REEDER RESERVOIR STUDY

Prepared for
City of Ashland, Oregon

February 25, 2008

BROWN AND CALDWELL

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CHAPTER 1

BACKGROUND

The City of Ashland (City) contracted with Brown and Caldwell in August 2006 to conduct a study of Hosler Dam and Reeder Reservoir. The purpose of the study was to provide an indication of the existing condition of the iron and steel appurtenances on the upstream face of the dam and to identify actions that the City could take that would improve the water quality of the reservoir. A specific concern was the impact on water quality and the operation of the City's water treatment plant on algae populations in the reservoir. The study included a visual inspection of the upstream appurtenances of the dam by divers, a bathometric survey of the reservoir, sampling and direct thickness measurements of the bottom sediments, and water quality sampling of the reservoir water by depth. The field work was conducted during the summer and fall of 2007.

The sampling and evaluation of the Reeder Reservoir water quality and sediments were conducted by Aquatic Ecosystem Sciences, LLC, of Ashland, Oregon, and MaxDepth Aquatics, Inc., of Bend, Oregon. The two firms provided a detailed report on their findings, which is included as Appendix A. Due to the thoroughness of the document, it can stand on its own merits and will not be repeated here. However, we have placed their recommendations in Chapter 2 of this report, and prioritized them with other operational recommendations, and provided an estimated cost for implementing each.

The visual inspection of Hosler Dam was conducted by divers of Advanced American Construction of Portland, Oregon. In addition to the initial inspection performed in July 2007, the firm returned in the fall and conducted another dive specifically to inspect and clean the water system outlet valves on the dam. Summaries of their findings and a CD containing a digital video record of each inspection is included in Appendix B.

The visual inspection of the Hosler Dam did not find any items of serious concern. The only unexpected find was that the metal appurtenances were in remarkably good condition. Many items show very little corrosion or wear. Other findings of note include the following:

- Sediment levels behind the center of the dam are at or over 10 feet deep and completely cover the trash racks of the dam's two sluice valves. The 10-foot-thick sediment extends out from the dam at least 20 feet at its center. The divers dug into the silt to try to uncover a portion of the racks, but were not able to get deep enough to expose them.
- The sediment is mostly sand with some silt and woody material. There are some larger pieces of wood (logs) evident in the material. There was a cloudy layer above the sediment at the time the dives were made. We believe that material to be dead algae and other small aquatic organisms.
- Gas bubbles were observed to be coming from the sediments.
- The divers looked for the "hinge" crack of the dam, including digging into the silt a few feet. They do not believe they found it and we cannot observe it in the video they provided. They did find some horizontal cracks, which are shown in the video.

- The silt layer extends right to the bottom flange of the lower water system outlet valve. The material was cleaned off the valve and away from its base to some degree by the divers.
- The middle water system outlet valve was slightly blocked open by a piece of wood. All the valves were cleaned and the wood piece removed from the middle valve by the divers.

During the summer and fall of 2007, the reservoir contained one of the heaviest growths of algae that has occurred for several years. The algae imparted sufficient taste and odor to the treated drinking water to generate numerous customer water quality complaints. To try to minimize the taste and odor of the water, operational changes were instituted during the summer. The more successful items are documented in Chapter 2 of this report.

CHAPTER 2

RECOMMENDATIONS

The findings from the inspection of Hosler Dam and study of Reeder Reservoir's water quality and sediment characteristics have allowed us to identify several options that will result in either improved water quality and/or more manageable control of the reservoir. The recommendations that follow are placed in priority order. We have recommended an implementation schedule to allow integration of the recommendations into a reasonable funding for the work. Implementation of the first two recommendations is expected to provide significant water quality improvements over the conditions in 2007.

1. Use East and West Fork Diversions

   During periods of each year, the water quality of the two main streams entering the reservoir is significantly better than the quality of the water in Reeder Reservoir. The City of Ashland has an existing old piping and diversion system that can divert water directly from these two streams to the new intake pipeline constructed for the water treatment plant. Until the old piping system fails, the City should develop and implement an operating plan that takes advantage of the use of the higher quality of water in these streams. Although several other recommendations herein will certainly improve the water quality of Reeder Reservoir, they will not improve the water quality above that of the two streams during normal late summer and fall periods when the City experiences the most significant taste and odor events. The streams have limited capacity and therefore cannot replace the volume of water in Reeder Reservoir which is needed to meet summertime peak demands. However, their contribution to the water treatment plant's raw water supply will improve the resulting treated water quality even if they can not fully supply the City's water demand.

   The cost to develop an operating plan to use the streams is estimated to be $6,000 and we have included that in the schedule for fiscal year (FY) 2009. If the plan is implemented in July 2009, there is time to have an impact on the water quality in the late summer and fall of that year. Also, there may be some additional valving or monitoring equipment needed to improve the reliability and operability of the old system. As an example, water level monitoring at both diversions would be extremely helpful to ensure that the system does not overdraft the limited water supplies available from these streams. We have included $35,000 in FY 2009 as an estimate for improvements necessary to implement the plan recommendations. We do not expect there to be a measurable increase in operation and maintenance (O&M) costs to implement such a plan over the next several years.

   In future years, if the City wants to continue using the system, the old pipeline and diversion will need to be replaced eventually. However, the system is in relatively good condition and, barring flood damage or other catastrophic events, it should last until the future role of the existing water treatment plant is determined. Specifically, if the existing plant is to be replaced with a plant that is not adversely affected by the water quality of Reeder Reservoir, then maintenance of the old steam diversion system may not be cost-effective.

2. Circulate the reservoir water

The approach with the highest probability of limiting blue-green algae concentrations in the reservoir is to install devices to circulate water both near the surface and near the bottom. Surface circulation can disrupt the buoyancy of the blue-green algal cells and bottom circulation can prevent nutrient release form the bottom sediments and the resulting buildup of nutrients in bottom reservoir layers. To be most effective for the summer of 2008, circulation devices should be installed by May. If installed after July 1, 2008, they will improve the water quality, but will not be as effective at impacting algae concentrations and summer taste and odor as would units installed prior to algal bloom development. An additional advantage of the units is that they can significantly improve the application and effectiveness of chemical applications intended to limit algae growth. Chemical use may be necessary occasionally, particularly in 2008 because it can require a full year to depress nutrient release from the sediments and until more nutrient testing is conducted on the incoming streams to Reeder Reservoir, we do not know the relative contributions to the nutrient loadings of the sediments and the incoming water.

The estimated cost to install and test the equipment in the spring of 2008 is $29,000. The cost to purchase a successful set of two circulation systems for the lake in the summer of 2008 is $97,000. We do not anticipate a significant impact to annual O&M costs from these units.

3. Track reservoir nutrient changes

The intent of the recommendation to circulate the reservoir water is to disrupt the nutrient supply and living environment of the algae. After the circulation system is established, monitoring changes in reservoir water quality provides valuable information on its effectiveness, how it might be adjusted to maximize its effectiveness, and what other measures may enhance the overall water quality of the reservoir. We recommend that the City fund a series of reservoir sampling to be done at least once a month from May to November. This should include a report of findings and recommendations that will define the nutrient characteristics of the reservoir and describe how they have changed from those found in this study. After the work is concluded, the City may want to consider whether to continue the testing on an annual basis with City staff collecting the samples. We are not recommending that at this time.

To estimate a cost to implement this recommendation, we have assumed that the work will begin in May 2008 and continue to November 2008. The estimated cost for the sample collection and study report is $22,500 and the laboratory sample testing fee estimate is $7,500. The $30,000 total cost has been scheduled with $6,000 occurring in FY 2008 and $24,000 in FY 2009.

4. Monitor the reservoir quality

Establish a permanent water quality sampling point in the reservoir and monitor the water quality by depth at that point. This will allow the City to track the effectiveness of the reservoir circulation equipment, identify unexpected changes in reservoir quality, and allow setting of the reservoir outlet depth to select the best water quality as it changes during the year. We recommend that the City conduct weekly water quality sampling by depth in the reservoir from May through October. The sampling should include temperature, dissolved oxygen, pH, and turbidity. Implementing the recommendation will include establishing the sampling point by setting a buoy in the reservoir and purchasing sampling equipment. We recommend that the City contract for a firm to set the sampling point, provide the testing equipment, and train the city personnel in its use. This work should be done in the summer of 2008 and continue annually thereafter.

The estimated cost for buoy, thermisters, and water quality monitoring equipment is $10,000 and the cost of the set-up and training is $6,000. The ongoing labor cost to the City for taking and recording the data from the sampling, assuming the City uses one person to take the samples, is 5 hours per week for 26 weeks (May through October). At a cost of $87,000 per full-time equivalent, the annual O&M cost of the sampling is $5,500.

5. Monitor the nutrients in tributaries

The water quality of the streams feeding Reeder Reservoir should be monitored to determine the sediment and nutrient loading the reservoir receives from the streams. In this study, the tributary streams were sampled only on one date in June. Further data collection is necessary to establish seasonal variability and the overall annual contribution to the reservoir's water quality by these steams. This information is valuable in determining the contributing factors to changes in reservoir quality, specifically, whether the stream flow or the bottom sediments are the main contributing factors to the reservoir's nutrient levels. That information, in turn, is helpful to determine what measures may be necessary to meet regulatory requirements for reservoir. For example, if the streams are providing a majority of the measurable loading to the reservoir, then the contribution from the road system adjacent to the reservoir would be less significant and measures to reduce the road's influence on reservoir water quality, such as paving, will not benefit the reservoir. Stream nutrient levels and their variability are necessary to determine if watershed management changes will impact the reservoir's water quality.

To obtain an initial estimate of the water quality of the two streams over a year will require a minimum of 20 samples from each of the two streams. The cost to collect, analyze, and prepare a report of the findings from the samples is $20,000. The sampling will take more than a full year to conduct and report on, so the cost has been scheduled over two budget periods. Depending on the findings from the initial study, the sampling program should be reviewed to determine the benefit of continuing.

6. Remove sediment from tributary dams

The accumulated sediment from behind the two small watershed dams should be removed on a routine basis. These small impoundments can be effective in controlling the normal, non-storm influx of settleable material into the reservoir. In addition, the removal of this material will improve the quality of water that can be taken from the streams under our recommendation 1.

We recommend that the City contract in FY 2009 to remove the existing material behind one of the dams. Dams can be emptied safely in the early fall by pumping the stream flow around the pond (or into the old inlet pipe to the water treatment plant) and using excavating equipment to remove the sediment to the natural stream bank level. We recommend the City contract for the removal of up to 300 yards of material from behind both dams on a per yard basis. Once this process has been conducted a couple of times, the City can estimate more accurately the volume required for each reservoir and refine the contracted amount. This process should be scheduled for every other year initially and done in any year in which a significant storm moves large amounts of material into one or both of the small impoundments. We have scheduled the emptying of each dam in separate years merely to ease the funding burden on the City. It would be more cost-effective to do both reservoirs a the same time.

After the first removal is made, a condition assessment of the impoundments should be conducted and cost-beneficial repairs identified that can be scheduled in the following year. The old dams and their appurtenances are in a state of disrepair and are too valuable to the water quality of the reservoir not to maintain.

The estimated cost to contract for the removal of the sediment behind the first dam in the fall of 2009 is $30,000 ($50 per yard plus $5,000 to dewater the ponds) and $10,000 to specify, permit, and monitor the work the initial year. We have scheduled the funding to empty the second impoundment in FY 2010 at a cost of $30,000 plus an additional $15,000 to develop plans and specifications for maintenance improvements to the two facilities and obtain the necessary permits. We recommend that $50,000 be budgeted in FY 2011 to conduct minor repairs to the diversion dam structures and hardware, remove hazardous trees, and monitor the work. Additional funds may be required, but cannot be estimated until the structures can be inspected after they are emptied and exposed.

A secondary benefit can be obtained from the work to empty the sediment from the impoundments. The City can have the same contractor remove some of the accumulated sediment in the Granite Street Swimming Hole pool at the same time. It will be less expensive to both dewater the pool and to haul away sediment from that location. We do not know the amount of sediment in the Swimming Hole, but it could be partially dug out on a fixed yard basis each time one of the two watershed pools are emptied. Over time, this will be a cost-effective way of maintaining the Swimming Hole as a public amenity and allowing it to continue its function as a trap to prevent fine sediment from proceeding any farther down Bear Creek.

7. Monitor surface algae concentrations

Conduct bi-weekly algae concentration monitoring in the reservoir surface from the walkway behind the dam and from the inlet to the water treatment plant. This will allow the City to develop a reliable database for the algae densities and species composition over time. If the warmer weather trend continues, this sampling can provide valuable warning of unwelcome trends in the algae concentrations and populations that may occur even with the reservoir circulation equipment in operation.

To implement this option, we recommend that the City contract for the first year for this service and obtain training from the contractor for City staff to assume the sampling in future years. The estimated cost for the first season is $25,000 (spread $15,000 in FY 2009 and $10,000 in FY 2010), including the sample analysis and reporting. In future years, the estimated additional annual O&M cost to implement this monitoring using existing city staff to collect the samples is primarily the cost of the sample testing. The number of samples per year of this program is 26. We estimate the added annual cost to be $10,000 in FY 2010 and $12,000 thereafter.

8. Monitor sedimentation rate

There is insufficient information to accurately determine the sediment accumulation rate in Reeder Reservoir due to the number of inconsistencies between the bathometric measurements made for this study and the previous surveys. Appendix A includes a rough estimate of the sediment loading rate for the reservoir and existing thickness of the sediments. In general, we believe the annual loading rate is small, except during extreme storm events. To obtain a reliable annual loading rate, another bathometric survey of the reservoir should be done in 5 years. Comparison of that survey to the map made for this study will provide a reliable annual rate of sediment deposition in the reservoir. The determination of the rate will allow the City to plan for the eventual removal of sediment, which may not be necessary for many years.

The estimated cost of performing the survey and the resulting analysis to determine the sediment loading rate is $7,000. We have scheduled this work to be done in FY 2012.

9. Monitor flood driven sediment

The City should conduct a sub-bottom profile and bathometric profile of the reservoir in any year that it appears a storm has moved large volumes of sediment into the reservoir. This will allow the City to determine the amount of sediment brought in by the then current storm and the total volume of sediment in the reservoir. This will allow an informed decision concerning whether the reservoir must have the sediment removed and, if so, the approximate total volume to be removed.

The estimated current cost for the surveys, analysis, and reporting is $21,500. Since the timing of this cost is uncertain, we have not included it in our budget recommendations.

10. Determine cost and means to remove sediment

The City should conduct a study to determine the least cost, feasible means to remove the accumulated material immediately behind the dam. The material behind the dam has accumulated to the point where it covers the major dam outlets and is at the level of the lower intake for the water treatment plant. The water quality produced from all three of these valves and possibly their operability can be impacted by this material. Confirming an acceptable means and accurate cost to remove the material is necessary to make an informed decision by the City of the benefit of its removal.

To provide a context to determine the importance of this recommendation, we have developed a rough cost estimate for the removal of the material. We assumed that in the current regulatory environment, it was not feasible to simply open the sluice gates, drain the dam, and remove the remaining material that did not exit out the sluicing tunnels. The selected method to remove approximately 5,500 cubic yards of fine silt by a suction dredge and 500 cubic yards of large woody debris by a small clam shell on a barge in the reservoir. To generate a cost estimate, we assumed that the material could be placed immediately below the dam to be dewatered and then re-handled to be moved out of the watershed and disposed of. At a cost of $100 per yard for the suctioned material, $200 per yard for material moved by the clam shell, and $50 per yard to re-handle the same material below the dam, the cost to remove the material is $950,000. By adding in the cost to permit, monitor, and control the work, the project would cost approximately $1.2 million.

The recommended initial review of options, consultation with stakeholders (citizen groups, the Oregon Department of Environmental Quality, U.S. Fisheries Service, Federal Energy Regulatory Commission, etc.), and preparation of a cost estimate is estimated to cost $25,000.

Table 2-1 lists the estimated implementation cost of the recommendations of this report.

Table 2-1. Estimated Implementation Costs

Recommendation	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
1. Use East Fork diversion		41,000				
2. Reservoir circulation improvements	29,000	97,000				
3. Track reservoir nutrient changes	6,000	24,000				
4. Reservoir water quality sampling station		16,000				
5. Inlet stream monitoring		3,500	16,500			
6. Sediment removal from behind inlet stream dams		30,000	45,000	50,000		40,000
7. Bi-weekly algae monitoring		15,000	20,000	12,000	12,000	12,000
8. Reeder reservoir sediment monitoring					7,000	
9. Storm sediment loading monitoring	$21,500 after a major storm					
10. Feasibility study on how to remove sediment from behind Hosler Dam		25,000				
Total cost	**35,000**	**251,500**	**81,500**	**62,000**	**19,000**	**52,000**

APPENDIX A

REEDER RESERVOIR
WATER QUALITY AND SEDIMENT ASSESSMENT, 2007

(prepared by Aquatic Ecosystem Sciences, LLC, and MaxDepth Aquatics Inc.)

Reeder Reservoir (Ashland Oregon) Water Quality and Sediment Assessment, 2007

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Feb 2008

EXECUTIVE SUMMARY

Several preliminary studies were initiated in Reeder Reservoir (City of Ashland Oregon water supply reservoir) in 2007 to gain a better understanding of reservoir processes and to evaluate these processes with respect to management and monitoring options to maintain and improve water quality, most notably blue-green algal blooms and associated taste and odor issues These studies included, 1) collection of water quality and algal data, 2) bathymetric mapping, 3) evaluation of changes in reservoir bathymetry since the previous survey performed in 1987, and 4) evaluation of reservoir sediment composition with respect to nitrogen, phosphorus, moisture content, carbon, and particle size.

Results showed that inflow nutrient and reservoir characteristics such as low ratio of nitrogen to phosphorus in the tributaries (with little available inorganic nitrogen), a high proportion of inflow phosphorus occurring in a form readily available to algae, temperature and dissolved oxygen profiles indicative of highly stratified in-reservoir conditions, and accumulation of nitrogen and phosphorus in lower reservoir layers, indicate that Reeder Reservoir is a eutrophic (productive) system that provides conditions conducive for surface blooms of the blue-green alga *Anabaena flos-aquae* such as those observed in 2007. Such conditions of low N:P ratios along with available phosphorus favor nitrogen-fixing blue-green algae because such algae are not dependant on ambient nitrogen concentrations, but rather can acquire atmospheric nitrogen gas to supply nitrogen needs. Moreover, the type of stratified conditions present in the reservoir allow these buoyant blue-green algae (cyanobacteria) to remain in the upper reservoir layer (epilimnion) where there is adequate light for photosynthesis. The type of stratification observed in Reeder Reservoir also fosters the release of nutrients from reservoir sediments that can become available for algal growth either from transport to upper layers or as stratification decreases in the fall and nutrients are mixed upward in the water column.

The major bloom-forming species in Reeder Reservoir in 2007 was the blue-green alga *Anabaena flos-aquae*. This species typically imparts potent taste and odor compounds to water supplies, and can be associated with the production of algal toxins. Although copper sulfate has been used in the past to manage these blooms, given a state-wide direction to reduce the use of such algicides which require repeated application, as well as the potential to release algal toxins to the water column through cell lysis as algicides are applied, other management options for bloom reduction are desirable. The availability of phosphorus in East and West Fork inflow, as well as from reservoir sediments combined with stable water column conditions, limits nutrient control measures such as aluminum sulfate (alum). However, water column circulation provides a high probability of preventing and/or disrupting blue-green algal blooms in Reeder Reservoir. These methods work both by disrupting buoyancy and circulating *Anabaena* cells out of the upper reservoir photic layers (the layer where enough light exists for photosynthesis to occur), and by preventing nutrient build-up in bottom layers by reduction of hypolimnetic anaerobic conditions. In-reservoir reduction of blooms is essential for management of both algal toxins and taste and odor compounds so that the need to remove these compounds in the water treatment plant is reduced.

Sediment data showed, as expected, that the area immediately in front of the dam is the most favorable deposition zone in the reservoir, and the deeper sediment core from this site is consistent with these expectations. Estimates from coring intervals indicate that additional accumulation since the 1997 flood ranges between approximately 3-4 ft of material immediately behind the dam. There is additional sediment accumulated adjacent to the dam as indicated by a sediment core with 5.25 ft of material. No collection of sediment below 5.25 ft was made because of repeated encounters with large-diameter material, possibly woody debris. The nutrient chemistry of the cores is consistent with high inputs of phytoplankton remains, thus causing higher nitrogen values in the upper sediments. Likewise, the sediments in Reeder Reservoir have high concentrations of phosphorus. Except for the surficial sediments, concentrations of nitrogen and phosphorus are similar, which would suggest that nitrogen is limiting to phytoplankton growth, and that the combination of high phosphorus and relatively low nitrogen in the reservoir is conducive to dominance by nitrogen-fixing cyanobacterial taxa such as *Anabaena flos-aquae*.

The comparison between the current bathymetry and the historical bathymetry illustrates some general patterns that might be anticipated in a reservoir where erosion continues from the steep sidewalls and deposition occurs in the reservoir trough. The greatest areas of apparent erosion are associated with the point between the main reservoir arm and Reeder Gulch. The second area of the reservoir with significant apparent erosion is on much of the east shore of the reservoir. This is the shoreline most exposed to wave action from wind, especially as the lake is drawn down during summer use. The locations of the apparent depositional zones in Reeder Reservoir are generally associated with the troughs in Reeder Gulch and the main arm of the reservoir. This is consistent with movement of material into the reservoir and deposition in some of the deeper, flatter portions of the catchment. However, the coarse precision of the historical bathymetry would lead us to believe that some of the extreme zones of apparent erosion and deposition are artifacts of the comparison process.

A brief analysis was conducted to provide a gross estimate of the sediment accumulated behind Hosler Dam and extending up-reservoir for about 200 ft. We believe that there are about 3000 to 6000 cubic yards of sediment in the reservoir at this location. We cannot quantify the uncertainty in this estimate because of the uncertainty in the elevations of the historical measurements for Reeder Reservoir. More precise estimates of sediment accumulation in the reservoir can be obtained through designed studies.

The findings from the study of Reeder Reservoir water quality and sediment characteristics result in the following recommendations: 1) Utilize water column circulation to improve reservoir water quality, 2) Monitor circulation effectiveness and reservoir water quality, 3) Monitor concentrations of potentially toxigenic algae and conduct periodic algal toxin testing, 4) Monitor tributary nutrient influx, and 5) Estimate annual rate of reservoir sedimentation.

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INTRODUCTION

Although the presence of filter-clogging algae in the City of Ashland (Oregon) water treatment plant and surface algal blooms in Reeder Reservoir (the City of Ashland water supply reservoir) have been noted by treatment plant staff in past years, little information was available relating to water quality dynamics and sediment characteristics of Reeder Reservoir. Thus, several preliminary studies were initiated in 2007 to gain a better understanding of reservoir processes and to evaluate these processes with respect to management and monitoring options to maintain and improve water quality. These studies included, 1) collection of water quality and algal data, 2) bathymetric mapping, 3) evaluation of changes in reservoir bathymetry since the previous survey performed in 1987, and 4) evaluation of reservoir sediment composition with respect to nitrogen, phosphorus, moisture content, carbon, and particle size.

STUDY RESULTS

Water Quality and Algal Data

Methods

Two sampling stations were established in Reeder Reservoir on June 27th, one located near the dam with a maximum depth of 87.3 ft and the other located in the shallower up-reservoir portion with a maximum depth of 55 ft (Figure 1). These stations were sampled during three periods, June 27th, July 31st, and September 14th. Because results from the two stations were not appreciably different with respect to measured parameters, for the sake of clarity only results from the deep R1 station are presented here. In addition, both the East Fork and the West Fork of Ashland Creek were sampled for nutrients, but due to budgetary constraints they were only sampled during the initial sample period of June 27th. Additional samples specifically for evaluation of potentially toxigenic blue-green algae were collected on June 14th, July 13th, and October 12th.

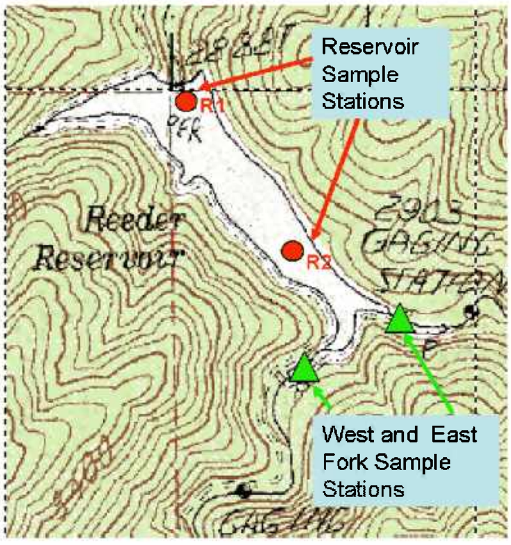

Figure 1. Reeder Reservoir water quality sampling site locations, 2007.

Samples were collected at discrete depths for algal species composition and biomass, total phosphorus (TP), soluble reactive phosphorus (SRP), ammonia (NH_3), nitrate-nitrite (NO_3-NO_2), total nitrogen (TN), and chlorophyll *a*. In addition, multi-parameter probe measurements were taken at 2 m intervals for temperature (T), dissolved oxygen (D.O.), pH, and specific conductivity. The total nitrogen to total phosphorus ratio (TN:TP), total inorganic nitrogen to SRP ratio (TIN:SRP), as well as estimates of particulate phosphorus (TP minus SRP) and organic nitrogen (TN minus NH_4 and NO_3-NO_2) were also computed.

Water Quality Results

Temperature and D.O. profile results at the time of the first water quality sample trip on June 27th indicated the onset of thermal stratification or stable water column conditions that prevent complete mixing (Figure 2a,b; red line showing decreasing T and D.O. beginning at around the 15 m layer).

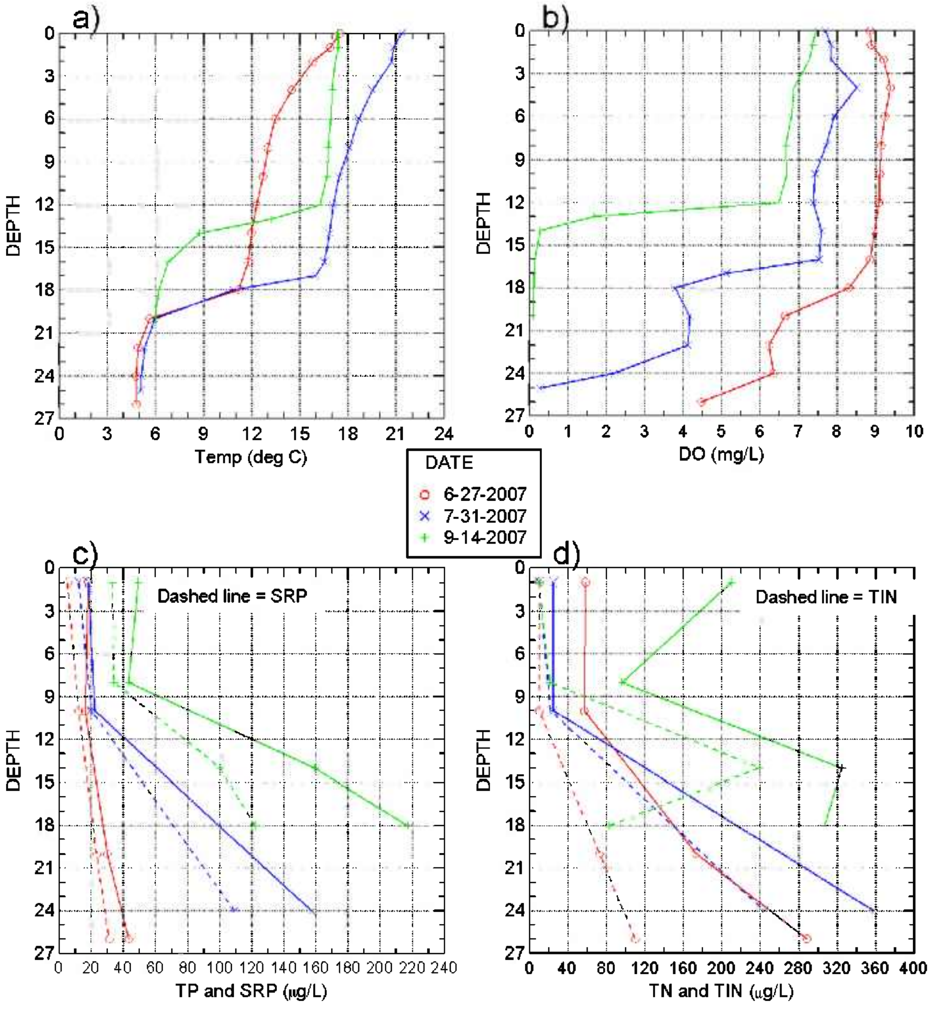

Figure 2. Reeder Reservoir water quality profiles for station R1, 2007. a) Temperature; b) dissolved oxygen; c) total phosphorus (TP) and soluble reactive phosphorus (SRP); and d) total nitrogen (TN) and total inorganic nitrogen.

Typical of more stable water column conditions, the June 27th profiles also showed an increase in total and soluble forms of nitrogen and phosphorus as depth increased (Figure 2c,d). Such nutrient increases occur from settling of organic material (originating either from inflow tributaries or from in-reservoir algal production) and release of nutrients from bottom sediments of the reservoir as D.O. declines. Lower layer nutrients continued to increase as the season progressed and the temperature profiles showed increased stratification and D.O. profiles showed extensive anaerobic to low D.O. conditions in the reservoir hypolimnion (the hypolimnion is the lower stratified layer that is in contact with reservoir sediments). During the last sample date of September 14th, temperature and D.O. profiles both continued to indicate stratified and stable conditions (Figure 2a,b) with a further increase in total phosphorus and total nitrogen at all depths (solid green line, Figure 2b,c). Although further sampling was not conducted in 2007 to determine when de-stratification or fall turnover (complete water column mixing) occurred, based on the continued and increased presence of surface blue-green blooms in October and early November (see below), as well as the protected nature of the reservoir due to surrounding topography and the dam itself as the reservoir is drawn down, it is likely that stratification persisted well into November.

Comparison of in-reservoir nutrient concentrations with inflow nutrients on June 27th revealed that both East Fork and West Fork total phosphorus concentrations were high (>20 µg/L) with respect to conditions required for algal productivity, and that 60-80% occurred as SRP, a form readily available for algal uptake (Figure 3a,b). Concentrations in the upper 1 m and 10m layers (R1-1m and R1-10m, Figure 3) or epilimnion of the reservoir (the epilimnion is the lighted and mixed layer where the majority of algal production occurs) decreased from those observed in tributaries, likely as a result of settling and algal uptake (see particularly the proportional decrease of SRP in the 1 m layer indicating algal uptake). As shown above in the profile data, the 20 m and 26 m layers showed increased TP with the majority occurring as SRP (Figure 3b).

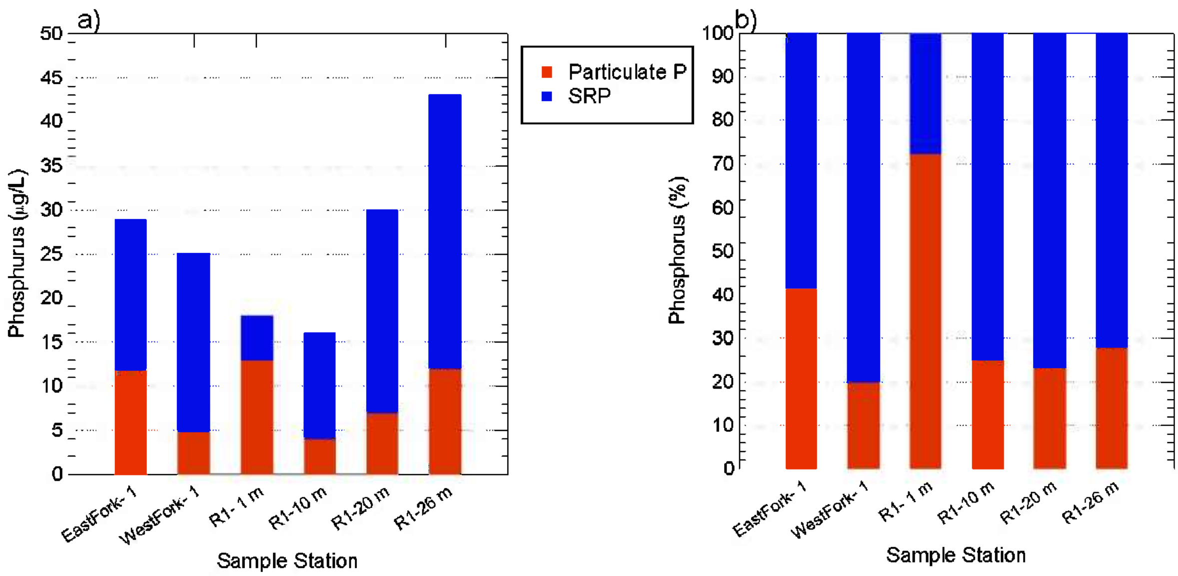

Figure 3. Reeder Reservoir and East and West Forks of Ashland Creek phosphorus concentration (a) and percent phosphorus (b), Station R1 June 27th, 2007.

In contrast, East Fork and West Fork nitrogen concentrations were very low with respect to conditions required for algal productivity, and TIN (the total of NH_4 and NO_3, the forms readily available for algal uptake) was below laboratory detection levels (Figure 4a,b). Reservoir TIN levels remained below detection at both the 1 m and 10 m layers, and then increased substantially in the 20 m and 26m layers, as did organic N.

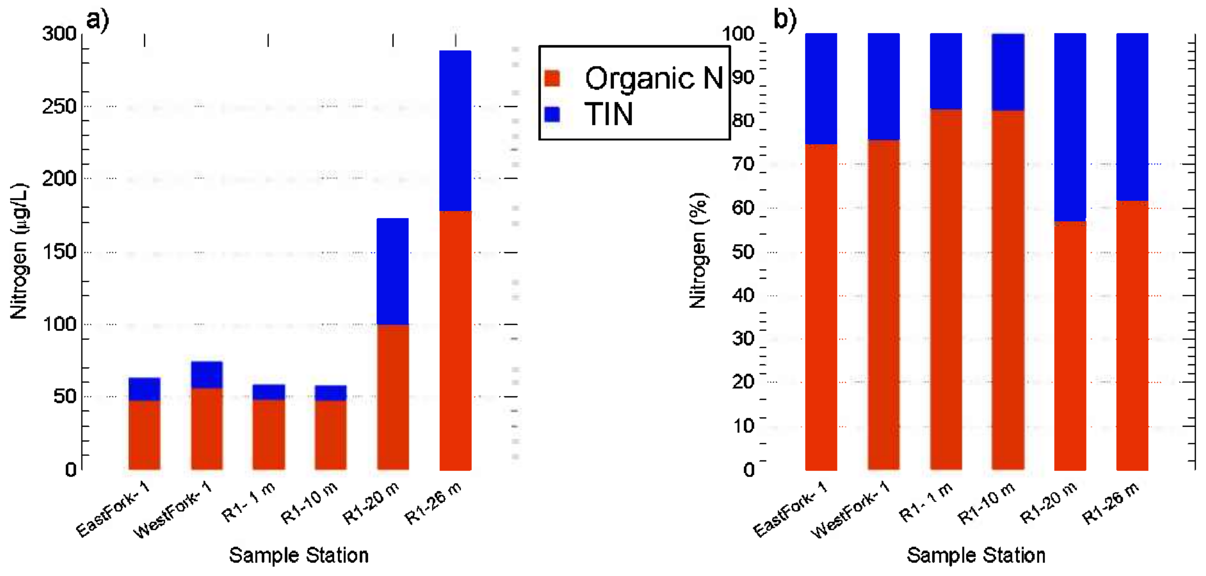

Figure 4. Reeder Reservoir and East and West Forks of Ashland Creek nitrogen concentrations (a) and percent nitrogen (b), station R1; June 27th, 2007. (Note that when values are below laboratory detection limits values are entered as ½ of the detection limit; the detection limit for TN is 50 µg/L and is 10 µg/L for both NH_4 and NO_3-NO_2).

Such conditions of relatively high TP and SRP combined with low TN and TIN equated to TN:TP ratios <3 and TIN:SRP ratios <1 in the East and West fork tributaries (Figure 5). Such low ratios, along with available SRP (see Figure 3a), generally favor nitrogen-fixing blue-green algae. These algae are not dependant on ambient nitrogen concentrations, but rather can obtain nitrogen directly from the atmosphere.

Although these nutrient comparisons with East and West Fork concentrations provide valuable insight, it should be noted that with only one date available for evaluation, seasonal variability in concentrations and loads is unknown. For example, a plot of East and West Fork discharge shows that the June 27th nutrient samples were taken at the tail end of the descending hydrograph when discharge was ~7.5 cfs (Figure 6). Further monitoring to determine seasonal (high discharge events as well as base-flow which was ~3 cfs in 2007) tributary nutrient flux is essential for understanding long-term dynamics of the reservoir and to determine potential watershed sources.

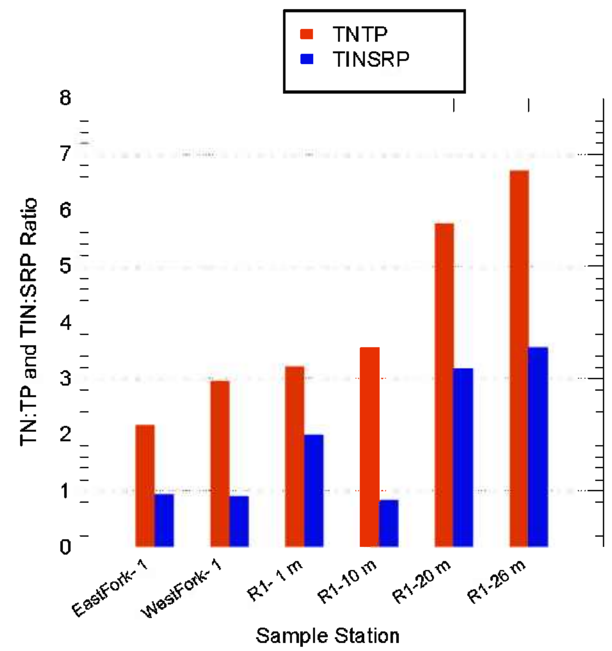

Figure 5. Reeder Reservoir (R1) TN:TP and TIN:SRP ratios compared to those occurring in the East and West Forks of Ashland Creek, June 27th, 2007.

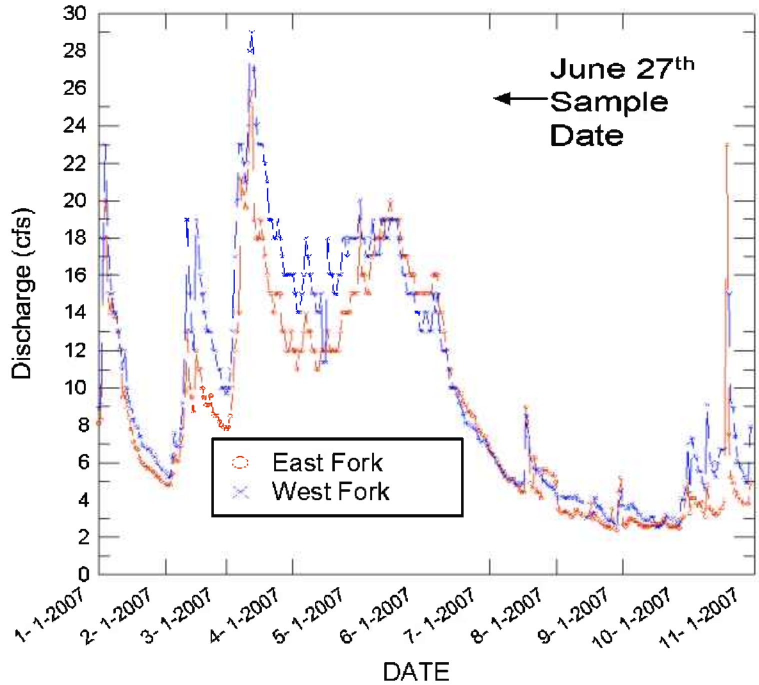

Figure 6. East Fork and West Fork Ashland Creek discharge into Reeder Reservoir, Jan-Oct, 2007. Data were downloaded from USGS: http://waterdata.usgs.gov/OR/nwis/current/?type=flow.

Algal Results

Algal sampling in 2007 clearly showed the development of surface blue-green blooms as early as mid-June, with noticeable blue-green algal colonies observed during the initial reservoir reconnaissance on June 14th. Subsequent microscopic analyses revealed that the dominant blue-green species was *Anabaena flos-aquae* (ABFA), a potentially toxigenic species (Appendix I: Table 1, Figures 1 and 2). Although the cell count at the reservoir surface was 7,771 cells/ml and exceeded the World Health Organization (WHO) guideline of 2000 cells/ml s for toxic algal species in drinking water supplies, ABFA was not detected in either the intake water to the plant (the intake depth was 30 ft at the time the sample was taken), or in the treated (finished) water (Appendix I: Table 1, Figures 1 and 2). Moreover, the common algal toxins, microcystin and anatoxin-a, were not detected in any of the samples (Appendix II).

Although blue-green concentrations continued to increase at the reservoir surface by the June 27th sample date (Figure 7), cell densities were less than 100 cells/ml at the first sample depth of 1 m indicating the bloom was confined to a thin layer near the reservoir surface (Appendix I: Table 2 and Figures 3 and 4).

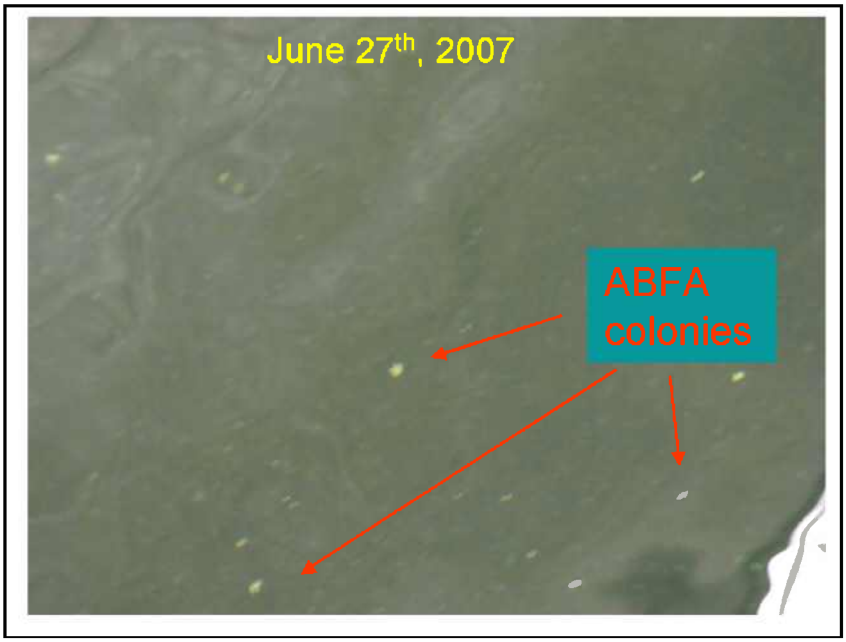

Figure 7. Surface of Reeder Reservoir on June 27th, 2007 showing *Anabaena flos-aquae* (ABFA) colonies.

During the subsequent week, treatment plant staff continued to notice dense surface concentrations of blue-green algae prompting treatment with copper sulfate (a potent algicide) on July 3rd. This treatment, likely in conjunction with a windy period in ensuing weeks, caused a bloom decline with only low densities of ABFA found on both July 13th and July 31st site visits (Appendix I: Figures 2 and 4). However, this decline was temporary, and treatment plant staff again noticed increasing concentrations of blue-green along Hosler Dam in August and

September. By September 14th, cell counts of ABFA at the surface were 26,789 cells/ml, well above WHO guidelines. Fortunately, density of ABFA declined to <1000 cells/ml at 1m, and was 16 cells/ml at 8m (which is still higher in the water column than intake levels to the treatment plant).

As the bloom continued to increase into October, another round of cell counts and toxin analysis showed that surface counts were extremely high and had increased to 31,570,000 cells/ml (Figure 8, Appendix I Figure 2). This value greatly exceeded not only the WHO Alert Level III value of 15,000 cells/ml for drinking water systems (Falconer et al. 1999, Yoo et al. 1995), but also Oregon's recreational guideline value of 100,000 cells/ml (Jacoby and Kann 2007). However, as expected based on buoyancy characteristics of ABFA, which tend to cause high surface concentrations, the ABFA level at 38 ft (taken to approximate the depth of withdrawal to the water treatment plant) was reduced substantially to 631 cells/ml (Figure 8). This level is well below the Alert Level II of 2,000 cells/ml for lakes and reservoirs utilized for drinking water. Finally, the ABFA density in the treated tap water collected at the treatment plant was further reduced to 103 cells/ml (Figure 2). Although low, this indicates only an 84% reduction of ABFA relative to the raw water concentration of 631 cells/ml, and should raw water concentrations increase, the potential for higher ABFA in tap water also increases.

Subsequent cyanotoxin results showed that despite the extremely high ABFA surface density on October 12th (31,570,000 cells/ml), that anatoxin-a was not detected (Appendix II). Anatoxin-a is the cyanotoxin most likely to be produced by ABFA, and given the high cell densities present on October 12th there would have been a high likelihood of detection if toxin production was occurring. In addition, as expected based on lower cell density, anatoxin-a was not detected in either the sample taken at the treatment plant intake or in the treated water sample. Although good news, because the mechanisms that control toxin production are poorly understood, continued monitoring is necessary to ensure that toxins are detected should toxin production occur in future years. For example, variable year-to-year toxin production by ABFA has been known to occur in other Oregon lakes such as Diamond Lake (Jacoby and Kann 2007).

The October 12th results did show a low level of the liver toxin microcystin (0.5 µg/L) at the reservoir surface; however, given the extreme cell density present, this is a relatively low concentration, and is 50% of the World Health Organization drinking water standard of 1 µg/L (Falconer et al. 1999). Moreover, microcystin was not detected in either the sample taken at the treatment plant intake or in the treated water sample.

Thus, results from Reeder Reservoir on October 12th showed that cyanotoxin levels were either not detected or were below drinking standards, and that the primary current issue with the ABFA blooms is due to potent taste and odor compounds such as geosmin or MIB, commonly associated with blue-green algal blooms. These cause a musty odor and taste that was highly reported by the public users of Ashland City water in 2007.

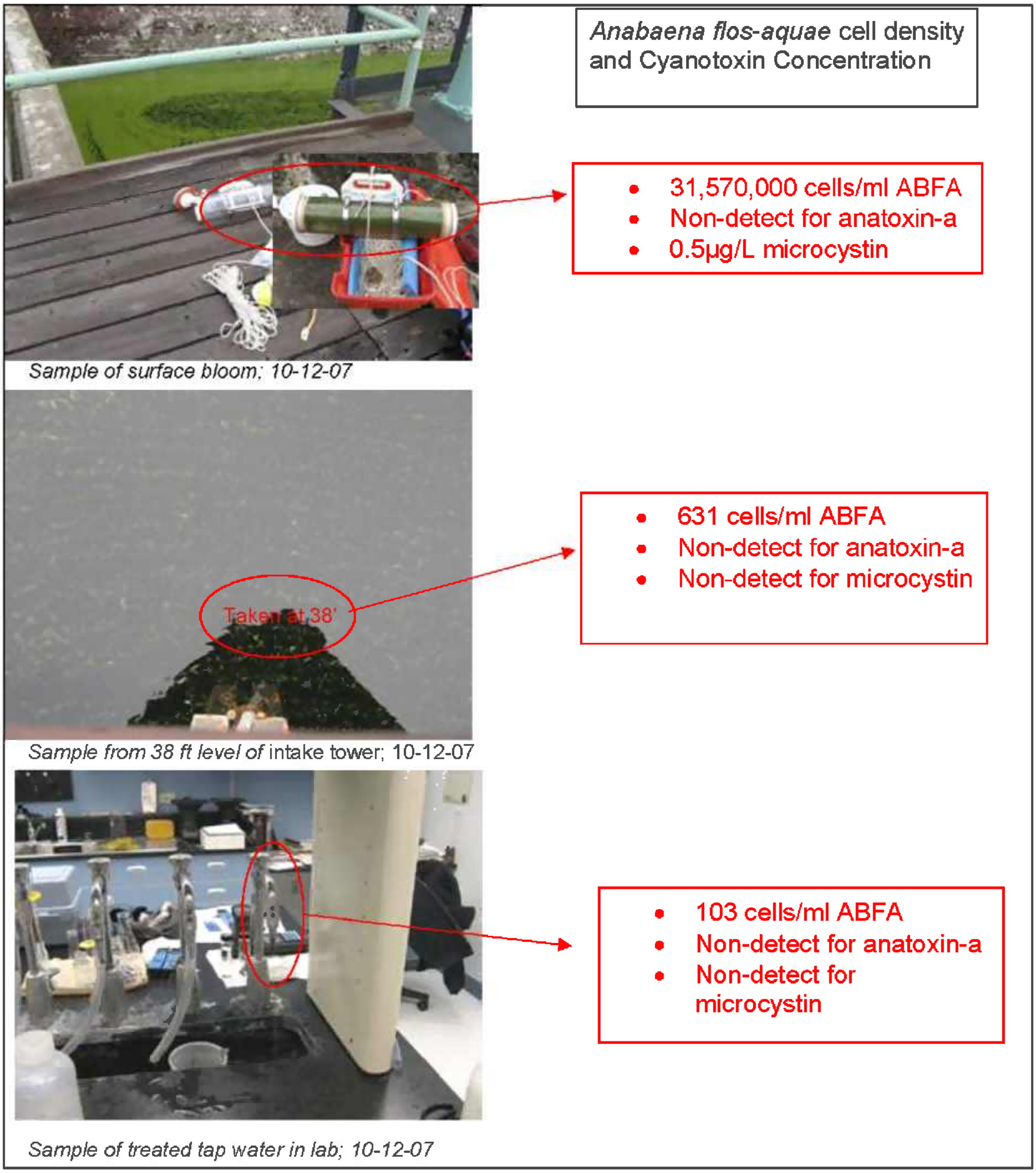

Figure 8. Cell density and algal toxin testing in Reeder Reservoir, October 12, 2007.

Although such blooms usually decline as seasonal cooling and mixing occurs in the fall, blooms persisted well into November and early December because the surrounding topography, as well as the dam itself, contribute to areas of poor circulation that can contribute to a prolonged bloom. In addition, as stratification weakens, nutrients that have accumulated in the lower reservoir layers (see above) can become available to algae in the upper reservoir layers further contributing to dense fall blooms.

In addition to the trends of *Anabaena* in upper reservoir layers discussed above, other important species present in Reeder Reservoir include the blue-green (cyanophyta) alga *Aphanizomenon*, the green (chlorophyta) algal genera *Oocystis* and *Mougeotia,* the cryptophyte *Cryptomonas erosa*, and the diatom *Asterionella* (Appendix II: Figure 3 and 4).

Water Quality and Algal Discussion

Inflow nutrient and reservoir characteristics such as low inflow N:P ratios (with little available inorganic nitrogen), a high proportion of inflow P as available SRP, temperature and dissolved oxygen profiles indicative of highly stratified in-reservoir conditions, and accumulation of N and P in lower reservoir layers, indicate that Reeder Reservoir is a eutrophic (productive) system that provides conditions conducive for surface blooms of the blue-green alga, *Anabaena flos-aquae*, such as those observed in 2007. As stated above, such conditions of low N:P ratios along with available SRP favor nitrogen-fixing blue-green algae because such algae are not dependant on ambient nitrogen concentrations, but rather can enzymatically fix atmospheric N_2 to useable NO_3. Moreover, the type of stratified conditions present in the reservoir allow these buoyant blue-green algae (cyanobacteria) to remain in the upper reservoir layer (epilimnion) where there is adequate light for photosynthesis. The type of stratification observed in Reeder Reservoir also fosters the release of nutrients from reservoir sediments that can become available for algal growth either from entrainment to upper layers or as stratification breaks down in the fall and nutrients are mixed upward in the water column.

Although copper sulfate has been used in the past to manage these blooms, given a state-wide direction to reduce the use of such algicides which require repeated application (note the rebounding bloom subsequent to the July treatment), as well as the potential to release algal toxins to the water column through cell lysis as algicides are applied, other management options for bloom reduction are desirable. The availability of nutrients in East and West Fork inflow as well as from reservoir sediments combined with stable water column conditions limits nutrient control measures such as aluminum sulfate. However, water column circulation provides a high probability of preventing and/or disrupting blue-green algal blooms in Reeder Reservoir. These methods work both by disrupting buoyancy and circulating ABFA cells out of the upper reservoir photic layers, and by preventing nutrient build-up in bottom layers by reduction of hypolimnetic anaerobic conditions. In-reservoir reduction of blooms is essential for management of both algal toxins and taste and odor compounds so that the need to remove these compounds in the water treatment plant is reduced.

Reservoir Sediment Characteristics

Methods

Two sediment cores were collected from Reeder Reservoir on September 14, 2007. The cores were collected using a SDI Vibra-Corer equipped with a 7.5 cm diameter polycarbonate core tube suspended over a floating crane. The cores were collected near the historical thalweg adjacent to the dam (Core 1) and near the middle of the reservoir (Core 2; Figure 9). In both cases, multiple core retrievals were made in order to achieve the deepest possible penetration at each site. In addition, as a further check of spatial variability, 3 surface sediment grabs with a Ponar dredge were collected along a transect between the dam and the upper 1/3 of the reservoir.

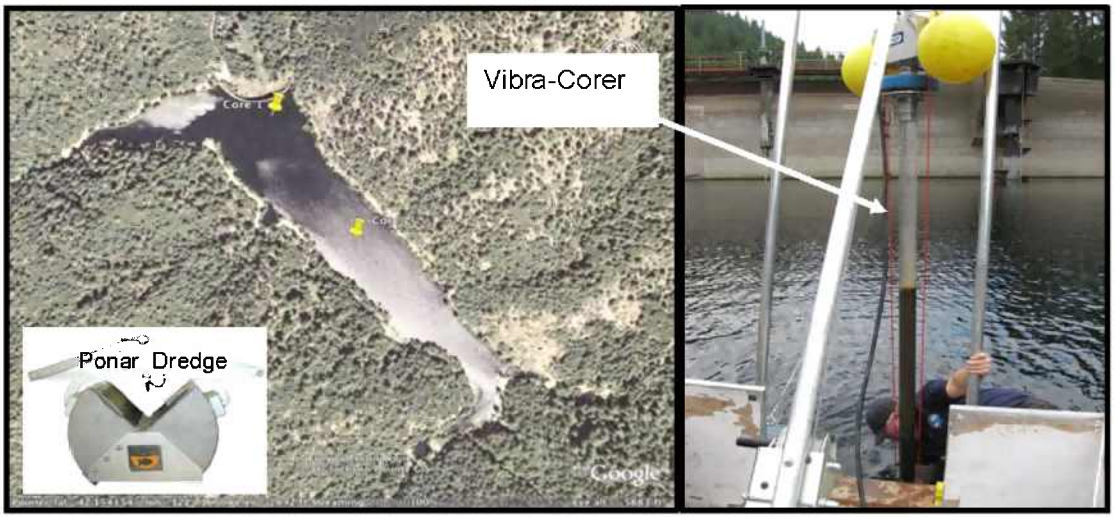

Figure 9. Sediment coring locations in Reeder Reservoir, 2007.

Vibra-Core Results

The moisture content of the two sediment cores illustrates complex patterns in sediment composition (Figures 10 and 11). The upper 25 cm of both cores were similar with respect to both physical appearance and moisture content. However, the appearance of the two cores below this depth differed considerably. The physical appearance of Core 1 below 25 cm remained relatively similar to the surficial sediments down through 120 cm, with the exception of a large piece of wood fiber at 95 cm (Figure 12a). Below 120 cm, much of the sediment included numerous large piece of woody debris (Figures 12b,c). The bottom interval of Core 1 contained a substantial amount of sand (Figure 12d). The textural classes for Core 1 are reasonably consistent with the water content and physical observations in which clay content was low throughout the core and increasing amounts of sand were present, especially below 120 cm (Figure 13).

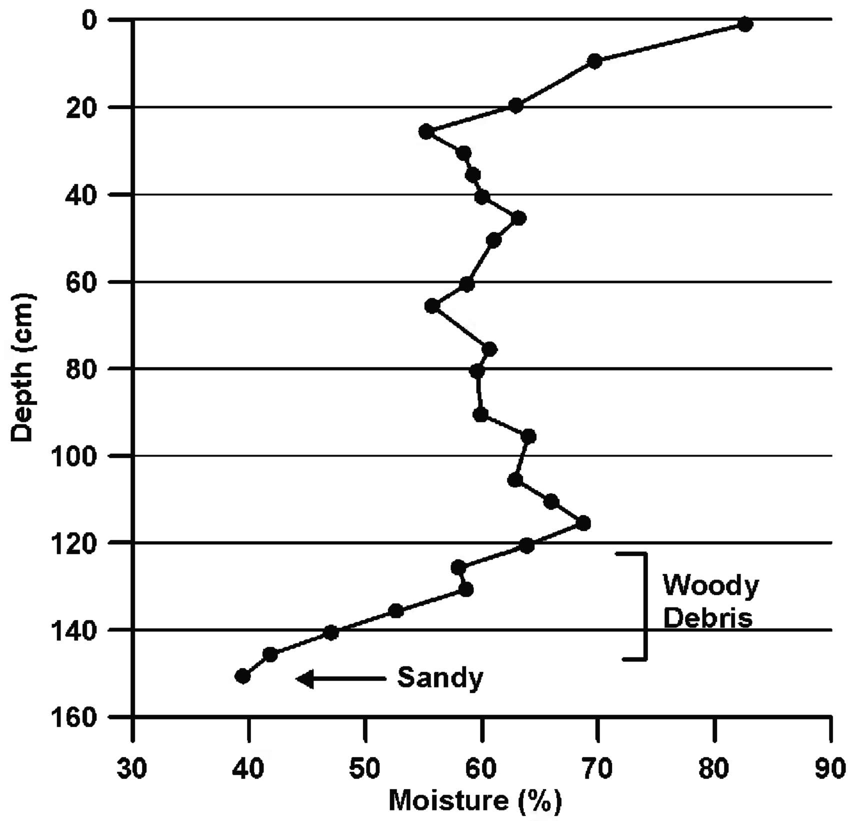

Figure 10. Moisture content of sediment from Core 1. Locations of notable changes in sediment composition are noted.

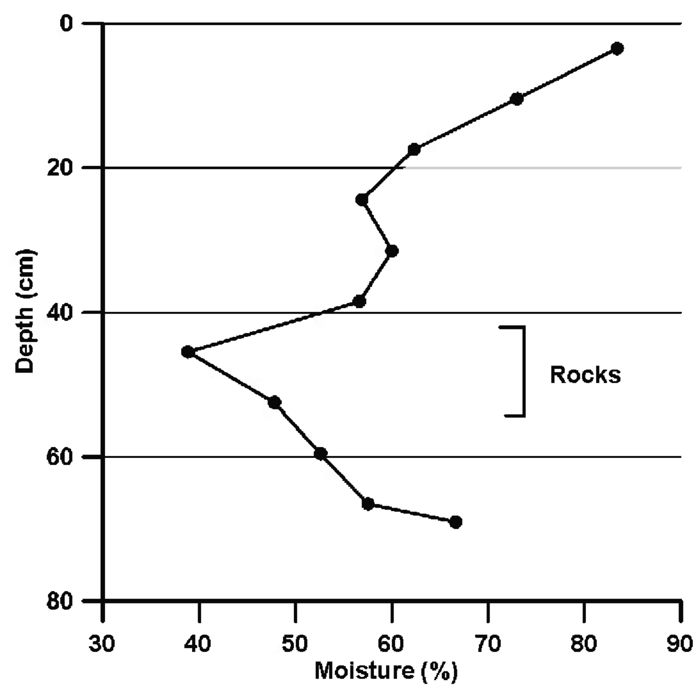

Figure 11. Moisture content of sediment from Core 2.

Figure 12. (a) Upper left shows sediment from the top of Core 1, illustrating its fine, organic texture and lack of cohesiveness. (b) Upper right shows large piece of woody debris at 95 cm. (c) Lower left shows small, numerous pieces of vegetation and larger woody debris and comparatively low water content. (d) Lower right shows bottom of core with higher sand content.

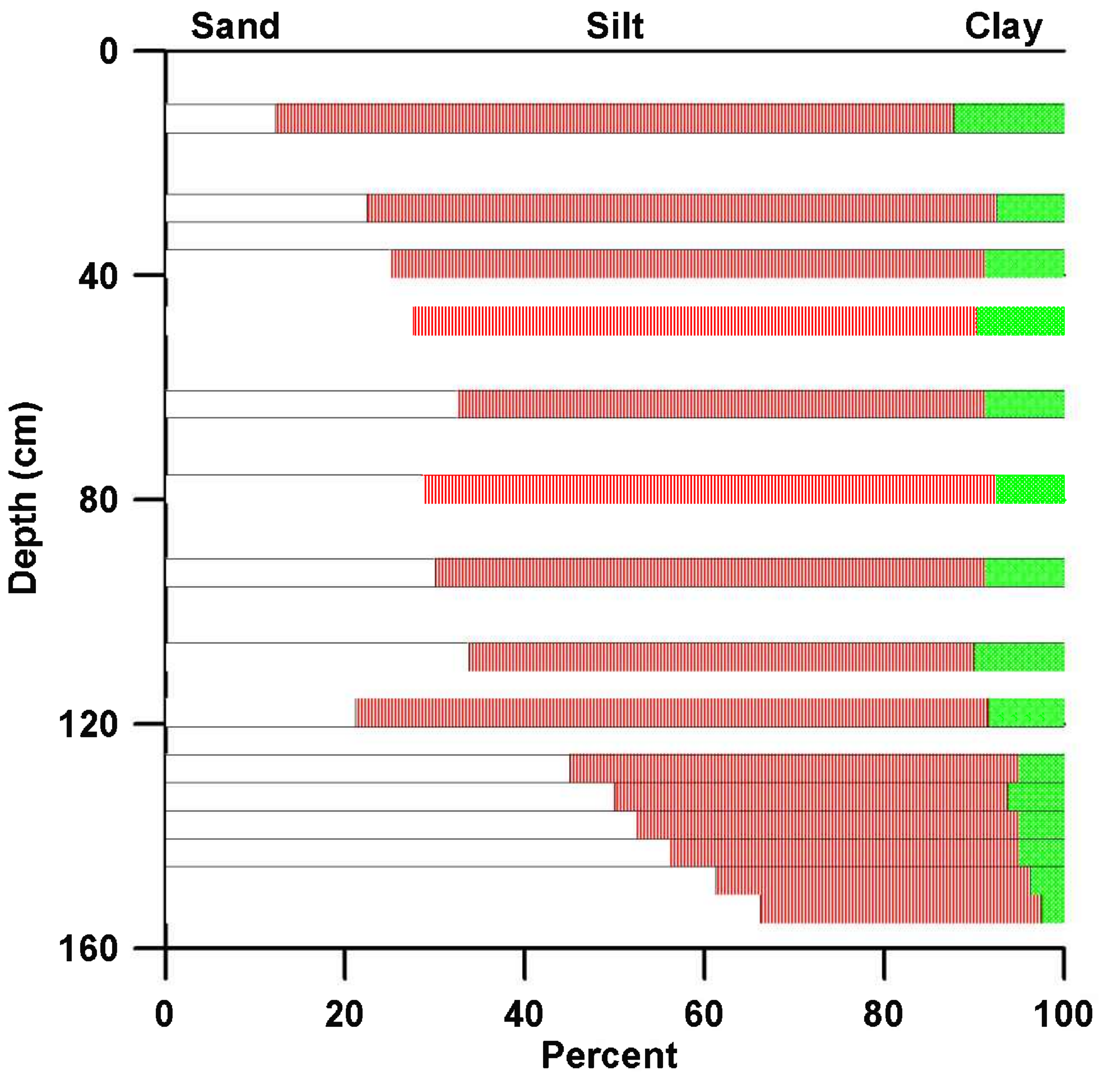

Figure 13. Textural classes for the sediment in Core 1.

Although the surficial sediments in the two cores were similar to one another, the deeper sediments in Core2 differed substantially from those in Core 1. The sediments in Core 2 did not contain woody debris. Instead the dominant material included small granitic rocks, some over 30 mm in diameter (Figure 14). Consequently, the water content in the middle depths of the core was sharply lower (Figure 11). The information on the textural classes in Core 2 are similar from top to bottom (Figure 15), however this is somewhat distorted by the omission of the rocks from the textural analysis.

Figure 14. (a) Top shows the second interval from Core 2, representing the material from 7-14 cm. (b) Bottom shows the rocks present in the sediment from 49-56 mm. Smaller rocks were present in the next lower interval.

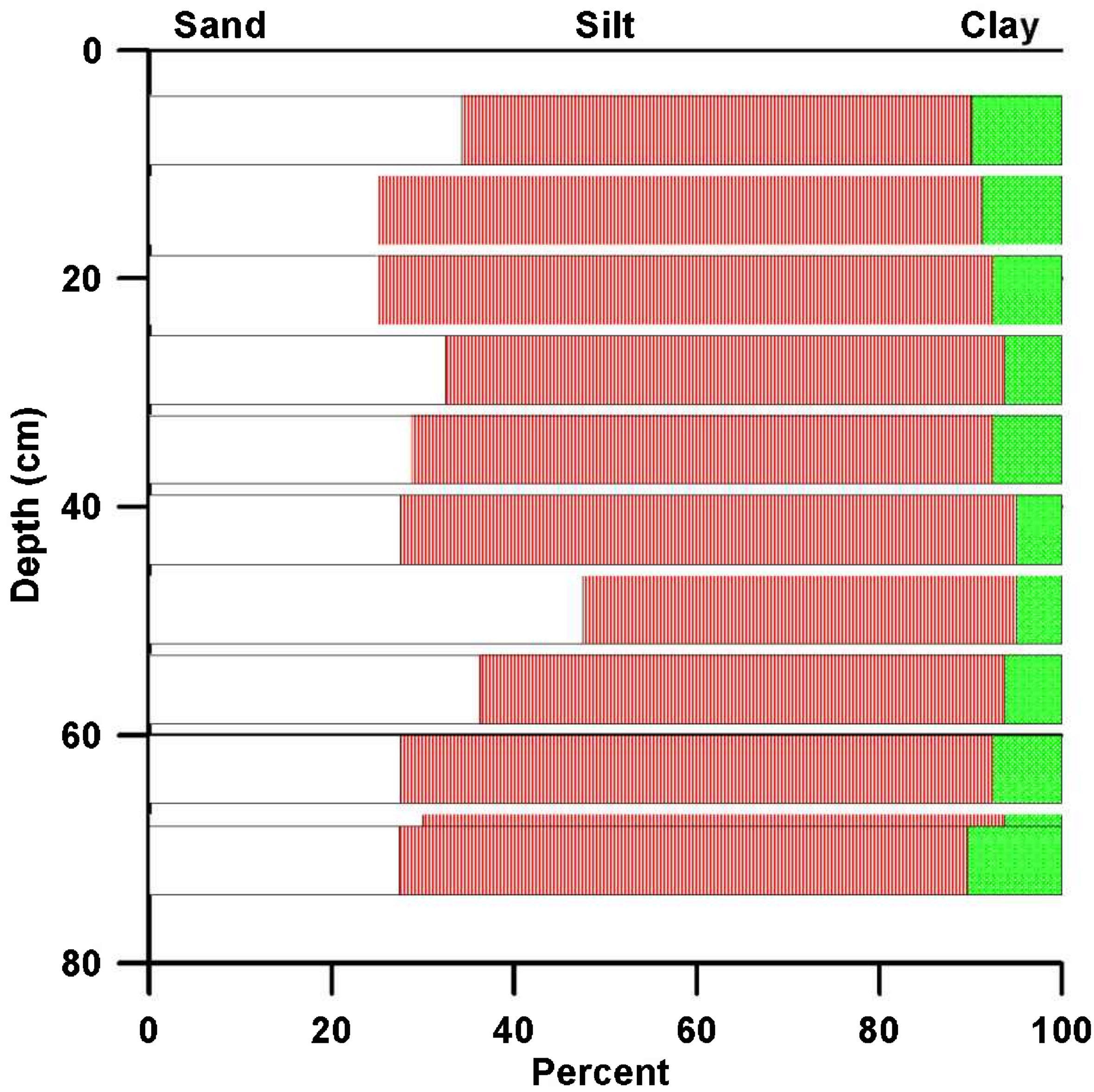

Figure 15. Textural classes for Core 2.

The chemistry of the sediments shows that the phosphorus concentrations in both cores ranged between 1000 to 2000 ppm (Figures 16 and 17). With the exception of an increase in phosphorus at ~ 30 cm, phosphorus concentrations are relatively stable and then decline below 120 cm. This is consistent with an increase in the proportion of sand and decrease in silt (Figure 13). Phosphorus concentrations in Core 2 exhibit a decrease between 40-60 cm, which is the region of the core with large numbers of rocks present (Figure 14). Both cores have high concentrations in the surficial sediments. Concentrations of nitrogen decline rapidly in both cores. Nitrogen values remain relatively stable from 20 to 120 cm, but decline throughout the bottom portion of the sediments. In contrast, concentrations of nitrogen reach a minimum ~ 50 cm and increase substantially at the base of the core.

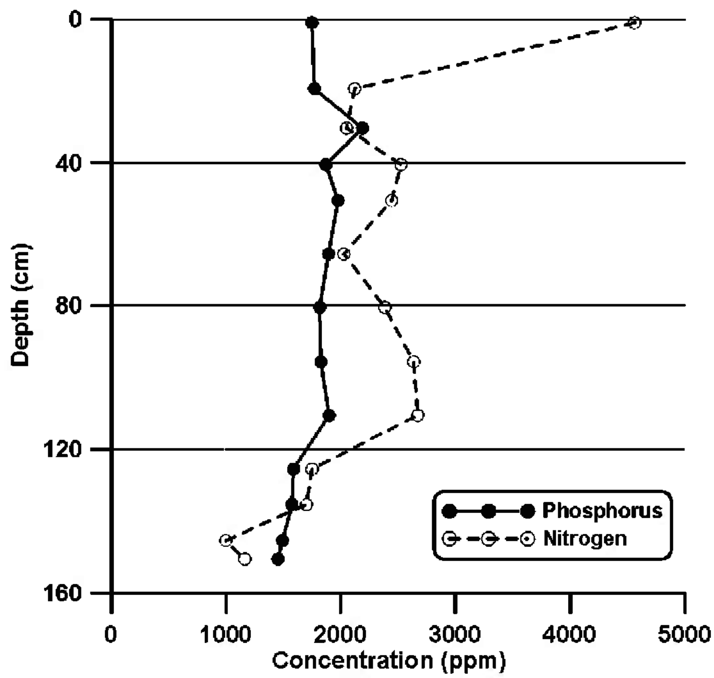

Figure 16. Concentrations of nitrogen and phosphorus (dry wt) in Core 1.

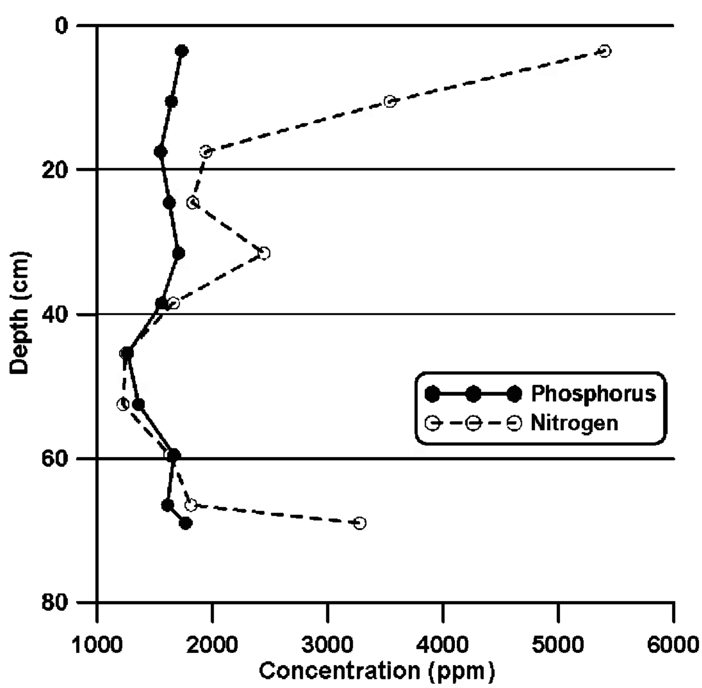

Figure 17. Concentrations of nitrogen and phosphorus (dry wt) in Core 2.

Ponar Results

Three Ponar samples were collected along a transect from near the deepest point in the reservoir upstream towards the south end of the reservoir. The Ponar samples represent a composite of about the upper 5-8 cm of sediment at each site. As expected, the results show a strong similarity with the top of each of the two core samples (Table 1). The average moisture content of the Ponar samples (83 %) is nearly identical to the two core samples, although the average nitrogen and phosphorus concentrations from the PONAR samples are slightly lower than the results from the top core samples. The average carbon content from the three Ponar samples is moderately high and indicates that there is substantial carbon deposition to the sediments. This carbon likely represents a combination of decaying algal cells derived from populations within the reservoir and inputs from leaves and other organic debris delivered from the watershed. The organic matter, represented by the carbon concentrations, provides a resident source of oxygen demand, contributing to anoxia in the deep waters of the lake.

Table 1. Results of Ponar dredge samples taken in Reeder Reservoir September 14, 2007.

Sample Number		%H2O	TKN	TKP	C
			ppm	ppm	%
R1		77.8	2710	1518	6.85
R2		89.9	4330	1278	14.53
R3		82.2	3736	1407	10.25
Average		**83.3**	**3592**	**1401**	**11**

Sediment Discussion

Neither of the cores penetrated to the depth of sediment possible with a Vibra Corer. In Core 1, we attribute the cause of halted penetration at 160 cm (5.25 ft) to woody material buried in the sediment. In Core 2, the penetration was halted by the presence of larger diameter rocks, which may have approached the base of the reservoir as excavated after the flood of January 1997. In this case, the accumulated fine sediment only represents about 30 cm (~ 1 ft) of accumulated material over the last decade. As expected, the area immediately in front of the dam is the most favorable deposition zone in the reservoir, and the deeper sediment core from this site is consistent with these expectations. If the interval containing the first large piece of woody debris (Figure 4b) at 95 cm represents the top of the sediment remaining after the 1997 flood, then the additional accumulation of sediment since then would be about 3 ft. If the demarcation between the debris from the 1977 flood occurred at about 125 cm, then the accumulation near the dam since that time would be about 4 ft.

The cross-sectional profile of the reservoir is strongly "V" shaped and the longitudinal profile shows a fairly constant slope towards the dam (Figure 18). This shape promotes a high degree of sediment focusing towards the historical thalweg and towards the base of the dam. This geometry explains the large differences in apparent sediment accumulation observed between the two sediment cores.

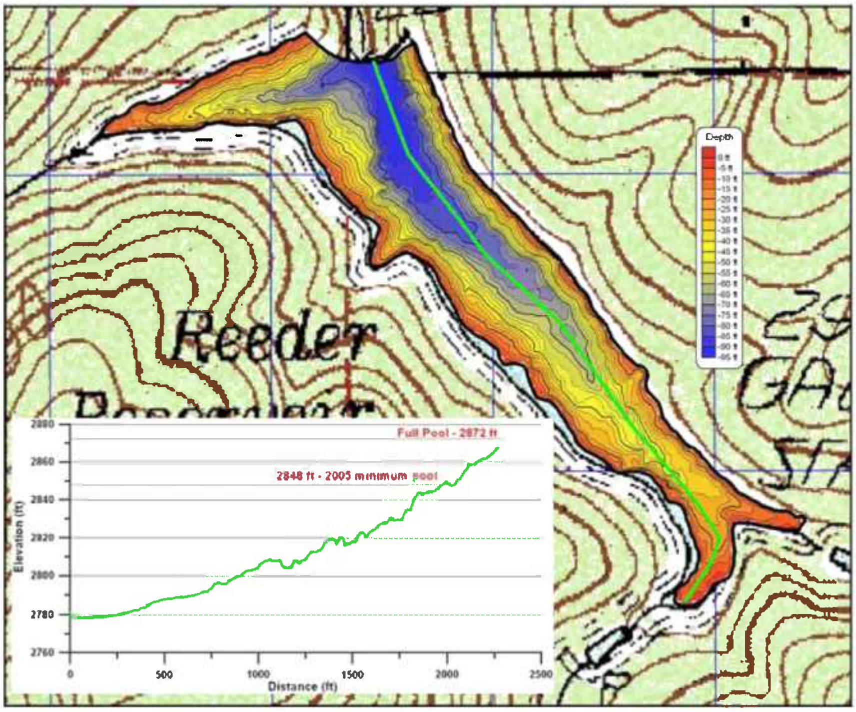

Figure 18. Longitudinal profile of Reeder Reservoir showing the near-continuous slope towards the dam.

The nutrient chemistry of the cores is consistent with high inputs of phytoplankton remains, thus causing higher nitrogen values in the upper sediments. Likewise, the sediments in Reeder Reservoir have high concentrations of phosphorus. Except for the surficial sediments, concentrations of nitrogen and phosphorus are similar, which would suggest that nitrogen is limiting to phytoplankton growth. As discussed earlier relative to water column chemistry, the combination of high phosphorus and relatively low nitrogen in the reservoir is conducive to dominance by nitrogen-fixing cyanobacterial taxa such as ABFA.

Reservoir Bathymetry and Comparison to 1987 Survey

New Bathymetry Methods

Reeder Reservoir was mapped on June 26, 2007 while the lake was at full pool (2872 ft). Hydroacoustic data were collected using a BioSonics echosounder equipped with a 200 KHz split-beam transducer (6.6 ° beam). Positional data was obtained with a Trimble Ag132 DGPS mounted over the top of the transducer. The unit was operating with a ping frequency of 5 per second and a pulse length of 0.4 ms. The vessel was operated at a velocity of about 9 kph. The reservoir was surveyed using a series of transects, supplemented by directed paths to complete the coverage of the lake (Figure 19).

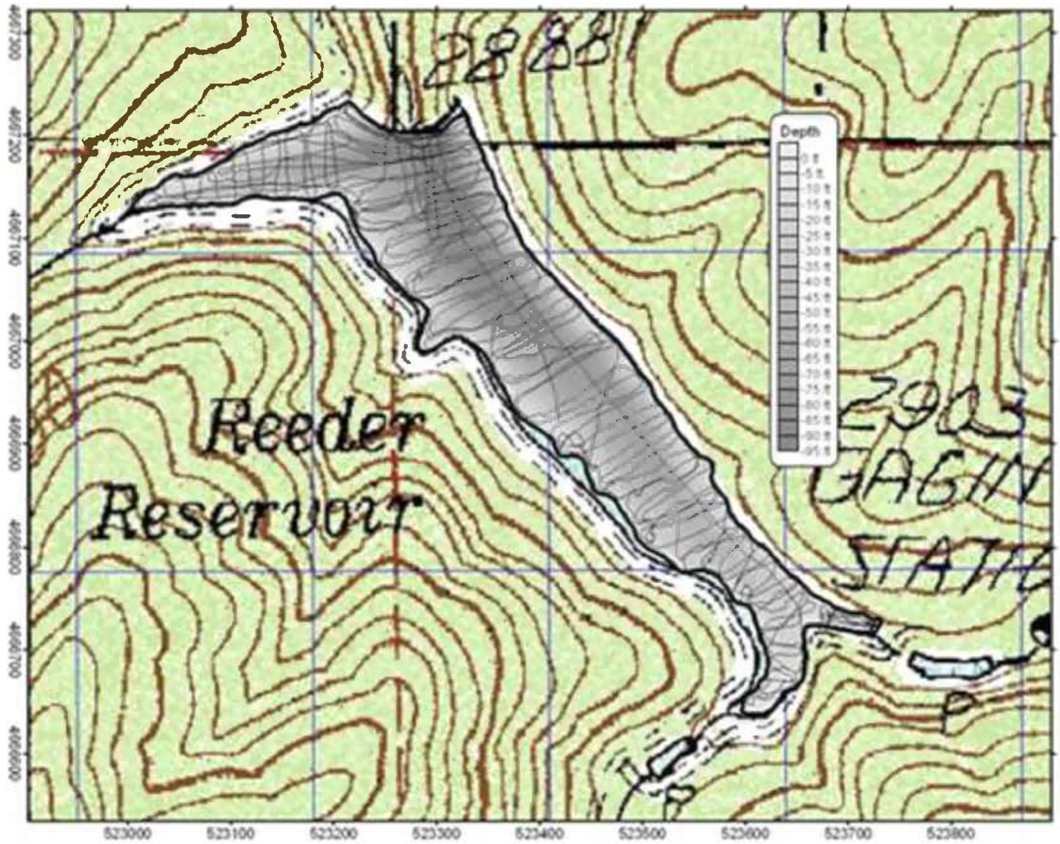

Figure 19. Survey transects used to acquire hydroacoustic data for Reeder Reservoir, OR.

Results

The bathymetric map generated from this project is shown in Figure 20. The morphometric properties of the lake bathymetry are shown in Table 2. A depth-volume curve showing the distribution of lake volume as a function of depth is provided in Figure 21.

Table 2. Morphometric properties of Reeder Reservoir, OR.

Attribute	English	Metric
Surface Area	20.12 acres	8.142 ha
Volume	859.6 ac-ft	1.060 X 10^6 m^3
Maximum Depth	94.1 ft	28.7 m
Average Depth	42.4 ft	12.9 m

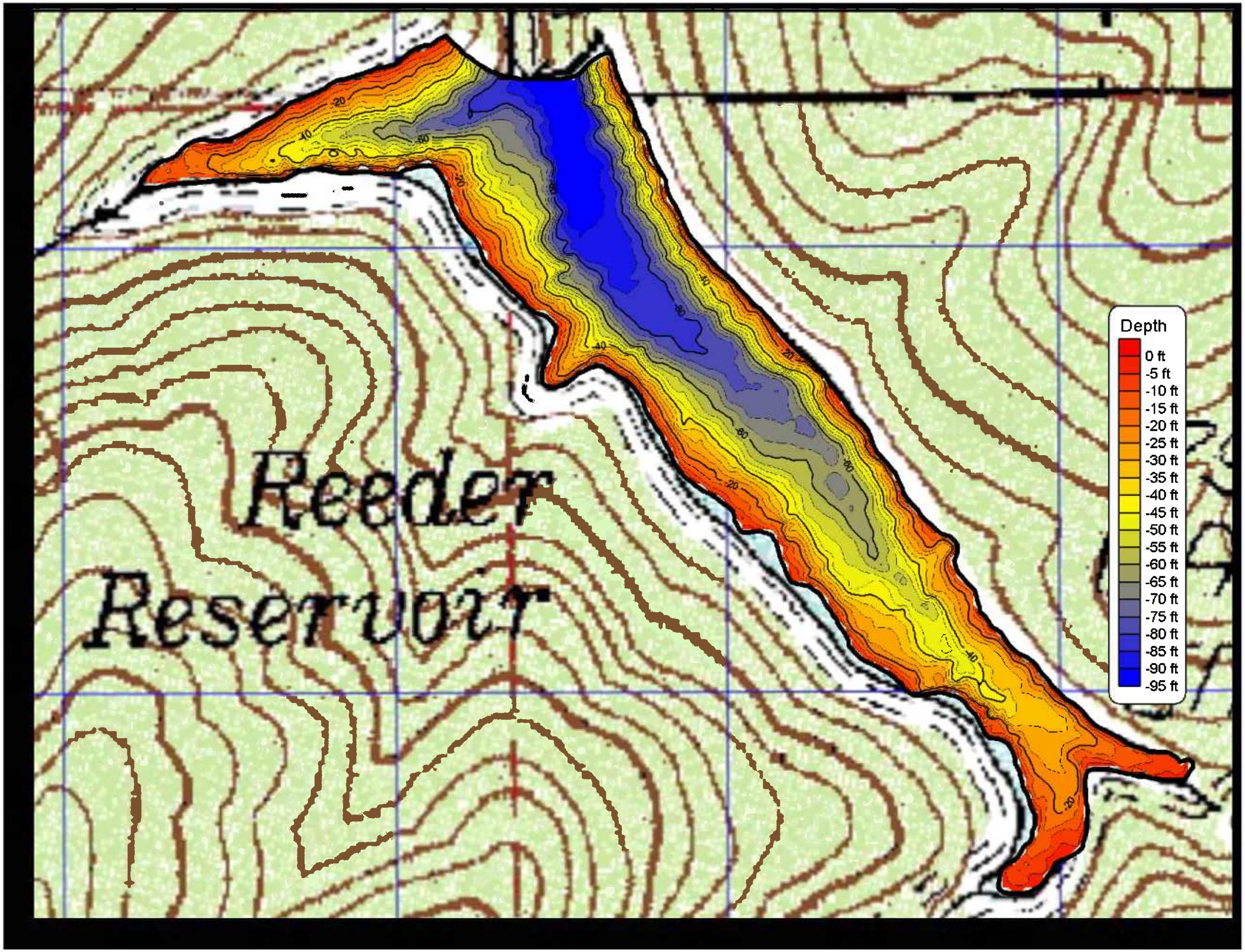

Figure 20. Bathymetric map of Reeder Reservoir, OR based on hydroacoustic data acquired on 6-26-2007 at full pool (2872.1 ft).

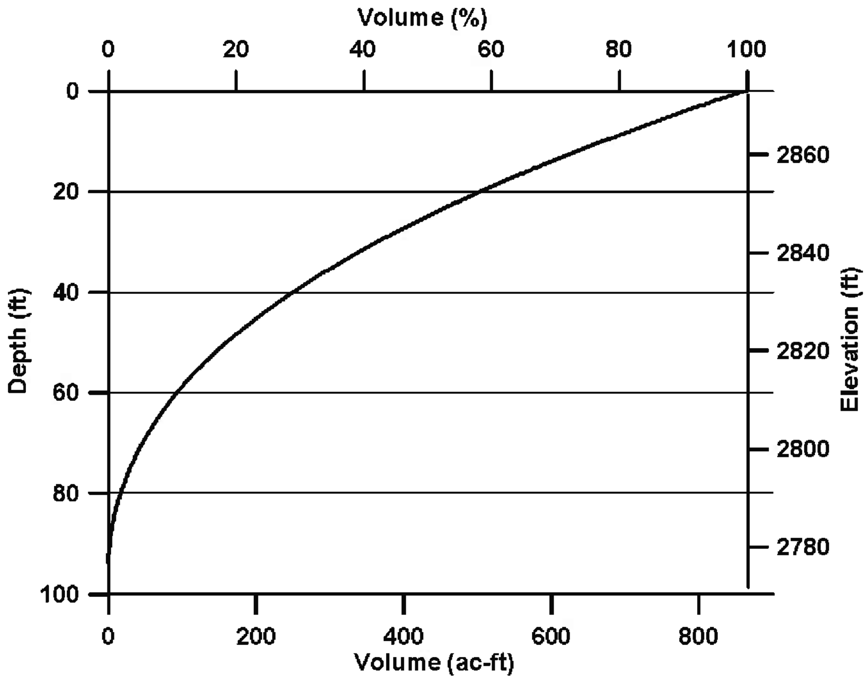

Figure 21. Depth-volume curve for Reeder Reservoir, OR.

Comparison to 1987 Survey

The bathymetry of Reeder Reservoir was generated through an earlier study by the City of Ashland and the Siskiyou National Forest in 1987 (Figure 22).

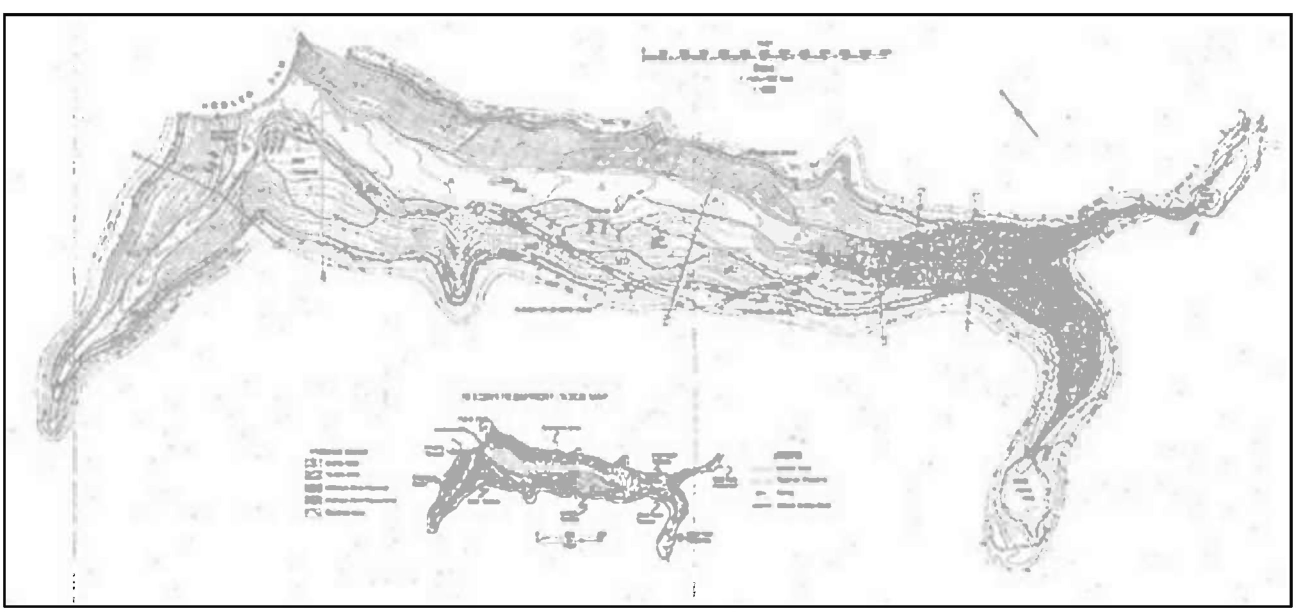

Figure 22. Bathymetry and surficial geology classification based on study in 1987.

The contours for this map were digitized, rectified, and overlaid with the current bathymetry (2007) to yield a difference map. The difference in elevations between the historical and current bathymetry are shown in Figure 23. The areas shaded in pink-to-red represent portions of the reservoir where the older bathymetry was displayed as a higher elevation. Thus, these areas would constitute erosional zones. The areas shaded in blue represent portions of the substrate that have shown an increase in elevation between the two surveys. These zones would constitute areas of deposition of sediment.

Bathymetry Discussion

The comparison between the current bathymetry and the historical bathymetry illustrates some general patterns that might be anticipated in a reservoir where erosion continues from the steep sidewalls and deposition occurs in the reservoir trough. The greatest areas of apparent erosion are associated with the point between the main reservoir arm and Reeder Gulch. The second area of the reservoir with significant apparent erosion is on much of the east shore of the reservoir. This is the shoreline most exposed to wave action from wind, especially as the lake is drawn down during summer use. This was evident during sampling trips to the reservoir in September when the lake stage was 21 ft below full pool (Figure 24).

The patterns near the two inlets from Ashland Creek reveal different types of sediment erosion and deposition. Much of the inlet area associated with the East Fork inlet appears to be erosional as illustrated with the exposed aqueduct footings and large-diameter rocks (Figure 25). The locations of the apparent depositional zones in Reeder Reservoir are generally associated with the troughs in Reeder Gulch and the main arm of the reservoir. This is consistent with movement of material into the reservoir and deposition in some of the deeper, flatter portions of the catchment. However, the coarse precision of the historical bathymetry would lead us to believe that some of the extreme zones of apparent erosion and deposition are artifacts of the comparison process. The best method to determine the actual patterns in deposition in Reeder Reservoir would be to conduct a sub-bottom profiling using low-frequency hydroacoustic methods, possibly combined with concurrent sediment coring to relate the signal returns with the composition of the sediment.

A brief analysis was conducted to provide a gross estimate of the sediment accumulated behind Hosler Dam and extending up-reservoir for about 200 ft. We believe that there are about 3000 to 6000 cubic yards of sediment in the reservoir at this location. We cannot quantify the uncertainty in this estimate because of the uncertainty in the elevations of the historical measurements for Reeder Reservoir. More precise estimates of sediment accumulation in the reservoir can be obtained through designed studies (see Recommendations section).

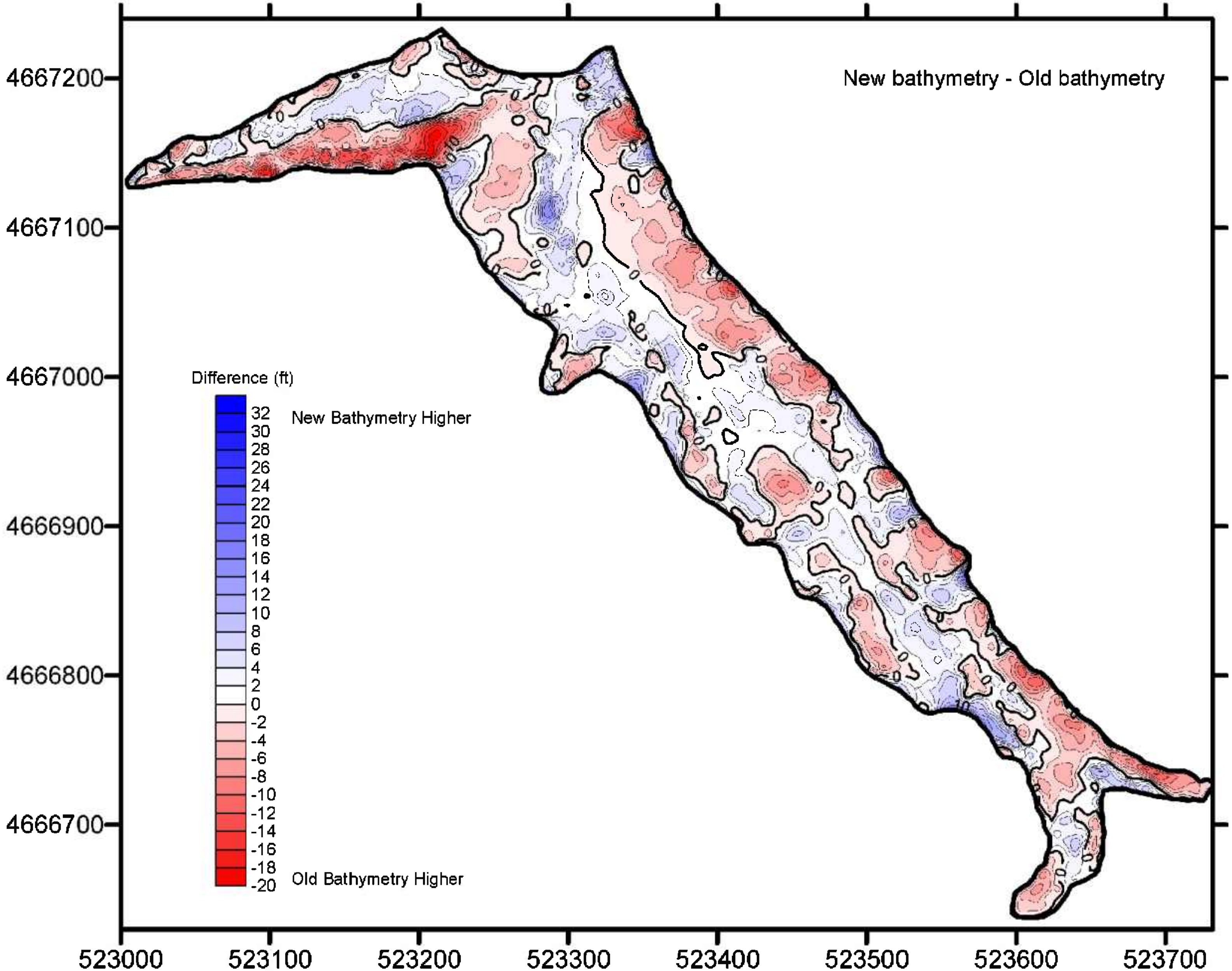

Figure 23. Map showing the differences in reservoir substrate elevation based on a historical study and the current bathymetry. Areas in blue represent zones of deposition and areas in read represent zones of erosion.

Figure 24. Erosional bands on the east shore of Reeder Reservoir created during drawdown. The light colored material in the middle is largely coarse sand comprised of "rotten" granite and the dark material is organic matter deposited during full-pool conditions. This image was taken on September 14, 2007, with the reservoir stage at 2851 ft (21 ft below full pool).

Figure 25. East Fork of Ashland Creek at the confluence with Reeder Reservoir, September 14, 2007.

In contrast, the West Fork inlet contains a large deltaic formation comprised of much finer-grained material (Figure 26).

Figure 26. West Fork of Ashland Creek at the confluence with Reeder Reservoir, September 14, 2007.

Table 3. Evaluation of management options to reduce blue-green algae in Reeder Reservoir.

Management Option	Mechanism	Pros	Cons
Circulation	1) Can shift the dominant species away from buoyant blue-green algae by reducing the amount of time algae spend in the lighted photic zone. 2) provided oxygen diffusion is sufficient, sediment oxidation can reduce sediment nutrients	Requires only one installation. Little maintenance. History of success with these types of problems. Requires no chemicals.	Possibly subject to vandalism. Moderately high capital costs.
Barley Straw	Inhibits the growth of some blue-green algae as lignins in the straw oxidize to humic acids	Use of natural mechanisms to control algae.	Takes 6-8 weeks to become active; needs sufficient water flow through the straw. Requires effort to place and remove periodically. Reeder likely too deep for effectiveness
Shade Chemicals	Dark colored dye reduces light penetration and photosynthesis in the water column	Relatively inexpensive; organic dyes are not toxic.	Buoyant algae can overcome the light limitation by concentrating near the surface. Indigo color may be viewed as unnatural by some.
Algicide: copper-based	Inhibits algal cell division, photosynthesis and nitrogen fixation	Quick results. Relatively inexpensive.	Toxic to aquatic life, can build up in sediments; effect very temporary; releases algal toxins to the water column
Algicide: non copper-based	Creates oxidation reaction (usually sodium carbonate peroxyhydrate) destroying algal cell membranes and chlorophyll	Less harmful to fish and aquatic life; Quick results	Effect very temporary; releases algal toxins to the water column
Alum	Phosphorus binds tightly to aluminum sulfate removing it from the water column and incorporating it into the sediments	Long history of use	Deals only with phosphorus not nitrogen; high nutrient inflow concentrations would rapidly negate effect. Other potential toxic side-effects.
Reduce Inflow Nutrient Concentration	Reduce loading of N and P and nutrient dilution if sufficient reduction in inflow concentration obtained.	Deals with the sources of nutrients supporting the algal blooms.	Must reduce both N and P. Will be ineffective if other sources (e.g., sediments) are not reduced as well.
Sonic Algae control	Sonicate cell walls of algae	May be effective if initiated before algae populations can grow quickly.	Uncertain if technique can keep up with rapidly expanding algae growth. Unknown effect on other biota. Releases algal toxins to the water column. Appears to be most effective in small, shallow ponds with filamentous green algae.
Aeration	Similar to circulation	See circulation	Electricity costs substantial; ability to circulate water at discrete depths limited.

RECOMMENDATIONS

The findings from the study of Reeder Reservoir water quality and sediment characteristics result in the following recommendations.

1. Utilize Circulation to improve reservoir water quality. Given reservoir characteristics as described above, the approach with the highest probability of limiting blue-green algae concentrations in the reservoir is to install water circulation devices to circulate both the near surface and near bottom water. Surface circulation can disrupt the buoyancy of the blue-green algal cells and bottom circulation can prevent sediment release and buildup of nutrients in bottom reservoir layers. There are several manufactures of this equipment, but given the power infrastructure in the reservoir vicinity, those circulators that completely rely on solar energy to power the circulators provide a significant advantage. Circulators should be installed prior to the onset of summer stratification in April.

2. Monitor circulation effectiveness and reservoir water quality. A minimum of once a month sampling (using similar techniques to the study described above) is recommended to determine circulation effectiveness with respect to stratification, and nutrient and blue-green algal dynamics. Such information can then be compared to the 2007 data, and utilized to determine how the circulation system might be adjusted to maximize effectiveness. In addition, a long-term water quality profile station (including temperature, dissolved oxygen, pH, and turbidity) should be established to monitor water quality at specific depths. This would allow: continued tracking of circulation effectiveness, identification of changes in reservoir quality, setting of the reservoir outlet depth to select the best water quality as it changes during the year.

3. Monitor concentrations of potentially toxigenic algae and conduct periodic algal toxin testing. Establish long-term stations at the reservoir surface (along the walkway behind the dam) and from the inlet to the water treatment plant to determine algae densities and species composition of potentially toxigenic cyanobacteria. This sampling can provide valuable warning of trends in potentially toxigenic algae. If reservoir circulation is shown to be effective, this monitoring may only need to consist of a visual survey, with periodic testing of raw water for algal toxins.

4. Monitor tributary nutrient influx. The water quality of the streams feeding Reeder Reservoir should be monitored to determine the sediment, carbon, and nutrient loading the reservoir receives from the streams. As noted above, the tributary samples were only collected on one date in June 2007, and further data collection is necessary to establish seasonal variability and to evaluate watershed sources. This information is valuable in determining the contributing factors to changes in reservoir quality and to determine what measures are necessary to meet regulatory requirements for reservoir.

5. Monitor reservoir sedimentation rate. Due to uncertainty in the previous bathymetric survey there is insufficient information to accurately determine the sediment accumulation rate in Reeder Reservoir. This report provides a rough estimate of the sediment loading rate for the reservoir. To obtain a reliable annual loading rate, another bathometric survey of the reservoir should be taken in five years and compared to the map made for this study to determine the annual rate of sediment filling the reservoir. In addition, a sub-bottom profile and bathometric profile of the reservoir in any year that it appears a storm has moved large volumes of sediment into the reservoir will allow the determination of the amount of sediment deposited by the storm as well as the total volume of sediment in the reservoir.

LITERATURE CITED

Falconer et al. 1999. Safe levels and safe practices. Pages 155-177 *in*: I. Chorus and J. Bartram, editors. *Toxic Cyanobacteria in water: a guide to their public health consequences.* World Health Organization Report. E & FN Spon, London and New York.

Jacoby, J.M. and J. Kann. 2007. The Occurrence and Response to Toxic Cyanobacteria in the Pacific Northwest, North America. Lake and Reserv. Manage. 23:123-143.

Yoo, S.R., W.W. Carmichael, R.C. Hoehn, and S.E. Hrudy. 1995. Cyanobacterial (blue-green algal) toxins: a resource guide. AWWA Research Foundation and American Water Works Association. Denver, CO. 229 p. (ISBN 0-89867-824-2)

APPENDIX I: Phytoplankton Tables and Graphs

Table 1: Phytoplankton data for determination of Ashland Water Treatment Plant effectiveness for removal of potentially toxigenic algal cells, 2007.

Date	Station Description	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (μm^3/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (μm^3/ml)	Taxonomic Group
14-Jun-07	reservoir surface at intake control structure	Anabaena flos-aquae	370	41.9	520,631	82.3	884	632,850	bluegreen
		Mallomonas sp.	109	12.3	41,356	6.5			chrysophyte
		Asterionella formosa	9	1.0	26,816	4.2			diatom
		Peridinium cinctum	4	0.5	18,284	2.9			dinoflagellate
		Navicula viridula	22	2.5	9,795	1.5			diatom
		Rhodomonas minuta	322	36.5	6,443	1.0			cryptophyte
		Fragilaria construens venter	4	0.5	3,343	0.5			diatom
		Chlamydomonas sp.	9	1.0	2,830	0.4			green
		Navicula sp.	13	1.5	1,959	0.3			diatom
		Achnanthes lanceolata	4	0.5	784	0.1			diatom
		Achnanthes minutissima	9	1.0	435	0.1			diatom
		Anabaena flos-aquae akinetes/mL =	57						
		Anabaena flos-aquae heterocysts/mL =	444						
		Anabaena flos-aquae cells/mL =	7,771						
14-Jun-07	treatment plant intake	Stephanodiscus hantzschii	130	46.5	15,644	25.1	280	62,243	diatom
		Stephanodiscus astraea minutula	44	15.7	15,415	24.8			diatom
		Fragilaria crotonensis	5	1.9	13,319	21.4			diatom
		Asterionella formosa	32	11.3	8,372	13.4			diatom
		Achnanthes lanceolata	12	4.4	2,220	3.6			diatom
		Cocconeis placentula	4	1.3	1,621	2.6			diatom
		Achnanthes minutissima	23	8.2	1,145	1.8			diatom
		Pinnularia sp.	2	0.6	705	1.1			diatom
		Cyclotella stelligera	11	3.8	581	0.9			diatom
		Chlamydomonas sp.	2	0.6	573	0.9			green
		Diatomella balfouriana	2	0.6	529	0.8			diatom
		Navicula sp.	4	1.3	529	0.8			diatom

Date	Station Description	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (μm^3/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (μm^3/ml)	Taxonomic Group
		Nitzschia acicularis	2	0.6	493	0.8			diatom
		Nitzschia dissipata	2	0.6	474	0.8			diatom
		Nitzschia frustulum	4	1.3	423	0.7			diatom
		Navicula cryptocephala veneta	2	0.6	167	0.3			diatom
		Rhodomonas minuta	2	0.6	35	0.1			cryptophyte
14-Jun-07	treated water	Stephanodiscus astraea minutula	2	47.4	793	73.3	5	1,082	diatom
		Stephanodiscus hantzschii	2	31.6	181	16.7			diatom
		Achnanthes lanceolata	0.3	5.3	45	4.2			diatom
		Navicula sp.	0.3	5.3	38	3.5			diatom
		Achnanthes minutissima	0.5	10.5	25	2.3			diatom
13-Jul-07	treatment plant intake	Asterionella formosa	70	42.6	84,780	56.7	164	149,626	diatom
		Rhopalodia gibba	2	1.0	41,234	27.6			diatom
		Anabaena flos-aquae	3	2.0	6,907	4.6			bluegreen
		Mougeotia sp.	4	2.5	5,702	3.8			green
		Stephanodiscus astraea minutula	7	4.4	2,537	1.7			diatom
		Achnanthes minutissima	27	16.2	1,329	0.9			diatom
		Glenodinium sp.	2	1.0	1,128	0.8			dinoflagellate
		Achnanthes lanceolata	6	3.4	1,015	0.7			diatom
		Cryptomonas erosa	2	1.0	838	0.6			cryptophyte
		Dinobryon sertularia	6	3.9	767	0.5			dinoflagellate
		Gomphonema subclavatum	1	0.5	483	0.3			diatom
		Amphora ovalis	1	0.5	465	0.3			diatom
		Cocconeis placentula	1	0.5	370	0.2			diatom
		Pinnularia sp.	1	0.5	322	0.2			diatom
		Synedra radians	1	0.5	290	0.2			diatom
		Rhodomonas minuta	11	6.9	226	0.2			cryptophyte
		Scenedesmus quadricauda	1	0.5	209	0.1			green
		Stephanodiscus hantzschii	2	1.0	193	0.1			diatom
		Gomphonema angustatum	1	0.5	145	0.1			diatom
		Ankistrodesmus falcatus	6	3.4	141	0.1			green
		Nitzschia frustulum	1	0.5	97	0.1			diatom

Date	Station Description	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (µm³/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (µm³/ml)	Taxonomic Group
		Rhoicosphenia curvata	1	0.5	94	0.1			diatom
		Fragilaria construens venter	1	0.5	77	0.1			diatom
		Fragilaria pinnata	1	0.5	48	0.0			diatom
		Navicula cascadensis	1	0.5	48	0.0			diatom
		Chromulina sp.	2	1.5	48	0.0			chrysophyte
		Navicula minima	1	0.5	35	0.0			diatom
		Anabaena flos-aquae heterocysts/mL =	6						
		Anabaena flos-aquae akinetes/mL =	15						
		Anabaena flos-aquae cells/mL =	103						
13-Jul-07	treated water	Rhopalodia gibba	0.2	50.0	4,637	99.0	0.4	4,683	diatom
		Fragilaria capucina mesolepta	0.2	50.0	46	1.0			diatom
12-Oct-07	reservoir surface at intake control structure	Anabaena flos-aquae	375,833	99.7	2,115,190,000	99.97	376,972	2,115,782,222	bluegreen
		Cryptomonas erosa	1,139	0.3	592,222	0.03			cryptophyte
		Anabaena flos-aquae heterocysts/mL =	1,634,306						
		Anabaena flos-aquae cells/mL =	31,570,000						
12-Oct-07	38' at intake control structure	Anabaena flos-aquae	30	16.1	42,304	48.7	187	86,880	bluegreen
		Cocconeis placentula	26	14.1	12,102	13.9			diatom
		Asterionella formosa	6	3.0	7,069	8.1			diatom
		Cryptomonas erosa	12	6.5	6,352	7.3			cryptophyte
		Achnanthes lanceolata	21	11.1	3,721	4.3			diatom
		Melosira granulata	3	1.5	2,636	3.0			diatom
		Cymbella affinis	1	0.5	1,691	1.9			diatom
		Stephanodiscus astraea minutula	5	2.5	1,644	1.9			diatom
		Mallomonas-like	18	9.5	1,607	1.8			chrysophyte
		Nitzschia sigmoidea	1	0.5	799	0.9			diatom
		Diatoma hiemale mesodon	1	0.5	752	0.9			diatom
		Ankistrodesmus falcatus	27	14.6	681	0.8			green
		Glenodinium sp.	1	0.5	658	0.8			dinoflagellate
		Stephanodiscus hantzschii	5	2.5	564	0.6			diatom
		Synedra parasitica	2	1.0	526	0.6			diatom
		Gomphonema angustatum	3	1.5	507	0.6			diatom

Date	Station Description	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (µm³/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (µm³/ml)	Taxonomic Group
		Rhoicosphenia curvata	4	2.0	440	0.5			diatom
		Pinnularia sp.	1	0.5	376	0.4			diatom
		Achnanthes minutissima	7	3.5	329	0.4			diatom
		Stauroneis sp.	1	0.5	319	0.4			diatom
		Diatoma tenue	1	0.5	272	0.3			diatom
		Nitzschia dissipata	1	0.5	253	0.3			diatom
		Nitzschia frustulum	2	1.0	226	0.3			diatom
		Cosmarium sp.	1	0.5	197	0.2			green
		Navicula cryptocephala veneta	2	1.0	179	0.2			diatom
		Nitzschia palea	1	0.5	169	0.2			diatom
		Cymbella sinuata	1	0.5	132	0.2			diatom
		Achnanthes linearis	1	0.5	124	0.1			diatom
		Nitzschia sp.	1	0.5	113	0.1			diatom
		Gomphonema clevei	1	0.5	85	0.1			diatom
		Rhodomonas minuta	2	1.0	38	0.0			cryptophyte
		Anabaena flos-aquae cells/mL =	631						
12-Oct-07	treated water	Anabaena flos-aquae	3.3	80.6	6,877	92.0	4.1	7,473	bluegreen
		Epithemia sorex	0.1	2.8	260	3.5			diatom
		Cymbella affinis	0.1	2.8	206	2.7			diatom
		Pinnularia sp.	0.1	2.8	46	0.6			diatom
		Gomphonema angustatum	0.2	5.6	41	0.5			diatom
		Navicula pupula	0.1	2.8	31	0.4			diatom
		Achnanthes exigua	0.1	2.8	13	0.2			diatom
		Anabaena flos-aquae heterocysts/mL =	3.9						
		Anabaena flos-aquae cells/mL =	102.6						

[1] for colonial blue-green species such as *Anabaena* there are multiple listings for density: the first listing is for colony density and other listings followed by cells/ml are cell/ml density values for comparison to toxic algal thresholds.

Table 2: Phytoplankton data for station R1 in Reeder Reservoir, 2007.

Date	Station	Depth	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (µm³/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (µm³/ml)	Taxonomic Group
27-Jun-07	R1	1	Aphanizomenon flos-aquae	30	6.0	33,991	41.0	500	82,897	bluegreen
			Asterionella formosa	14	2.8	15,827	19.1			diatom
			Mallomonas sp.	18	3.7	7,009	8.5			chrysophyte
			Rhodomonas minuta	300	59.9	5,995	7.2			cryptophyte
			Chlamydomonas sp.	16	3.2	5,246	6.3			green
			Anabaena flos-aquae	7	1.4	4,635	5.6			bluegreen
			Mallomonas-like	30	6.0	2,698	3.3			chrysophyte
			Mougeotia sp.	5	0.9	2,449	3.0			green
			Ankistrodesmus falcatus	30	6.0	2,023	2.4			green
			Dinobryon sertularia	14	2.8	1,646	2.0			dinoflagellate
			Achnanthes lanceolata	2	0.5	415	0.5			diatom
			Chromulina sp.	18	3.7	369	0.4			chrysophyte
			Oocystis pusilla	2	0.5	249	0.3			green
			Achnanthes minutissima	2	0.5	115	0.1			diatom
			Anabaena flos-aquae heterocysts/mL =	7						
			Aphanizomenon flos-aquae heterocysts/mL =	9						
			Anabaena flos-aquae cells/mL =	69						
			Aphanizomenon flos-aquae cells/mL =	540						
27-Jun-07	R1	4	Mougeotia sp.	19	18.8	30,890	65.5	99	47,169	green
			Asterionella formosa	9	8.9	7,329	15.5			diatom
			Ankistrodesmus falcatus	46	46.4	3,557	7.5			green
			Chlamydomonas sp.	4	3.6	1,173	2.5			green
			Quadrigula closterioides	3	2.6	990	2.1			green
			Achnanthes lanceolata	4	4.2	743	1.6			diatom
			Anabaena flos-aquae	1	1.0	691	1.5			bluegreen
			Dinobryon sertularia	3	2.6	491	1.0			dinoflagellate
			Glenodinium sp.	0.5	0.5	361	0.8			dinoflagellate
			Achnanthes minutissima	6	5.7	284	0.6			diatom
			Cocconeis placentula	0.5	0.5	237	0.5			diatom

Date	Station	Depth	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (μm³/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (μm³/ml)	Taxonomic Group
			Cymbella minuta	0.5	0.5	191	0.4			diatom
			Fragilaria vaucheria	0.5	0.5	149	0.3			diatom
			Rhodomonas minuta	4	4.2	83	0.2			cryptophyte
			Anabaena flos-aquae heterocysts/mL =	1						
			Anabaena flos-aquae cells/mL =	10						
27-Jun-07	R1	10	Asterionella formosa	36	16.7	42,542	71.4	218	59,570	diatom
			Mougeotia sp.	7	3.3	8,664	14.5			green
			Rhodomonas minuta	137	62.8	2,736	4.6			cryptophyte
			Chlamydomonas sp.	4	1.9	1,318	2.2			green
			Achnanthes lanceolata	5	2.3	912	1.5			diatom
			Achnanthes minutissima	8	3.7	649	1.1			diatom
			Cryptomonas erosa	1	0.5	527	0.9			cryptophyte
			Oocystis pusilla	1	0.5	438	0.7			green
			Ankistrodesmus falcatus	8	3.7	405	0.7			green
			Hemidinium sp.	1	0.5	304	0.5			dinoflagellate
			Sphaerocystis schroeteri	1	0.5	284	0.5			green
			Gomphonema angustatum	1	0.5	182	0.3			diatom
			Achnanthes prava	1	0.5	142	0.2			diatom
			Nitzschia frustulum	1	0.5	122	0.2			diatom
			Nitzschia sp.	1	0.5	122	0.2			diatom
			Gomphonema clevei	1	0.5	91	0.2			diatom
			Mallomonas-like	1	0.5	91	0.2			chrysophyte
			Chromulina sp.	1	0.5	20	0.0			chrysophyte
31-Jul-07	R1	1	Oocystis lacustris	124	49.3	121,954	92.9	251	131,290	green
			Chlamydomonas sp.	13	5.1	4,134	3.1			green
			Glenodinium sp.	2	0.9	1,619	1.2			dinoflagellate
			Rhodomonas minuta	68	27.2	1,365	1.0			cryptophyte
			Cryptomonas erosa	1	0.5	601	0.5			cryptophyte
			Ankistrodesmus falcatus	17	6.9	434	0.3			green
			Chromulina sp.	17	6.9	347	0.3			chrysophyte
			Sphaerocystis schroeteri	1	0.5	324	0.2			green

Date	Station	Depth	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (µm³/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (µm³/ml)	Taxonomic Group
			Synedra rumpens	1	0.5	162	0.1			diatom
			Chlorella sp.	2	0.9	139	0.1			green
			Dinobryon sertularia	1	0.5	138	0.1			dinoflagellate
			Navicula minima	1	0.5	51	0.0			diatom
31-Jul-07	R1	4	Chlamydomonas sp.	105	12.7	34,271	45.6	831	75,157	green
			Oocystis lacustris	57	6.8	26,233	34.9			green
			Rhodomonas minuta	406	48.8	8,112	10.8			cryptophyte
			Chromulina sp.	187	22.4	3,731	5.0			chrysophyte
			Ankistrodesmus falcatus	61	7.3	1,521	2.0			green
			Dinobryon sertularia	8	1.0	965	1.3			dinoflagellate
			Chlorella sp.	4	0.5	243	0.3			green
31-Jul-07	R1	10	Oocystis lacustris	25	24.5	10,171	55.7	104	18,262	green
			Cymbella affinis	2	1.5	2,799	15.3			diatom
			Nitzschia acicularis	5	4.5	1,306	7.2			diatom
			Cocconeis placentula	3	2.5	1,192	6.5			diatom
			Nitzschia paleacea	4	4.0	406	2.2			diatom
			Rhodomonas minuta	18	17.5	363	2.0			cryptophyte
			Chlamydomonas sp.	1	1.0	337	1.8			green
			Ankistrodesmus falcatus	13	13.0	337	1.8			green
			Gomphonema angustatum	2	1.5	280	1.5			diatom
			Stephanodiscus astraea minutula	0.5	0.5	181	1.0			diatom
			Diploneis elliptica	0.5	0.5	135	0.7			diatom
			Synedra rumpens	0.5	0.5	73	0.4			diatom
			Dinobryon sp.	0.5	0.5	65	0.4			dinoflagellate
			Mallomonas-like	0.5	0.5	47	0.3			chrysophyte
			Chromulina sp.	2	2.0	41	0.2			chrysophyte
31-Jul-07	R1	20	Asterionella formosa	2.7	12.0	2,510	35.4	23	7,092	diatom
			Anabaena flos-aquae	2.2	9.6	2,184	30.8			bluegreen
			Diatoma hiemale mesodon	0.3	1.2	435	6.1			diatom
			Stephanodiscus hantzschii	3.5	15.7	424	6.0			diatom
			Achnanthes lanceolata	2.2	9.6	391	5.5			diatom

Date	Station	Depth	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (µm³/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (µm³/ml)	Taxonomic Group
			Oocystis lacustris	0.3	1.2	167	2.4			green
			Achnanthes minutissima	2.7	12.0	136	1.9			diatom
			Cocconeis placentula	0.3	1.2	125	1.8			diatom
			Navicula cryptocephala veneta	1.1	4.8	103	1.5			diatom
			Stephanodiscus astraea minutula	0.3	1.2	95	1.3			diatom
			Chlorella sp.	1.4	6.0	82	1.1			green
			Navicula rhynchocephala	0.3	1.2	80	1.1			diatom
			Fragilaria vaucheria	0.3	1.2	78	1.1			diatom
			Nitzschia sp.	0.5	2.4	65	0.9			diatom
			Rhodomonas minuta	3.0	13.3	60	0.8			cryptophyte
			Gomphonema sp.	0.3	1.2	54	0.8			diatom
			Synedra rumpens	0.3	1.2	38	0.5			diatom
			Nitzschia frustulum	0.3	1.2	33	0.5			diatom
			Nitzschia communis	0.5	2.4	24	0.3			diatom
			Ankistrodesmus falcatus	0.3	1.2	7	0.1			green
			Anabaena flos-aquae heterocysts/mL =	2.2						
			Anabaena flos-aquae cells/mL =	32.6						
14-Sep-07	R1	0	Anabaena flos-aquae	1,488	58.7	1,794,890	86.8	2,537	2,068,816	bluegreen
			Asterionella formosa	135	5.3	193,479	9.4			diatom
			Cryptomonas erosa	101	4.0	52,767	2.6			cryptophyte
			Rhodomonas minuta	733	28.9	14,658	0.7			cryptophyte
			Achnanthes lanceolata	23	0.9	4,059	0.2			diatom
			Stephanodiscus astraea minutula	11	0.4	3,946	0.2			diatom
			Stephanodiscus hantzschii	23	0.9	2,706	0.1			diatom
			Gomphonema angustatum	11	0.4	2,030	0.1			diatom
			Ankistrodesmus falcatus	11	0.4	282	0.0			green
			Anabaena flos-aquae akinetes/mL =	147						
			Anabaena flos-aquae heterocysts/mL =	1,714						
			Anabaena flos-aquae cells/mL =	26,789						
14-Sep-07	R1	1	Cryptomonas erosa	237	20.4	123,123	38.3	1,161	321,614	cryptophyte
			Anabaena flos-aquae	34	2.9	61,189	19.0			bluegreen

Date	Station	Depth	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (µm³/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (µm³/ml)	Taxonomic Group
			Mougeotia sp.	28	2.4	59,870	18.6			green
			Asterionella formosa	11	1.0	34,727	10.8			diatom
			Sphaerocystis schroeteri	17	1.5	15,982	5.0			green
			Rhodomonas minuta	614	52.9	12,290	3.8			cryptophyte
			Diatoma tenue elongatum	6	0.5	4,059	1.3			diatom
			Glenodinium sp.	6	0.5	3,946	1.2			dinoflagellate
			Chromulina sp.	169	14.6	3,383	1.1			chrysophyte
			Diploneis elliptica	6	0.5	1,466	0.5			diatom
			Mallomonas-like	11	1.0	1,015	0.3			chrysophyte
			Ankistrodesmus falcatus	23	1.9	564	0.2			green
			Anabaena flos-aquae akinetes/mL =	6						
			Anabaena flos-aquae heterocysts/mL =	56						
			Anabaena flos-aquae cells/mL =	913						
14-Sep-07	R1	4	Asterionella formosa	75	17.5	90,952	69.2	430	131,487	diatom
			Cryptomonas erosa	19	4.5	10,022	7.6			cryptophyte
			Mougeotia sp.	12	2.7	9,620	7.3			green
			Rhodomonas minuta	262	61.0	5,242	4.0			cryptophyte
			Anabaena flos-aquae	4	0.9	4,649	3.5			bluegreen
			Gloeocystis ampla	2	0.4	1,974	1.5			green
			Chlamydomonas sp.	6	1.3	1,879	1.4			green
			Sphaerocystis schroeteri	6	1.3	1,619	1.2			green
			Diatoma hiemale mesodon	2	0.4	1,542	1.2			diatom
			Gyrosigma spencerii	2	0.4	867	0.7			diatom
			Stephanodiscus astraea minutula	2	0.4	675	0.5			diatom
			Caloneis ventricosa minuta	2	0.4	540	0.4			diatom
			Ankistrodesmus falcatus	17	4.0	434	0.3			green
			Nitzschia palea	2	0.4	347	0.3			diatom
			Achnanthes minutissima	6	1.3	289	0.2			diatom
			Achnanthes linearis	2	0.4	254	0.2			diatom
			Dinobryon sertularia	2	0.4	229	0.2			dinoflagellate
			Navicula cryptocephala veneta	2	0.4	183	0.1			diatom

Date	Station	Depth	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (µm³/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (µm³/ml)	Taxonomic Group
			Nitzschia innominata	2	0.4	93	0.1			diatom
			Chromulina sp.	4	0.9	77	0.1			chrysophyte
			Anabaena flos-aquae heterocysts/mL =	2						
			Anabaena flos-aquae cells/mL =	69						
14-Sep-07	R1	8	Asterionella formosa	51	43.8	80,134	63.8	117	125,636	diatom
			Anabaena flos-aquae	16	13.8	20,546	16.4			bluegreen
			Mougeotia sp.	3	2.5	8,672	6.9			green
			Gloeocystis ampla	2	2.0	4,722	3.8			green
			Fragilaria crotonensis	2	1.5	2,905	2.3			diatom
			Glenodinium sp.	2	2.0	1,614	1.3			dinoflagellate
			Synedra radians	3	3.0	1,245	1.0			diatom
			Hannaea arcus	1	0.5	1,009	0.8			diatom
			Diatoma hiemale mesodon	1	0.5	922	0.7			diatom
			Sphaerocystis schroeteri	1	1.0	646	0.5			green
			Cryptomonas erosa	1	1.0	599	0.5			cryptophyte
			Chlamydomonas sp.	1	1.0	375	0.3			green
			Achnanthes lanceolata	2	1.5	311	0.2			diatom
			Cocconeis placentula	1	0.5	265	0.2			diatom
			Rhodomonas minuta	12	9.9	231	0.2			cryptophyte
			Nitzschia capitellata	1	0.5	208	0.2			diatom
			Nitzschia dissipata	1	0.5	155	0.1			diatom
			Diploneis elliptica	1	0.5	150	0.1			diatom
			Fragilaria pinnata	2	1.5	104	0.1			diatom
			Navicula minima	2	2.0	101	0.1			diatom
			Ankistrodesmus falcatus	4	3.4	101	0.1			green
			Achnanthes minutissima	2	1.5	86	0.1			diatom
			Synedra rumpens	1	0.5	81	0.1			diatom
			Nitzschia frustulum	1	0.5	69	0.1			diatom
			Stephanodiscus hantzschii	1	0.5	69	0.1			diatom
			Rhoicosphenia curvata	1	0.5	67	0.1			diatom
			Achnanthes exigua	1	0.5	65	0.1			diatom

Date	Station	Depth	Algal Species or Genus[1]	Density (#/ml)	% Density	Biovolume (µm³/ml)	% Biovolume	Total Density (#/ml)	Total Biovolume (µm³/ml)	Taxonomic Group
			Fragilaria construens venter	1	0.5	55	0.0			diatom
			Navicula cryptocephala veneta	1	0.5	55	0.0			diatom
			Navicula minuscula	1	0.5	26	0.0			diatom
			Chromulina sp.	1	1.0	23	0.0			chrysophyte
			Anabaena flos-aquae cells/mL =	307						

[1] for colonial blue-green species such as *Anabaena* there are multiple listings for density: the first listing is for colony density and other listings followed by cells/ml are cell/ml density values for comparison to toxic algal thresholds.

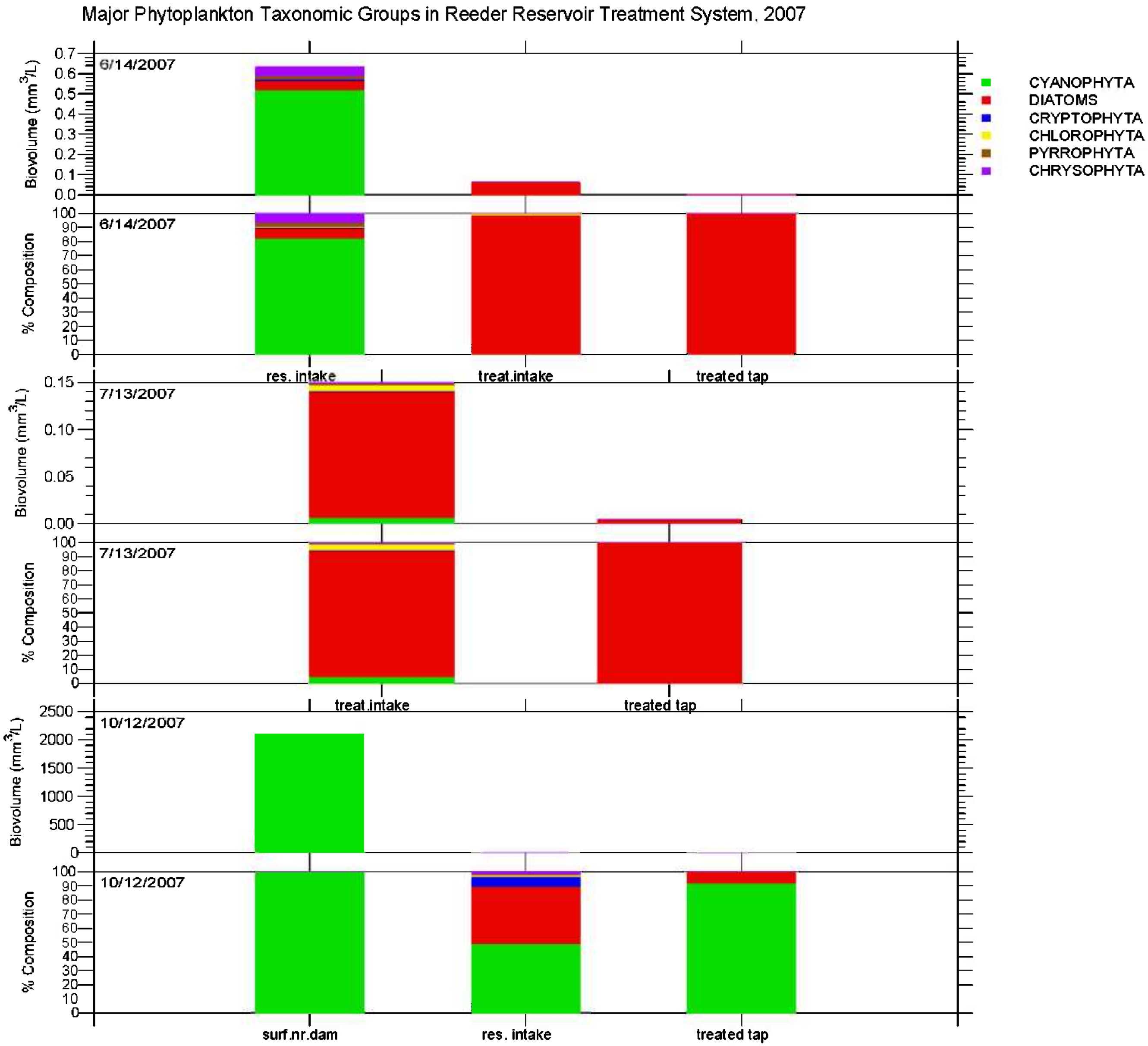

Figure 1. Biovolume and percent composition of major phytoplankton taxonomic groups in Ashland Water Treatment Plant, 2007.

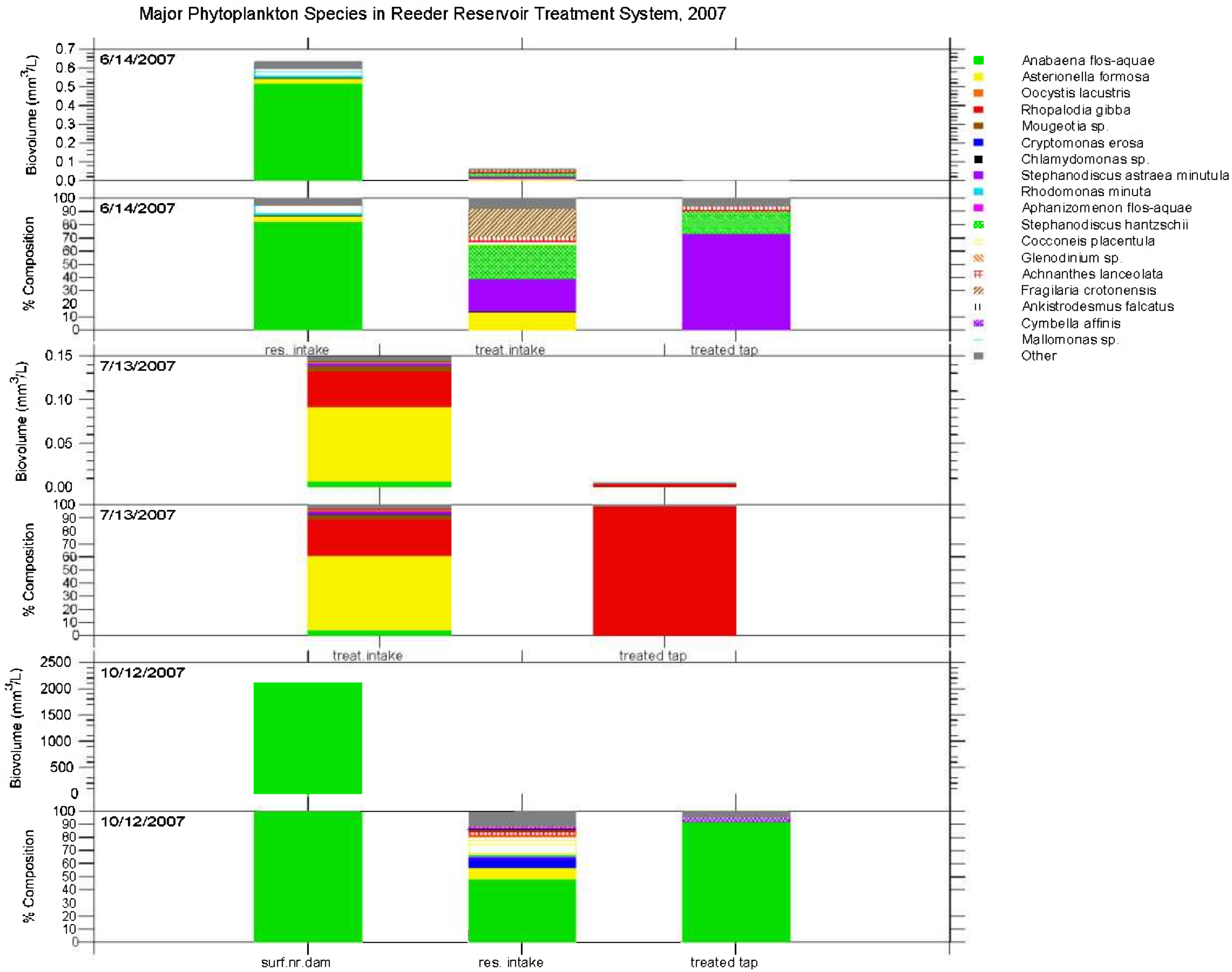

Figure 2. Biovolume and percent composition of major phytoplankton species in the Ashland Water Treatment Plant, 2007.

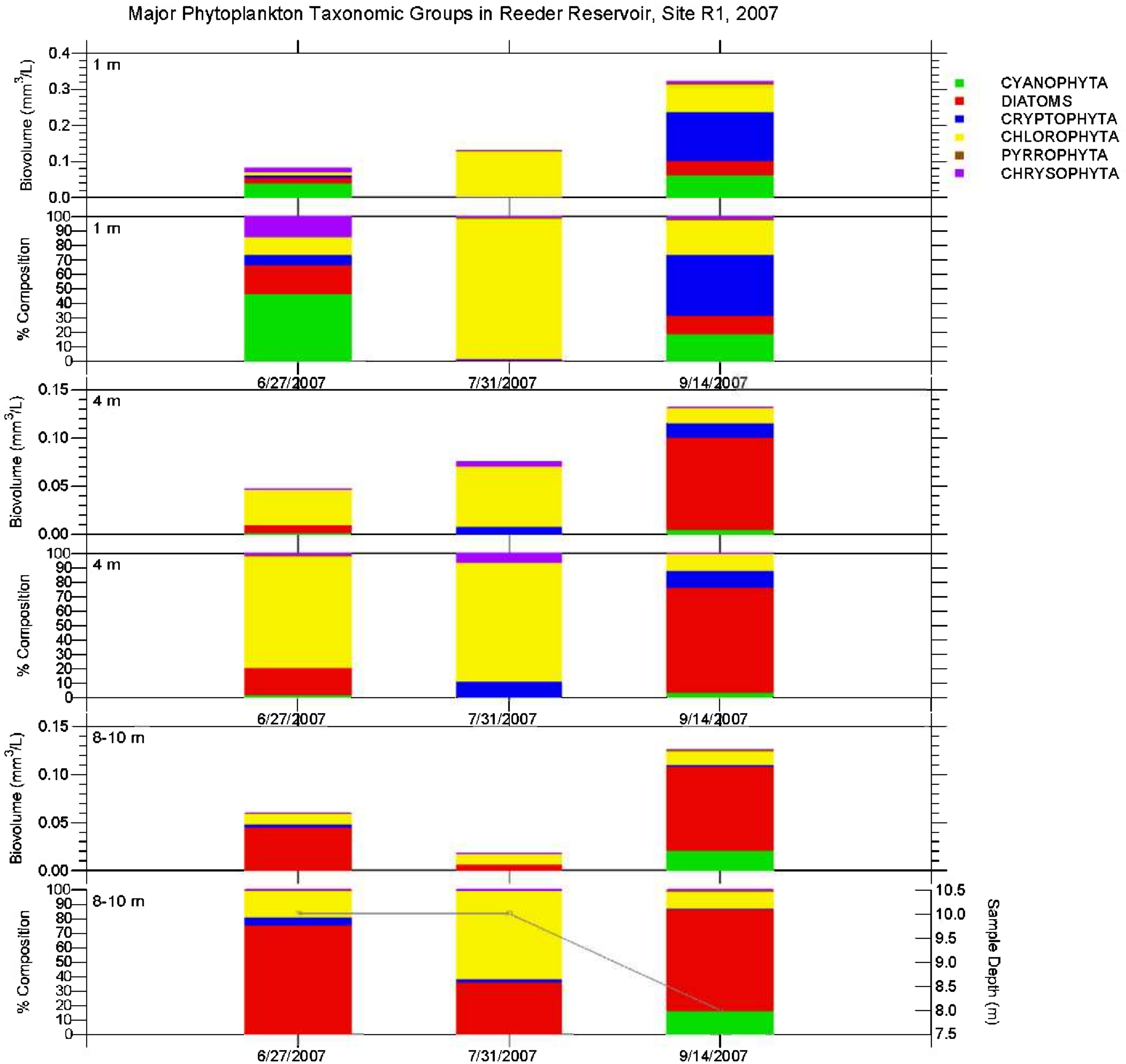

Figure 3. Biovolume and percent composition of major phytoplankton taxonomic groups in Reeder Reservoir, 2007.

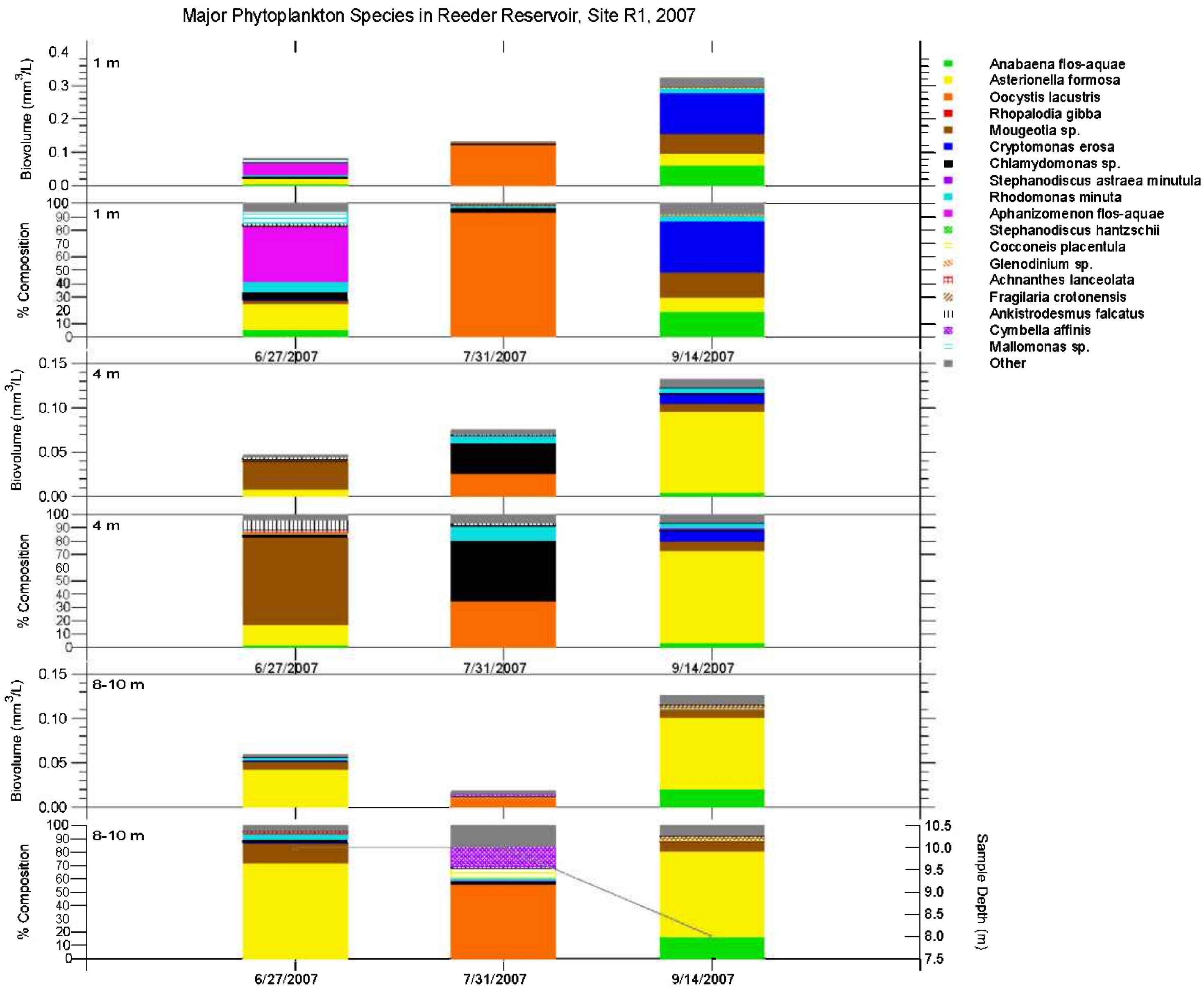

Figure 4. Biovolume and percent composition of major phytoplankton species in Reeder Reservoir, 2007.

APPENDIX II: Algal Toxin Laboratory Results for Reeder Reservoir

GreenWater laboratories — aquatic analysis ... research ... consulting

Anatoxin-a/Microcystin Data Report
Project: Aquatic Ecosystem Sciences
(Reeder Reservoir and Treatment Plant)

Sample Identification	Sample Collection Date
Reeder Reservoir Intake (surface)	070614
Treatment Plant Intake	070614
Lab Tap (treated water)	070614

Toxins – Anatoxin-a (ANTX-A) and microcystin (MC)

Sample Prep – The samples were ultra-sonicated to lyse all cells and release toxins. Microcystin analysis prep required ultra-sonication and filtration. Solid phase extraction (SPE) was utilized for anatoxin-a prep and preconcentration (100x). Duplicate samples were spiked with 1.0 µg/L MCLR and 0.1 µg/L ANTX-A which provided quantitative capability and additional qualitative confirmation.

Analytical Methodology – Liquid chromatography/ mass spectrometry/ mass spectrometry (LC/MS/MS) was utilized for the determination of ANTX-A. The $[M+H]^+$ ion for ANTX-A (*m/z* 166) was fragmented and the major product ions (*m/z* 149, 131, 107, and 91) provided both specificity and sensitivity. The current methodology established a detection limit of 0.05 µg/L and a quantification limit of 0.1 µg/L for ANTX-A.

A microcystins enzyme linked immunosorbent assay (ELISA) was utilized for the quantitative and sensitive congener-independent detection of MCs. The current assay is sensitive to down to a detection/quantification limit of 0.15 µg/L for total MCs.

Summary of ANTX-A/MC Results

Sample	ANTX-A levels (µg/L)	MC level (µg/L)
Reeder Reservoir Intake (surface)	ND	ND
Treatment Plant Intake	ND	-
Lab Tap (treated water)	ND	ND

ND = Not detected above the detection limit
Detection Limit = 0.05 µg/L (ANTX-A), 0.15 µg/L (MC)
Limit of Quantification = 0.1 µg/L (ANTX-A), 0.15 µg/L (MC)

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GreenWater laboratories
aquatic analysis ... research ... consulting

Anatoxin-a/Microcystin Data Report
Project: Aquatic Ecosystem Sciences
(Reeder Reservoir and Treatment Plant)

Sample Identification	Sample Collection Date
Reeder Reservoir (surface)	071012
Reeder Reservoir Intake (38 ft)	071012
Reeder Reservoir Treated Tap	071012

Toxins – Anatoxin-a (ANTX-A) and microcystin (MC)

Sample Prep – The samples were ultra-sonicated to lyse all cells and release toxins. Microcystin analysis prep required ultra-sonication and filtration. Solid phase extraction (SPE) was utilized for anatoxin-a prep and preconcentration (100x). A duplicate Intake sample was spiked with 1.0 µg/L MCLR and a duplicate Tap sample was spiked with 0.1 µg/L ANTX-A which provided quantitative capability and additional qualitative confirmation.

Analytical Methodology – Liquid chromatography/ mass spectrometry/ mass spectrometry (LC/MS/MS) was utilized for the determination of ANTX-A. The $[M+H]^+$ ion for ANTX-A (*m/z* 166) was fragmented and the major product ions (*m/z* 149, 131, 107, and 91) provided both specificity and sensitivity. The current methodology established a detection limit of 0.05 µg/L and a quantification limit of 0.1 µg/L for ANTX-A.

A microcystins enzyme linked immunosorbent assay (ELISA) was utilized for the quantitative and sensitive congener-independent detection of MCs. The current assay is sensitive to down to a detection/quantification limit of 0.15 µg/L for total MCs.

Summary of ANTX-A/MC Results

Sample	ANTX-A levels (µg/L)	MC level (µg/L)
Reeder Reservoir (surface)	ND	≈ 0.5
Reeder Reservoir Intake (38 ft)	ND	ND
Reeder Reservoir Treated Tap	ND	ND

ND = Not detected above the detection limit
Detection Limit = 0.05 µg/L (ANTX-A), 0.15 µg/L (MC)
Limit of Quantification = 0.1 µg/L (ANTX-A), 0.15 µg/L (MC)

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APPENDIX B

HOSLER DAM OUTLET STRUCTURE INSPECTION SUMMARY (JULY 20, 2007)

HOSLER DAM OUTLET STRUCTURE GATE INSPECTION SUMMARY (NOVEMBER 8, 2007)

CD CONTAINING A DIGITAL VIDEO RECORD OF EACH INSPECTION

Advanced American Construction, Inc.

Marine Construction and Consulting

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RECEIVED

AUG 13 2007

August 6, 2007

Mr. Bob Willis
Brown & Caldwell
6500 S.W. Macadam Avenue, Suite 200
Portland, Oregon 97239

Subject: City of Ashland Reeder Reservoir Study - Hosler Dam Inspections

Mr. Willis,

In reference to the Brown & Caldwell Reeder Reservoir Study Dam Inspections project, Advanced American Construction, Inc. (AAC) provides the following record.

On July 20, 2007, AAC Worked with Brown & Caldwell, and provided diving services for conducting underwater visual inspections of the Hosler Dam Outlet structures. Inspections were performed in reference to City of Ashland Drawing MKE 5126 HD-C-02, Hosler Dam Outlet Modifications / General Arrangement. The elevation view is referenced in Figure 1.

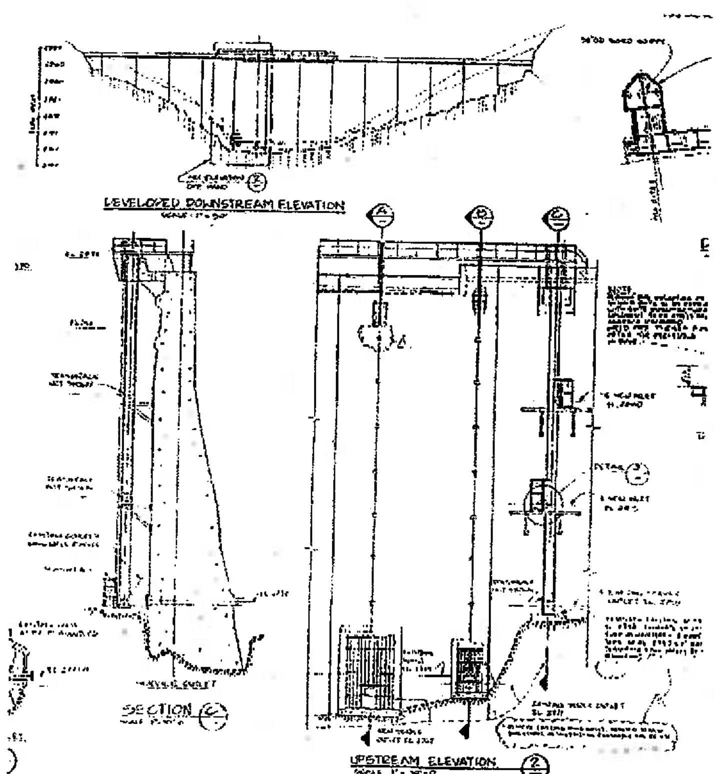

Figure 1 - Inspections Reference Structure A, B, and C.

The purpose of inspections was to determine the existing conditions of the fixtures on the dam, which included reach rods, reach rod guides, trash racks, visible portions of the gates, and trash rack support structures. Inspections noted for component corrosion, material accumulations, and general conditions.

AAC conducted three dives at the Outlet structures. The Outlet structures are referenced as indexed in the drawing sections A, B, and C.

The following is noted from inspections:

Structure C

- Inspections of Structure C included assemblies associated with the three inlets. Inlets were inspected at elevations 2840, 2815, and 2790.
- Reach rods, Reach rod guides and Trash Racks are intact at all three elevations.
- Gates appeared to be intact with no apparent abnormalities.
- Trash rack steel and support steel appears to be coated, with no apparent corrosion.
- Moderate corrosion is noted at the fasteners securing the trash racks. **(Fig. 1)**
- 4" - 12" Silt accumulation at the top portion of the trash racks.

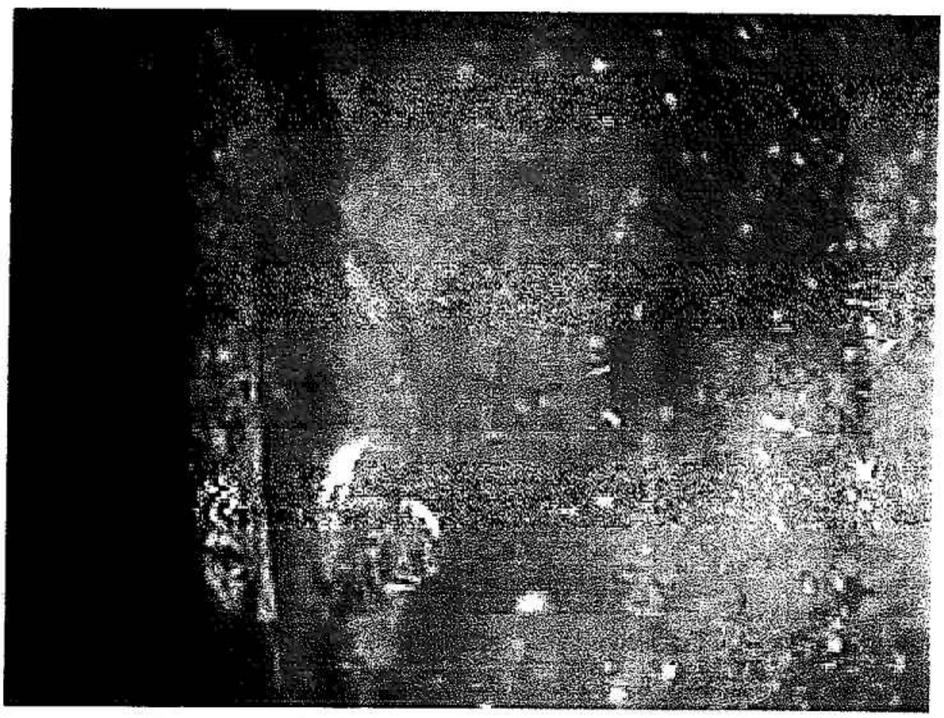

Fig. 1 - Moderate Corrosion at Trash Rack Fasteners
(Noted on Video - Video Counter Time 26:35)

Structure A and B

- Structure B Video Counter Time 38:35
- Structure A Video Counter Time 1:06:30
- Inspections of Structure A & B included reach rods and reach rod guides to lower sediment level. (Approximate Elevation 2788)
- Moderate corrosion is noted at the reach rod guides. **(Fig. 2)** Figure 2 also notates a worn bushing at location A.
- Material accumulation appeared to be of soft sediment and small sticks. (No excavation was performed)
- Material accumulation appeared to be bermed at the dam and tapered down as the diver inspected upstream away from the dam.
- The gates were not located at structure A or B, and appeared to be covered in materials accumulation.
- Location A was surveyed for cracks at the face of the dam. Apparent construction joints were observed, with reported scour / pitting. (Approximate Elevation 2790)

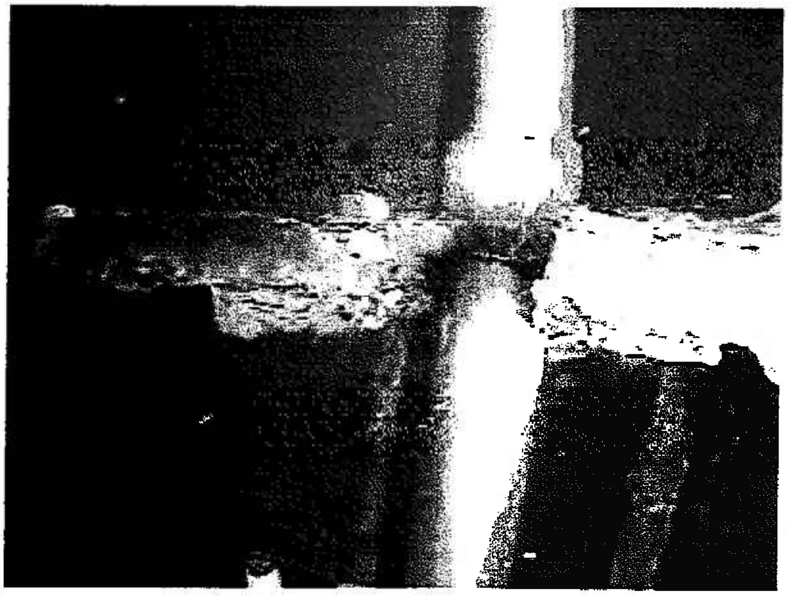

Fig. 2 - Moderate Corrosion at a reach rod guide (typical)

Inspections are documented on CD which may be viewed on computer with the use of standard media viewer software.

If you have any questions or require additional information please contact us at our Portland office 503-445-9000.

Respectfully,

Jay Stevens
Diver
Advanced American Construction, Inc.

Advanced American Construction, Inc.

Marine Construction and Consulting

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Fax: 503-546-3031

December 3, 2007

Mr. Bob Willis
Brown & Caldwell
6500 S.W. Macadam Avenue, Suite 200
Portland, Oregon 97239

Subject: City of Ashland Reeder Reservoir Study - Hosler Dam Outlet Structure Gate Inspections.

Mr. Willis,

In reference to the Brown & Caldwell Reeder Reservoir Study Dam Inspections project, Advanced American Construction, Inc. (AAC) provides the following record.

On November 8, 2007, AAC Worked with Brown & Caldwell and the City of Ashland, and provided diving services for conducting underwater visual inspections of the Hosler Dam Outlet structures. Primary focus of these inspections included determination of leakage and sealing the existing East location gates. Inspections were performed in reference to City of Ashland Drawing MKE 5126 HD-C-02, Hosler Dam Outlet Modifications / General Arrangement. The gates in question are located at Detail "C" as noted in the elevation view is referenced in Figure 1.

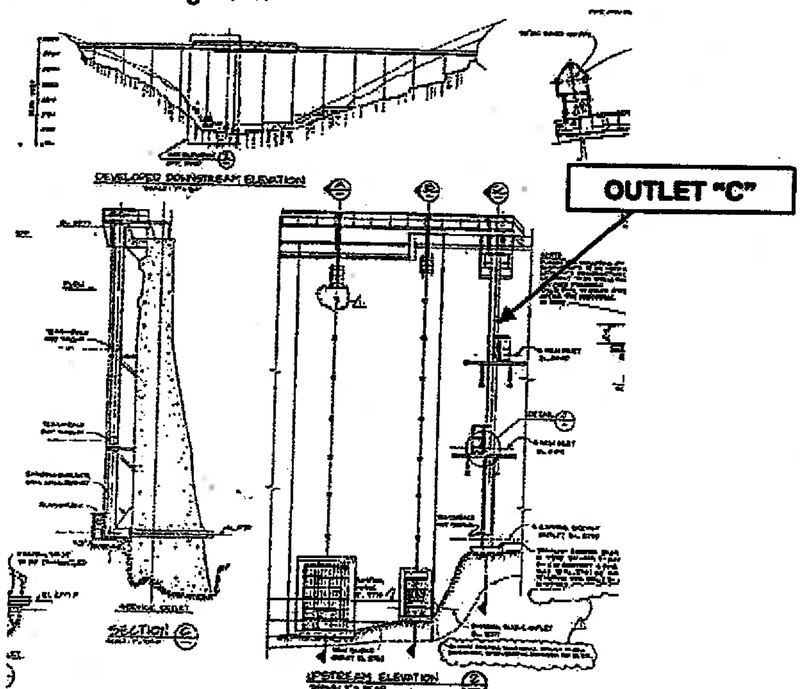

Figure 1 - Inspections Reference Structure A, B, and C.

The AAC dive team worked at the direction of Peter Smeenk and Morgan Wayman of the City of Ashland.

Forebay Pool elevation at the time of inspections was 2858.6'.

The following is a summary of operations:

Dive #1 & 2

Diver Dale Howe performed inspections of the middle gate at structure "C" The middle gate is located at Elevation 2813. The gate was in the open position, with isolation of water flow obtained by locking out the downstream butterfly valve.

Loose corrosion was removed from the sealing surfaces which were visible. The diver noted light pitting and surface nodules of corrosion.

The gate was then closed. This was witnessed by the diver. After removal of silt, small sticks, leaves, and debris the gate was confirmed to be in the closed position. The valve operator at the surface was indexed to indicate the closed position. The butterfly valve was opened, and the gate was inspected for leakage. No apparent leakage was detected.

Dive #3

Diver Russ Banna Jr. performed inspections at Structure "A" and "B". The diver descended down the reach rod at structure "A" to collect bottom material samples.

The diver reported the bottom materials (Elevation 2784) consisted of fine silt, mud, sticks, logs, and leaves. Also noted from bottom inspections included :

- Observation of vent pockets at the reservoir floor
- Observation of a white milky stratification extending up from the bottom approximately 5'.

The diver cleared material immediately in front of the gates at structures "A" & "B".

Dive #4

Diver Hugh Gunn. performed inspections at the lower gate Elevation 2790 and upper gate at structure "C". The lower gate was verified in the closed position, and the valve operator was indexed to locate the closed position. The diver removed fine silt, mud, sticks, and leaves from the area inside of the trashracks.

This process was repeated at the upper gate at Elevation 2838. While at the upper gate, the diver observed the opening of the gate to an approximate 5" - 6" opening. The gate was then cycled to the closed position and verified closed.

Inspections are documented on CD which may be viewed on computer with the use of standard media viewer software.

If you have any questions or require additional information please contact us at our Portland office 503-445-9000.

Respectfully,

FOR RUSS BANNA JR.

Russ Banna Jr.
Dive Master
Advanced American Construction, Inc.