Final Technical Report

Assessment of an Intake Barrier for Water Quality Control at Iron Gate Reservoir – 2013 Study Results

Prepared for

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1.0 INTRODUCTION

On February 18, 2010, the United States, the states of California and Oregon, PacifiCorp, Native American tribes, and a number of other stakeholder groups signed the Klamath Hydroelectric Settlement Agreement (KHSA). The KHSA lays out the process for additional studies, environmental review, and a determination by the Secretary of the Interior regarding whether removal of four dams owned by PacifiCorp on the Klamath River will advance restoration of the salmonid fisheries of the Klamath Basin and is in the public interest (which includes local communities and tribes).

The KHSA includes provisions for the interim operation of the dams and mitigation activities prior to potential removal of the hydroelectric facilities. One such provision—titled Interim Measure 11: Interim Water Quality Improvements—emphasizes water quality improvement projects in the Klamath Basin during the interim period.

As a means of improving water quality downstream of Iron Gate Reservoir, located in Northern California near the Oregon border, PacifiCorp implemented a multi-year study to assess the efficacy of an intake barrier to potentially reduce cyanobacteria entrainment into the existing Iron Gate Reservoir intake.

An intake barrier could provide a straightforward means of controlling the depth at which intake waters are withdrawn from the reservoir at or near the surface; thus, providing a method for potentially reducing the amount of algae entrained into the Iron Gate intake and discharged from the powerhouse. Specifically, for this study, the focus of control is on reducing the cyanobacteria (i.e., *Microcystis aeruginosa*) and potential associated algal toxin (i.e., microcystin) concentrations downstream of the reservoir in the Klamath River. To assess the potential for a barrier that could easily be fitted to the existing intake to accomplish this, an understanding of the relationship between in-reservoir velocities, the intake barrier, and diel movements of algae in the reservoir were developed.

The first phase of the study established baseline velocity conditions near the log boom and intake tower and informed the second phase of the study. The second phase of the study tested the deployment of a barrier fitted directly onto the intake tower and assessed the effects of that deployment on velocity profiles and downstream water quality conditions. The third phase of the study determined the effects of the intake barrier over longer periods of deployment (i.e., days). Coupled with these deployments was a study of diel movement and the vertical distribution of algae in the reservoir to inform the further refinement of concepts related to algae exclusion from the reservoir intake. The fourth phase of the study, conducted in 2013, focused on performing a bathymetric survey of the reservoir to understand the complex dynamics that occur in the reservoir, especially near the intake tower. ADCP velocity transects were also performed to generate comprehensive and detailed velocity profiles near the A-frame log structure immediately upstream of the intake tower and the log boom approximately 1,800 feet upstream of the dam. A vertical profile buoy device (vertical profiler) borrowed from the United States Environmental Protection Agency was also deployed in the reservoir during the 2013 study. However, due to strong wind conditions at the reservoir during the field study period, the cable that connected the multi-parameter sonde to the vertical profiler became tangled and limited vertical profile data were recorded during the study.

This report presents the findings of the fourth phase of the study conducted in 2013. Section 2 provides background information on the Iron Gate intake tower. Section 3 summarizes the prior – first, second, and third – phases of the study. Section 4 describes the study approach and methods for the fourth phase. Section 5 presents and discusses results, followed in section 6 by conclusions and recommendations.

2.0 BACKGROUND

Iron Gate Dam, completed in 1962, impounds Iron Gate Reservoir, which has a storage capacity of approximately 53,000 acre-feet at normal full pool (PacifiCorp 2004). The outlet works consist principally of an intake tower for the Iron Gate Powerhouse, two fish hatchery intakes, an overflow weir spillway with a leaf gate (Table 1, Figure 1), and a low-level outlet tunnel from the original construction. The low-level outlet is not used during normal operations. The intake tower is screened with a trash rack that extends from above the water surface to the bottom of the structure, which is approximately the invert of the penstock intake to the powerhouse. In addition, there is a small debris boom structure (termed herein “A-frame debris boom”, or simply “A-frame”) attached to the upstream face of the intake tower to prevent larger floating debris from impinging on the intake trash rack. Water depth near the intake tower is approximately 10 m (35 ft) at maximum reservoir operating elevation (709.6 m msl [2,328 ft msl]), but varies with powerhouse operations, with a normal low operating elevation of 708.4 m msl (2324 ft msl).

Table 1. Iron Gate Dam Outlet Facilities Information (PacifiCorp 2002)
English units are also presented in parenthesis.

Outlet	Diameter/Width/Length (m)	Invert (m msl)	Capacity (cfs)
Iron Gate Powerhouse Intake Tower	3.7 m (12 ft) Diameter	699 m (2,293 ft)	52.4 cms (1,850 cfs)
Upper Fish Hatchery Intake	0.6 m (2 ft) Diameter	704 m (2,309 ft)	1.4 cms (50 cfs)
Lower Fish Hatchery Intake	0.6 m (2 ft) Diameter	687 m (2,253 ft)	1.5 cms (50 cfs)
Leaf Gate[a]	3.1 m (10 ft) Width	708 m (2,322 ft)	13.0 cms (460[b] cfs)
Spillway (Weir)	220.7 m (724 ft) Length	710 m (2,328 ft)	2,011 cms (71,000[c] cfs)

[a] Source: PacifiCorp.

[b] At 709.8 m (2,328.5 feet) (at the water surface elevation).

[c] At 713.8 m (2,342.0 feet) (at the water surface elevation).

Figure 1. Iron Gate Reservoir Intake Tower, Trash Rack, and A-frame Debris Boom.

3.0 PREVIOUS STUDY PHASES

The first and second phases of the Intake Barrier Study were completed in 2009 and 2011, respectively. The third phase was completed in 2012. The details describing the methods and results are documented in Deas and Miao (2010) and Appendix A. A general overview of these previous studies is included here to provide background for the objectives and methods of the fourth phase of study conducted in 2013 as discussed below in Section 4.

3.1 2009 Study

The main purpose of the 2009 study was to assess the feasibility of using an Acoustic Doppler Current Profiler (ADCP) for monitoring water column velocities to determine the depth profile (or “envelope”) from where reservoir water was being entrained into the penstock intake (Deas and Miao, 2010). ADCP measurements also were identified as a means to characterize flow conditions prior to and during cover deployment by providing insight into the velocity and direction of water entering the penstock intake immediately upstream of the intake tower.

Velocity measurements were taken with the ADCP along the A-frame debris boom and near the intake tower. Velocity measurements indicated that the velocity profile was not uniform throughout the water column and faster velocities were observed at deeper depths, near the elevation of the penstock intake. Despite the asymmetrical water velocity distribution, the velocity profiles indicated that water was being entrained from all elevations extending from the invert of the penstock intake to the water surface. The velocity profiles supported the hypothesis that installation of an intake barrier cover could potentially reduce cyanobacteria concentrations downstream of Iron Gate Dam by:

- Reducing the amount of surface water (with presumably higher algal concentrations) withdrawn from the reservoir into the penstock intake; and

- Increasing velocities near the penstock inlet at the bottom of the intake tower and thus increasing the contribution of flow into the intake from deeper reservoir waters (with presumably lower algal concentrations).

Based on these results, the second phase of the study was conducted in 2011.

3.2 2011 Study

In 2011, an intake cover was constructed and installed on the Iron Gate intake tower trash rack. The cover consisted of two, 5.2 m by 1.8 m (17 feet by 6 feet), steel-frames that were assembled together and attached to a hoist in front of the intake tower. The hoist allowed the cover to be lowered to different depths (Figure 2). Water quality conditions were characterized prior to and after the cover was deployed (i.e., lowered into place on the intake tower trash rack). Water quality monitoring included physical measurements (i.e., water temperature, dissolved oxygen, and pH); nutrients, algae, and chlorophyll *a* grab samples; and ADCP velocity measurements.

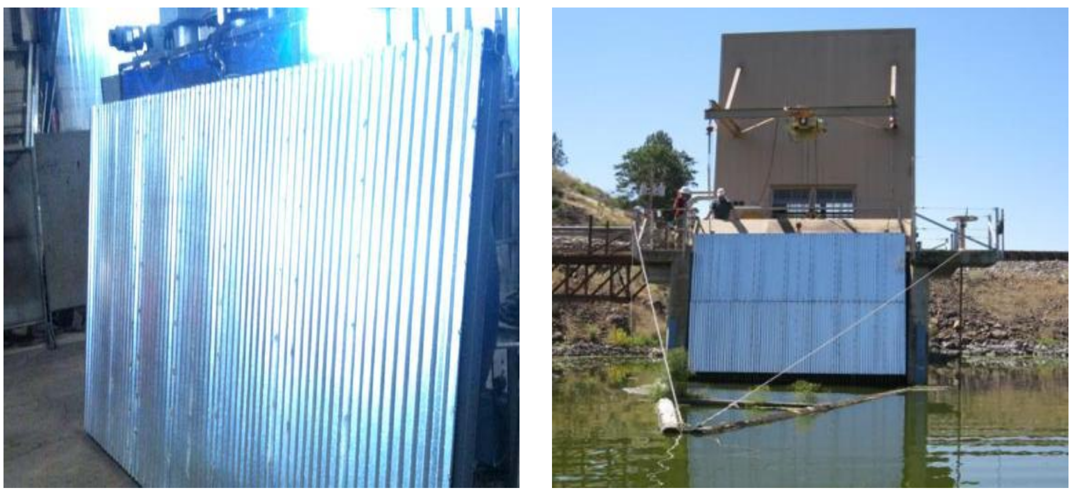


Figure 2. One of Two Steel Frames Shown Prior to Installation (left) and After Installation onto the Intake Tower (right).

The intake cover was placed over the intake tower trash rack to screen the upper portion of the intake at two test deployment depths – 1.8 m (6 ft) and 3.6 m (12 ft)[1] below the surface. The cover was placed at each depth for approximately 45 minutes. During the two test deployment periods, ADCP measurements were taken and indicated an increase in velocity near the penstock intake elevation, indicating the withdrawal profile (or "envelope") was altered due to the placement of the cover. When the intake cover was

[1] The intake trash rack is slightly inclined (one foot horizontal per six feet vertical). Thus the 6 ft and 12 ft cover deployment depths actually correspond to 1.8 m (5.9 ft) and 3.6 m (11.8 ft) of vertical depth. For simplicity, this report will use 6 ft and 12 ft to denote cover deployment depth when referring to English units.

lowered to the test depths, *Microcystis aeruginosa* (MSAE) cell counts were 19 percent and 44 percent lower downstream during the 1.8 m (6 ft) and 3.6 m (12 ft) test deployments, respectively, compared to cell counts when the cover was not present. These results suggested the cover could be an effective means of reducing entrainment of MSAE into downstream releases. Physical water quality parameters, such as dissolved oxygen, temperature, pH, and nutrient concentrations did not change during the two test cover deployments compared to conditions when the cover was not present.

The ADCP velocity data indicated that velocity profiles in the vicinity of the intake tower had not stabilized during the two brief test deployment periods. As a result, it was recommended that the effects of longer-term deployment of the cover should be studied.

The 2011 Iron Gate Cover Study provided insight on the complex hydrodynamics near the intake tower. Based on these findings, recommendations for the third phase of the study included:

- Extend the study period to span two weeks and deploy the cover for longer periods of time (i.e., multiple sequential days) to test the effects of the cover when stable hydraulic conditions are attained as determined from consistent velocity readings over a range of days.
- Conduct a vertical migration study of cyanobacteria within the vicinity of the intake structure by deploying a phycocyanin probe in the reservoir for a full day or over several days (including overnight) to provide information about the depth to which the intake cover should be deployed.

3.3 2012 Study

In 2012, the design of the intake cover study included: (1) increased test deployment periods (multi-day continuous deployment); (2) increased horizontal spatial sampling locations upstream in the reservoir and downstream in the river; (3) additional vertical grab samples in-reservoir at three depths; and (4) continuous sonde measurements upstream of the intake in the reservoir and downstream in the river.

The study spanned the period from August 20, 2012 to August 30, 2012. Prior to the deployment of the cover, one full day of pre-deployment monitoring occurred. Mid-day and afternoon samples were collected on August 20 and a morning sample was collected on August 21. Subsequently, three separate cover deployment events were conducted to a depth of approximately 3.6 m (12 ft). These included a 31-hour deployment on August 22-23 and about a 72-hour deployment during August 27-30.

The results of study included the following observations:

- Cyanobacteria (*Microcystis aeruginosa (MSAE)*, *Aphanizomenon flos-aquae (APFA)*, and *Pseudo-anabaena (PSAB)*) were observed to be vertically segregated at or near the surface in the vicinity of the intake. This is an important finding since an intake barrier would be infeasible if vertical segregation of algal species in the upper portion of the water column was not observed.

- Most primary production during the study occurred in water depths of less than 9.1 m (30 ft). This was consistent with data provided by Lincoff (Andy Lincoff, EPA, pers comm). Considerably more algal biomass was observed in near-surface waters (surface to 4.6 m (15 ft)).

- The velocity, algae species, and phycocyanin data collected during the 2012 study suggest that barrier deployment to its full depth of approximately 3.6 m (12 ft) results in short-term changes in local in-reservoir velocities and reductions in downstream cyanobacteria concentrations. These changes occurred over a period of less than 24 hours, and then appeared to diminish thereafter as the hydraulics in the vicinity of the intake adjusted over time in response to the placement of the barrier and more near-surface water is entrained. The data also indicated that conditions in the reservoir, particularly the concentrations and distribution of algae, are variable spatially and temporally (**Figure 3**).

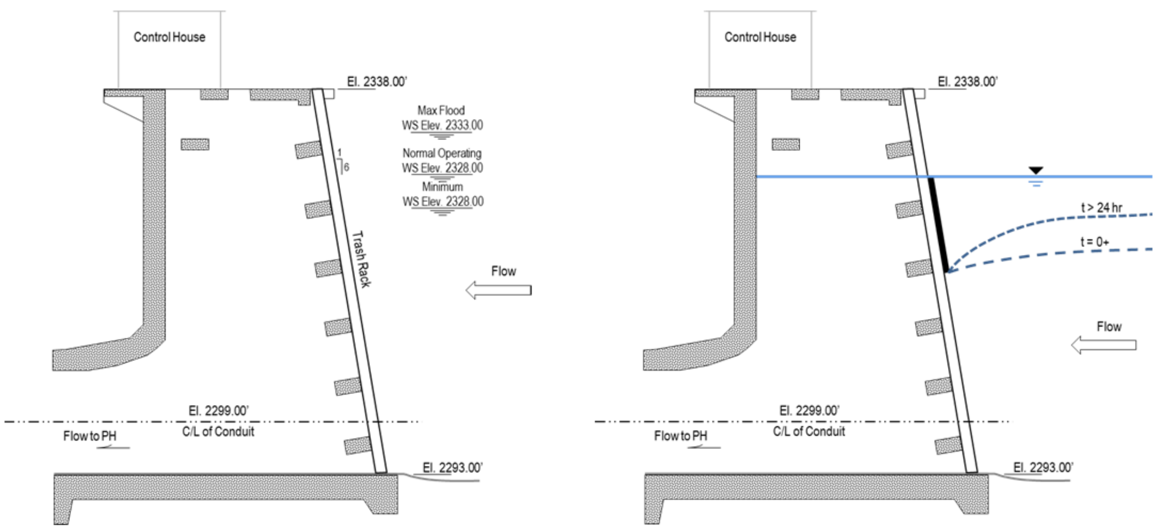


Figure 3. Profile View of the Iron Gate Intake Tower (left) Showing the Trash Rack, Elevation of the Powerhouse (PH) Penstock Invert and Centerline, and Range of Operating Elevations and (right) Depiction of Intake Zone with Cover in Place for the Period Shortly after Deployment (t=0+) and after 24 hours (t>24 hr).

Based on these findings, recommendations for further studies included:

- Conduct a bathymetric survey and ADCP measurements in the vicinity of the intake tower to improve the interpretation of data collected to date and to inform potential future work to better understand local velocities and hydraulics near the intake and assist in the design of an improved intake barrier system.

- Variable diel cover deployment durations (e.g., daytime only, nighttime only) of the existing cover should be considered for future test deployments with additional downstream sample collection to provide additional insight into the effects of cover deployment.

- A weather station should be installed at or near Iron Gate Dam to characterize meteorological (i.e., cloud cover, wind speed, air temperature) conditions. Site-specific meteorological data would enhance the understanding of factors affecting reservoir hydrodynamic and thermal conditions.

- Consideration should be given to the design and deployment of a cover with a depth greater than 12 feet since a deeper cover may more effectively isolate surface water and with more persistent effects.

The 2013 study focused on the first recommendation above. The second recommendation was addressed in part daily operation of the cover for several weeks during the fall of 2013. These barrier operations occurred late in the year after much of the thermal stratification had broken down and had no discernible impacts on downstream water quality. However, testing the deployment of the cover on a daily basis informed the feasibility of such operations. The third recommendation was addressed through the installation of a meteorological station at Iron Gate Reservoir in the late summer of 2013. Finally, the fourth recommendation was not pursued since PacifiCorp indicated that a deeper cover deployment could create conditions in which a cover could be difficult to deploy and retrieve from the intake, and since prior results indicated that a reduction in approach velocities with a barrier system to reduce vertical velocity gradients would likely be a more productive approach to reduce algae entrainment at the intake.

3.4 2013 Study Approach and Methods

Based on the findings and recommendations of the 2012 study (as described above), the design of the 2013 study included: (1) perform a 2-week vertical profile of total algae and physical water quality using the YSI EXO2 sonde attached to a vertical profiler buoy device; (2) complete a bathymetric survey of the reservoir from the A-frame to the log boom; (3) collect ADCP measurements using the RiverRay to create velocity boundary conditions at the A-frame and at the log boom for assistance in the design of an improved intake barrier system.

3.4.1 Study Duration

The 2013 study at Iron Gate Reservoir occurred on three days: August 27, August 28, and November 7, 2013. In August, the bathymetry survey occurred in the morning and the ADCP velocity measurements in the afternoon. In November, a bathymetric survey occurred near the intake tower in the morning.

3.4.2 Meteorological Station

PacifiCorp completed the installation of a meteorological station at the top of Iron Gate dam in October 2013 to improve hydrologic forecasting for its river operations and gather data that may be useful in ongoing reservoir studies. The meteorological station records air temperature, relative humidity, barometric pressure, precipitation, solar radiation, wind speed and wind direction. PacifiCorp operates and maintains the meteorological station and maintains the data within its operations data management system. Continuous data collection from the station commenced on October 11, 2013. PacifiCorp anticipates this information may assist in future assessment of dynamic water quality conditions within Iron Gate reservoir and in downstream releases.

3.4.3 Total Algae and Physical Sonde Measurements

Due to cable tangling issues, water quality data was not collected for in-reservoir work. Future studies will include a vertical buoy and anchoring system to accommodate Iron Gate Reservoir conditions near the intake. See Section 4.1 for more information.

3.4.4 Bathymetric Survey

A 200-KHz Hydrolite depth-finder was used to survey the Iron Gate reservoir from the dam to the log boom (Figure 4). The survey involved traveling from left bank to right bank, starting near the dam and moving upstream to the log boom. The purpose of the November visit was to refine the bathymetry around the intake tower and left bank where the geometry was notably altered to accommodate vehicles during the construction phase of the tower decades ago. The surveys on August and November required three hours to complete and resulted in over 20,000 data points. The Hydrolite measures depth continuously and synchronizes latitude and longitude data from the Trimble GeoXT 6000 Global Positioning System (GPS). The data is post-processed in SonarMite (by Lymtech LLC) which can be exported to Microsoft Excel and/or plotted using any of various surface modeling software program.

.Figure 4. Trimble GeoXT and Hydrolite-TM boat setup in Iron Gate Reservoir.

3.4.5 ADCP Velocity Measurements

A RiverRay ADCP (by Teledyne) was used to measure water column velocities in Iron Gate Reservoir. A transect consisted of traveling from one bank to other while the ADCP was measuring instantaneous data. Transects ranged from one to three minutes in duration near the dam and four to five minutes at the log boom. Transects were measured at two locations: near the A-frame and at the log boom (Figure 5). The boat speed for each transect was approximately 1.0 m/s (3.3 ft/s). A Hemisphere R130-RTK was used to collect GPS data. Multiple transects are recommended at each location to ensure data are consistent (Dan Murphy pers. comm.). The locations and transect start times for August 27 and 28 are presented in Table 2.

Table 2. Start times for ADCP velocity transects at the three locations: at the A-frame and the log boom. GPS coordinates are based off WGS 84 datum

Location	Start and End Points	August 27, 2013	August 28, 2013
A-frame	41° 56.061306' N, 122° 26.074449' W 41° 56.057021' N, 122° 26.111287' W	4 Transects (12:33:41, 12:35:09, 12:36:57, 12:38:57)	4 Transects (12:12:44, 12:14:12, 12:17:20, 12:22:34)
Log boom	41° 56.245766' N, 122° 25.842522' W 41° 56.342426'N, 122° 25.992737' W	3 Transects (12:09:34, 12:15:05, 12:20:33)	3 Transects (12:42:25, 12:47:36, 12:53:49)

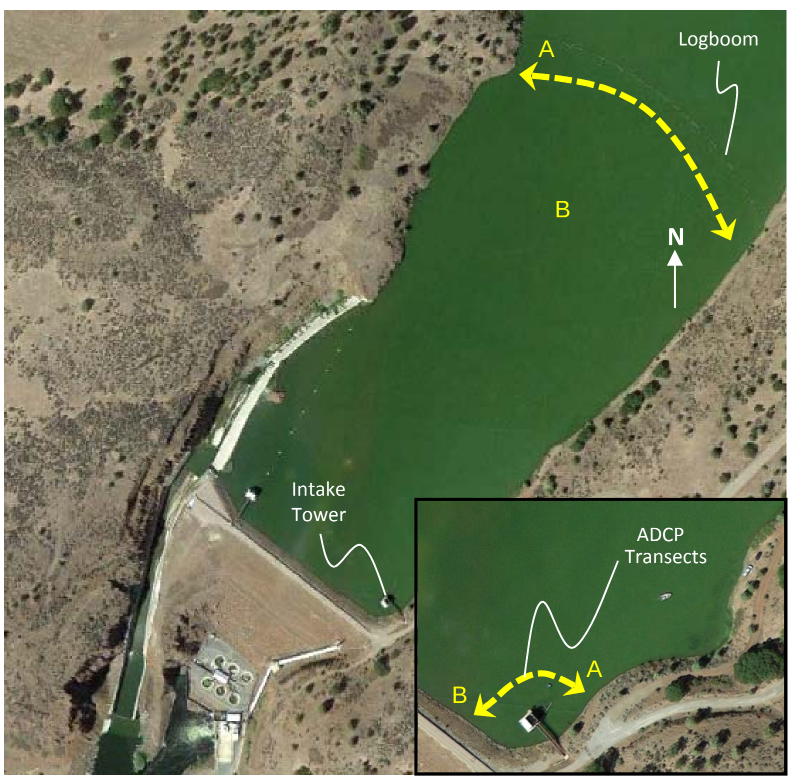


Figure 5. Iron Gate Reservoir; approximate location of ADCP transects near the intake tower and at the log boom (Photo Source: Google Earth).

4.0 RESULTS AND DISCUSSION

The 2013 Iron Gate Reservoir study results are presented and discussed in the following subsections below, including water quality sonde measurements, bathymetric surveys results, and ADCP velocity transects in the reservoir.

4.1 Water Quality Sonde Measurements

In late August 2013, PacifiCorp deployed the YSI-EXO2 multi-parameter sonde attached to a vertical buoy device to measure total algae and physical water quality parameters for several weeks. The buoy device (known as BOB) has been used by the United States Environmental Protection Agency (USEPA) for similar studies.

The BOB consists of a platform measuring 1.2 m by 1.2 m (4 ft by 4 ft) with eye bolts on the side to connect anchors. On the platform, there is a solar cell, a backup battery, and a gray case. Inside the case is a simple mechanical system which controls the raising and lowering of a sonde (attached to a cable and safety line) at specified time intervals and depth. PacifiCorp operators deployed the BOB slightly upstream of the intake tower (Figure 6). Due to wind conditions in the reservoir, the platform moved into shallower water and rotated upon itself, causing the cable that attached to the YSI EXO2 sonde and safety line to become tangled. In August 26, 2013 Watercourse personnel retrieved the YSI EXO2 sonde and added a new cable line, but the cable tangled again the next day. As a result of these deployment challenges, little useful data were acquired during this aspect of the study. The BOB was removed from the intake tower location on September 4, 2013 and deployed at Long Gulch Cove for use in the 2013 algaecide study project.

Figure 6. The vertical buoy device (B.O.B) is deployed upstream of the intake tower in Iron Gate Reservoir (August 2013).

While no long-term data were available from the vertical profiler within the reservoir, a review of data from the water quality station below Iron Gate Dam suggests complex dynamics are at play with respect to blue-green algae concentrations entrained in the Iron Gate intake. As shown in Figure 7, there appears to be little to no pattern in the data from first two weeks of August but then a fairly strong diel pattern in the third and fourth weeks of August. However, this pattern breaks down around August 29, 2013 and there is no discernible pattern for the remainder of the period through late September. In the periods where there was a diel pattern that may be indicative of vertical migration or mixing of BGA, the timing of the maxima and minima was not always consistent. The variability in the timing and magnitude of the swings in BGA cell counts (as indicated by the microcystin sensor), and the lack of a discernible pattern at other times indicates that BGA population dynamics and distribution within Iron Gate reservoir may be affected by vertical migration, reservoir mixing processes (e.g., wind mixing and convective cooling), or both, and these conditions likely contribute to variable BGA concentrations downstream of Iron Gate Dam. Recommendations for future in-reservoir vertical profile monitoring of BGA concentrations and for further monitoring to assess dominant reservoir mixing processes are included at the end of this report.

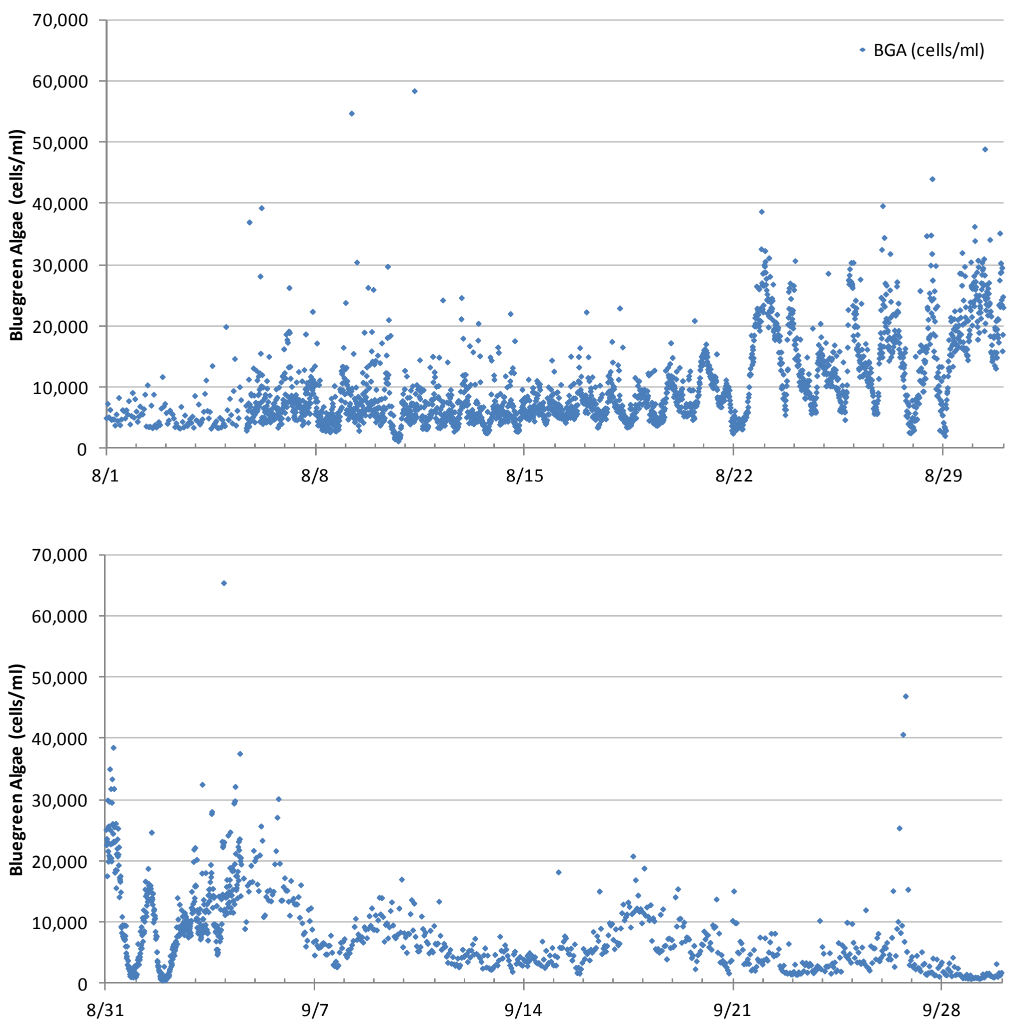
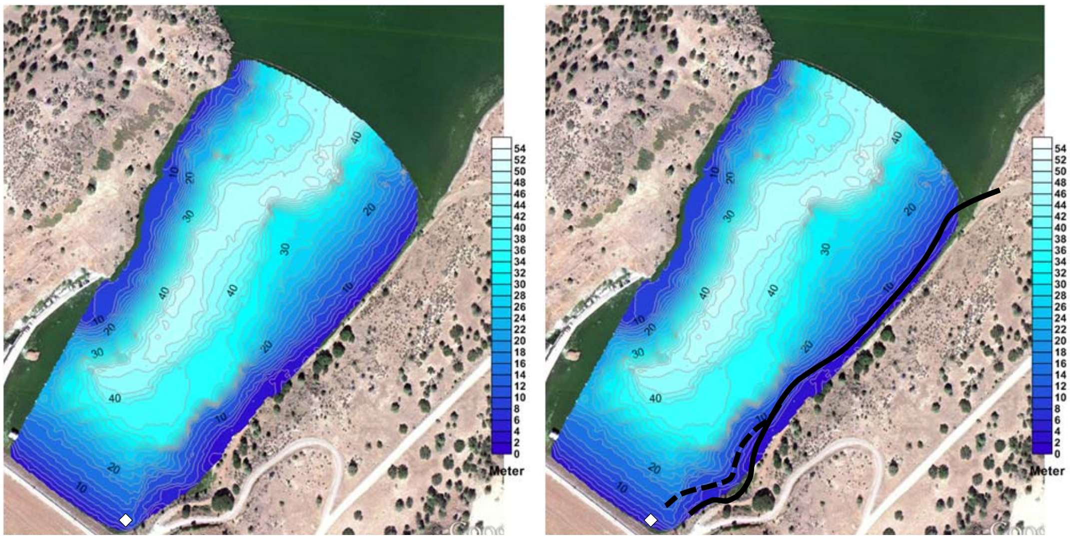


Figure 7. Blue-green Algae Sonde Data below Iron Gate Reservoir for August and September 2013.

4.2 Bathymetric Survey

The bathymetric survey covered approximately 35 acres between the log boom and Iron Gate Dam. Depths ranged up to 45.7 m (150 ft) along the original river channel, and the approximate location of the low level intake tunnel can be seen (Figure 8a). These results are consistent with previous surveys (Eilers and Raymond 2003). Review of these data with historic photographs of dam construction allowed an approximate reconstruction of submerged roads (Figure 8b). The location and detailed bathymetric mapping of these roads in the region of the intake tower were important outcomes of the study because of their potential impact on local hydrodynamics.



(a) (b)

Figure 8. Iron Gate bathymetry (a) with 2 m (6.6 ft) contours, and (b) showing approximate locations of roads during dam construction. Depths from water surface elevation of 709.2 m (2326.8 ft).

4.3 ADCP Velocity Measurements

ADCP transects in the form of arcs across the reservoir were measured on Tuesday, August 27, 2013 and Wednesday, August 28, 2013 at two locations: near the A-frame and at the log boom (Figure 5). Four transects were performed on Tuesday and five transects were performed on Wednesday. During this study, the penstock intake invert was approximately 10 meters (33 ft) below the water surface and the withdrawal rate from the reservoir was approximately 25.4 cms (900 cfs). While transects traversed waters in excess of 12 m (40 ft), returns from the ADCP were typically limited to approximately 10 m (33 ft). A slower boat speed would yield deeper readings. The depth of the reservoir and depth of data collection are shown in Figure 9.

Velocities near the mid-point of the transect (deepest portion in Figure 9) ranged from approximately 0.04 m/s (0.13 ft/s) at the surface to 0.10 to 0.20 m/s (0.33 to 0.66 ft/s) at depth. Velocities at the left and right shorelines of the transect ranged from approximately 0.04 m/s (0.13 ft/s) at the surface to 0.10 to 0.40 m/s (0.33 to 1.32 ft/s) at depth (Figure 9 and Figure 10). While velocities were lower in near surface waters, the remainder of the vertical profile illustrated fairly uniform velocities. These values are consistent with the results found in previous phases of this work. Certain near-shore areas also had notable velocities, most likely due to complex hydrodynamics and morphology in the intake tower vicinity. Slightly lower velocities were identified near the bottom of the profile, presumably due to the reservoir bed boundary. Results indicate that the penstock tunnel to the powerhouse and the screened intake tower generate a withdrawal envelop that extends to the surface of the reservoir. Averaged horizontal velocity profiles for each transect further support this finding (Figure 11). The velocity profiles for August 27 and 28 are within approximately 10 percent of their respective means, indicating that velocity transects are reproducible, consistent, and representative of conditions upstream of the intake tower.

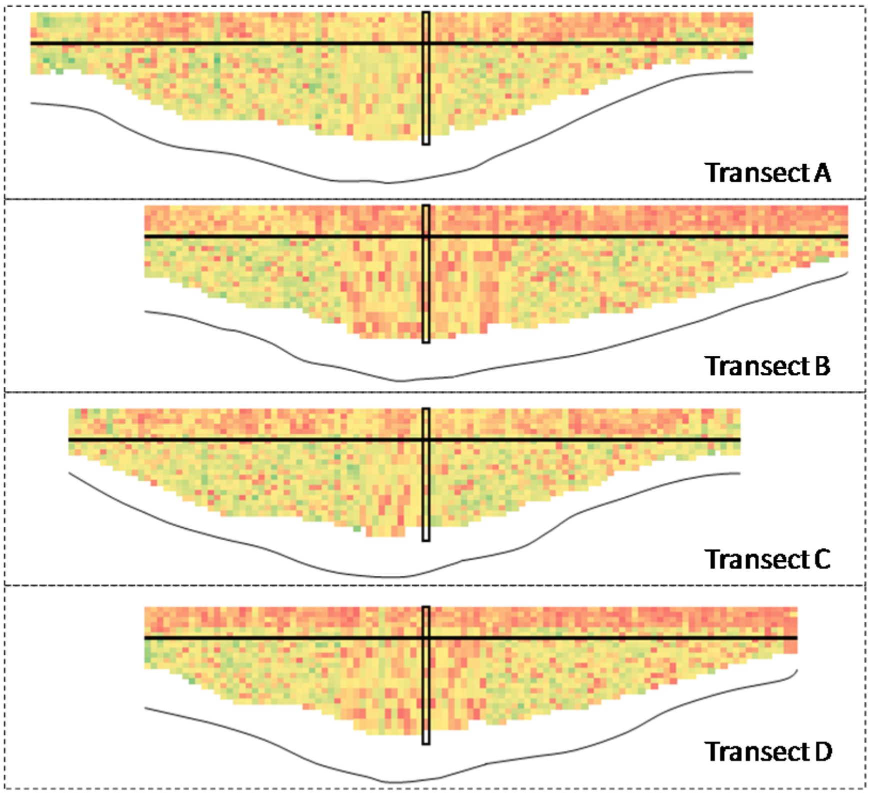


Figure 9. ADCP velocity magnitude from the A-frame transect (Tuesday, Aug 27th). Horizontal line represents the depth at 1 meter below the surface. Vertical rectangle represents the region due north of the intake tower. Red colors represent lower magnitudes (0.0-0.05 m/s); yellow colors represent average magnitudes (0.05-0.15 m/s); and green colors represent higher magnitudes (0.15-0.5 m/s).

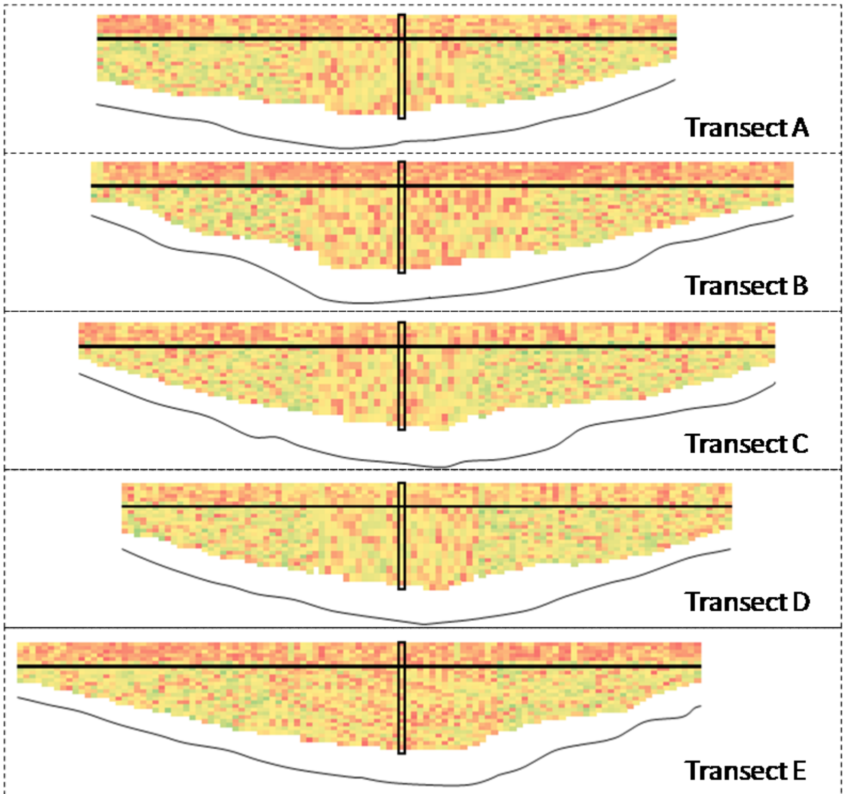


Figure 10. ADCP velocity magnitude from the A-frame transect (Wednesday, Aug 28th). Horizontal line represents the depth at 1 meter below the surface. Vertical rectangle represents the region due north of the intake tower. Red colors represent lower magnitudes (0.0-0.05 m/s); yellow colors represent average magnitudes (0.05-0.15 m/s); and green colors represent higher magnitudes (0.15-0.5 m/s).

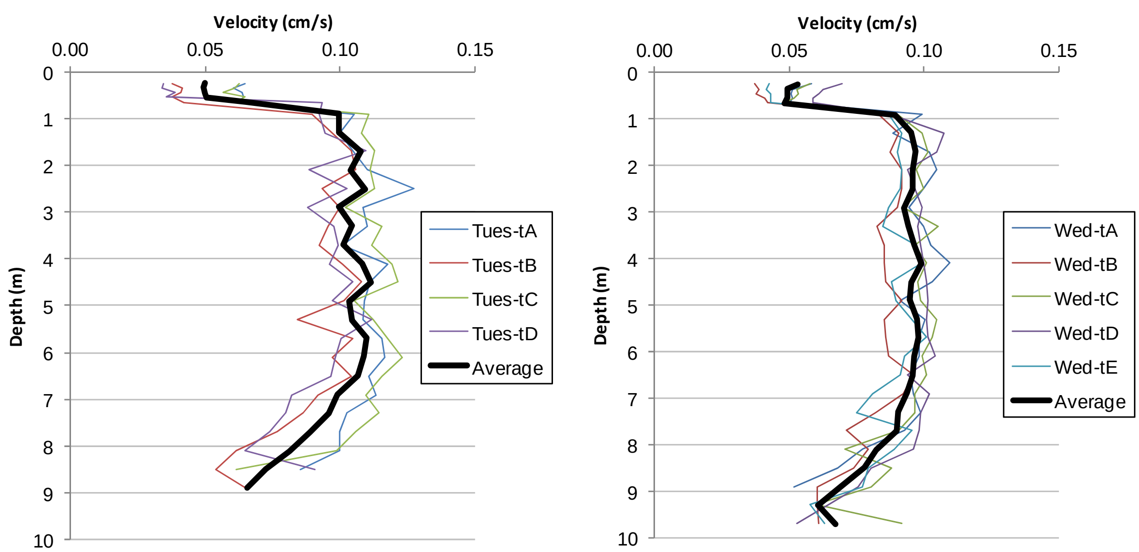


Figure 11. A-frame depth-averaged velocities magnitude during the study period for the 4 transects on Tuesday, Aug 27th (Tues-tA through Tues-tD) and the five transects on Wednesday Aug 28th (Wed-tA through Weds-tE).

The mean bias for the four surveys on Tuesday is presented in Table 3. The range of the bias was -0.009 to 0.009 cm/s. The minimum bias was -0.023 cm/s and the maximum bias was 0.028 cm/s. The maximum mean *absolute* bias was 0.011 cm/s. The mean bias for the five surveys on Wednesday is presented in Table 5. The range of the bias was -0.008 to 0.006 cm/s. The minimum bias was -0.018 cm/s and the maximum bias was 0.025 cm/s. The maximum mean *absolute* bias was 0.008 cm/s.

Table 3. Mean Bias: Average, Max, and Mean for the Tuesday (8/27) ADCP Transects.

Transects	Tues-tA	Tues-tB	Tues-tC	Tues-tD
Average	0.008	-0.009	0.009	-0.007
Max	0.019	0.002	0.019	0.028
Min	-0.003	-0.023	-0.011	-0.017
Mean Absolute Bias	0.008	0.009	0.010	0.011

Table 4. Mean Bias: Average, Max, and Mean for the Wednesday (8/28) ADCP Transects.

Transects	Wed-tA	Wed-tB	Wed-tC	Wed-tD	Wed-tE
Average	0.002	-0.008	0.004	0.006	-0.004
Max	0.010	0.001	0.025	0.016	0.008
Min	-0.017	-0.018	-0.012	-0.014	-0.015
Mean Absolute Bias	0.005	0.008	0.005	0.007	0.006

These results identify that the majority of the water entering the intake tower comes from the north within the main body of the reservoir (Figure 12), with the principal direction of flow at roughly 180 degrees (due South). In the vicinity of the dam face, waters appear to move along the dam face from the north and then head roughly eastward (angle of approximately 90 degrees) to enter the intake tower. Field data indicate that hydrodynamics along the left bank (southwest) of the reservoir are complex, experiencing wide range of vector directions. This may be due to the fact that the intake tower, located within the reservoir, allows waters to flow past and behind the tower.

Data suggest the short-term mixing, upwelling, and other directional movements are occurring, albeit at small scales. In addition to intake tower effects, complex hydrodynamics in the near shore areas could be due to extensive macrophyte growth (which can occupy waters several meters deep and extend over 10 meters offshore), reservoir morphology, other shoreline roughness features, as well as local wind sheltering and possibly baroclinic circulation (Fisher et al. 1979) associated with differential heating.

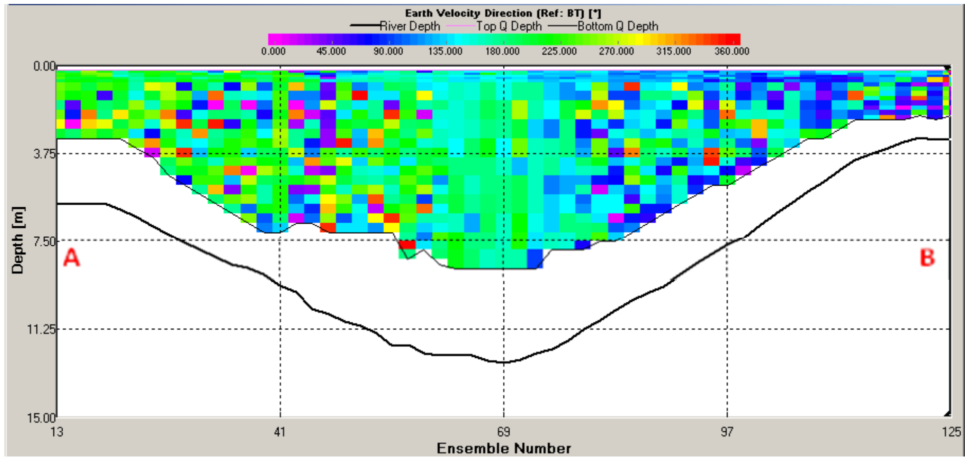


Figure 12. Representative ADCP velocity vector direction from the A-frame transect. Velocity vector direction based on *magnetic* north from WinRiverII software (see Figure 5 for true north, declination at Iron Gate Reservoir is approximately 14° 51' east)). Labels "A" and "B" refer to transect begin and end point identified in Figure 5.

5.0 CONCLUSIONS AND RECOMMENDATIONS

A bathymetric survey of the reservoir between the log boom and Iron Gate dam was completed through several days of field surveys, and with the assistance of PacifiCorp field staff. These data were developed to better characterize the region in general, but more specifically in the intake tower vicinity. Detailed surveys led to useful information about the reservoir bed morphology in this area, and submerged features associated with original project construction. Coupled with this bathymetry work were updated ADCP observations. These observations yielded a more refined understanding of the velocity field in this area, confirming previous observations (the bulk of the water approaches the intake tower from the north) and identifying potentially complex hydrodynamics in certain areas. Deployment of an automated profiler to collect physical water quality conditions and phycocyanin readings was unsuccessful due to fouling of the profiler line in several instances.

Based on the 2013 study results, the following recommendations were identified:

- Deploy a more robust instrument to collect the vertical profiling data. Such a system should incorporate a more flexible design to allow appropriate anchorage in various settings and conditions, as well as an ability to control the mechanical system more effectively and to upload information to PacifiCorp's data system.

- If additional ADCP observations are necessary or desired, complete future surveys at slower boat speeds (less than or equal to 1 m/s) to capture a greater depth of readings. This is particularly applicable in the deeper portions of the reservoir.

- Consider longer ADCP deployments (multiple days) and analyze with local meteorological data to determine potential wind-driven mixing processes. These observations, coupled with phycocyanin readings both above the intake and below the reservoir would lend insight into potential cover or other barrier design analyses and considerations.

- Use the ADCP and bathymetry data developed during the 2013 study to refine concepts for the design and placement of an intake barrier that can be deployed to exclude algae from the Iron Gate intake, and thus improve water quality downstream of Iron Gate dam.

6.0 REFERENCES

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APPENDIX A
2013 Study Data

This appendix contains supporting data and information compiled for the Iron Gate study in 2013.

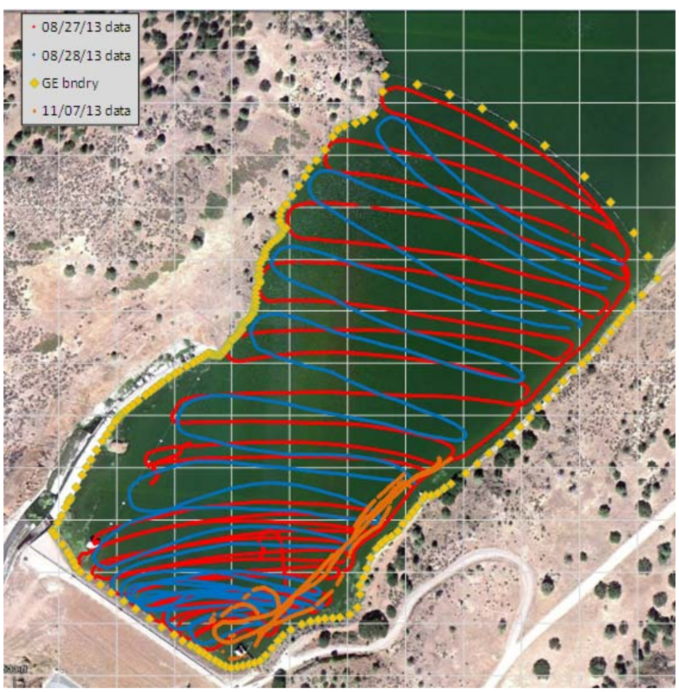
A.1 Water Surface Elevation

Table 5. Daily average water surface elevation (in meters and feet) for Iron Gate Reservoir in August and November (2011-2013). Courtesy of PacifiCorp.

Date	2011	2012	2013
August 26	709.3 m (2,327.1 ft)	709 m (2,326.24 ft)	709.2 m (2,326.82 ft)
August 27	709.3 m (2,327.05 ft)	709 m (2,326.14 ft)	709.2 m (2,326.8 ft)
August 28	709.3 m (2,327.05 ft)	709 m (2,326.16 ft)	709.2 m (2,326.8 ft)
November 6	709.2 m (2,326.9 ft)	709 m (2,326.16 ft)	708.4 m (2,324.14 ft)
November 7	709.1 m (2,326.45 ft)	709 m (2,326.2 ft)	708.4 m (2,324.23 ft)*
November 8	709.1 m (2,326.3 ft)	709 m (2,326.25 ft)	708.5 m (2,324.33 ft)

*The elevation used for the bathymetry was 708.36 m (2,324.00 ft). This is the exact elevation when the survey took place.

A.1.1 Surface 11 Boundary Points and Bathymetric Survey Track



A.2 Personal Communications

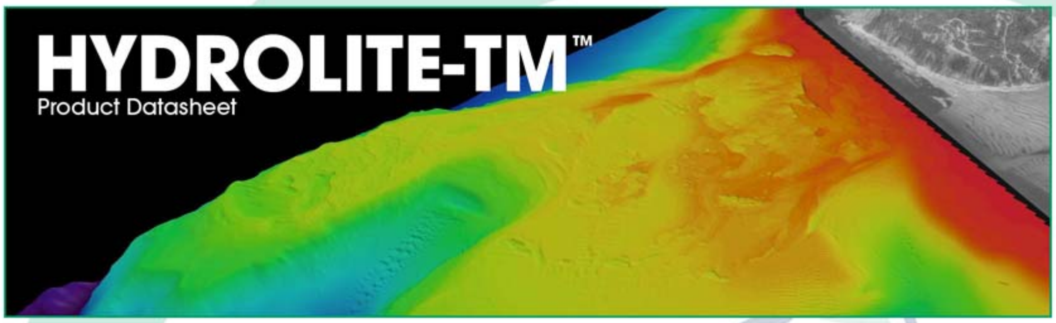
Dan Murphy, October 25, 2013 (phone communication interpreting ADCP velocity data)

APPENDIX B
2013 Equipment Datasheet

This appendix contains datasheets for the equipment used during the Iron Gate Study in 2013.

B.1 Hydrolite-TM

Seafloor



ABOUT

The HydroLite-TM™ should be included in every Survey and Engineering company's standard equipment kit for hydrographic surveying. Developed to meet the requirements of the U.S. Army Tactical Dive Teams, the rugged, wireless HydroLite-TM™ looks and feels like your traditional survey instrument. It quickly measures and logs depths more accurately than standard systems, making fast work of ponds, rivers, lakes, and more.

FEATURES

- Portable, integrated hydrographic survey solution
- Adaptable to any vessel
- Wireless data transfer
- Meets IP-65 standards
- Quickly export XYZ data

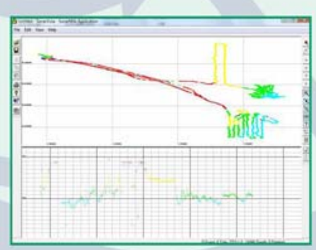
OPTIONS

- Coast Guard Beacon receiver
- Ruggedized shipping case
- PC data acquisition
- Digital Bar Check
- Tide Gauge

ECHOSOUNDER

- Frequency: 200-KHz
- Beam width: 4-degrees
- Ping Rate: 6 Hz
- Depth Accuracy: 1cm /0.1% of depth
- Output Formats: NMEA, ASCII, Quality
- Range: 0.3m-75m
- I/O: Serial, Bluetooth
- Power: Rechargeable 12V battery
- Compatibility: Trimble, Leica, Topcon Sokkia, Epoch, Ashtech, Magellan, Carlson

Sonarmite PDA Software



SonarVista Processing Software

T: (530) 677-1019 | E: info@seafloorsystems.com | W: seafloorsystems.com | 3941 Park Drive, Suite 20-218. El Dorado Hills, CA 95762

B.2 RiverRay ADCP

A Teledyne RD Instruments **Water Resources** Datasheet

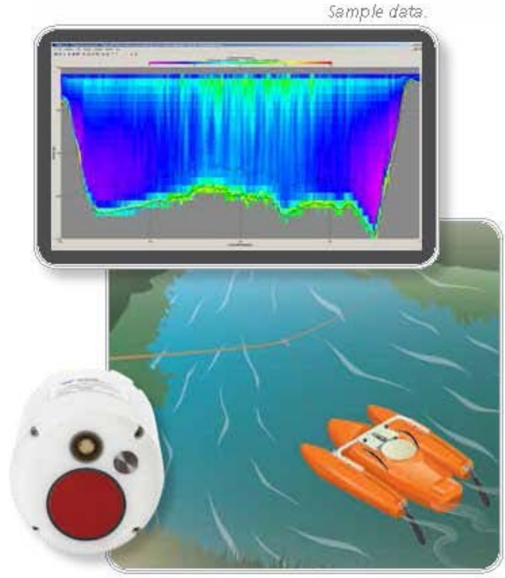
Teledyne RD Instruments

RiverRay ADCP

Intelligent River Discharge System

A Revolution in Discharge Measurement

Sample data.



Go straight to work collecting highly accurate stream and river discharge data with the RIVERRAY ADCP (Acoustic Doppler Current Profiler). This economical turnkey system comes complete with: the RiverRay ADCP, a custom-designed boat, user-friendly software, and convenient wireless communication—everything you need to begin making precision river discharge measurements.

With over thirty years experience delivering acoustic Doppler products, Teledyne RDI's RiverRay is the culmination of years of technology advances and invaluable customer feedback.

From a shallow stream to a raging river, the revolutionary RiverRay delivers the simplicity and reliability your operations require, at a price that won't break your budget.

The RiverRay ADCP utilizes a flat surface 4-beam phased-array transducer. A dedicated fifth beam is used to measure depth.

PRODUCT FEATURES

- **Ease of use:** Easy to carry, easy to deploy, and easy to operate; just power and go.
- **Intelligent:** Automatic adaptive sampling based on flow conditions continuously optimizes your discharge measurement from bank to bank, thus ensuring the highest quality data without your intervention.
- **Flat transducer:** The sleek phased array transducer design provides reduced size, weight, and flow disturbance.
- **Versatile:** A single instrument can deliver high quality data in environments ranging from a 0.4m stream to a 60m deep river.
- **Superior surface measurements:** Interwoven independent and short range measurements improve the discharge computation in your critical surface layer.
- **Platform stability:** RiverRay's float boasts reduced drag, causes less flow disturbance, and provides superior handling—even in high water velocities and rough surface.
- **No cables required:** Data is wirelessly transmitted to your shore station via Bluetooth™ technology.
- **DGPS compatible:** Integrate an external DGPS for difficult conditions, such as moving beds.

A Teledyne Marine Company

TELEDYNE RD INSTRUMENTS
Everywhereyoulook™

A Teledyne RD Instruments Water Resources Datasheet

RiverRay ADCP

Intelligent River Discharge Measurement

TECHNICAL SPECIFICATIONS

Water Velocity Profiling	Operation mode	Broadband or pulse-coherent, automatic
	Velocity range	±5m/s default, ±20m/s max.
	Profiling range	0.4m[1] to 60m[2]
	Accuracy	±0.25% of water velocity relative to ADCP, ±2mm/s
	Resolution	1mm/s
	Number of cells	25 typical, 200 max. (automatic selection)
	Cell size:	10cm min. (automatic selection)
	Surface cell range	25cm[3]
	Data output rate	1-2Hz (typical)
Bottom Tracking	Operation mode	Broadband
	Velocity range	±9.5m/s
	Depth range	0.4m to 100m[2]
	Accuracy	±0.25% of bottom velocity relative to ADCP, ±2mm/s
	Resolution	1mm/s
Depth Measurement	Range	0.3m to 100m[2]
	Accuracy	±1% (with uniform water temperature and salinity profile)
	Resolution	1mm[4]
Vertical Beam	Range	0.2m to 80m
	Accuracy	±1% (with uniform water temperature and salinity profile)
	Resolution	1mm

Standard Sensors		Temperature	Tilt (pitch and roll)	Compass
	Range	-5°C to 45°C	±90°	0-360°
	Accuracy	±0.5°C	±0.3°	±1°[5]
	Resolution	0.0625°C	0.06°	0.10°

Transducer and Hardware	System frequency	614.4kHz
	Configuration	Phased array (flat surface), Janus four beams at 30° nominal beam angle
	Internal memory	16MB
Communications	Standard	RS-232, 1200 to 115,200 baud. Bluetooth, 115,200 baud, 200m range.
	Optional	Radio modem, range >30km (line of sight)
Software (included)	• WinRiver II (standard) for moving-boat measurement • SxS Pro (optional) for stationary measurement; comes with an uncertainty model for in situ quality evaluation and control	
Power	Input voltage	10.5–18V DC
	Power consumption	1.5W typical
	Battery (inside float)	12V, 7A-hr lead acid gel cell (rechargeable)
	Battery capacity	>40 hrs continuous operation
Float (included)	Configuration	Three hulls (trimaran)
	Material	Polyethylene
	Dimensions	Length 120cm, width 80cm, height 20cm
	Weight	10kg bare; 17kg with instrument and battery
GPS Integration (optional)	Integration with GPS (customer supplied) through RS-232 to RR data stream	
Environmental	Operating temperature	-5°C to 45°C
	Storage temperature	-20°C to 50°C

1 Assumes one good cell (10cm); range measured from the transducer surface.
2 Assume fresh water; actual range depends on temperature and suspended solids concentration.
3 Distance measured from the center of the first cell to the transducer surface.
4 For averaged depth data.
5 For combined tilt <+/-70° and dip angle <70°.

TELEDYNE RD INSTRUMENTS
Everywhereyoulook™
www.rdinstruments.com

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B.3 Trimble GeoExplorer 6000 Series (GeoXT)

KEY FEATURES

Trimble Floodlight satellite shadow reduction technology
More positions and increased accuracy in tough environments

Sunlight readable display
For unmatched clarity in bright sunlight

3.5G cellular capability
High-speed Internet connectivity in the field

5 megapixel autofocus camera
Capture high quality photographs and link directly to features

Field-swappable battery
All day operation and the convenience of swap-and-go battery replacement

THE ACCURACY YOU NEED ANYWHERE YOU NEED IT

Bringing together the essential functionality for productive GIS data collection in one device, the Trimble® GeoExplorer® 6000 series also delivers positioning accuracy in challenging GNSS situations such as under trees and near buildings with Trimble Floodlight™ technology. Wherever you work, it just works.

Accurate, productive, reliable data collection

Integrating both a GPS/GLONASS receiver and a dual frequency GNSS antenna, the Trimble GeoExplorer 6000 series delivers accuracy you can depend on to record new assets, or reliably navigate back to previously recorded locations.

Used with Trimble's range of powerful field and office software, GeoExplorer 6000 series handhelds allow you to work faster and in more places than ever before. The Trimble GeoExplorer series can deliver down to centimeter accuracy—either postprocessed or in real time for the confidence the job is done right while still on site.

Trees and buildings create "satellite shadows", limiting the areas where you can reliably collect high-accuracy GNSS data. Using Trimble Floodlight technology, the GeoExplorer 6000 series continues to deliver productive, usable data under tree canopy or in urban canyons. You can work with fewer disruptions, meaning better data, faster, at less cost.

Designed for work, wherever you work

The Trimble GeoExplorer series works for the way you work. The built-in 5 megapixel autofocus camera, with geotagging capability, gives you one of the best ways to capture information about an asset, event, or site. A sunlight-optimized display maintains exceptional clarity in all outdoor conditions for crisp on screen text and images. And you can stay connected with an optional integrated 3.5G cellular modem for continuous network and Internet access to real-time map data, web-based services, Trimble VRS™ corrections, and live update of field information.

With the Trimble GeoExplorer 6000 series you get it all.

TRIMBLE GEOEXPLORER 6000 SERIES

PRODUCT MODELS

	GeoXH	GeoXT
Accuracy	Decimeter/Centimeter	Submeter
Floodlight	Yes	Optional
Cellular modem	Optional	Optional
Camera	5 MP	5 MP

GNSS

Receiver .... Trimble Maxwell™ 6 GNSS chipset
Channels .... 220 channels
Systems .... GPS, GLONASS[1] WAAS/EGNOS/MSAS/GAGAN
Update rate .... 1 Hz
Time to first fix .... 45 s (typical)
NMEA-0183 support .... Optional
Trimble Floodlight technology .... Optional
RTCM support RTCM2.x/RTCM3.x
CMR support .... CMR/CMR+/CMRx

GeoXT handhelds

GPS L1C/A
GLONASS L1C/A, L1P

GeoXH handhelds

GPS L1C/A, L2C, L2E
GLONASS L1C/A, L1P, L2C/A, L2P

GNSS ACCURACY[2]

GeoXH Centimeter Edition

Real-time Centimeter output

Horizontal (external antenna[3]) .... 1 cm + 1 ppm
Vertical (external antenna) .... 1.5 cm + 2 ppm
Horizontal (internal antenna) .... 2.5 cm + 1.2 ppm
Vertical (internal antenna) .... 4 cm + 2 ppm

Postprocessed Centimeter output

Horizontal (external antenna[3]) .... 1 cm + 1 ppm
Vertical (external antenna) .... 1.5 cm + 1 ppm
Horizontal (internal antenna) .... 2.5 cm + 1.2 ppm
Vertical (internal antenna) .... 4 cm + 1.5 ppm

All GeoXH configurations

Real-time and postprocessed H-Star (Horizontal RMS)

H-Star .... 10 cm + 1 ppm

All GeoXH and GeoXT configurations

Real-time DGNSS (Horizontal RMS)

Code .... 75 cm + 1 ppm
SBAS[4] (WAAS/EGNOS/MSAS) .... typically < 1 m

Postprocessed DGNSS (Horizontal RMS)

Code .... 50 cm + 1 ppm
Carrier (after 45 minutes) .... 1 cm + 2 ppm

ENVIRONMENTAL (MIL-STD-810G)

Drop shock ..... 1.2 m (4 ft) to plywood over concrete
Functional shock .... Method 516.6 Procedure I
Vibration .... Method 514.6 Procedure I
Relative humidity .... 95% non-condensing
Maximum operating altitude .... 9,000 m (29,000 ft)
Maximum storage altitude .... 12,000 m (40,000 ft)

TEMPERATURE

Operation .... –20 °C to +60 °C (–4 °F to +140 °F)
Storage .... –30 °C to +70 °C (–22 °F to +158 °F)

INGRESS PROTECTION

Water/Dust IP65

SIZE AND WEIGHT

Height .... 234 mm (9.2 in)
Width .... 99 mm (3.9 in)
Depth .... 56 mm (2.2 in)
Weight (inc. battery) .... 925 g (2.0 lb)

BATTERY

Type .... Rechargeable, removable Li-Ion
Capacity .... 11.1 V 2.5 AH
Charge time .... 4 hours (typical)

BATTERY RUN TIME[5]

	GeoXH	GeoXT
GNSS	9 hours	11 hours
GNSS & Wi-Fi	8 hours	9.5 hours
GNSS & cellular	6.5 hours	7 hours
Standby time (typical)	50 days	50 days

CONNECTORS & INPUTS

- Internal microphone and speaker
- Mini USB connector
- DE-9 serial via optional USB to serial converter
- External power connector
- SIM socket
- SDHC card socket

CAMERA

Still mode .... Autofocus 5 MP
Still image format .... JPG
Video mode .... Up to VGA resolution
Video file format .... WMV with audio

CELLULAR[6] & WIRELESS[7]

UMTS/HSDPA .... 850/900/2100 MHz
GPRS/EDGE .... 850/900/1800/1900 MHz
Wi-Fi .... 802.11 b/g
Bluetooth .... Version 2.1 + EDR

DISPLAY

Type .... Transflective LED-backlit LCD
Size .... 4.2" (diagonal)
Resolution 480x640
Luminance 280 cd/m2

HARDWARE

Processor .... TI OMAP 3503
RAM .... 256 MB
Flash .... 2 GB
External storage .... SD/SDHC up to 32 GB

LANGUAGES

- English, Spanish, French, German, Italian, Portuguese (Brazilian), Chinese (Simplified), Korean, Japanese, Russian

IN THE BOX

GeoExplorer 6000 series handheld, rechargeable battery pack, pouch and strap, USB data cable, AC power adaptor, screen protector kit, spare stylus & tether, documentation

OPTIONAL ACCESSORIES

- Trimble Zephyr™ Model 2 external GNSS antenna
- Trimble Tornado™ external GNSS antenna
- Trimble Tempest™ external GNSS antenna
- Vehicle power supply
- 1.5 m & 5 m external antenna cable
- Range pole kit for external antenna
- Carbon fiber monopole kit
- Backpack kit for external antenna
- Vehicle mount
- Hard carry case
- Null modem cable
- USB to serial converter cable

SOFTWARE COMPATIBILITY

- Trimble TerraSync software
- Trimble GPS Pathfinder® Office software
- Trimble Positions™ software suite
- Trimble GPScorrect™ extension for Esri ArcPad software
- Trimble GPS Analyst™ extension for Esri ArcGIS for Desktop software
- Trimble GPS Controller software
- Trimble GNSS Connector software
- Trimble TrimPix™ Pro system
- Custom applications built with a Mobile GIS Developer Community software development kit (SDK)
- Third party NMEA-based applications

1 GLONASS is enabled on GeoXT and GeoXH handhelds with Floodlight technology enabled.
2 Accuracy and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions. Always follow recommended GNSS data collection practices. Specified Centimeter accuracy can normally be achieved for baselines of 30 km or less. Specified H-Star accuracy can normally be achieved for baseline lengths of 100 km or less. Centimeter and H-Star accuracy is typically achieved within 2 minutes. Carrier postprocessed accuracy is limited to data collected within 10 km of the base station used for corrections.
3 Stated accuracy is for the Zephyr Model 2 antenna.
4 SBAS (Satellite Based Augmentation System). Includes WAAS; available in North America only, EGNOS; available in Europe only and MSAS; available in Japan only.
5 Actual run time will vary with conditions and environment of use.
6 Not available on all configurations. The GeoXH and GeoXT 3.5G edition handhelds are PTCRB certified and can operate on supported networks that do not require carrier certification. Consult with your local reseller for more information.
7 Bluetooth and Wi-Fi type approvals are country specific. GeoExplorer 6000 series handhelds have Bluetooth and Wi-Fi approval in the U.S. and in most European countries. For further information please consult your local reseller.

Specifications subject to change without notice.

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store.trimble.com

B.4 Hemisphere R130-RTK

Hemisphere GPS

A101 Smart Antenna

The Affordable All-In-One DGPS Receiver Solution

Powered by Crescent.

Work smarter, not harder. The A101™ Smart Antenna offers an affordable, portable solution with professional-level accuracy for agricultural, marine, GIS mapping, and other applications.

Focus on the job at hand with fast start-up and reacquisition times, 60 cm accuracy, and an easy-to-see status indicator for power, GPS, and DGPS. The durable enclosure houses both antenna and receiver. It can be powered through various sources, making the A101 Smart Antenna ideal for a variety of applications. Dual-serial, CAN, and pulse output options make this DGPS receiver compatible with almost any interface.

Key A101 Smart Antenna Advantages

- Affordable solution for unparalleled sub-meter performance – 60 cm accuracy, 95% of the time
- COAST™ technology maintains accurate solutions for 40 minutes or more after loss of differential signal
- Exclusive e-Dif® option where other differential signals are not practical
- Compatible with our exclusive L-Dif™ technology, for applications requiring accuracy better than 20 cm
- Fast output rates of up to 20 times per second provide the best visual guidance and automated steering signals for all types of applications
- Compact, low-profile design with fixed or magnetic mounting options is ideal for portable and dynamic applications
- Radar-simulated pulse output provides accurate ground speed

www.hemispheregps.com • precision@hemispheregps.com

Hemisphere GPS

A101 Smart Antenna

GPS Sensor Specifications

Receiver Type:	L1 GPS	
Channels:	12 L1CA GPS 12 L1P GPS 3 SBAS or 3 additional L1CA GPS	
GPS Sensitivity	-142 dBm	
SBAS Tracking	3-channel, parallel tracking	
Update Rate:	10 Hz standard, 20Hz optional (with subscription)	
Horizontal Accuracy:	RMS(67%)	2DRMS (95%)
RTK[1,2]	10 mm+1 ppm	20 mm+2 ppm
SBAS (WAAS)[1]	0.3 m	0.6 m
Autonomous, no SA[1]	1.2 m	2.5 m
Pitch/Roll Accuracy	1° using tilt sensor	
Timing (1PPS) Accuracy:	20 ns	
Cold Start:	< 60 s typical (no almanac or RTC)	
Warm Start:	< 30 s typical (almanac and RTC)	
Hot Start:	< 10 s typical (almanac, RTC and position)	
Maximum Speed:	1,850 kph (999kts)	
Maximum Altitude	18,288 m (60,000 ft)	

Communications

Serial Ports:	2 full-duplex RS-232, CAN
Baud Rates:	4800 - 115200
Data I/O Protocol:	NMEA 0183, NMEA 2000[3], Hemisphere GPS binary
Correction I/O Protocol:	Hemisphere GPS proprietary, RTCM v2.3 (DGPS), RTCM v3 (RTK), CMR (RTK), CMR (RTK)[4]
Timing Output:	1 PPS CMOS, active high, rising edge sync, 10 kΩ, 10 pF load
Event Marker Input:	CMOS, active low, falling edge sync, 10 kΩ, 10 pF load

Environmental

Operating Temperature:	-40°C to +70°C (-40°F to +158°F)
Storage Temperature:	-40°C to +85°C (-40°F to +185°F)
Humidity:	95% non-condensing
Shock and Vibration:	Mechanical Shock: EP455 Section 5.41.1 Operational Vibration: EP455 Section 5.15.1 Random
EMC:	CE (ISO 14982 Emissions and Immunity), FCC Part 15, Subpart B, CISPR 22
Enclosure:	IP67

Power

Input Voltage:	7 - 36VDC with reverse polarity operation
Power Consumption:	< 3W @ 12VDC typical
Current Consumption:	249 mA @ 12VDC typical
Power Isolatioin:	No
Reverse Polarity Protection:	Yes
Antenna Voltage:	Internal Antenna

Mechanical

Dimensions:	10.4 H x 14.5 D (cm) 4.1 H x 5.7 D (in)
Weight:	<558 g (<19.7 oz)
Status Indicators (LED):	Power, GPS Lock
Power/Data Connector:	12-pin male (metal)
Antenna Mounting:	1-14 UNS-2A female, 5/8-11 UNC-2B adapter, and mag-mount available

Authorized Distributor:

1 Depends on multipath environment, number of satellites in view, satellite geometry, and ionospheric activity
2 Depends on baseline length
3 Requires NMEA certification
4 Receive only: does not transmit this format

HEMISPHERE GPS
4110 - 9th Street S.E.
Calgary, AB T2G 3C4
Canada

Phone: 403.259.3311
Fax: 403.259.8866
precision@hemispheregps.com
www.hemispheregps.com


Sondes: EXO1 EXO2
Removable Bail
6-Pin Cable Connector
High-impact Xenoy Housing
Pressure Transducer Opening
Red LED Indicator - Status
Blue LED Indicator - Bluetooth
On/Off Magnetic Switch for Power and Bluetooth
4-Pin Wet-Mateable Connectors
Port Plug
Anti-fouling Wiper
Cable connector, battery valve, and expansion port for an additional sensor
EXO2 sonde contains 6 universal sensor ports plus a central port for an anti-fouling wiper
Battery Compartment
Cutaway: Reinforced internal structure
Anti-fouling wiper keeps sensors clear of biofouling and lengthens deployment times by 25%
Welded Titanium Housing
EXO1 sonde contains 4 universal sensor ports
9

Instrument Specifications*

EXO1 Sonde		
Ports	4 sensor ports Peripheral port: 1 power communication port	
Size	Diameter: 4.70 cm (1.85 in) Length: 64.77 cm (25.50 in)	
Weight	1.42 kg (3.15 lbs) with 4 probes, guard and batteries installed	
EXO2 Sonde		
Ports	7 sensor ports (6 ports available when central wiper used) Peripheral ports: 1 power communication port; 1 auxiliary expansion port	
Size	Diameter: 7.62 cm (3.00 in) Length: 71.10 cm (28.00 in)	
Weight	3.60 kg (7.90 lbs) with 5 probes, guard and batteries installed	
Sondes		
Operating Temperature	-5 to 50°C	
Storage Temperature	-20 to 80°C (except 0 to 60°C for pH and pH/ORP sensors)	
Depth Rating	0 to 250 m (0 to 820 ft)	
Communications	Computer Interface: Bluetooth wireless technology, RS-485, USB Output Options: USB with signal output adapter (SOA); RS-232 & SDI-12 with DCP-SOA	
Sample Rate	Up to 4 Hz	
Battery Life	90 days**	
Data Memory	512 MB total memory; >1,000,000 logged readings	
Sensors		**Calculated Parameters**
Ammonium	ORP	Salinity
Chloride	pH	Specific Conductance
Conductivity	Temperature	Total Dissolved Solids
Depth	Total Algae (Chlorophyll + BGA-PC or PE)	Total Suspended Solids
Dissolved Oxygen	Turbidity	
Fluorescent Dissolved Organic Matter (fDOM)	Vented Level	
Nitrate		
EXO Handheld		
Size	Width: 12.00 cm (4.72 in) Height: 25.00 cm (9.84 in)	
Weight	0.71 kg (1.56 lbs) without batteries	
Operating System	Windows CE 5.0	
Operating Temperature	-10 to 50°C	
Storage Temperature	-20 to 80°C	
IP Rating	IP-67	
Data Memory	2 GB total memory; >2,000,000 data sets	
Accessories		
Cables (vented and non-vented)	Flow cells	Sonde/sensor guard
Carrying case	KOR software	Calibration cup
DCP Signal Output Adapter	USB Signal Output Adapter	Anti-fouling components
Warranty		
3 months	Replaceable reagent modules for ammonium, chloride, and nitrate	
1 Year	Optical DO membranes and replaceable reagent moldules for pH and pH/ORP	
2 Years	Cables; sonde bulkheads; handheld; conductivity, temperature, depth, and optical sensors; electronics base for pH, pH/ORP, ammonium, chloride, and nitrate sensors; and accessories	

* Specifications indicate typical performance and are subject to change.
Please check EXOwater.com for up-to-date information.

** Typically 90 days at 20°C at 15-minute logging interval; temperature/conductivity, pH/ORP, DO, and turbidity sensors installed on EXO1; or temperature/conductivity, pH/ORP, DO, total algae, and turbidity sensors installed with central wiper that rotates once per logging interval on EXO2. Battery life is heavily dependent on sensor configuration.

EXO Bluetooth modules comply with Part 15C of FCC Rules and have FCC, CE Mark and C-tick approval. Bluetooth-type approvals and regulations can be country specific. Check local laws and regulations to insure that the use of wireless products purchased from Xylem are in full compliance.

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Sensor Specifications*

Sensor	Range	Accuracy*	Response	Resolution
Ammonium [11] (ammonia with pH sensor)	0 to 200 mg/L [1]	±10% of reading or 2 mg/L-N, w.i.g.	-	0.01 mg/L
Barometer	375 to 825 mmHg	±1.5 mmHg from 0 to 50°C	-	0.1 mmHg
Blue-green Algae Phycocyanin (PC) (part of Total Algae sensor)	0 to 100 RFU; 0 to 100 µg/L PC	Linearity: $R^2 > 0.999$ for serial dilution of Rhodamine WT solution from 0 to 100 µg/mL PC equivalents	T63<2 sec	0.01 RFU; 0.01 µg/L PC
Blue-green Algae Phycoerythrin (PE) (part of Total Algae sensor)	0 to 100 RFU; 0 to 280 µg/L PE	Linearity: $R^2 > 0.999$ for serial dilution of Rhodamine WT solution from 0 to 280 µg/mL PE equivalents	T63<2 sec	0.01 RFU; 0.01 µg/L PE
Chloride [11]	0 to 1000 mg/L-Cl [2]	±15% of reading or 5 mg/L-Cl, w.i.g.	-	0.01 mg/L
Chlorophyll (part of Total Algae sensor)	0 to 400 µg/L Chl; 0 to 100 RFU	Linearity: $R^2 > 0.999$ for serial dilution of Rhodamine WT solution from 0 to 400 µg/L Chl equivalents	T63<2 sec	0.01 µg/L Chl; 0.01 RFU
Conductivity [3]	0 to 200 mS/cm	0 to 100: ±0.5% of reading or 0.001 mS/cm, w.i.g.; 100 to 200: ±1% of reading	T63<2 sec	0.0001 to 0.01 mS/cm (range dependent)
Depth [4] (non-vented)	0 to 10 m (0 to 33 ft)	±0.04% FS (±0.004 m or ±0.013 ft)	T63<2 sec	0.001 m (0.001 ft) (auto-ranging)
	0 to 100 m (0 to 328 ft)	±0.04% FS (±0.04 m or ±0.13 ft)		
	0 to 250 m (0 to 820 ft)	±0.04% FS (±0.10 m or ±0.33 ft)		
Vented Level	0 to 10 m (0 to 33 ft)	±0.03% FS (±0.003 m or ±0.010 ft)		
Dissolved Oxygen Optical	0 to 500% air saturation	0 to 200%: ±1% of reading or 1% saturation, w.i.g.; 200 to 500%: ±5% of reading [5]	T63<5 sec [6]	0.1% air saturation
	0 to 50 mg/L	0 to 20 mg/L: ±0.1 mg/L or 1% of reading, w.i.g.; 20 to 50 mg/L: ±5% of reading [5]		0.01 mg/L
fDOM	0 to 300 ppb Quinine Sulfate equivalents (QSE)	Linearity: $R^2 > 0.999$ for serial dilution of 300 ppb QS solution Detection Limit: 0.07 ppb QSE	T63<2 sec	0.01 ppb QSE
Nitrate [11]	0 to 200 mg/L-N [1]	±10% of reading or 2 mg/L-N, w.i.g.	-	0.01 mg/L
ORP	-999 to 999 mV	±20 mV in Redox standard solutions	T63<5 sec [7]	0.1 mV
pH	0 to 14 units	±0.1 pH units within ±10°C of calibration temp; ±0.2 pH units for entire temp range [8]	T63<3 sec [9]	0.01 units
Salinity (Calculated from Conductivity and Temperature)	0 to 70 ppt	±1.0% of reading or 0.1 ppt, w.i.g.	T63<2 sec	0.01 ppt
Specific Conductance (Calculated from Cond. and Temp.)	0 to 200 mS/cm	±0.5% of reading or .001 mS/cm, w.i.g.	-	0.001, 0.01, 0.1 mS/cm (auto-scaling)
Temperature	-5 to 50°C	-5 to 35°C: ±0.01°C [10] 35 to 50°C: ±0.05°C [10]	T63<1 sec	0.001 °C
Total Dissolved Solids (TDS) (Calculated from Conductivity and Temperature)	0 to 100,000 g/L Cal constant range 0.30 to 1.00 (0.64 default)	Not Specified	-	variable
Total Suspended Solids (TSS) (Calculated from Turbidity and user reference samples)	0 to 1500 mg/L	Not Specified	T63<2 sec	variable
Turbidity [11]	0 to 4000 FNU	0 to 999 FNU: 0.3 FNU or ±2% of reading, w.i.g.; 1000 to 4000 FNU: ±5% of reading [12]	T63<2 sec	0 to 999 FNU: 0.01 FNU; 1000 to 4000 FNU: 0.1 FNU

All sensors have a depth rating to 250 m (820 ft), except shallow and medium depth sensors and ISEs. EXO sensors are not backward compatible with 6-Series sondes.

* Specifications indicate typical performance and are subject to change. Please check EXOwater.com for up-to-date information.
Accuracy specification is attained immediately following calibration under controlled and stable environmental conditions. Performance in the natural environment may vary from quoted specification.

[1] 0-30°C [2] 0-40°C w.i.g. = whichever is greater

[3] Outputs of specific conductance (conductivity corrected to 25°C) and total dissolved solids are also provided. The values are automatically calculated from conductivity according to algorithms found in *Standard Methods for the Examination of Water and Wastewater* (Ed. 1989).

[4] Accuracy specifications apply to conductivity levels of 0 to 100,000 µS/cm.
[5] Relative to calibration gases
[6] When transferred from air-saturated water to stirred deaerated water
[7] When transferred from water-saturated air to Zobell solution
[8] Within the environmental pH range of pH 4 to pH 10
[9] On transfer from water-saturated air to rapidly stirred air-saturated water at a specific conductance of 800 µS/cm at 20°C; T63<5 seconds on transfer from water-saturated air to slowly-stirred air-saturated water.
[10] Temperature accuracy traceable to NIST standards
[11] Calibration: 1-, 2-, or 3-point, user-selectable
[12] Specification is defined in AMCO-AEPA Standards