 miles north of Metaline Falls (Figure 1). The dam is at Project river mile (PRM) 17.0 on the Pend Oreille River.


Legend
Roads
Streams
FERC Project Boundary
Unpublished Work Copyright 2007 Seattle City Light
CANADA
UNITED STATES
Boundary Dam
Crescent Lake
Pewee Falls
Fence
Creek
Lime
Creek
Styx
Creek
Pewee
Hooknose Lake
Upper Lead King Lake
Lower Lead King Lake
Slumber
Creek
Uncas
River
Everett
Creek
Beaver
Slate
Gulch
Flume
Middle
Fork
Flume
Creek
Ledbetter Lake
C2975
31
Orielle
Creek
Creek
Threemile
Creek
Sullivan
Pend
Fork
Crater Lake
South
Fork
Flume
Creek
Lime Lake
North
C9345
Sweet
Linton
Creek
Metaline Falls
Sullivan
Creek
Mill Pond
Metaline
Creek
Pocahontas
Creek
STEVENS CO
PEND OREILLE CO
Lunch
Cedar
Creek
Wolf Lake
Wolf
Creek
Hell
Lost Lake
Creek
Sullivan Lake
Creek
Creek
Sand
Noisy
Creek
Jim
Box Canyon Dam
31
Creek
Cedar
Little
Muddy
Creek
Ione
Creek
Draft
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 1
Boundary Project Area
Project Location
Washington
0
1
Miles
Map Version 11/21/07
N

2 PROJECT DESCRIPTION

The goals of Study No. 6, *Evaluation of the Relationship of pH and DO to Macrophytes in Boundary Reservoir*, are to assess whether macrophytes are contributing to high pH and low DO readings in the reservoir, and to investigate potential effects of Project operations on pH and DO via macrophytes. Study objectives to fulfill these goals are:

- *Objective 1* - Document and determine the magnitude of the impact macrophyte respiration/photosynthesis and senescence have on pH and DO levels in Boundary Reservoir (1A – continuous water quality sampling; 1B – influence of bed on river water quality).
- *Objective 2* - Assess the effect of varying densities of macrophyte beds on changes in pH and DO in support of fish habitat analysis.
- *Objective 3* - Assess the effect of Project operations, specifically inundation and duration of dewatering, on changes in pH and DO in macrophyte beds.

Objective 3 is important because it addresses the potential for Project operations to influence the physiology of macrophytes and, as a result, water quality. It will also allow for the assessment of how Project operations can potentially be used to control non-native plants in the reservoir.

Although SCL has been collecting water quality data since 2004, no continuous monitoring of pH has been conducted, and only limited water quality data have been collected for comparing water quality in and around macrophyte beds. A pilot study was conducted in 2006 to preliminarily assess the relationship between macrophytes and pH; however, a more robust study is needed for the definitive analysis and for purposes of the application for certification under Section 401 of the CWA.

To address differences in reservoir morphology and habitat types, data will be collected within two reaches, upstream and downstream of Metaline Falls. Different macrophyte beds upstream and downstream of Metaline Falls will be used to meet each of the objectives; however, if appropriate and based on site conditions, data to satisfy one or more objectives may occur in the same macrophyte bed.

For objective 1, data collection will include measurement of pH, DO, conductivity, and temperature and estimation of cloud cover at sites within and apart from macrophyte beds. Data will be compared to document whether pH or DO is similar among sites or between sampling sites and the main channel of the reservoir. The analysis will also attempt to quantify the magnitude of any differences.

For objective 2, data collection will include pH, DO, conductivity, and temperature at sites with various degrees of macrophyte density. Data from low, medium, and high macrophyte density sites will be compared to evaluate how macrophyte abundance influences pH and DO. Data analysis will specifically identify whether macrophyte density influences the range of pH and DO measurements.

For objective 3, data collection will include measurements of pH, DO, conductivity, and temperature at different sites characterized by various levels of inundation and dewatering. The pH and DO data will be compared among macrophyte beds with different durations of inundation/dewatering to assess influences on macrophyte growth and potential corresponding impact on pH and DO.

Work products for the *Evaluation of the Relationship of pH and DO to Macrophytes in Boundary Reservoir* study consist of this QAPP, a draft study report, a final study report, and a project summary.

3 ORGANIZATION AND SCHEDULE

This section provides an overview of the staffing organization and schedule. With respect to organization, the key personnel involved in the *Evaluation of the Relationship of pH and DO to Macrophytes in Boundary Reservoir* are listed in Table 1.

Table 1: Project/task organization and responsibility summary.

Personnel	Responsibility	Address/E-Mail	Phone Number
Christine Pratt, Seattle City Light	Responsible for project coordination with local, county, state, and federal government officials; and for reviewing drafts of the study plan, QAPP and summary data reports.	Seattle City Light Seattle Municipal Tower 700 5th Ave., Ste.3300 P.O. Box 34023 Seattle, WA 98124 christine.pratt@seattle.gov	206-386-4571
Harry Gibbons Tetra Tech, Inc.	Responsible for managing the project, preparing the project QAPP, coordinating and completing sampling activities, analyzing project data, and preparing the draft and final data reports. Serves as the principal project team contact for the technical aspects of the study.	Tetra Tech, Inc. 1420 5th Ave. Suite 550 Seattle, WA 98101 Harry.Gibbons@tetratech.com	206-728-9655
Project Assistants Tetra Tech, Inc.	Responsible for field sampling assistance quality assurance and quality control of field protocols.	Tetra Tech, Inc. 1420 5th Ave. Suite 550 Seattle, WA 98101	206-728-9655
Gene Welch, Ph.D. Tetra Tech, Inc.	Reviews QAPP and provides technical assistance on QA/QC issues during the implementation and assessment of the project.	Tetra Tech, Inc. 1420 5th Ave. Suite 550 Seattle, WA 98101	206-728-9655

The study will begin in June 2007 and continue through November 2007. The exact scheduling of the continuous and profile sampling will be determined by Seattle City Light and Tetra Tech staff in response to the macrophyte growing season during the study year. Table 2 gives the projected schedule of activities and deliverables.

Table 2: Projected schedule of activities and deliverables.

Phase	Target Date
QAPP	March 31, 2007
Field Collection	June–November 2007
Prepare draft study report with recommendations for any additional 2008 sampling	November–December 2007
Distribute draft study report for relicensing participant review	January 2008
Meet with relicensing participants to review efforts and results	February 2008
Include final study report in Initial Study Report (ISR) filed with FERC	March 2008
Meet with relicensing participants to review ISR and file meeting summary with FERC	March 2008

4 QUALITY OBJECTIVES

Measurement quality objectives (MQOs) are the performance or acceptance criteria for individual data quality indicators, including precision, bias, and sensitivity (Ecology 2004). The MQOs for this project are presented in Table 3. Industry standard field methods will be used throughout this project to minimize measurement bias (systematic error) and to improve precision (to reduce random error). Standardized sampling procedures will be used to measure field parameters. State of the art multi-probe instruments will be used to collect all data.

Table 3: Measurement quality objectives.

	Check Standard (LCS)	**Duplicate Samples**	**Lowest Concentration of Interest**
Parameter	**% Recovery Limits**	**RPD**	**Units of Concentration**
pH (field)[(a)]	± 0.2 pH units	± 0.1 pH units	2.0
Dissolved Oxygen (field) [(a)]	± 0.2 mg/L	± 0.2 mg/L	0.2 mg/L
Conductivity (field) [(a)]	± µmhos/cm	± 10%	25 µmhos/cm@ 25 ºC
Temperature (field) [(a)]	± 0.1 ºC	± 5%	± 0.1 ºC

Notes:

1 pH, DO, conductivity and temperature are field measured parameters. Values are stated in terms of maximum allowable differences from the field check standards. Accuracy will be ensured by twice per day (pre and post-sampling) calibration and standard checks. Field temperatures will be verified by comparing any difference with pre-calibrated instrument thermistors.

Method detection limits and field measurement resolution for water quality variables analyzed for the Boundary Reservoir monitoring program are listed in Table 4.

Table 4: Detection limits, field measurement resolution, reporting detection limits and analytical methods for water quality data.

Water Quality Parameter	Units	Detection Limit	Field Measurement Resolution	Reporting Detection Limits	Method
Temperature	ºC	0.01	0.01	0.1	Duplicate Thermistor
		0.01	0.01	0.1	Thermistor
Dissolved Oxygen	mg/L	0.2	0.2	0.2	Dissolved oxygen probe, with optical probe
pH	pH units	0.01	0.1	0.1	pH probe
Conductivity	µmhos/cm	5	5	5	Conductivity probe

5 SAMPLING PROCESS DESIGN

The goals of this study are to explore the relationship of pH and DO to macrophytes in Boundary Reservoir to evaluate whether macrophytes are contributing to elevated levels of pH and, if so, to explore the indirect effect of Project operation on pH and DO in the reservoir via the Project's influence on macrophyte distribution and growth.

Boundary Reservoir contains shallow-water areas with substrate conducive to macrophyte growth. Operation of the Project affects the reservoir's water surface elevation and velocity, which in turn can influence macrophyte growth and water quality conditions, especially pH and DO. The direct effect of the Project on macrophyte distribution and abundance will be addressed under the Mainstem Aquatic Habitat Modeling Study (Study No. 7) being conducted within the Fish and Aquatics resource area. This study QAPP addresses the potential effects of Project operations on existing macrophyte beds and in turn, any effect macrophyte beds have on DO and pH in Boundary Reservoir.

The goals of this study are: 1) to assess whether macrophytes are contributing to high pH and low DO readings in Boundary Reservoir, and 2) to investigate potential indirect effects of Project operations on pH and DO via macrophytes. To achieve these goals, the following objectives have been defined:

- *Objective 1:* Determine and document the effect of macrophyte respiration/photosynthesis and senescence on pH and DO levels in Boundary Reservoir (1A – continuous water quality sampling; 1B influence of bed on river water quality).
- *Objective 2:* Assess the effect of varying densities of macrophyte beds on changes in pH and DO in support of the fish habitat analysis.
- *Objective 3:* Assess the effect of Project operations, specifically inundation and duration of dewatering, on changes in pH and DO in macrophyte beds.

Monitoring of pH, DO, temperature and conductivity will be conducted at six sites, three upstream from Metaline Falls and three downstream. Sampling locations are described herein to meet the monitoring objectives.

Macrophyte study sites are shown in Figure 1. Figures 2 through 8 show detailed layouts of the sampling positions for data collection related to each objective. The sampling locations have been selected as part of an initial site review using aerial photography (DeGross, 2005) and differ from those in the Revised Study Plan..

Table 5 is a summary of the water quality monitoring parameters to be measured; sampling methods, depth positions; equipment, sensor or measurement range; and measurement and reporting accuracy. Table 6 is a summary of sampling locations, schedule and sampling frequency.

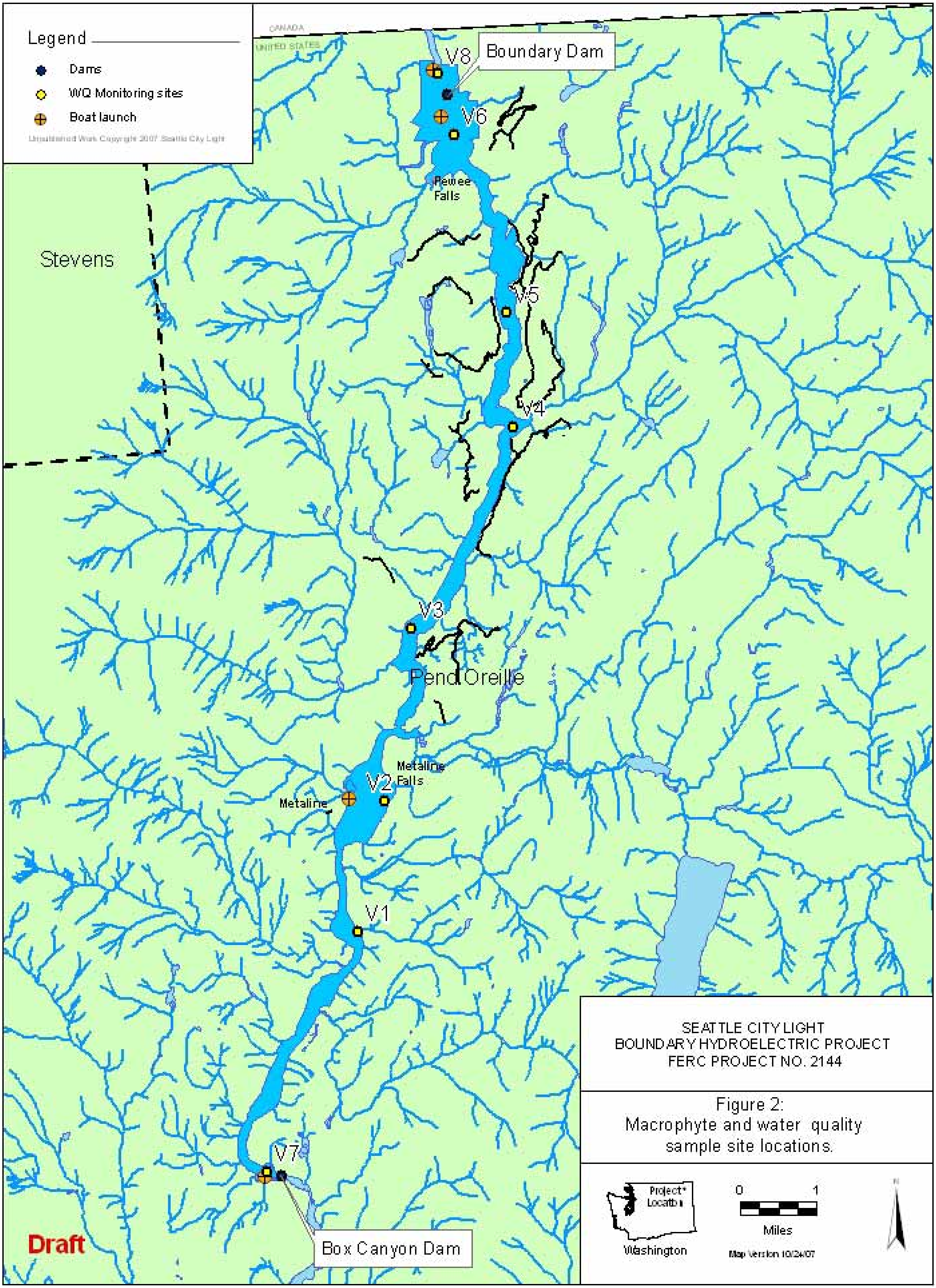


Figure 2:
Macrophyte and water quality sample site locations.

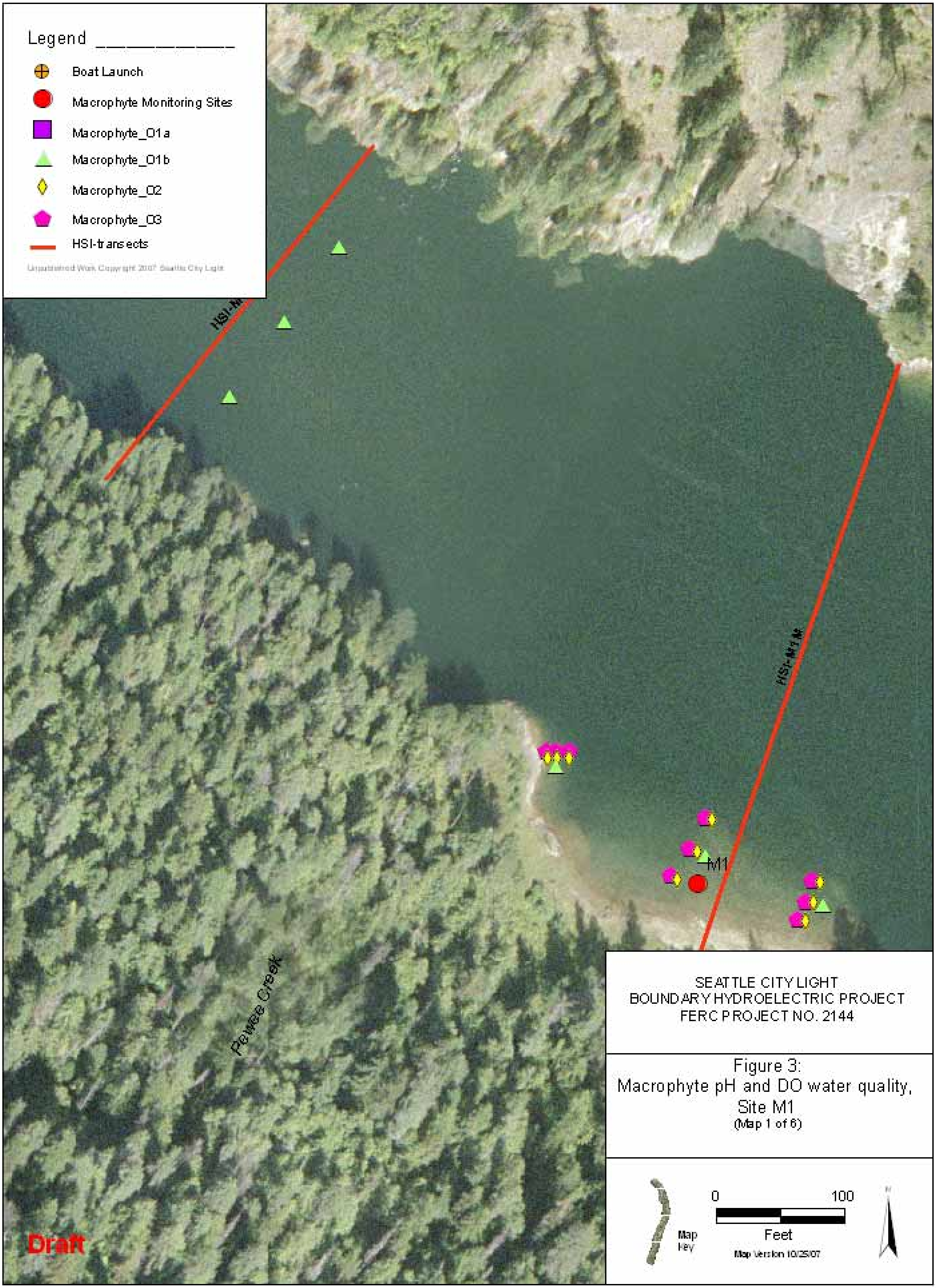
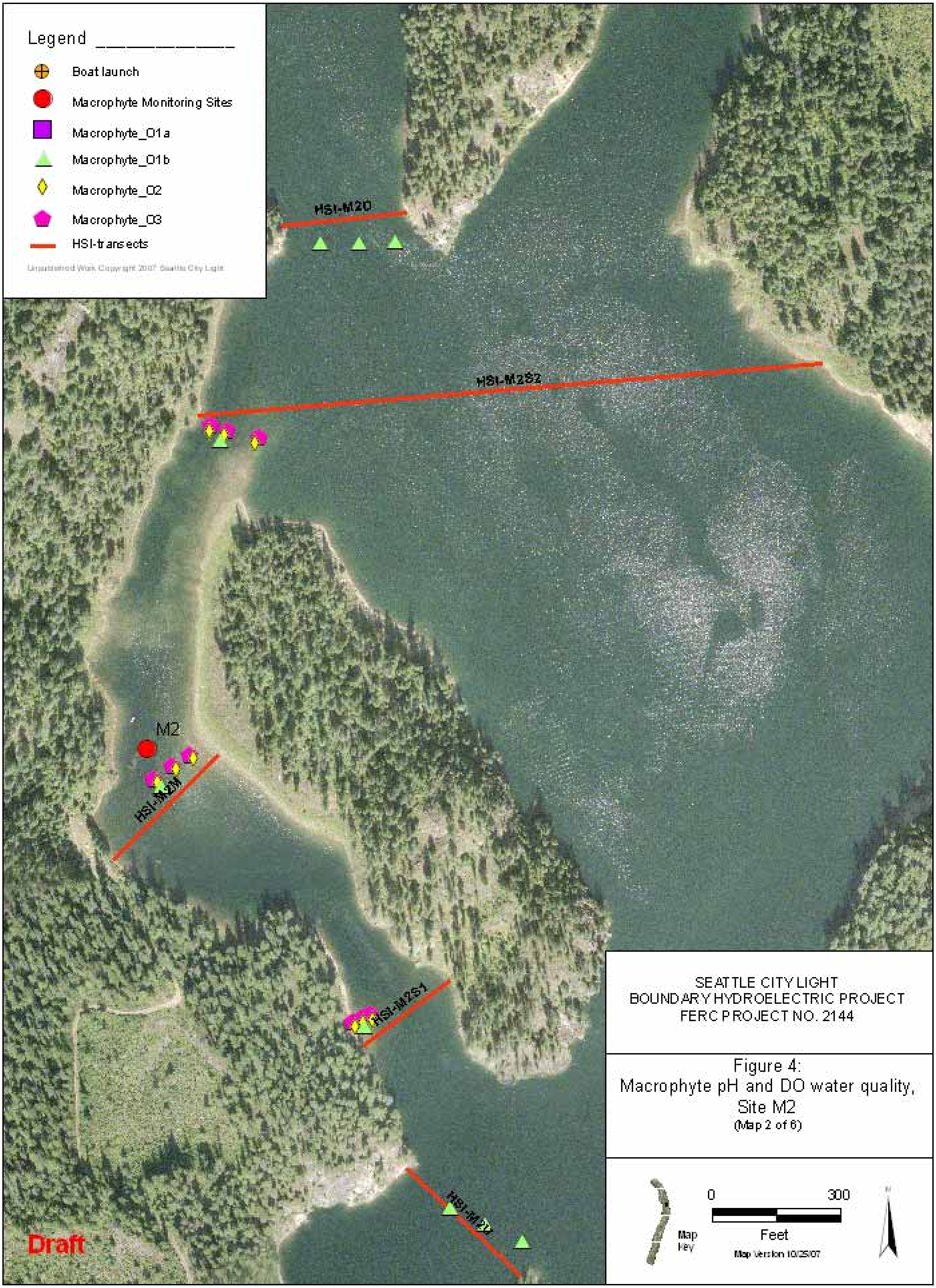


Figure 3:
Macrophyte pH and DO water quality, Site M1
(Map 1 of 6)


Legend
Boat launch
Macrophyte Monitoring Sites
Macrophyte_O1a
Macrophyte_O1b
Macrophyte_O2
Macrophyte_O3
HSI-transects
Unpublished Work Copyright 2007 Seattle City Light
HSI-M2D
HSI-M2S2
M2
HSI-M2M
HSI-M2S1
Draft
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 4:
Macrophyte pH and DO water quality,
Site M2
(Map 2 of 6)
Map Key
0
300
Feet
Map Version 10/25/07

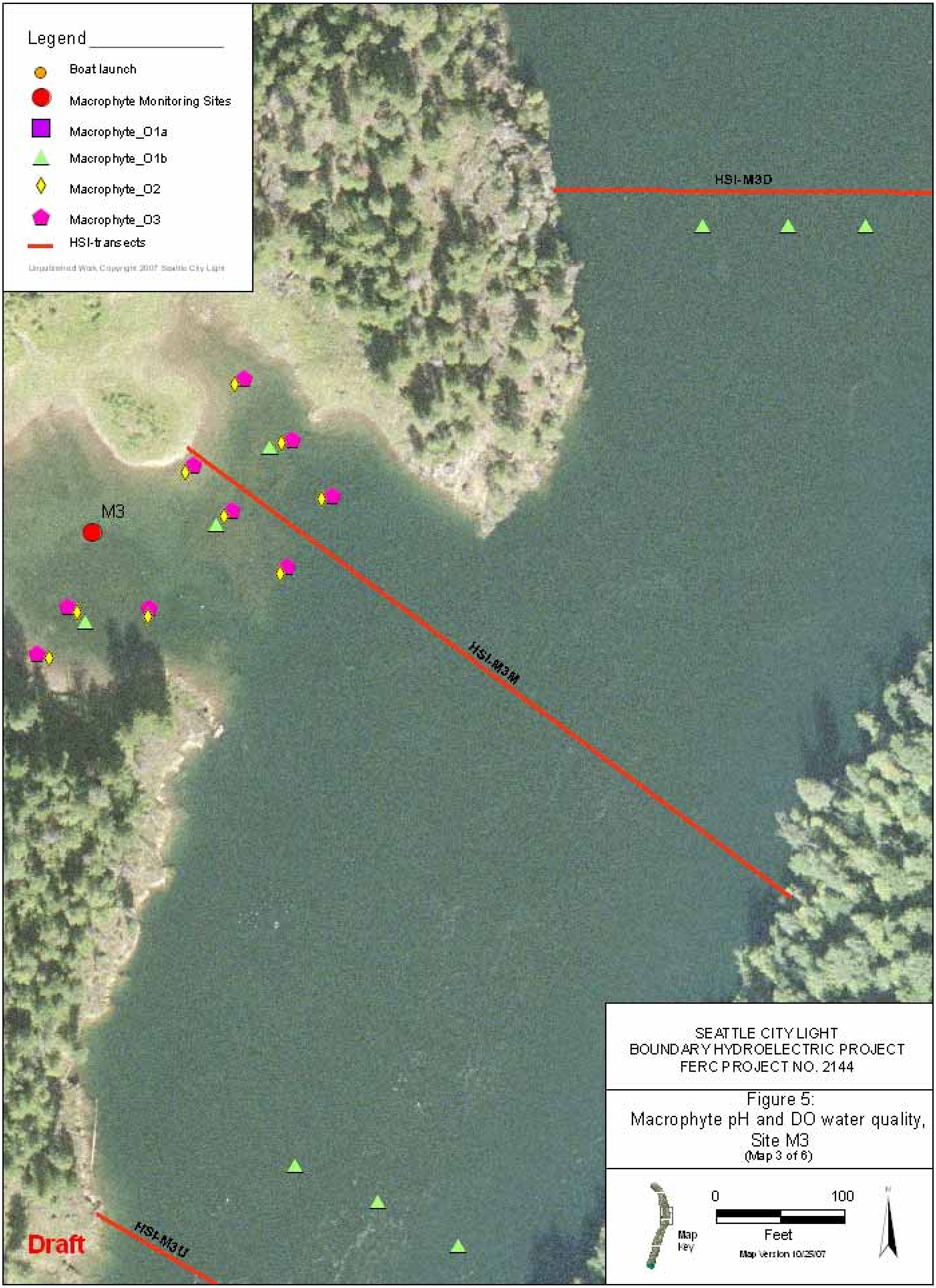
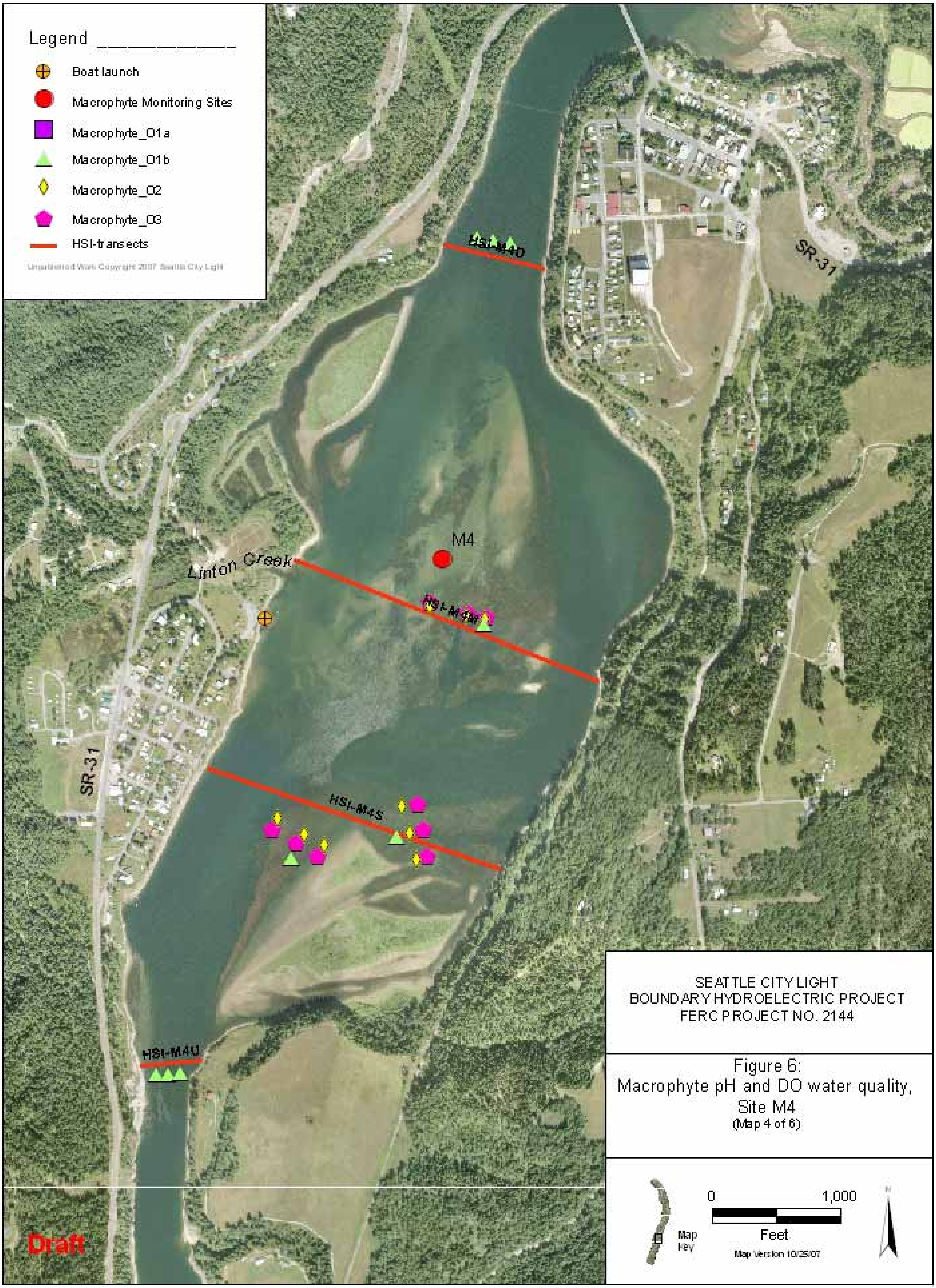


Figure 5:
Macrophyte pH and DO water quality,
Site M3
(Map 3 of 6)



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FERC PROJECT NO. 2144

Figure 6:
Macrophyte pH and DO water quality, Site M4
(Map 4 of 6)

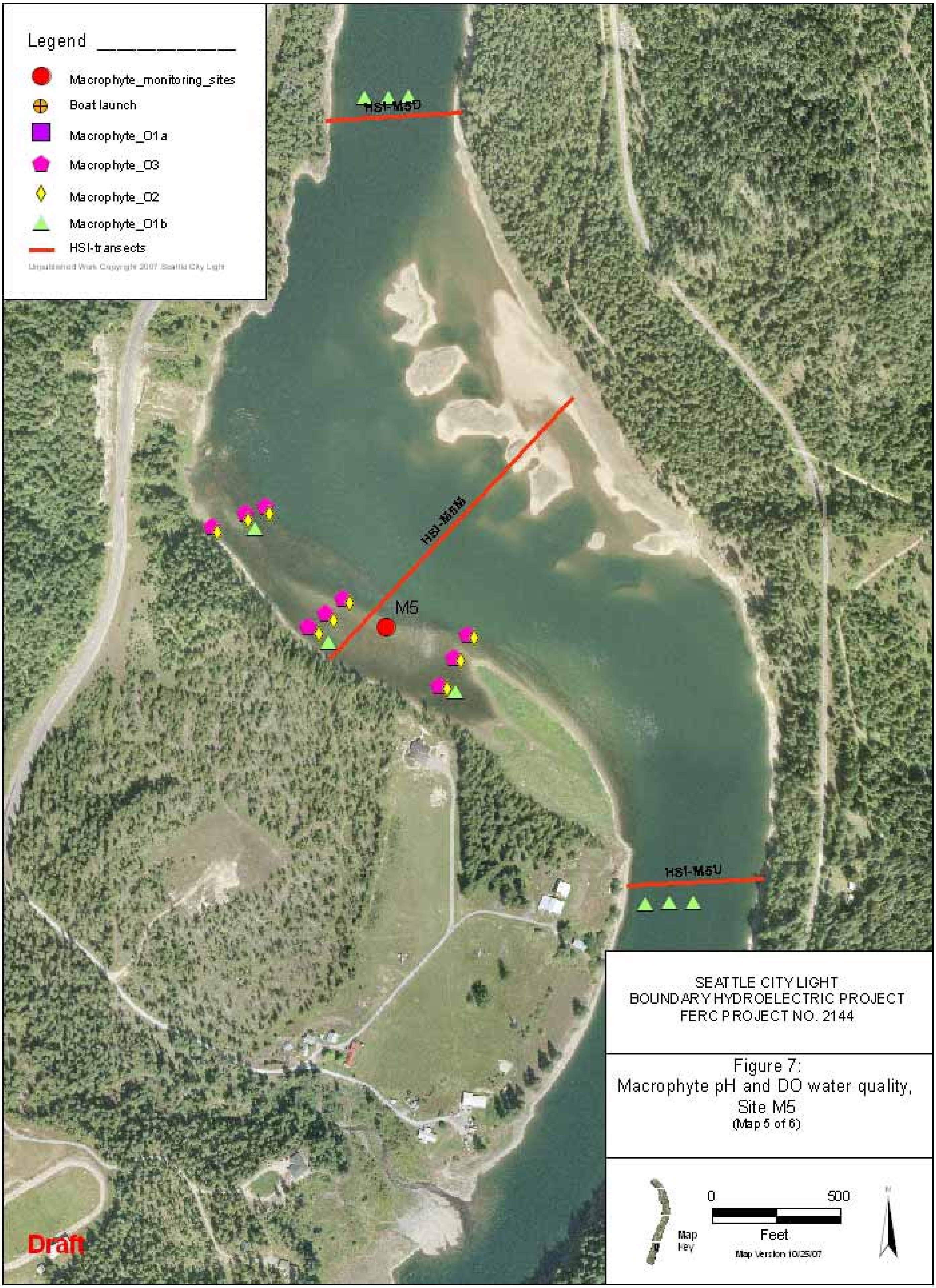


Figure 7:
Macrophyte pH and DO water quality, Site M5
(Map 5 of 6)

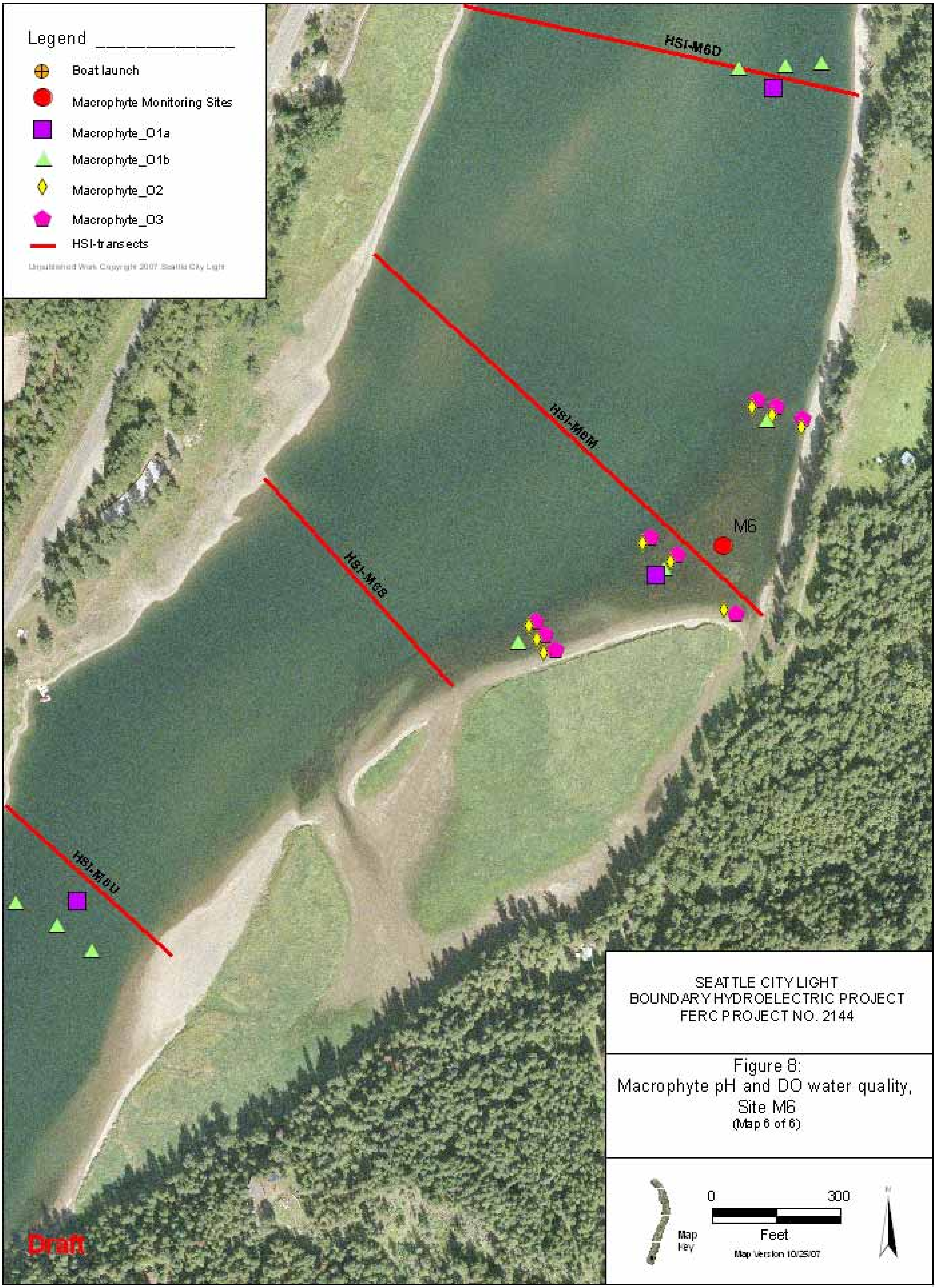


Figure 8:
Macrophyte pH and DO water quality,
Site M6
(Map 6 of 6)

Table 5: Macrophyte water quality monitoring parameters.

Parameter	Units	Sampling Method	Sampling Depth Position	Measurement Equipment	Sensor or Measurement Range	Measurement and Reporting Accuracy
pH	Negative logarithm of the hydrogen ion active	Vertical profile of entire water column	Surface to bottom at evenly spaced intervals	Hydrolab MS5	0.0 to 14.0 pH units	±0.1 Units
Dissolved oxygen (D.O.)[1]	Milligrams per liter (mg/l)	Vertical profile of entire water column	Surface to bottom at evenly spaced intervals	Hydrolab MS5	0.0 to 20.0 mg/l	±0.1 mg/l @ <8mg/l ±0.2 mg/l @ >8mg/l
Temperature (Temp)	Degrees Celsius (°C)	Vertical profile of entire water column	Surface to bottom at evenly spaced intervals	Hydrolab MS5	-5.0°C to 50.0°C	±0.1 °C
Conductivity (Cond)	Micro Siemens per centimeter (mS/cm)	Vertical profile of entire water column	Surface to bottom at evenly spaced intervals	Hydrolab MS5	0.0 to 100.0 mg/l	±0.001mS/cm
Cloud Cover (Cloud)	Visual percentage estimate of cloud cover density	Visual Inspection	1 for each sampling location	Sampler	N/A	N/A

Notes:
1 Sensor uses a trademark Hach LDO.

Table 6: Water quality monitoring schedule.

Sampling Location	Sampling Type (Objective)	Sampling locations	No. Samples	Sample Depth and Frequency	2007					
					Jun	Jul	Aug	Sept	Oct	Nov
All sampling locations (M1 - M6)	O1a[1]	U/S	1	Continuous sampling every 0.5hr at single depth	●	●	●	●	●	●
		MAC - High density macrophyte bed	1							
		D/S	1							
	O1b[2]	Upstream locations	3	Vertical profile every 4-6 hrs for either 24-hr or 72-hr period		○	■	■		○
		MAC - High density macrophyte bed locations	3							
		Downstream Locations	3							
	O2[2]	Low Density	3	Vertical profile every 4-6 hrs for either 24-hr or 72-hr period		○	■	■		○
		Medium density	3							
		High density	3							
	O3[2]	Continuously inundated	3	Vertical profile every 4-6 hrs for either 24-hr or 72-hr period		○	■	■		○
		Exposed 4-6 hrs	3							
		Exposed 8-12hrs	3							

● Indicates continuous sampling every 0.5hrs for period of interest at Site M6, 3/4 mi U/S from Lost Creek (Right Bank)
○ Indicates discrete sampling every 4-6hrs over a 24 hour period.
■ Indicates discrete sampling every 4-6hrs over a 72 hour period.
1 Continuous sampling for objective O1a occurs only at M6 site.
2 Multiple samples will overlap in position (i.e. 3 low density samples at same position of 3 exposed 8-12hrs position. See data collection sheet)

6 SAMPLING PROCEDURES

When visiting a sampling station, the sample collector will record water quality information on waterproof field datasheets shown at Figure 9. The complexity of the sampling plan and nomenclature for identifying and characterizing the sampling type objective is evident. Wherever possible a site was selected for duplicate characteristics at a sampling position and was incorporated into the sampling procedures. Figures 10 through 13 represent schematics of the potential naming and sampling duplicates that may occur at site M6.

In-situ Water Quality Data Collection
In-situ data for vertical profiles of temperature, pH, DO and conductivity will also be collected using a Hydrolab MS5, a multiprobe water quality sampling instrument. Calibration and sampling will be performed per manufacturer specifications. Field technicians will be trained for sampling and calibrating equipment, and a copy of the Hydrolab manual will be kept with the field crew during sampling operations. The Hydrolab MS5 multiprobe will be lowered through the water column either by the data cable or with a reel system. The Hydrolab data cable will have demarcations, and the reel will have a depth measurement gage. Samples will be collected at 0.5 m intervals from surface to bottom. In situ vertical profile measurements will be taken at predetermined positions within the five macrophyte monitoring sites and positions upstream and downstream of each monitoring site (Figures 2 through 8).

There will likely be locations where a single sample represents multiple sampling objectives (or parameters). For instance, there will likely be locations where Objective 2 (low macrophyte density) and Objective 3 (continuously inundated macrophytes) can be sampled at a single location. Section II of the data collection field sheet at Figure 9 has entry spaces where duplicate sampling can be recorded. At a minimum, 15 vertical profiles will be taken at any given site (M1 through M6). If there are no samples meeting duplicate monitoring objectives, then as many as 27 vertical profile measurements could be taken at a site.

Several of the monitoring objectives (O1a, O1b, O2, see Table 6) use macrophyte density as a criterion for locating a sample. The following are the macrophyte density criteria for delineating low, medium and high density of macrophytes in the field.

Low Macrophyte Density – < 3 stems / m^2 (Objective 1a)
Medium Macrophyte Density – 4 to 6 stems / m^2 (Objective 2b)
High Macrophyte Density – > 7 stems / m^2 (Objective 2)

Another set of criteria will be used to identify the exposure and inundation zones related to Project operations and hydrologic runoff at each of the six macrophyte pH and DO monitoring sites. Field monitoring of macrophytes in varying exposure/inundation areas (Continuously, Exposed 4-6 hrs, Exposed 8-12 hrs) will be based on inundation/duration curves or maps developed for each of the six monitoring sites.

Continuous Water Quality Monitoring
Temperature, pH, DO and conductivity will be measured continuously using a Hydrolab MS5 multiprobe water quality sampling instrument attached 1 meter beneath the water’s surface at a

marker/retrieval buoy containing a radio telemetry system. Calibration and sampling will be performed per manufacturer specifications and distributor configuration. Water quality will be measured every 0.5 hr from May through November 2007. Telemetry readings will be checked every other day (during the work week) during the seven-month monitoring period to ensure that equipment is functioning properly. If water quality data signals are lost, in error, or cannot be identified, due to environmental conditions, fouling of equipment or vandalism, field crews will attempt to repair the equipment in question within 48 hours of identification of a problem. The project manager will notify SCL of the problem and steps taken to address it. Water quality will be sampled at site M6, approximately 0.75 miles upstream from Lost Creek on the right bank (looking downstream – north) (Figure 8). The continuous monitoring buoys will be checked for maintenance at a minimum of every 30 days.

Field Sampling Decisions

There may be instances when data collection requires judgment and decision making in the field. The protocol for field-based decisions is as follows. Any decisions made in the field to deviate or modify sampling locations or methods will require approval of the field crew chief. The field crew chief will document the decision on field note sheets, and email a copy of the sheet or telephone the information to the study manager. If the field decision is important enough to significantly affect the study's data, scope, schedule or budget, the field crew chief is authorized to stop work until the study manager is contacted.

During the initial site investigation in late April 2007, the Tetra Tech study manager will work closely with the lead field crew chief and instrument manufacturer's technical support engineer to finalize the study plan and sampling methods. Potential sampling problems and trouble shooting were discussed during the initial site investigation. The study team identified and characterized the type of decision the field crew chief is allowed to make in the field, and those decisions that need to be coordinated with the study manager.

Seattle City Light - Boundary Hydroelectric Project (FERC No. 2144)							
Study No. 6, Water Quality, pH and DO to Macrophyte Relationship Monitoring							
I. General Information							
Party:				Temp:			
Date:				%Cloud Cover			
Time:				Photo Numbers:			
Station I.D.:							
II. WQ In-Situ Sampling Information							
	Obj. Type	Primary Long	Secondary Long		Lateral Position		ID
Sampling Position ID:							
Duplicate 1:							
Duplicate 2:							
Duplicate 3:							
Reservoir Depth (m):							
Sampling Meas. Interval (Depth/10ft):							

Interval	**Meas. Depth** (m)	**Temp** (°C)	**pH**	**D.O.** (mg/l)	**Cond** (mS/cm)	**Notes**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

III. Sample Naming Information

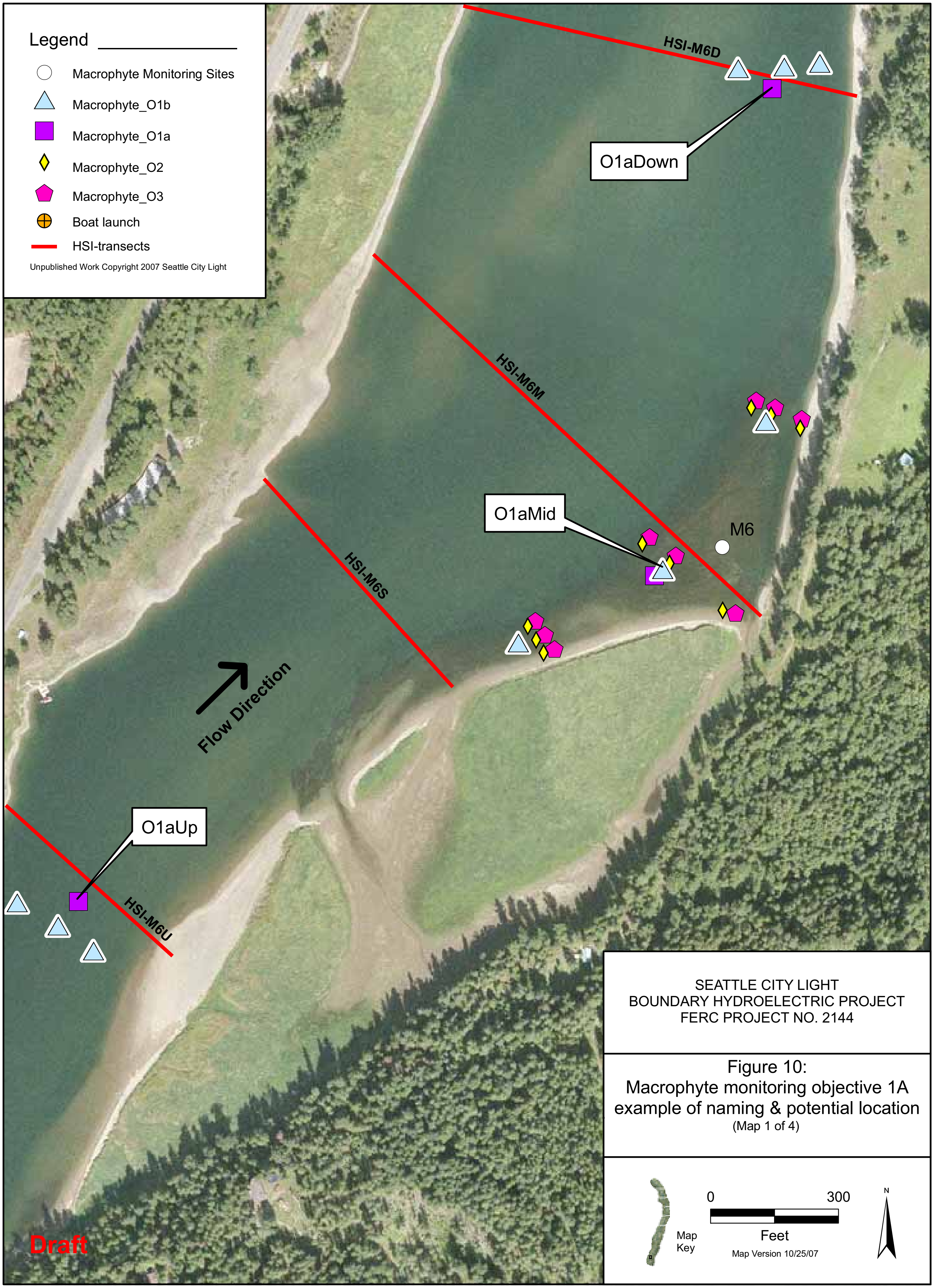
Objective Type	Primary Longitudinal Position (O1a, O1b, O2, O3)	Secondary Longitudinal Position (O1bM Only)	Lateral Position (Excluding O1bM)
O1a	U	1	L
O1b	M	2	M
O2-	D	3	R
O3-			

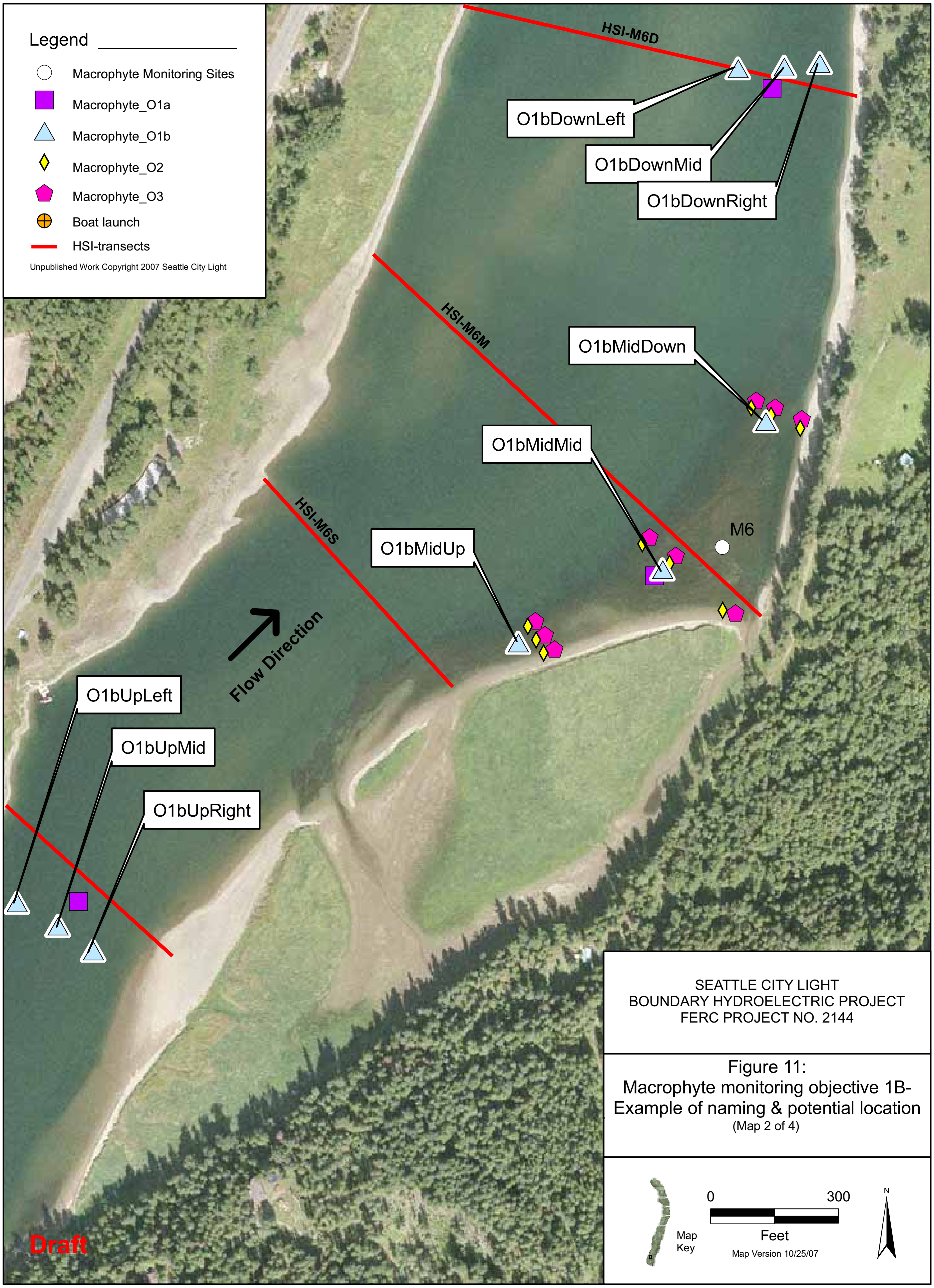
IV. General Notes/Observations

Figure 9: Water Quality, pH and DO to macrophyte relationship monitoring data sheet.

Completeness
Completeness is a measure of the amount of valid data needed to meet the study's objectives. Completeness will be judged by the amount of valid data compared to data expected and instrument operation. While the goal for the above criteria is 100 percent completeness, a level of 95 percent is considered acceptable. However, at any time when data are not complete, decisions regarding resampling and/or reanalysis will be made by Tetra Tech, Inc. These decisions will take into account the project data quality objectives as presented above.

Comparability
Comparability is a measure of the confidence with which one data set can be compared to another. This is a qualitative assessment and is addressed primarily in sampling design through use of comparable sampling procedures and schedules. In the laboratory, comparability is assured through the use of comparable analytical procedures and ensuring that project staff are trained in the proper application of the procedures. Within-study comparability will be assessed through analytical performance (quality control instrument duplicate measurements).
[Move Figures 10 through 13 to this location – immediately following the first reference and before the next major section.]


Legend
Macrophyte Monitoring Sites
Macrophyte_O1b
Macrophyte_O1a
Macrophyte_O2
Macrophyte_O3
Boat launch
HSI-transects
Unpublished Work Copyright 2007 Seattle City Light
HSI-M6D
O1aDown
HSI-M6M
O1aMid
M6
HSI-M6S
Flow Direction
O1aUp
HSI-M6U
Draft
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 10:
Macrophyte monitoring objective 1A
example of naming & potential location
(Map 1 of 4)
Map Key
0
300
Feet
Map Version 10/25/07
N



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 11:
Macrophyte monitoring objective 1B-
Example of naming & potential location
(Map 2 of 4)

Map Version 10/25/07

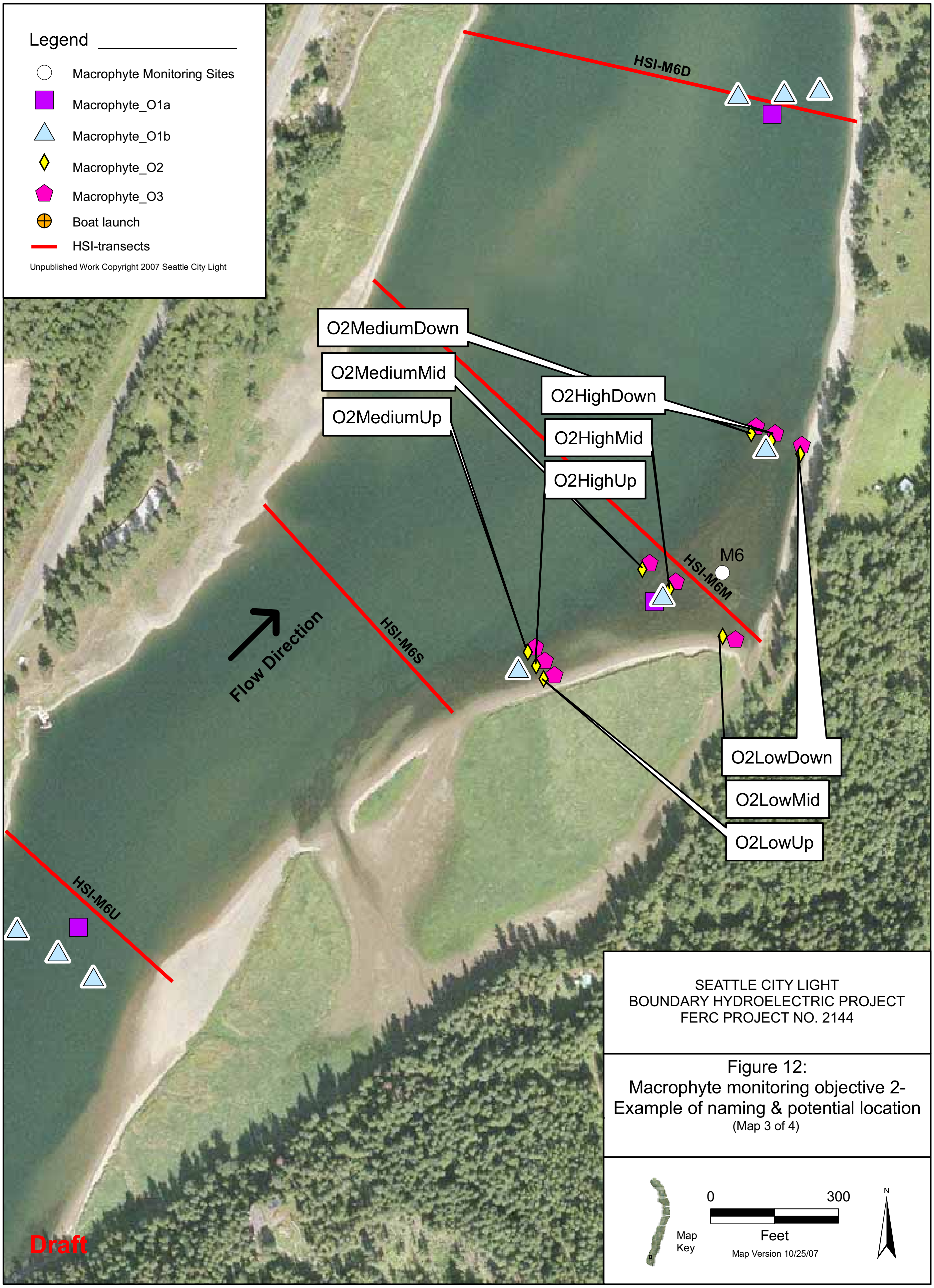


Figure 12:
Macrophyte monitoring objective 2-
Example of naming & potential location
(Map 3 of 4)

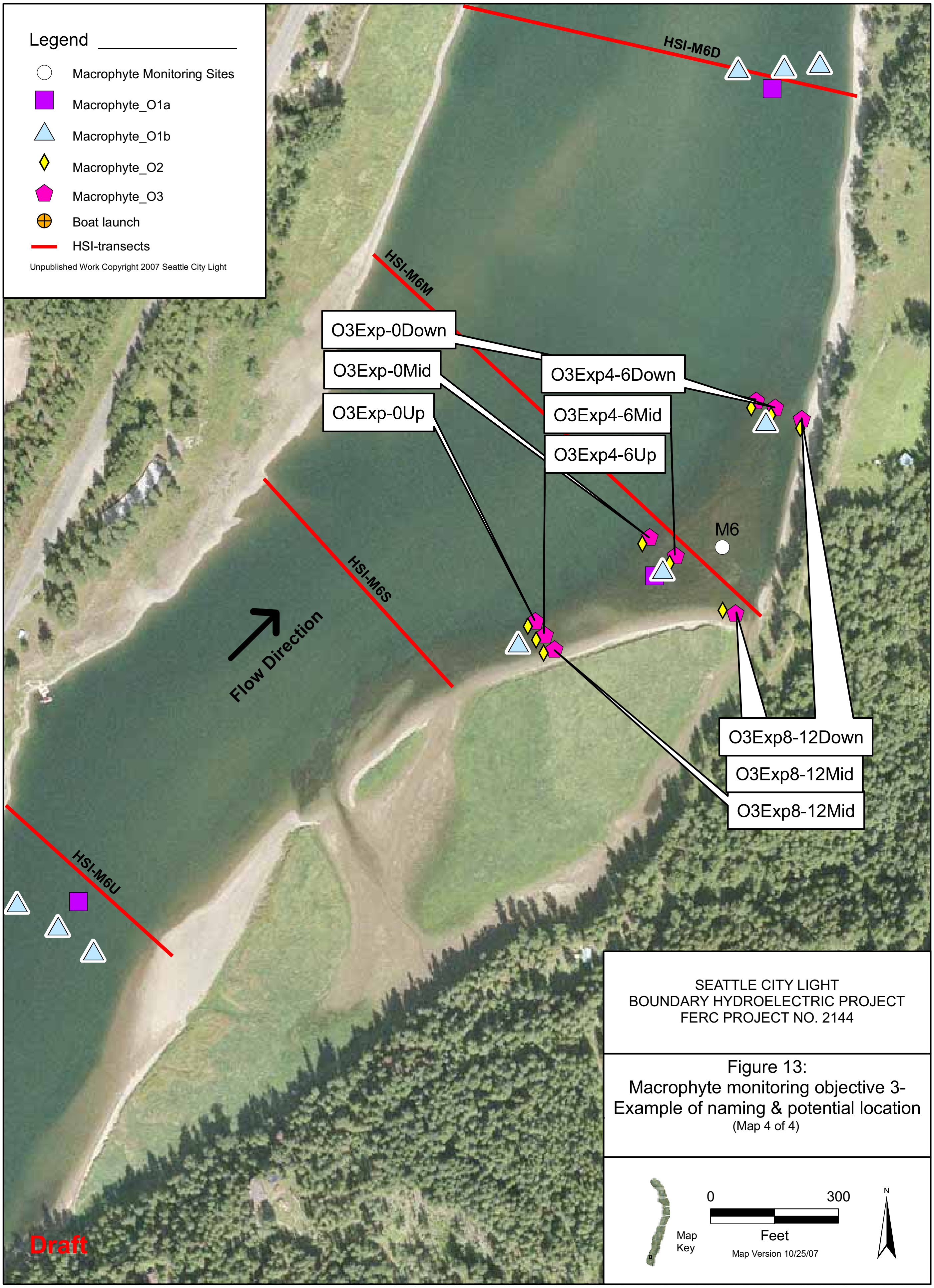


Figure 13:
Macrophyte monitoring objective 3-
Example of naming & potential location
(Map 4 of 4)

7 MEASUREMENT PROCEDURES

This study will employ field based measurements. Field analytical procedures will follow U.S. EPA (1983, 1991) or APHA *et al*. (1998) methods. The expected detection or reporting limits for field parameters and constituents are listed in Table 5 along with the anticipated analytical method.

8 QUALITY CONTROL

Standard protocols for surface water constituents will be followed throughout this study. All measurement equipment will be cleaned and inspected prior to use to verify that it is working properly. All field meters will be calibrated according to the manufacturers' instructions before and after each monitoring event. Only fresh, commercially-prepared standards will be used for calibrations. All pertinent information about each field meter will be recorded in field notebooks.

Accurate records of dates, times, sampling staff, sampling location, measuring point descriptions, and other observations will be assured through the use of standardized field forms specifically designed for this activity, i.e. Figure 9. All field forms will be checked by the field crew chief at the completion of sampling and prior to leaving the site to ensure all measurements and sampling-related data were accurately recorded.

Equipment and instrument logs will be maintained and will include serial numbers, manufacturer, model number, and date of production for each piece of equipment used in the field. All maintenance and calibration protocols will be documented and service checks will be recorded. Any variations from written protocol will be recorded by the field crew chief. An example of a variation from the written protocol would be placing the continuous water quality monitoring buoys in the reservoir beginning in June instead of May due to the lack of macrophyte growth in May. Calibration of equipment and instruments will be conducted by comparison with standards from the National Bureau of Standards.

Records of instrument calculation will be maintained by the field technician. The calculation records will include the name and signature of the person performing the measurement and calculations. The sources of all data and assumptions in the calculations will also be noted. Corrections to any calculations will be signed and dated with explanatory notes.

9 DATA MANAGEMENT PROCEDURES

At the completion of each sampling event, all field data will be compiled and evaluated against the project measurement quality objectives, Table 6. Data will be checked for improbable or missing data. Analytical precision will be evaluated using standard statistical techniques {relative percent difference (RPD), standard deviation (s), pooled standard deviation (sp)} as appropriate.

10 DATA VERIFICATION AND VALIDATION

Data verification requires confirmation by examination or provision of objective evidence that the requirements of these specified QC acceptance criteria are met. Each step of the data collection and analysis process must be evaluated and its conformance to the protocols established in this QAPP verified, including:

- Sampling design
- Sample collection procedures
- Analytical procedures
- Quality control
- Data reduction and processing data

Validation involves detailed examination of the complete data package using professional judgment to determine whether the established procedures were followed. Validation will be done by the study lead.

Evaluation criteria will include the acceptability of instrument calibrations, precision of data, and the appropriateness of assigned data qualifiers, if any.

The study lead will review the case narratives to determine if the results met the MQOs for bias, precision, and accuracy for that sampling episode and to ensure that all analyses were performed. Field duplicates and results will be evaluated and compared to the quality objectives shown in Table 3. Based on these assessments, the data will either be accepted, accepted with appropriate qualifications, or rejected.

After the field data have been reviewed and verified by the study lead, they will be independently reviewed for errors before study completion. The initial data review will consist of a 10 percent random sampling of the project data. If any errors are discovered during the initial data review, a full independent review will be undertaken by study QA officer.

11 DATA QUALITY (USABILITY) ASSESSMENT

The data collected during this study will be used to assess the relationship of pH and DO to macrophytes within the Boundary Reservoir. The data collected during this study will be used to assess water quality and productivity conditions within the Boundary Reservoir. Assuming the project MQOs are ultimately met, the data will be deemed acceptable for use (except as qualified during the data review and validation process).

A draft data report will be prepared and forwarded to Seattle City Light following the schedule in Table 2. The study report will include the following:

- Description of the project purpose, goals, and objectives.
- Map(s) of the study area and sampling sites.
- Descriptions of field methods.

- Discussion of data quality and the significance of any problems encountered in the analyses.
- Summary tables of field data.
- Observations regarding significant or potentially significant findings.
- Recommendations based on study goals.

12 REFERENCES

DeGross, 2005. Aerial Photography from flight lines taken in August 20, 2005.

Seattle City Light (SCL). 2007. Revised Study Plan for the Boundary Hydroelectric Project (FERC No. 2144). Seattle, Washington. February 2007. Available online at http://www.seattle.gov/light/news/issues/bndryRelic/br_document.asp

Washington State Department of Ecology (Ecology). 1993. Field Sampling and Measurement Protocols for the Watershed Assessment Section, Washington State Department of Ecology. 72. Publication No. 93-e04.

Ecology. 2004. Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. July 2004. No. 04-03-030. Olympia, WA.

Appendix 1. Field Checklist and Data Sheets

Study No. 6: 24-Hour & 72-Hour Macrophyte pH & DO Monitoring Checklist

Field Equipment

- Hydrolab
- Weights
- Quick Links
- Aquascope (2)
- Secchi Disk with rope
- Depth Sounder
- DO Winkler Kit
- Permanent Markers, Fine Point
- Macrophyte Bed Location Maps
- Maps with Station Locations
- Field Notebook
- Radio
- 5-gallon bucket
- Laminated Sampling Procedures
- GPS
- Digital Camera

Data to be Collected

- In-situ Water Quality Data
  - Secchi Disk Depth
  - Temperature, pH, Dissolved Oxygen, Conductivity
  - Macrophyte Density

- General Observations
  - Cloud Cover

Seattle City Light - Boundary Hydroelectric Project (FERC No. 2144)						
Study No. 6, Water Quality, pH and DO to Macrophyte Relationship Monitoring						
I. General Information						
Party:				Temp:		
Date:				%Cloud Cover		
Time:				Photo Numbers:		
Station I.D.:	O3Exp8-12Down					
II. WQ In-Situ Sampling Information						
Reservoir Depth (m):						
Sampling Meas. Interval (Depth/10):						
Interval	**Meas. Depth** (m)	**Temp** (°C)	**pH**	**D.O.** (mg/l)	**Cond** (mS/cm)	**Notes**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
IV. General Notes/Observations Note: Mark and attached duplicate sample sheet if necessary.						

Figure A.1-1. Water quality, pH and DO to macrophyte relationship monitoring example data sheet. There is one data sheet for each of the following sampling locations: O3Exp8-12Down, O3Exp8-12Mid, O3Exp8-12Up, O3Exp4-6Down, O3Exp4-6Mid, O3Exp4-6Up, O3Exp-0Down, O3Exp-0Mid, O3Exp-0Up, O2HighDown, O2HighMid, O2HighUp, O2MediumDown, O2MediumMid, O2MediumUp, O2LowDown, O2LowMid, O2LowUp, O1bDownRight, O1bDownMid, O1bDownLeft, O1bMidDown, O1bMidMid, O1bMidUp, O1bUpLeft, O1bUpMid, O1bUpRight

Appendix 2: Water Quality Buoy Data

(Note: Data are presented here in graphical form. The number of records for continuous monitoring at each buoy exceeds 18,000; the full monitoring record is available in electronic form upon request.)

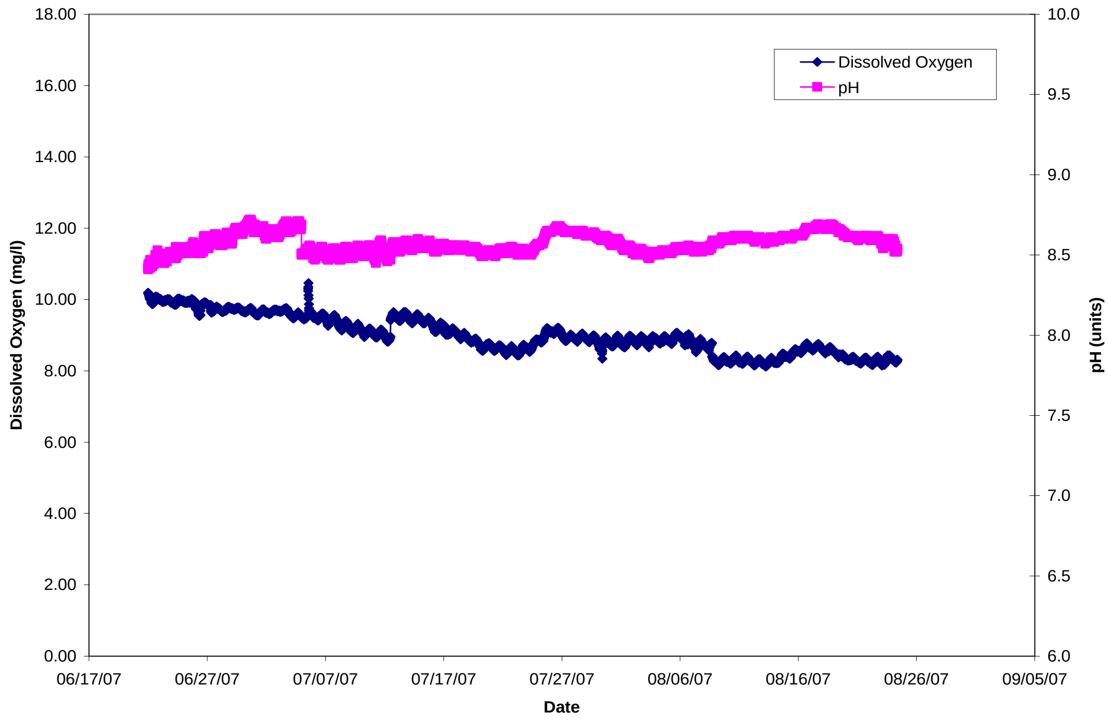


Figure A.2-1. Buoy 1 pH and DO data collected from 6/22/07 to 8/24/07 at site M6.

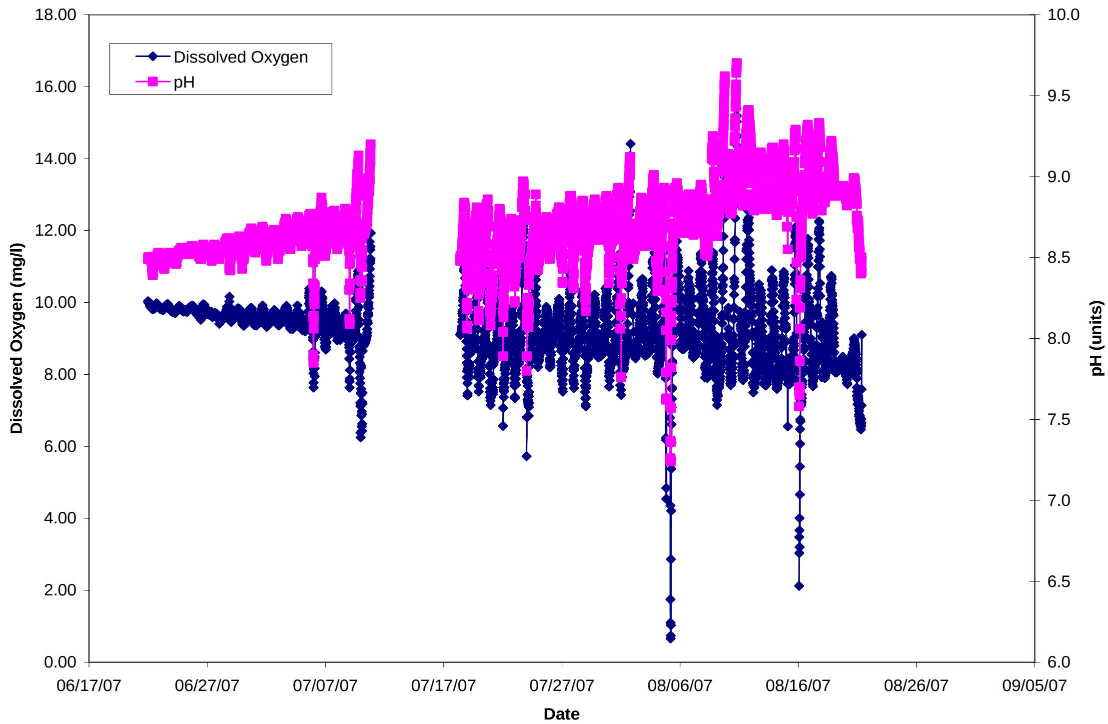


Figure A.2-2. Buoy 2 pH and DO data collected from 6/22/07 to 8/24/07 at site M6.

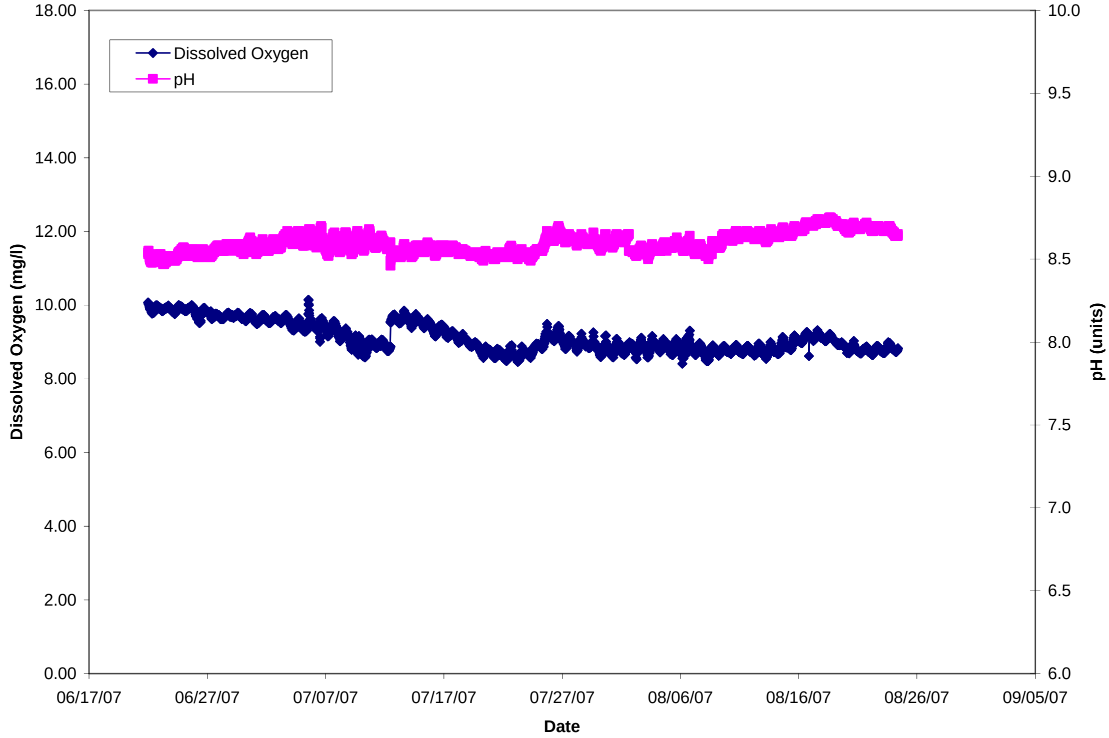


Figure A.2-3. Buoy 3 pH and DO data collected from 6/22/07 to 8/24/07 at site M6.

Appendix 3: Comparison of Pool Elevation and Flow with pH and DO Concentrations

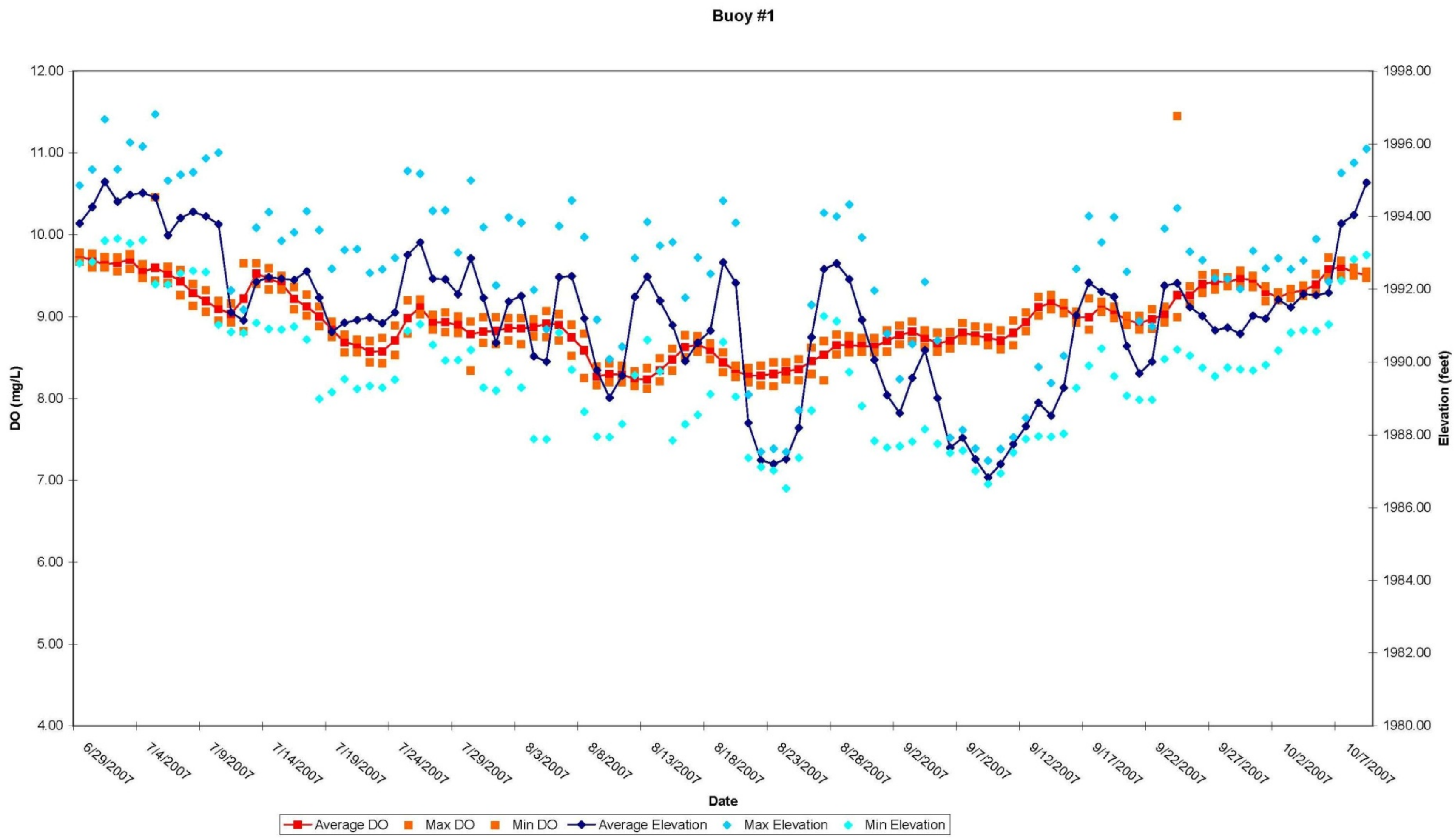


Figure A.3-1. Buoy 1 (upstream) daily average DO values and daily average pool elevations from 6/29/07 to 10/09/07 at site M6.

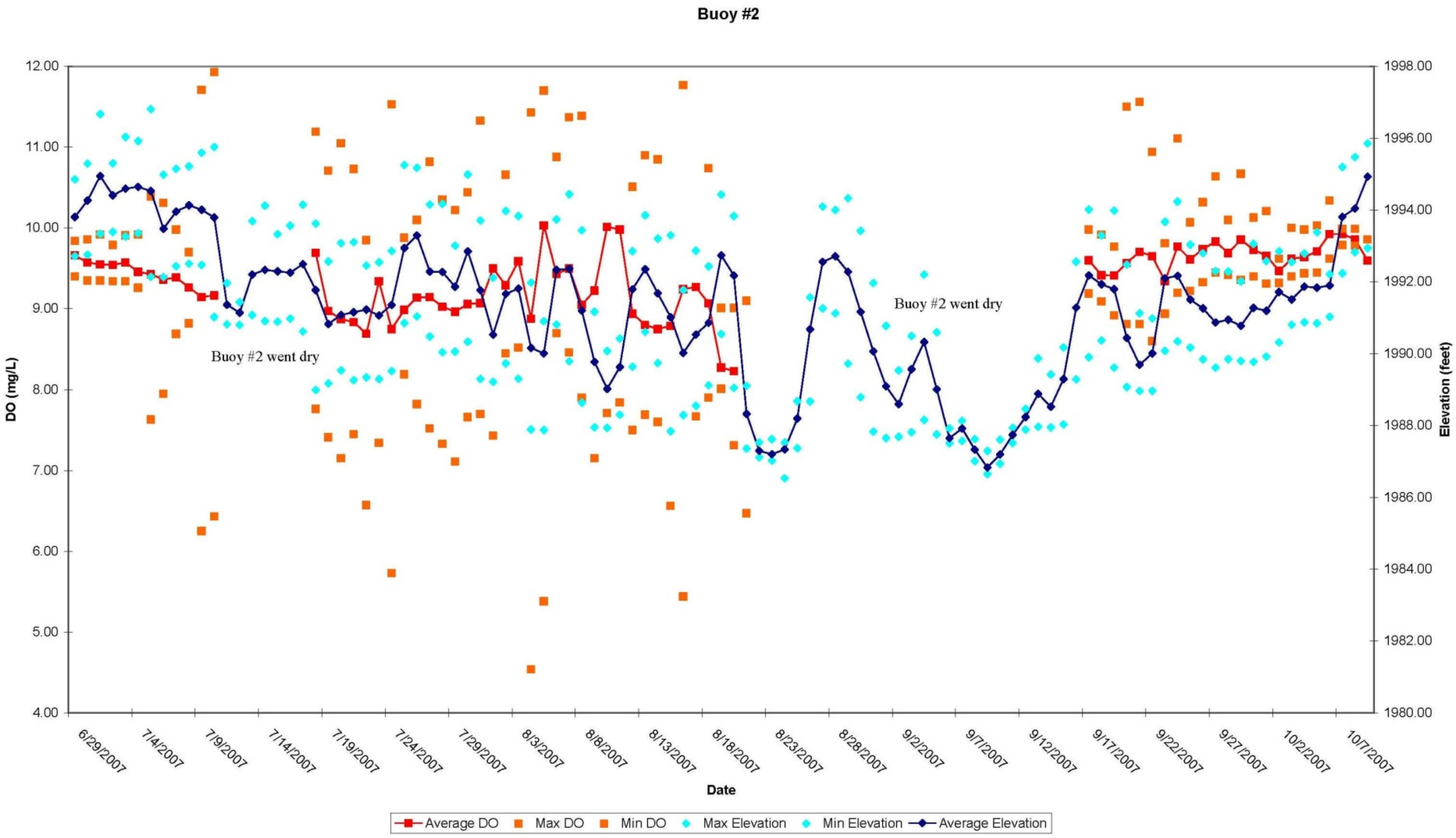


Figure A.3-2. Buoy 2 (macrophyte bed) daily average DO values and daily average pool elevations from 6/29/07 to 10/09/07 at site M6.

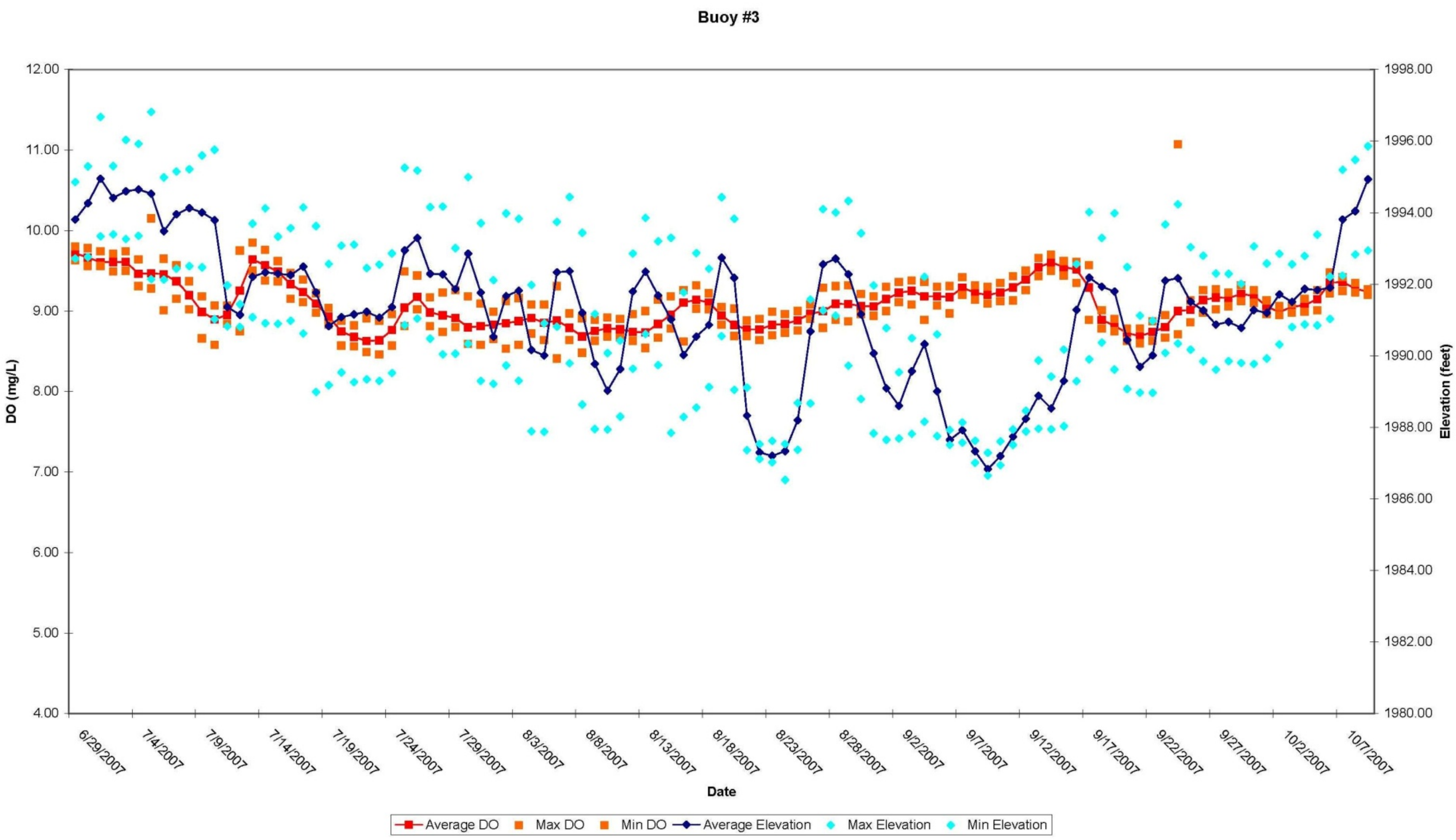


Figure A.3-3. Buoy 3 (downstream) daily average DO values and daily average pool elevations from 6/29/07 to 10/09/07 at site M6.

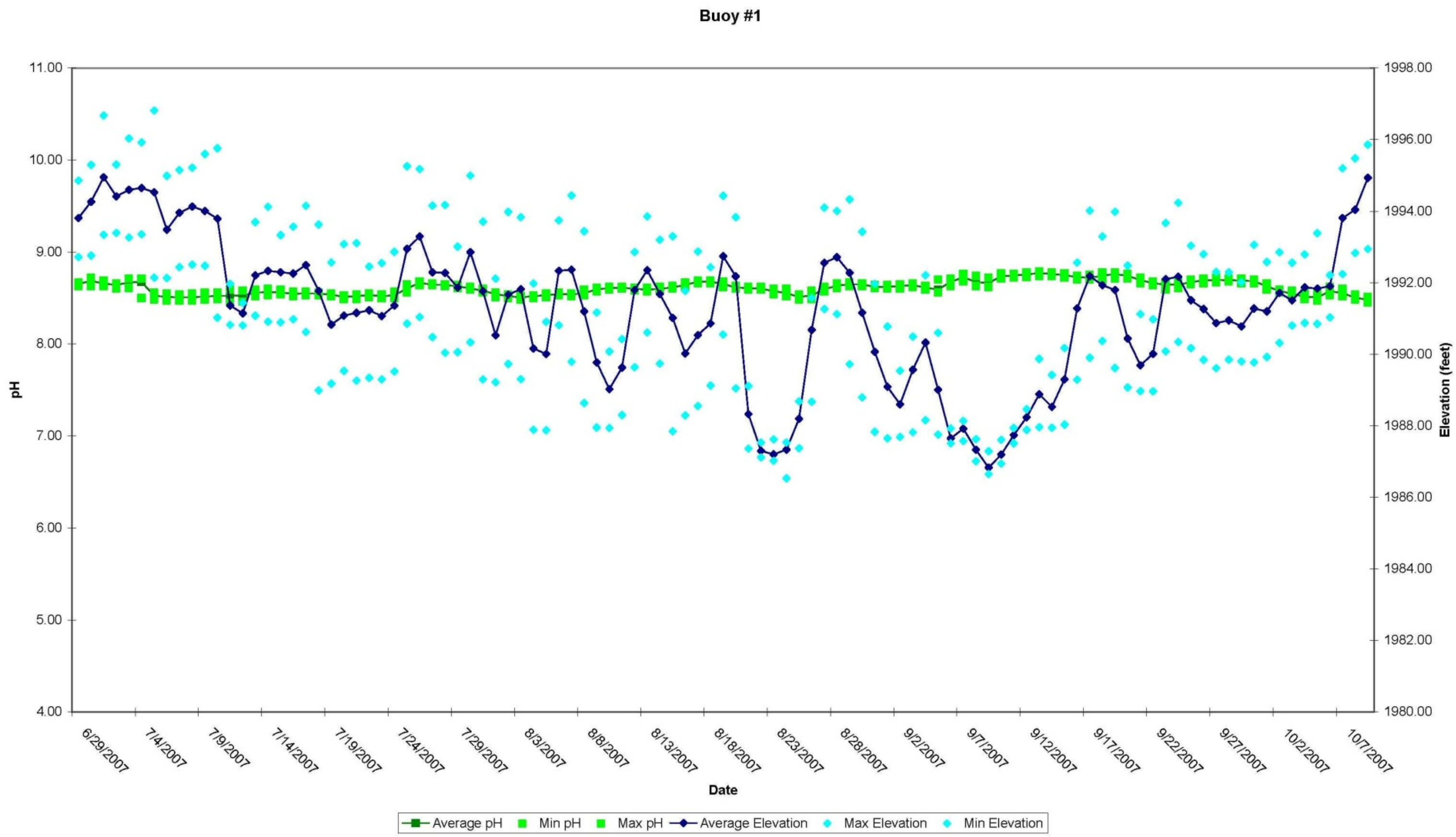


Figure A.3-4. Buoy 1 (upstream) daily average pH values and daily average pool elevations from 6/29/07 to 10/09/07 at site M6.

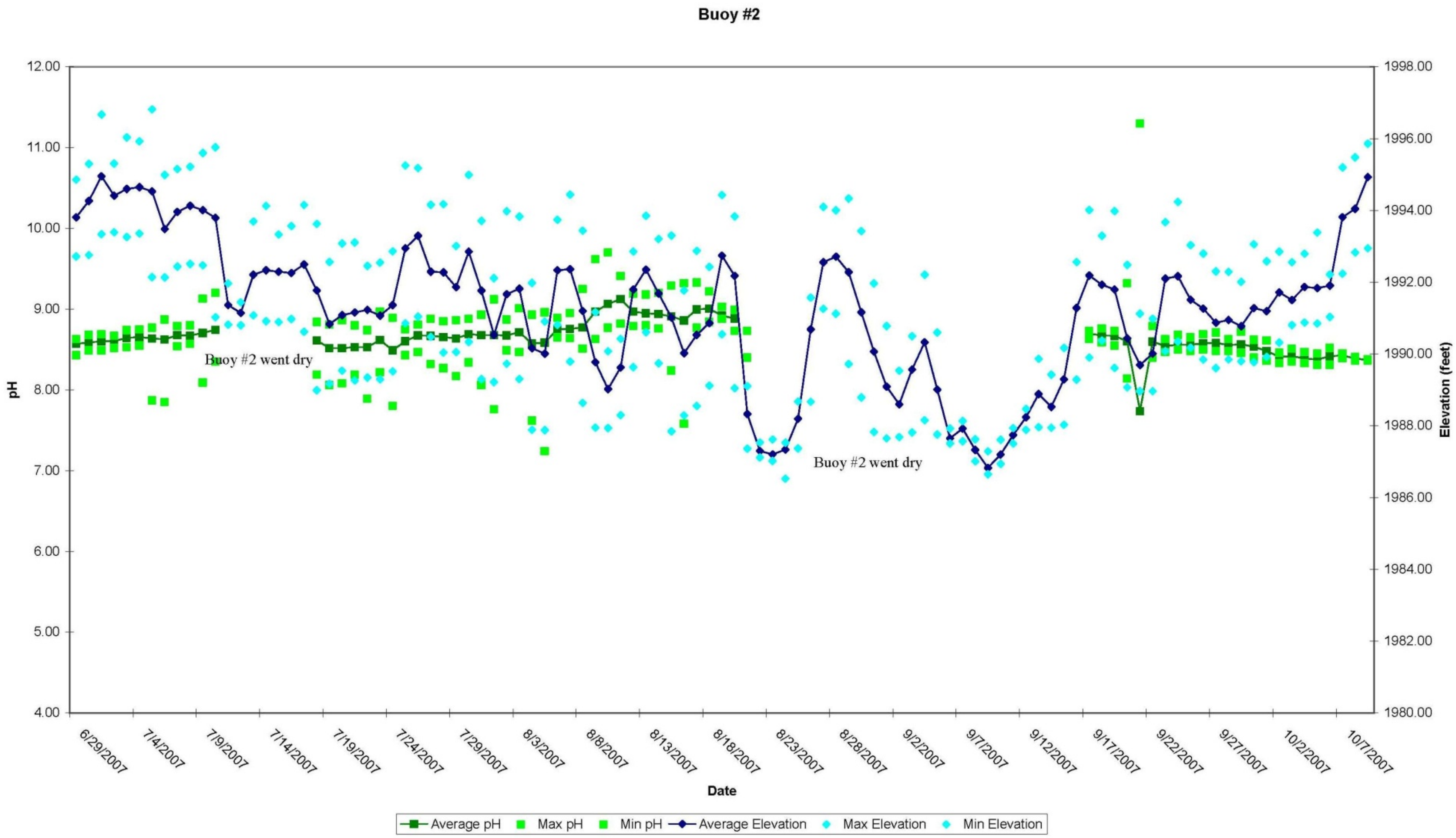


Figure A.3-5. Buoy 2 (macrophyte bed) daily average pH values and daily average pool elevations from 6/29/07 to 10/09/07 at site M6.

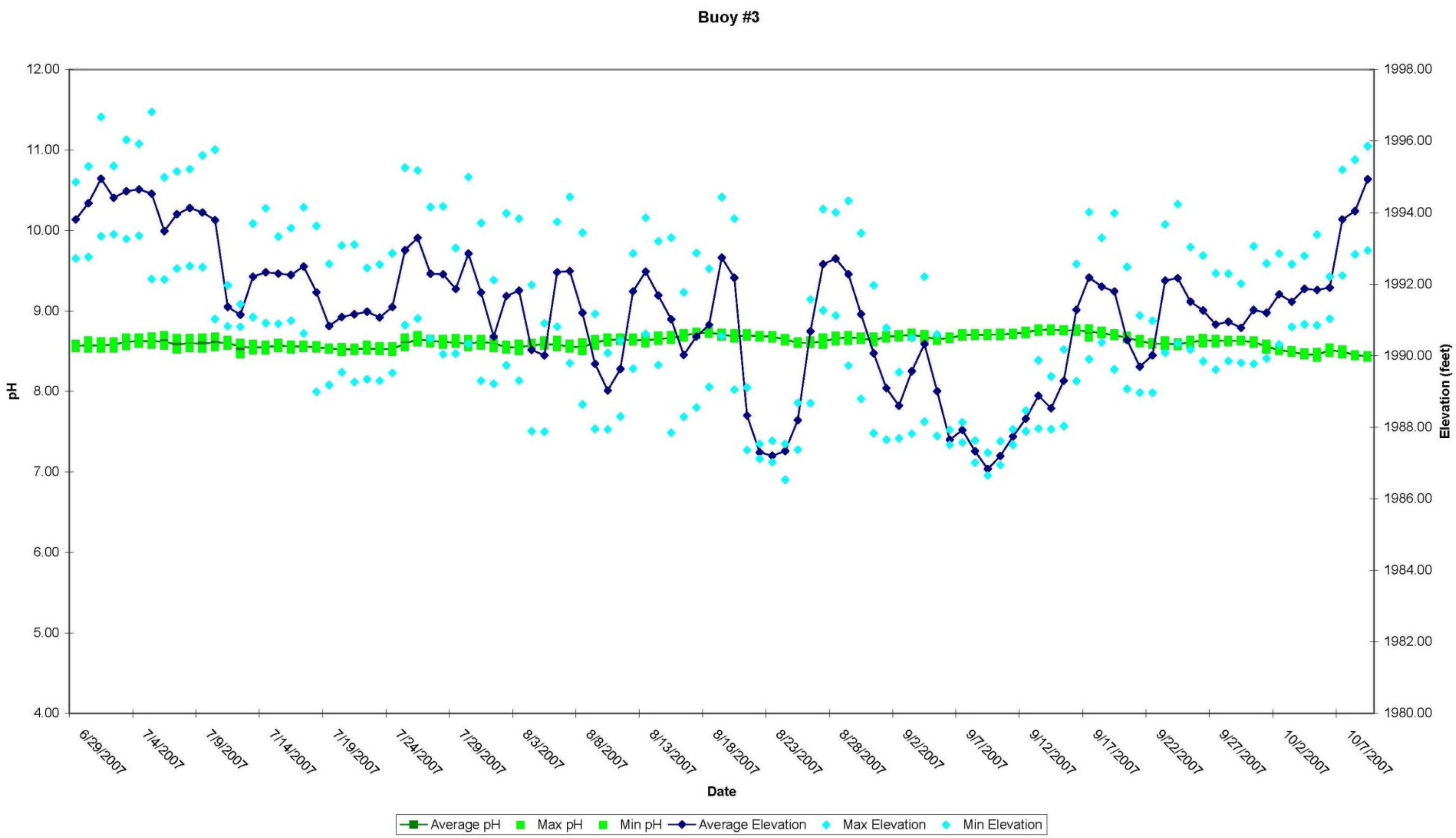


Figure A.3-6. Buoy 3 (downstream) daily average pH values and daily average pool elevations from 6/29/07 to 10/09/07 at site M6.

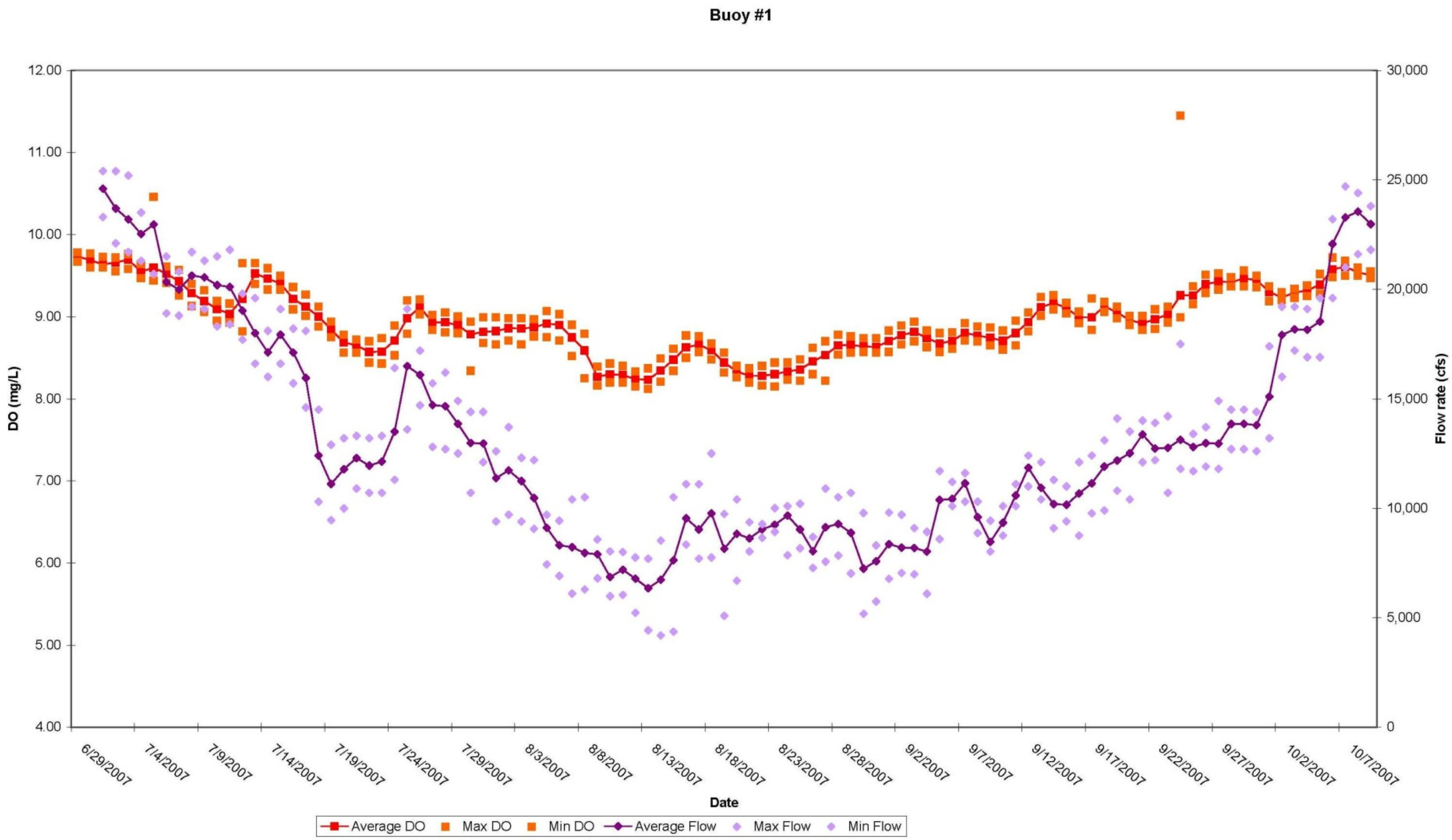


Figure A.3-7. Buoy 1 (upstream) daily average DO values and daily average flow rate from 6/29/07 to 10/09/07 at site M6.

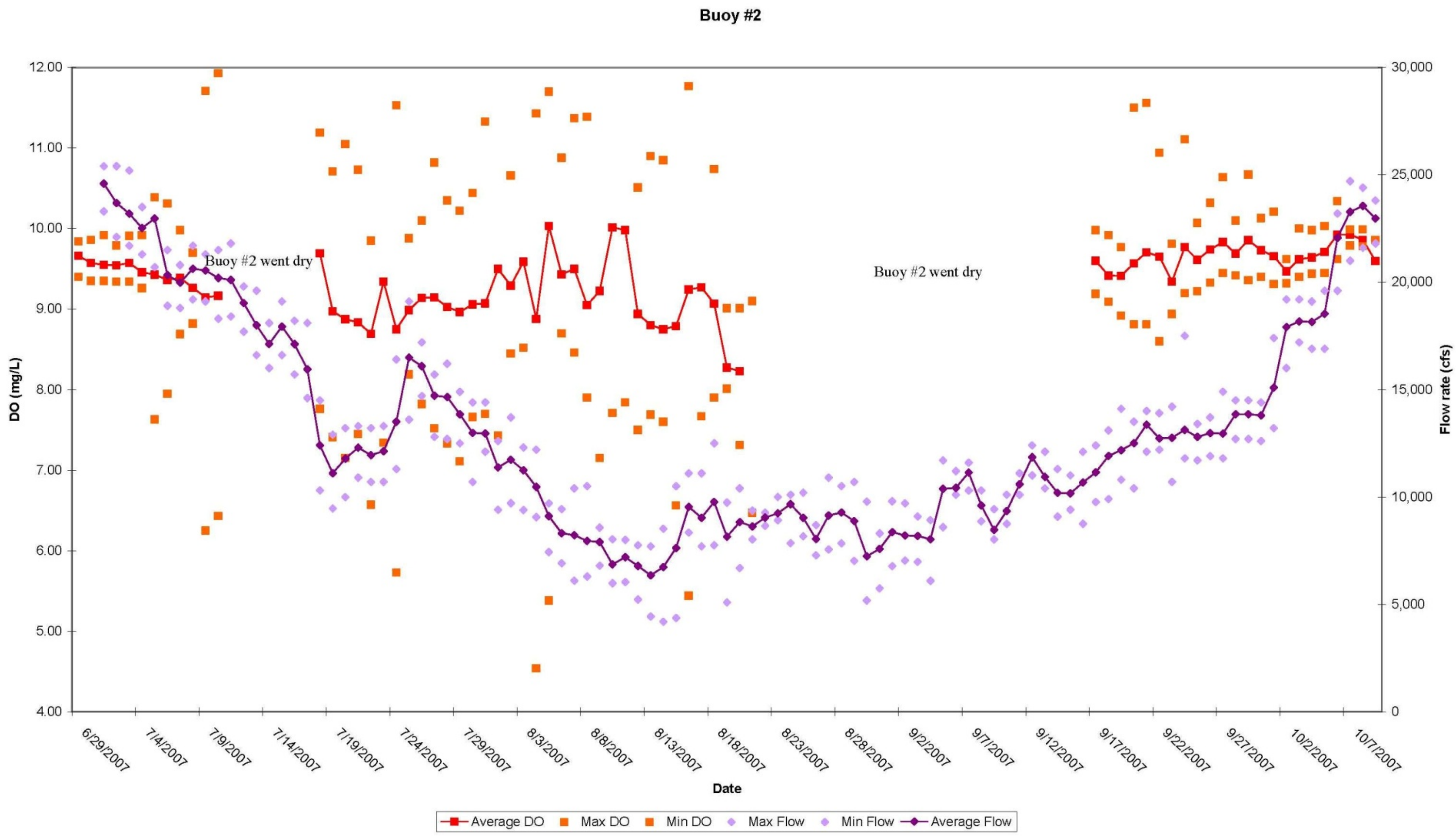


Figure A.3-8. Buoy 2 (macrophyte bed) daily average DO values and daily average flow rate from 6/29/07 to 10/09/07 at site M6.

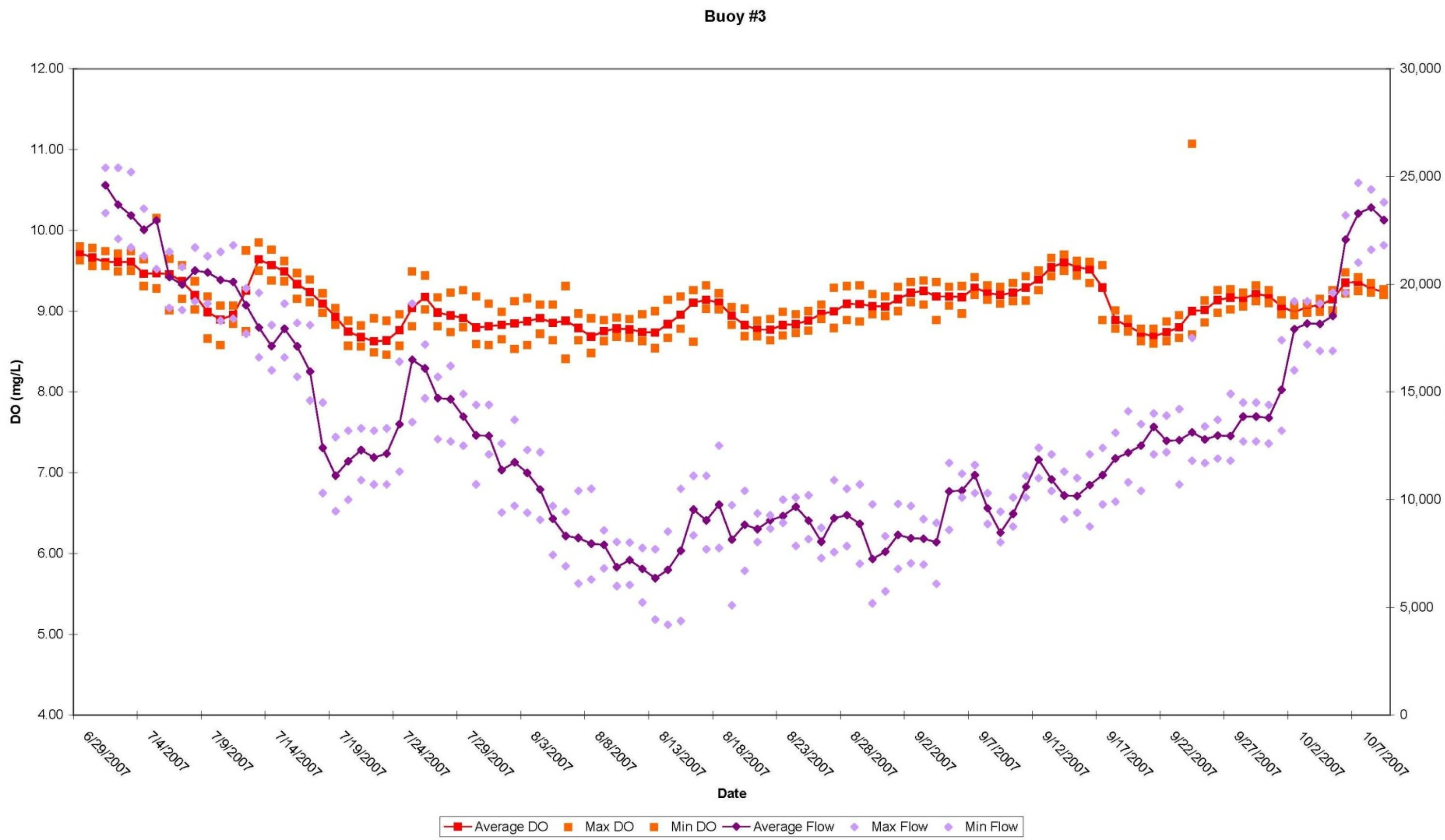


Figure A.3-9. Buoy 3 (downstream) daily average DO values and daily average flow rate from 6/29/07 to 10/09/07 at site M6.

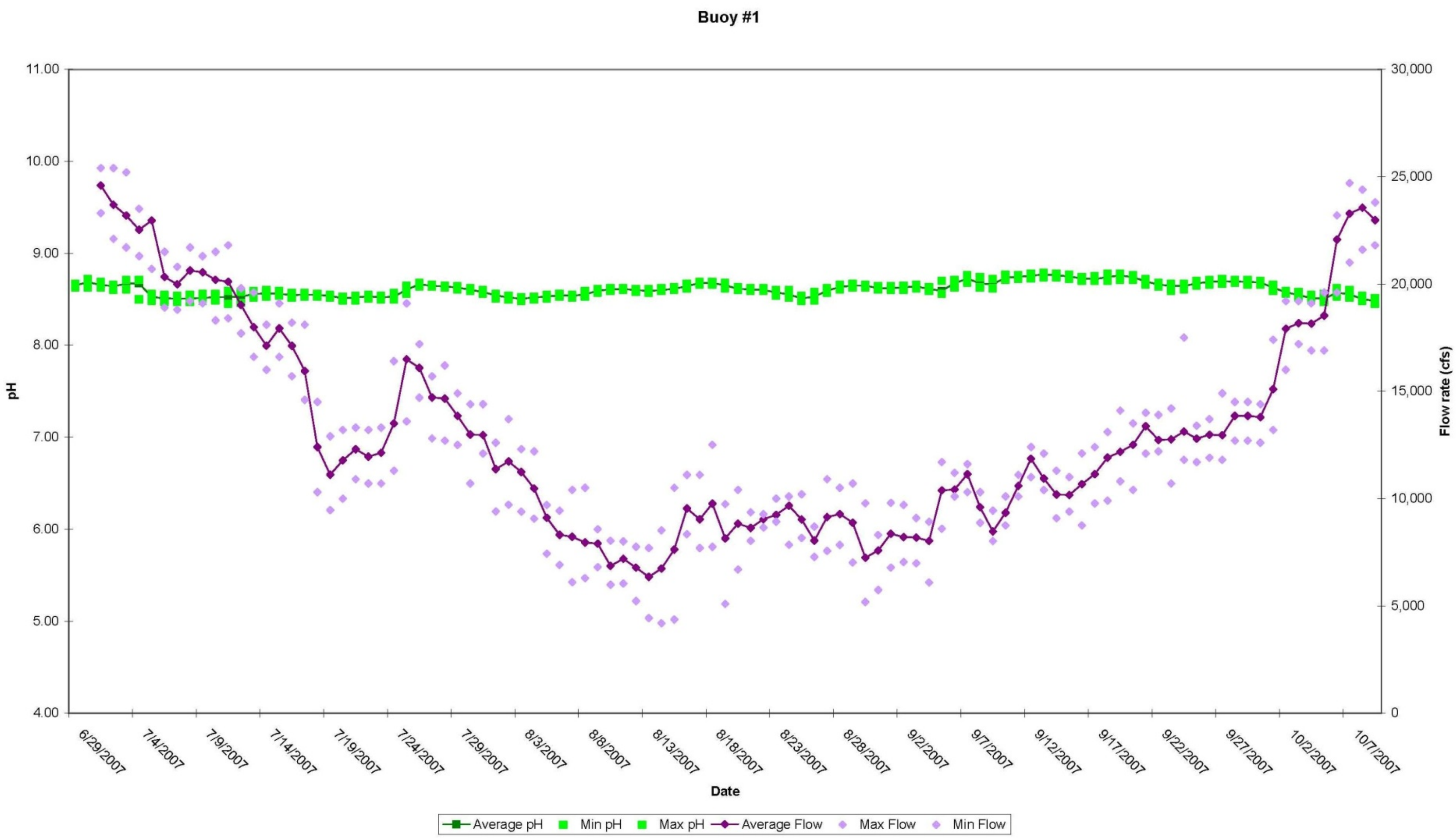


Figure A.3-10. Buoy 1 (upstream) daily average pH values and daily average flow rate from 6/29/07 to 10/09/07 at site M6.

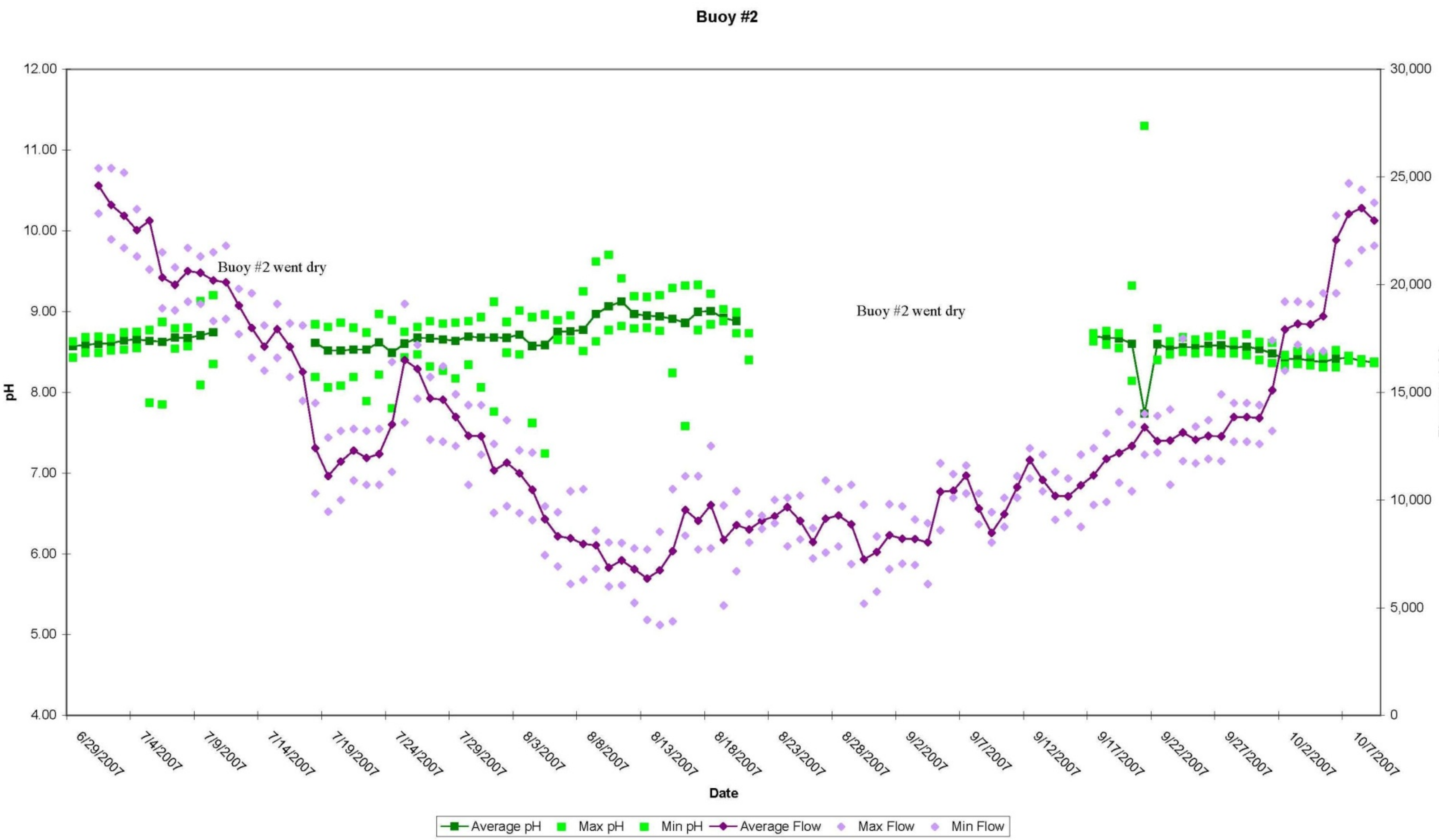


Figure A.3-11. Buoy 2 (macrophyte bed) daily average pH values and daily average flow rate from 6/29/07 to 10/09/07 at site M6.

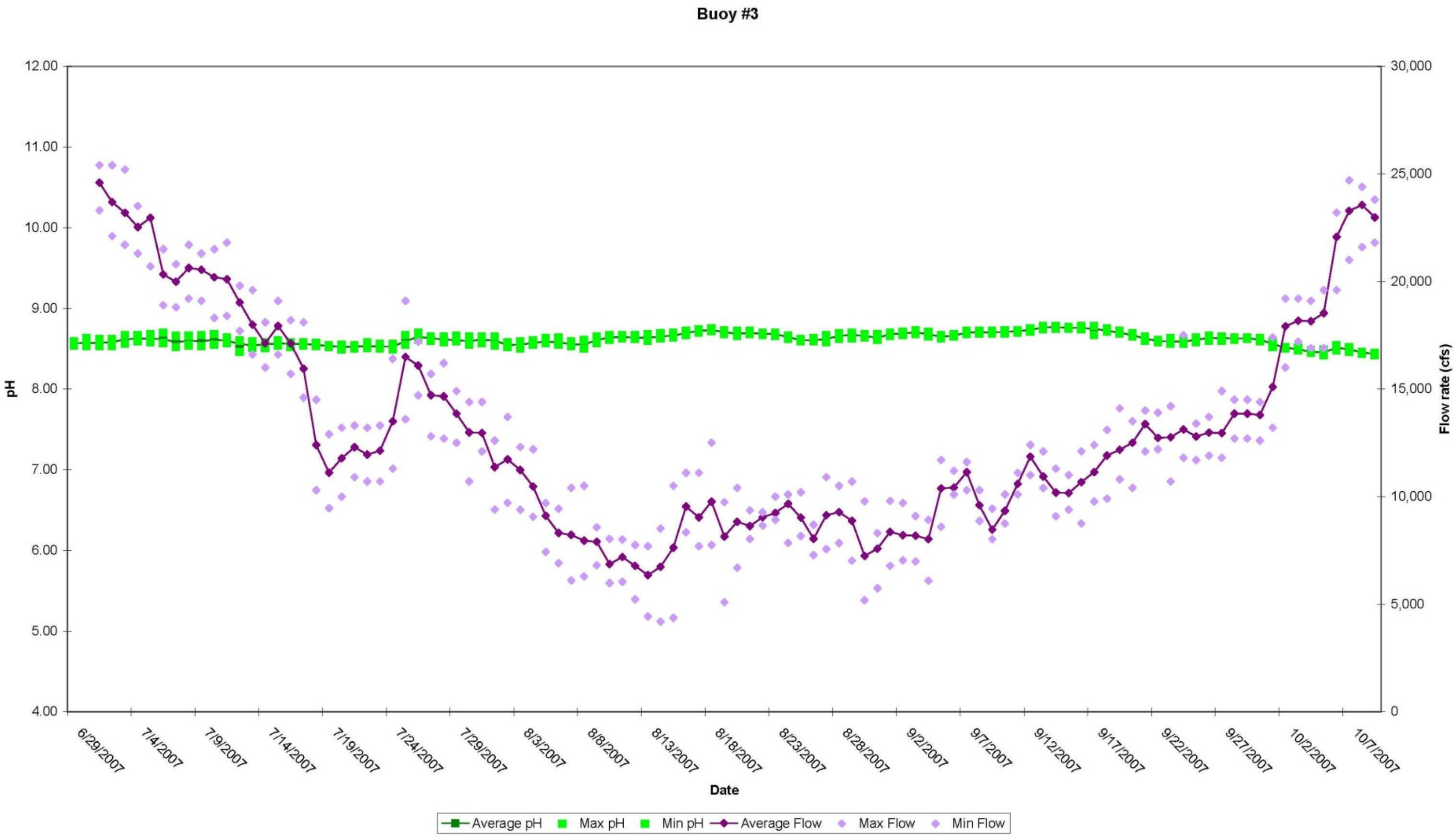


Figure A.3-12. Buoy 3 (downstream) daily average pH values and daily average flow rate from 6/29/07 to 10/09/07 at site M6.

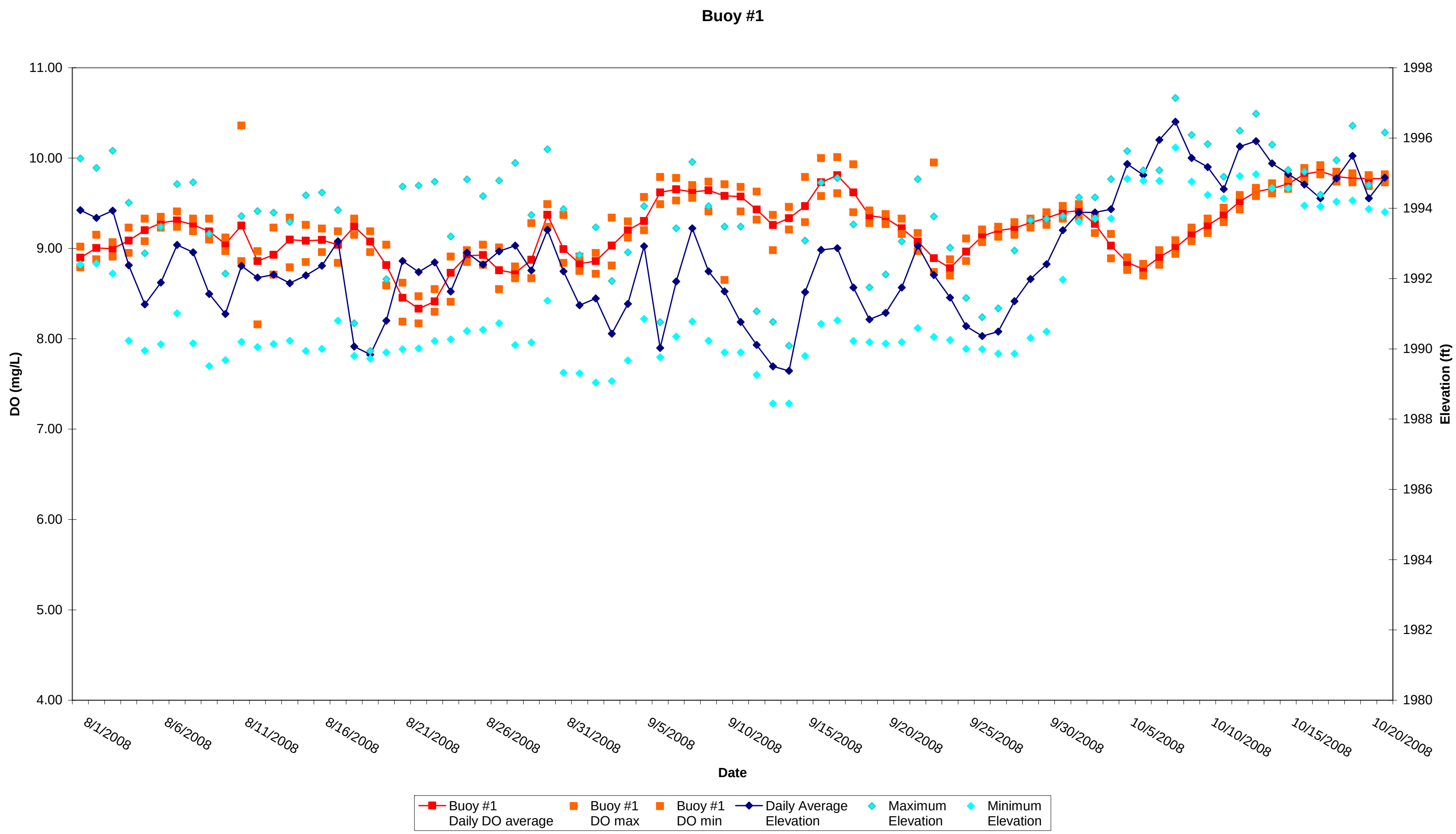


Figure A.3-13. Buoy 1 (upstream) daily average DO values and daily average pool elevations from 8/01/08 to 10/21/08 at site M6.

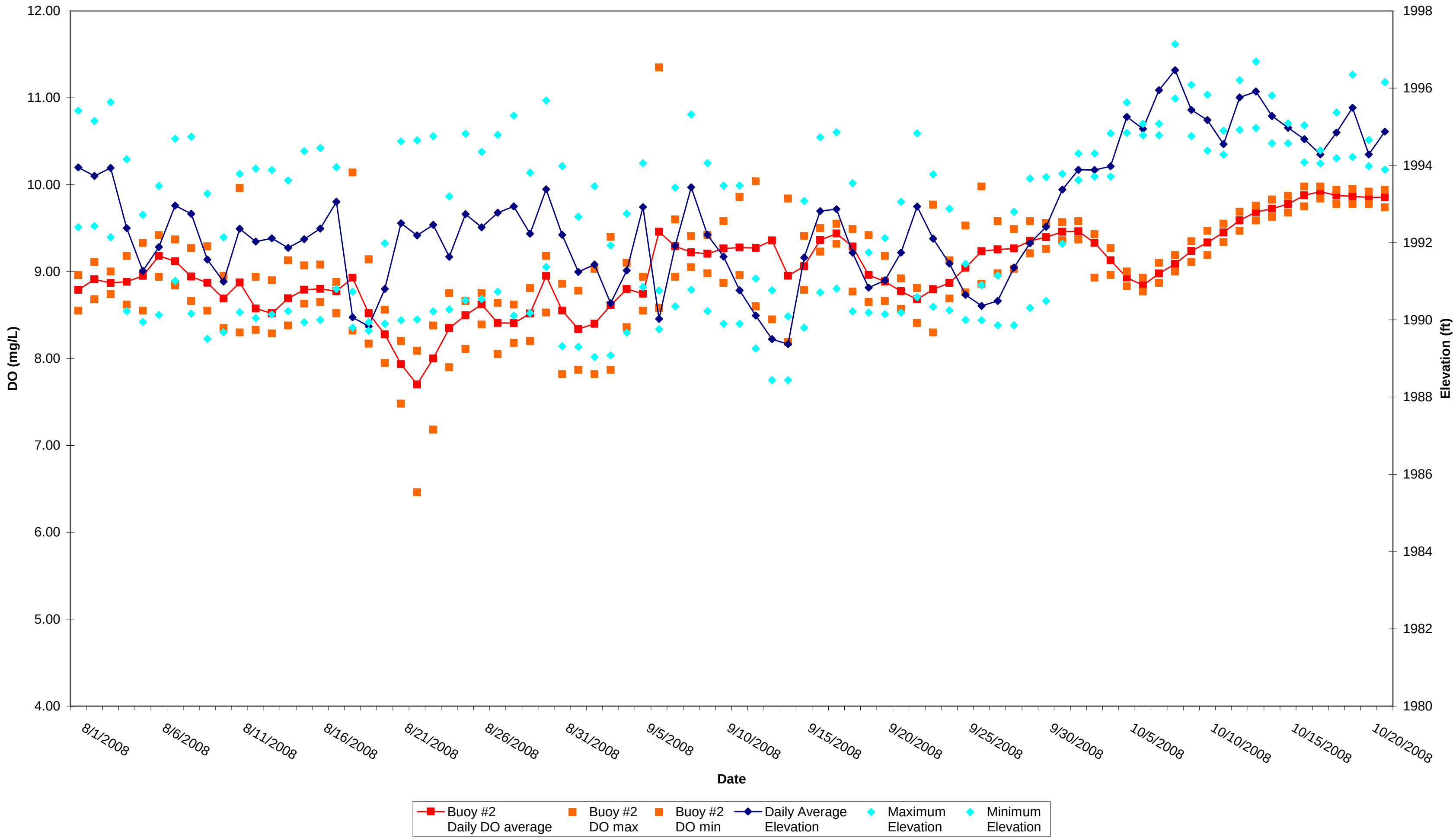


Figure A.3-14. Buoy 2 (macrophyte bed) daily average DO values and daily average pool elevations from 8/01/08 to 10/21/08 at site M6.

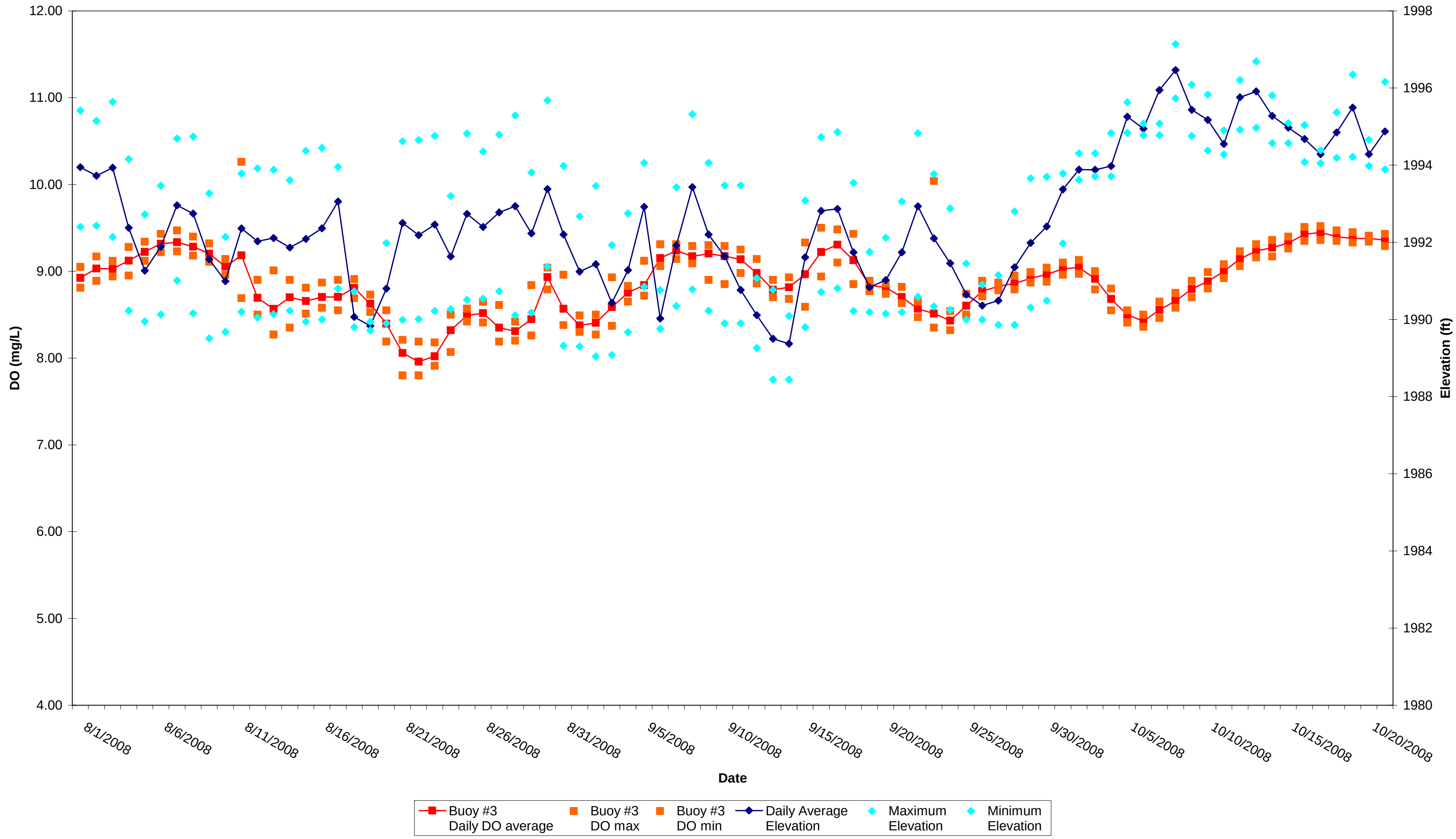


Figure A.3-15. Buoy 3 (downstream) daily average DO values and daily average pool elevations from 8/01/08 to 10/21/08 at site M6.

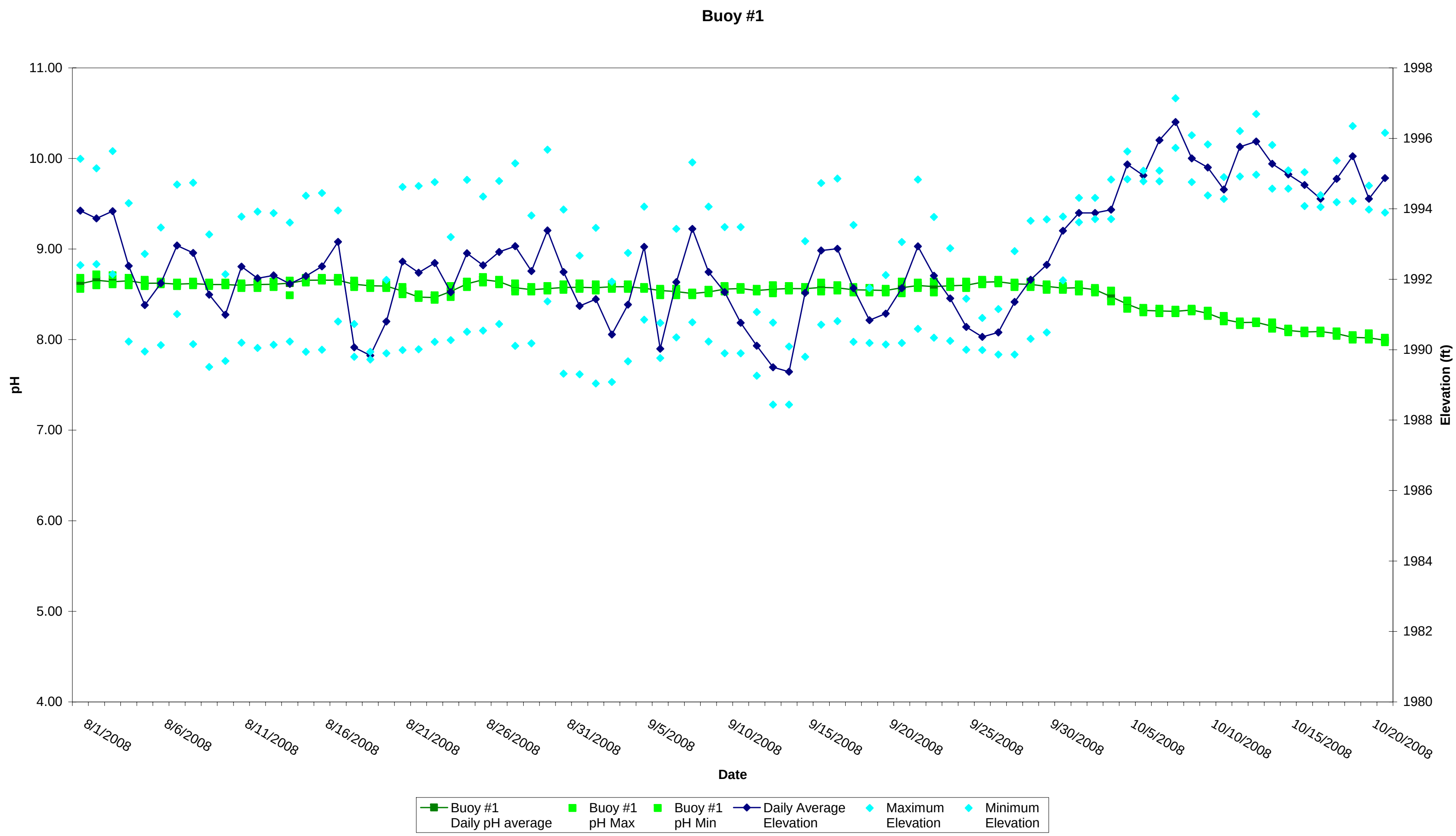


Figure A.3-16. Buoy 1 (upstream) daily average pH values and daily average pool elevations from 8/01/08 to 10/21/08 at site M6.

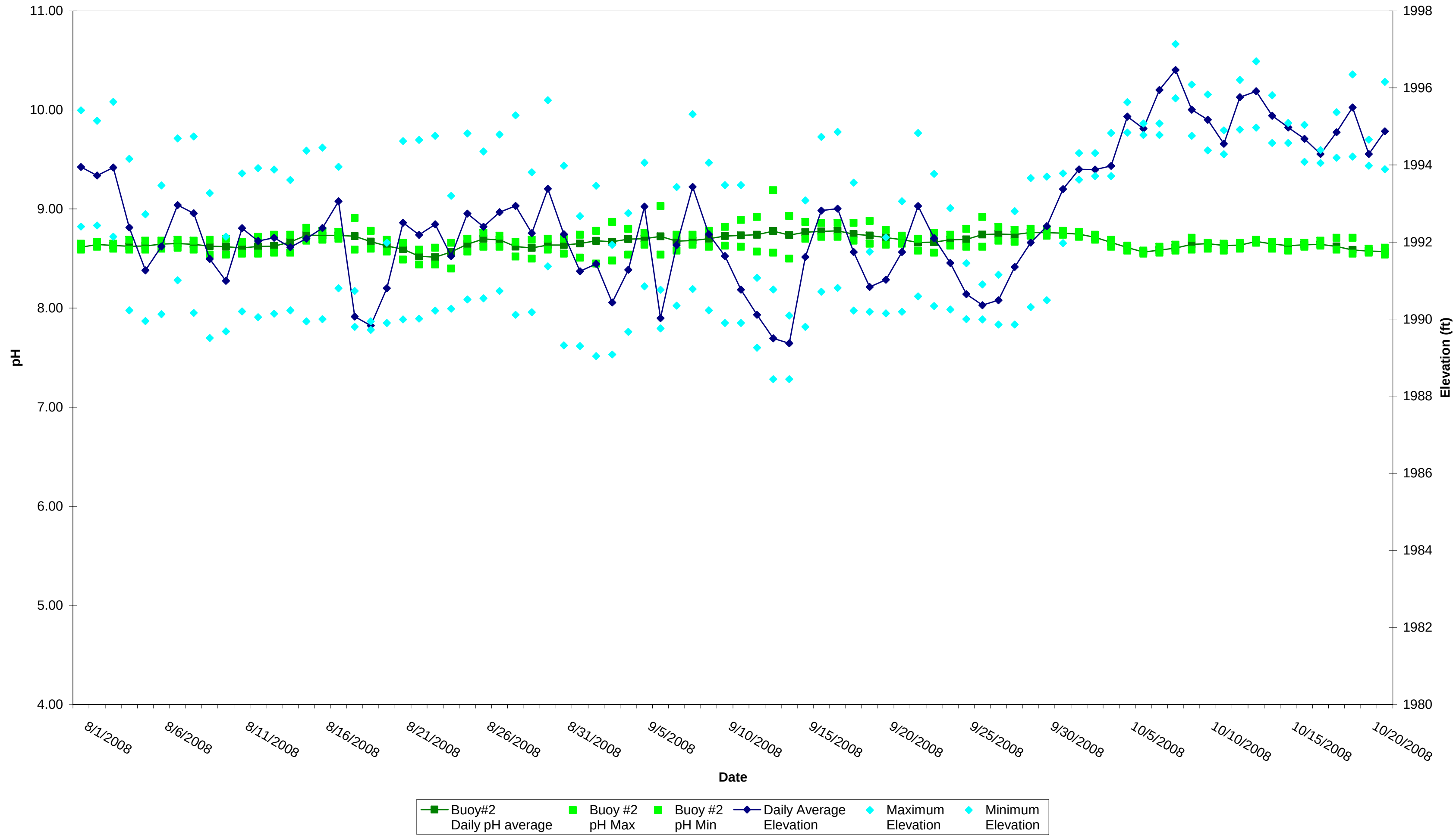


Figure A.3-17. Buoy 2 (macrophyte bed) daily average pH values and daily average pool elevations from 8/01/08 to 10/21/08 at site M6.

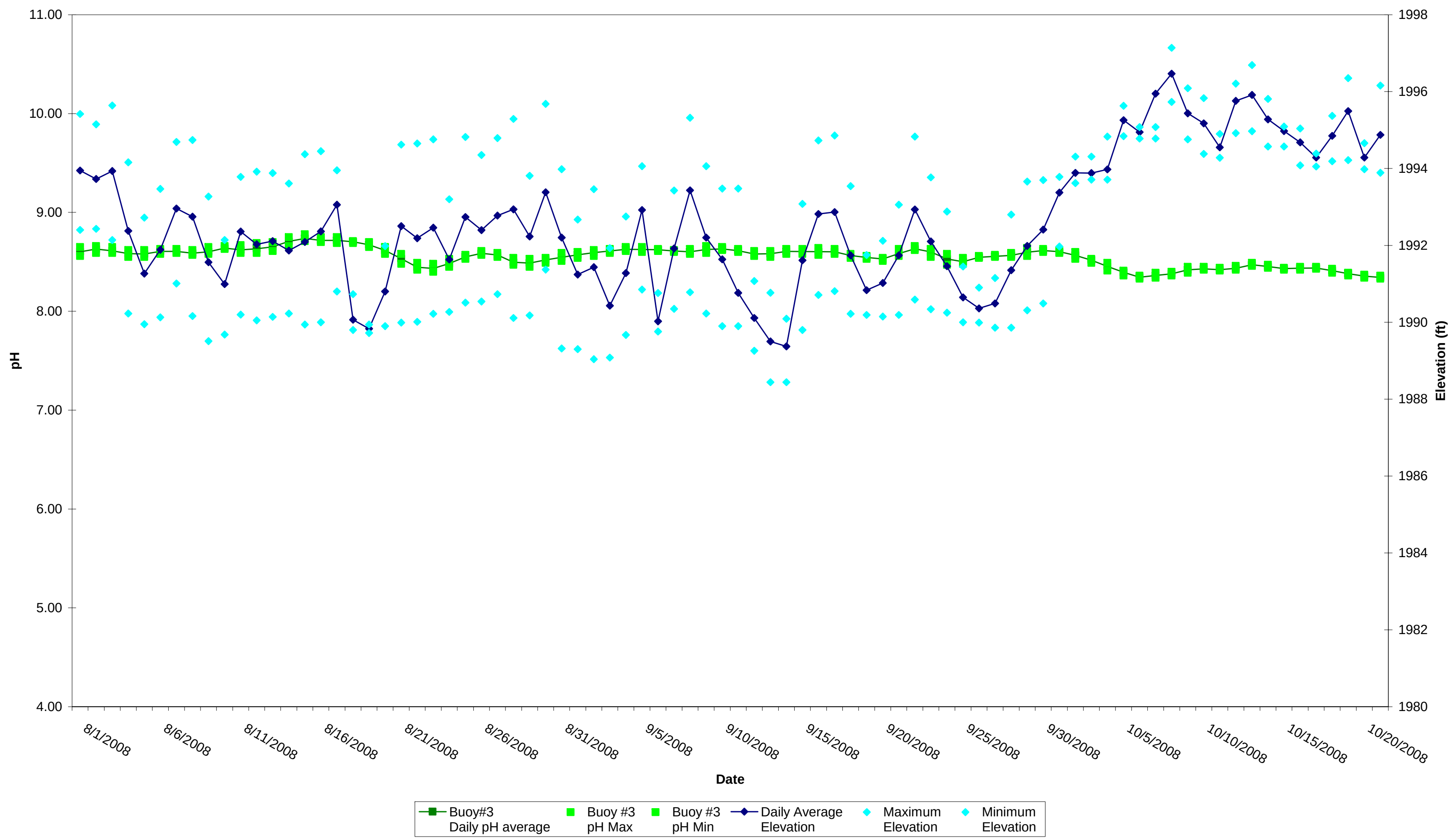


Figure A.3-18. Buoy 3 (downstream) daily average pH values and daily average pool elevations from 8/01/08 to 10/21/08 at site M6.

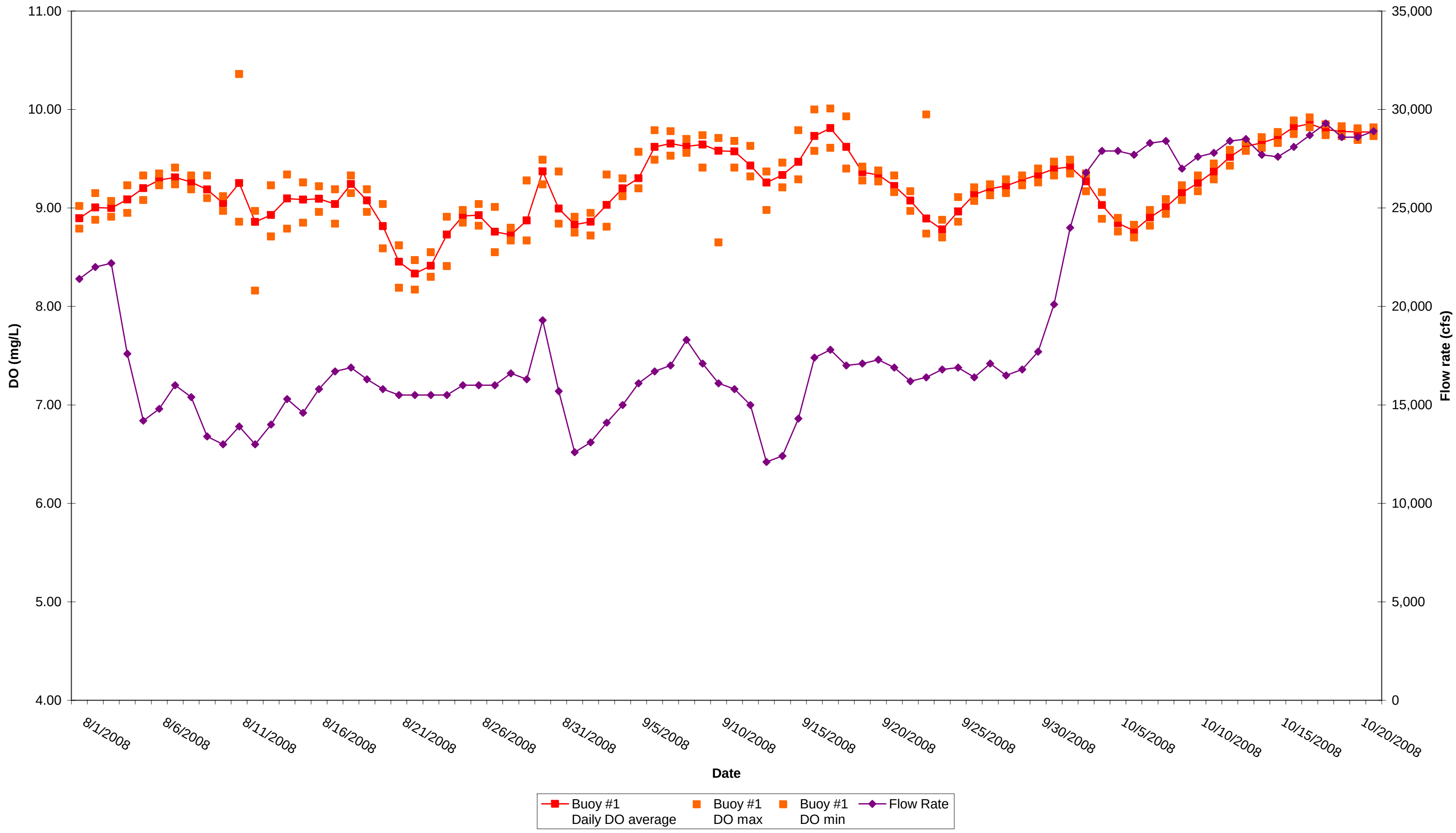


Figure A.3-19. Buoy 1 (upstream) daily average DO values and daily average flow rate from 8/01/08 to 10/21/08 at site M6.

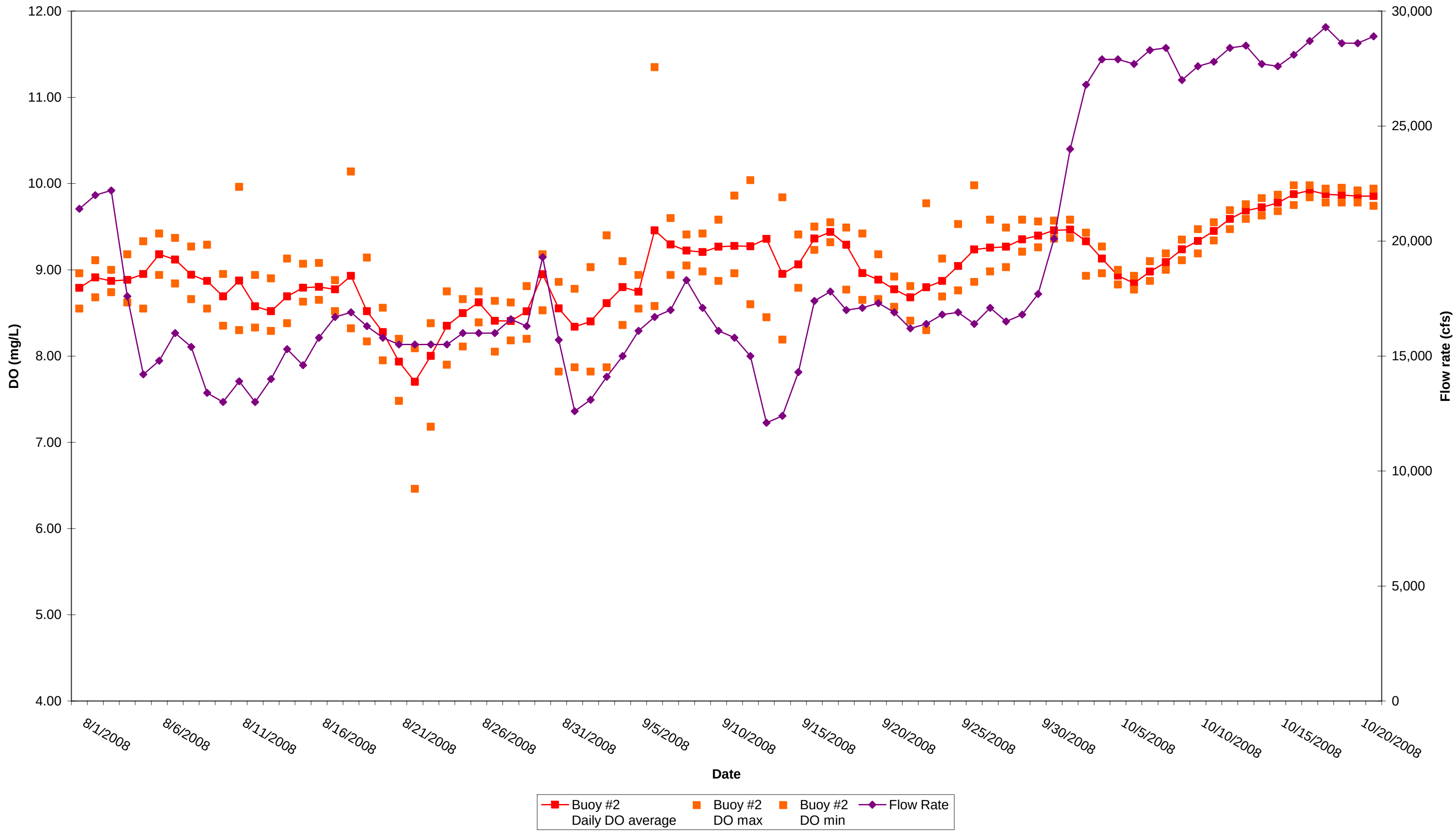


Figure A.3-20. Buoy 2 (macrophyte bed) daily average DO values and daily average flow rate from 8/01/08 to 10/21/08 at site M6.

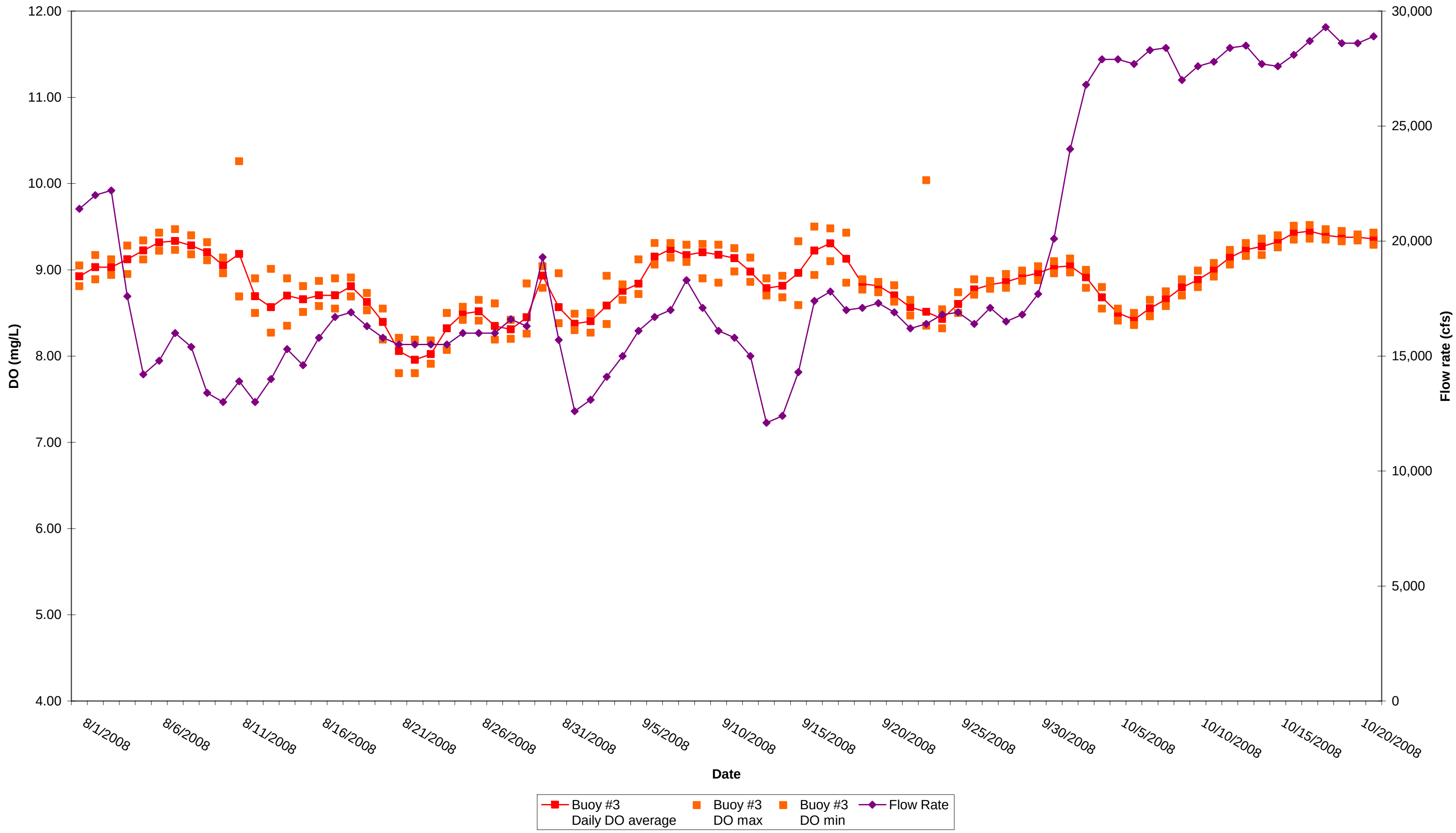


Figure A.3-21. Buoy 3 (downstream) daily average DO values and daily average flow rate from 8/01/08 to 10/21/08 at site M6.

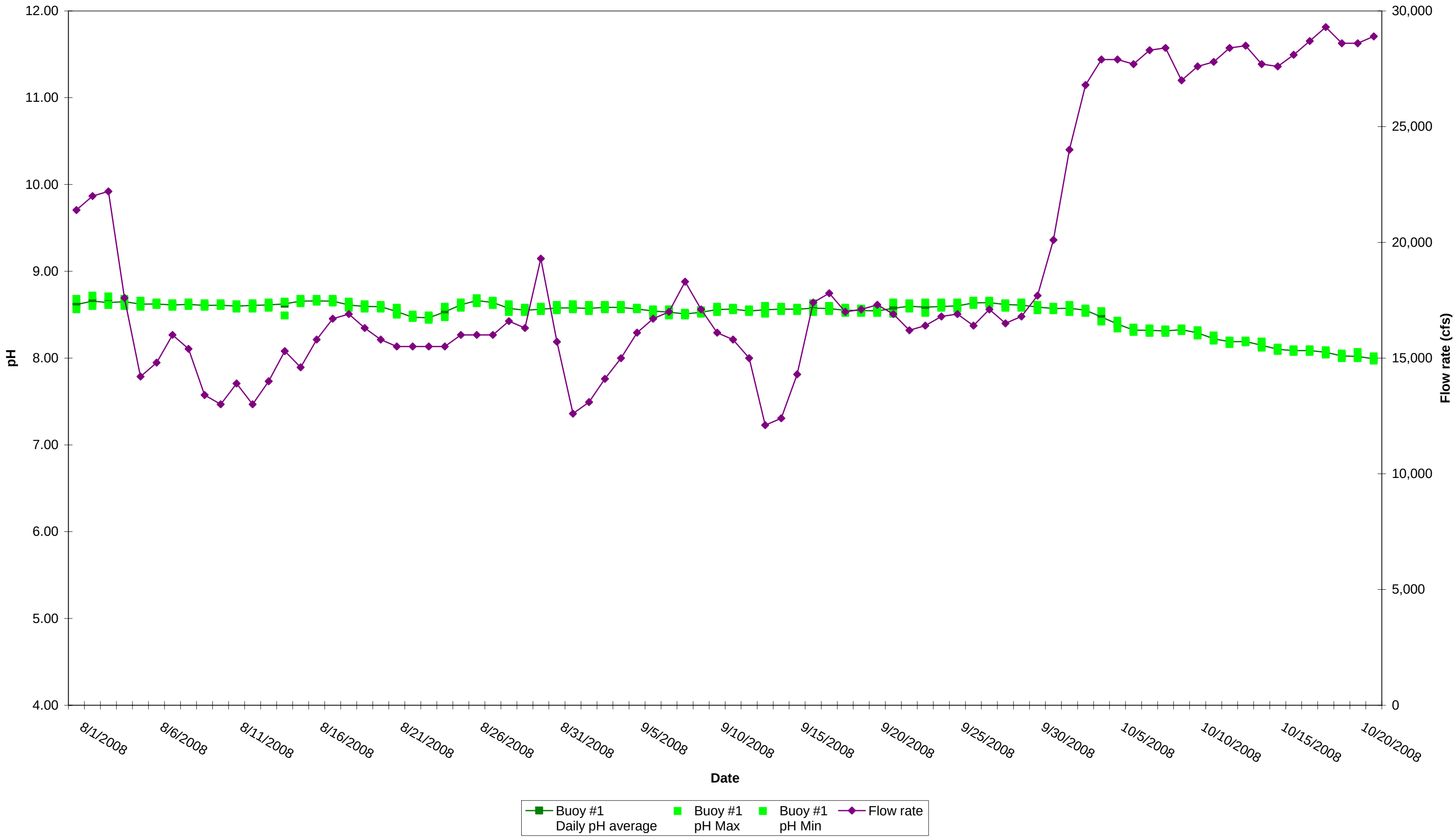


Figure A.3-22. Buoy 1 (upstream) daily average pH values and daily average flow rate from 8/01/08 to 10/21/08 at site M6.

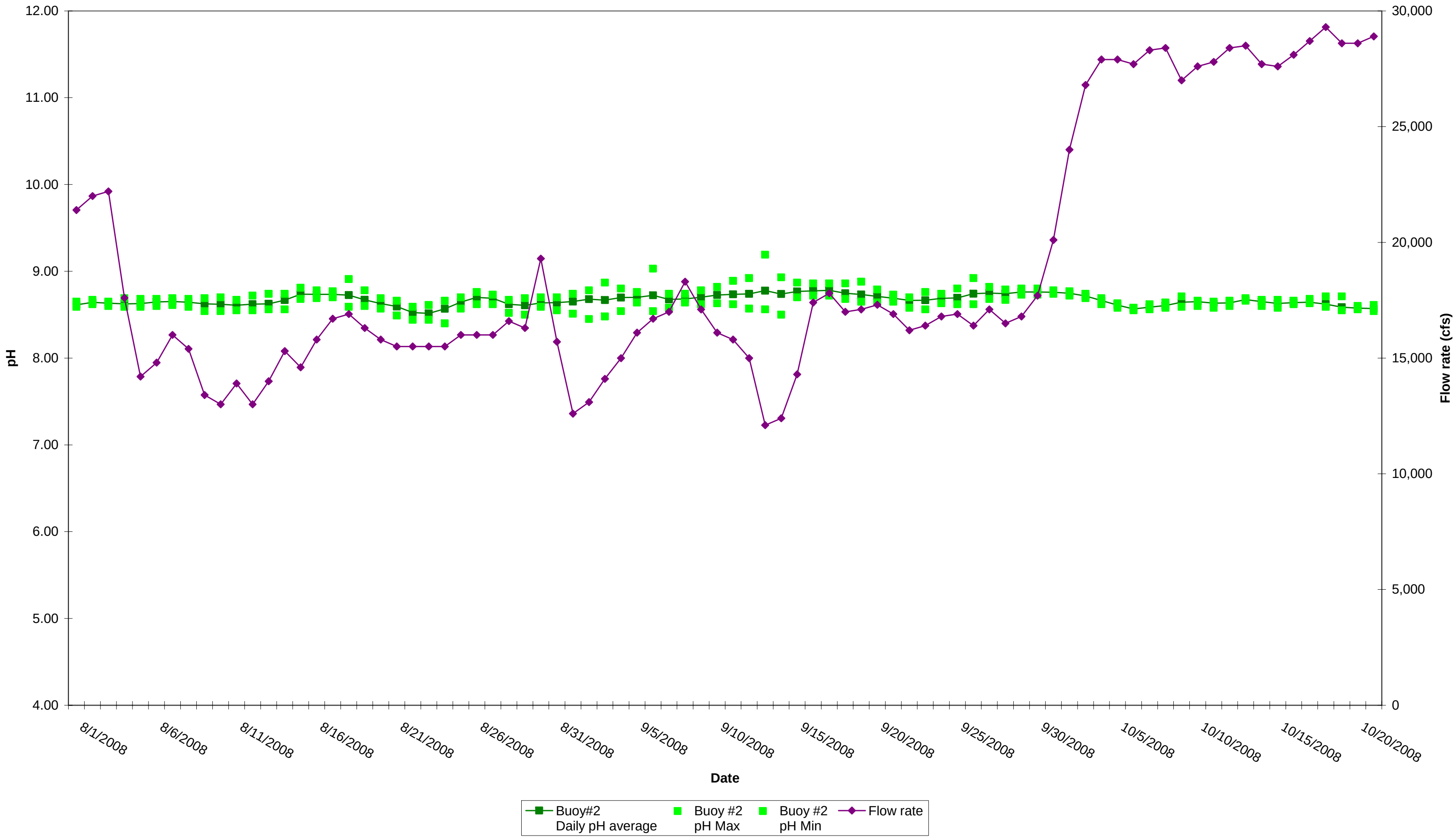


Figure A.3-23. Buoy 2 (macrophyte bed) daily average pH values and daily average flow rate from 8/01/08 to 10/21/08 at site M6.

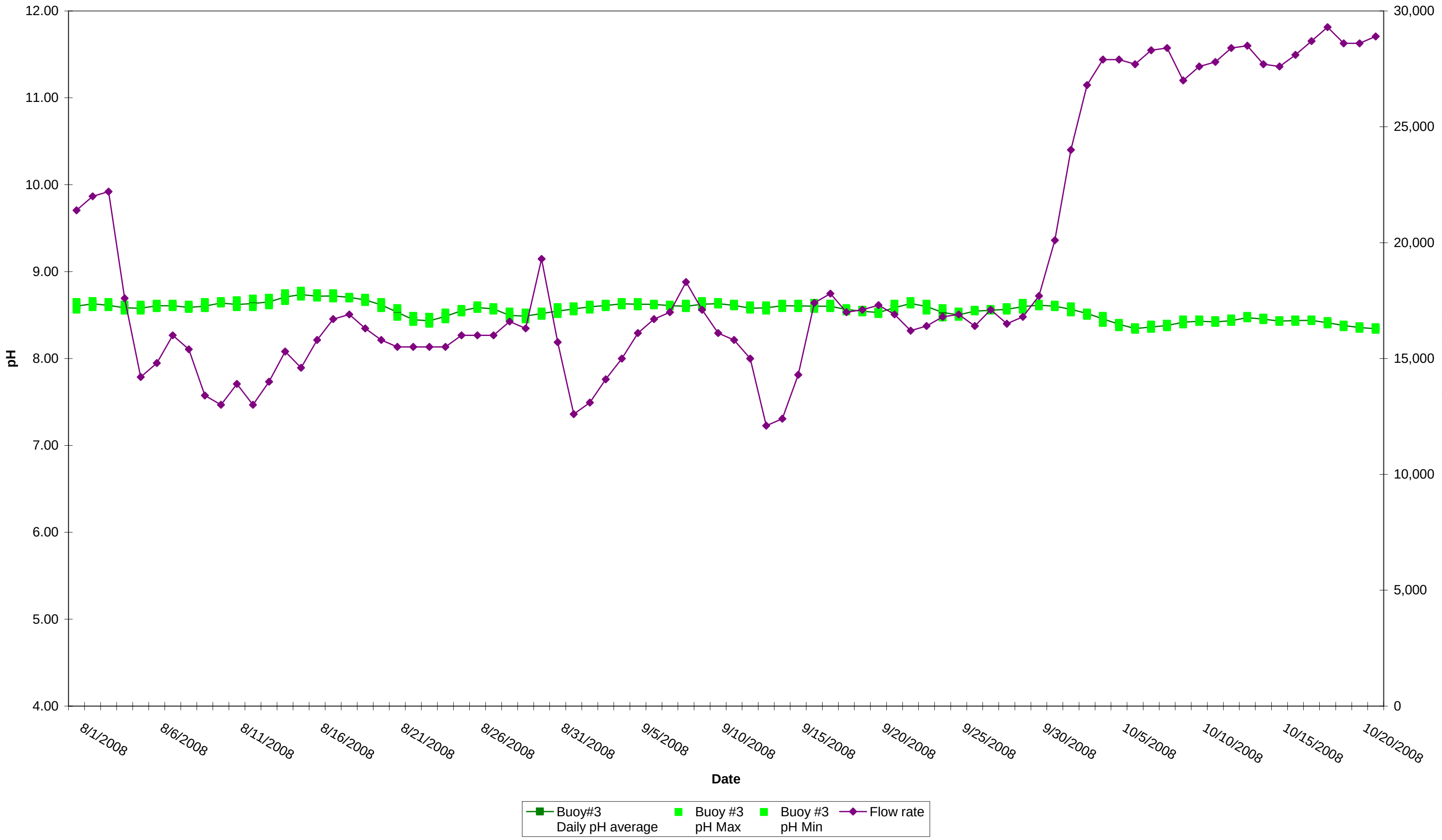


Figure A.3-24. Buoy 3 (downstream) daily average pH values and daily average flow rate from 8/01/08 to 10/21/08 at site M6.