Alex Horne Associates

amec

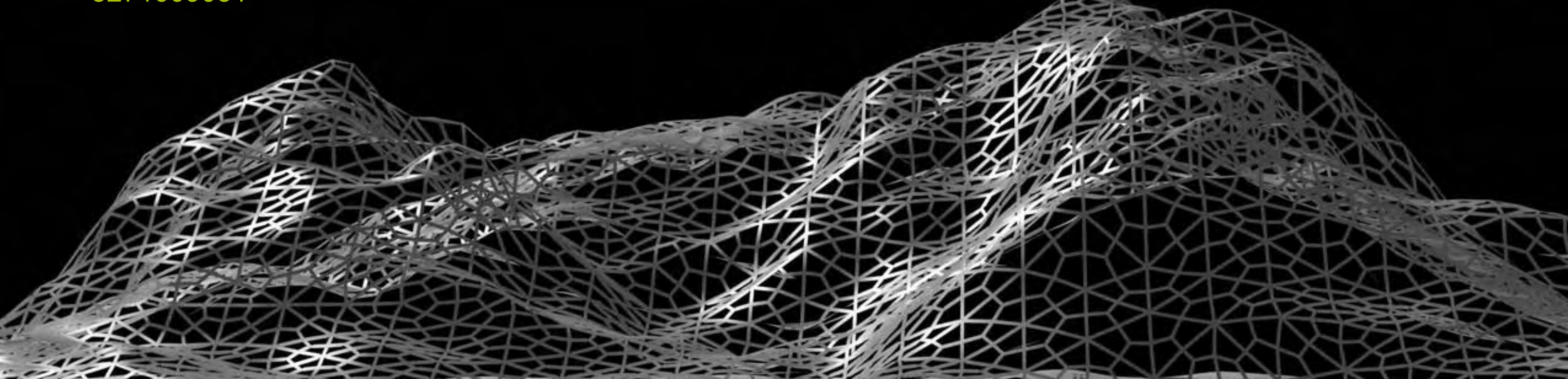
HYDROSPHERE
Resource Consultants

Feasibility Report
Cherry Creek Reservoir Destratification

Submitted to:
Cherry Creek Basin Water Quality Authority
Greenwood Village , Colorado

December 5, 2005
5271009031

Submitted by:
AMEC Earth & Environmental
355 South Teller Street
Suite 300
Lakewood, Colorado 80226



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Summary

Recommendations

The AMEC Earth & Environmental, Inc. consulting team (AMEC, Alex Horne Associates and Hydrosphere Resource Consultants) recommends the installation of a submerged focused mixing system in the 330 acre portion of the reservoir greater than 16 feet deep.

This system should be designed to:

1) Destratify and strongly mix the deepest portions of the reservoir,
2) Vertically mix algae to compromise their habitat and reduce production of blue-green algae, and
3) Oxidize of the deep bottom sediments to reduce the release of nutrients from the sediments into the water column.

Conclusions

The recommended system will achieve the following program objectives:

1) Reduce the releases of phosphorus and nitrogen nutrients from the bottom sediments into the reservoir in a typical year by 810 lbs/yr and 1,140 lbs/yr, respectively (See Attachment A),
2) Decrease the seasonal mean (July-September) chlorophyll *a* (Chl *a*) concentrations by approximately 8 ug/L under typical year conditions (See Attachment B),
3) Decrease annual peak Chl *a* concentrations by up to 30 ug/L (See Attachment B),
4) Increase dissolved oxygen concentrations in the deepest and most vulnerable zones of the reservoir into the range of 5 mg/L, and
5) Reduce the production of blue-green algae by making the habitat of the reservoir less suitable for the production of blue-green algae via vertical mixing.

The recommended system will accomplish these objectives without harming the existing uses of the lake and will compliment the watershed-based control measures to reduce nutrient loadings to the reservoir.

The capital costs for the recommended submerged focused aeration system are estimated to $520,000 to &700,000 depending upon the degree of protection provided for the aeration lines and the annual operation, maintenance and replacement costs are estimated to be $27,700 to $33,100, depending upon the degree of protection for the aeration lines. The life cycle costs, assuming a capital recovery factor of 7% over 35 years, are $69,000 to $88,700 per year. This produces an equivalent phosphorus removal cost of $85 to $109 per pound. This management option is competitive with the most cost-effective Pollution Reduction Facilities currently under consideration for the 2006 Capital Improvements Program of the Cherry Creek Basin Water Quality Authority (Authority).

Next Steps

If the recommended option is acceptable to the Authority, the following steps should be taken to provide the opportunity for the system to be installed for the 2006 season:

1) Complete the preliminary design to fine tune costs and to identify sites for the major components of the system
2) Seek approval for the installation of the system from the Corps of Engineers and the Cherry Creek State Park
3) Seek support for the installation of the system from the Colorado Department of Public Health and Environment (CDPHE),
4) Solicit bids from qualified suppliers for the final design and installation of the recommended system

Background

Introduction

Cherry Creek Reservoir is a eutrophic, relatively shallow high elevation reservoir located in a large catchment near Denver, Colorado (volume: 13,148 acre-feet (AF); mean depth: 8.5 feet (ft); surface area 850 acres (Ac); recreation pool elevation: 5,550.4 ft). It was originally designed as a flood control structure and still supports this purpose but is now heavily used as a recreational boating-fishing-swimming reservoir.

The Cherry Creek Basin Water Quality Authority (Authority) has been implementing watershed-based, best management practices (BMPs) and constructing pollution reduction facilities (PRFs) for many years. However, the chlorophyll *a* (Chl *a*) standard (15 μg/l) and phosphorus goal (40μg/l) have not been met. The recent special study of in-lake nutrient enrichment completed by Dr. Bill Lewis indicates that nitrogen is the limiting nutrient at this time. Despite the Authority's programs to reduce phosphorus loads from the watershed, it will likely take many years before phosphorus once again becomes the limiting nutrient and water quality benefits are seen in Reservoir.

As a result, the Authority is considering in-lake management techniques that could be beneficial in reducing Chl *a*, reducing nutrient concentrations, and increasing dissolved oxygen (DO) concentrations in the near term. Dr. Lewis suggested destratification (mixing) as a method to address internal loading and other factors that increase algal growth and therefore, chlorophyll *a* and phosphorus and nitrogen concentrations. Watershed management, however, will continue to see a necessary component of the Watershed Plan 2003 and both BMPs and PRFs will continue to be implemented.

Considerable effort has been made to reduce total phosphorus in the inflows. Nonetheless there remains an overabundance of phosphorus in the reservoir and algal growth is currently limited by nitrogen and possibly iron. Thus, high algal crops (up to 80 ug/L Chl *a*) and low water clarity (< 1 m) are common occurrences. In addition, anoxic bottom water typical of eutrophic conditions occurs irregularly in summer despite the top-to-bottom mixing (polymixis) that occurs on windy days in shallow water areas. When the reservoir is stratified, significant amounts of ammonia, iron and phosphate are released to the deep water and subsequently thus to the surface waters when the lake mixes a few days/weeks later.

Effects of Mixing or Oxygenation on the Release of Nutrients from Sediments

The alternate mixed and thermally stratified conditions (with anoxia near the bottom in the deepest areas of the lake) ensure internal "shock loading" of phosphorus and nitrogen nutrients during the critical July-September period. Algae use these internally loaded nutrients to grow to nuisance blooms in late summer and fall. The amount of nutrients released depends on the degree of anoxia, the kind of sediments produced form the previous spring algae bloom and the inflow of nutrients from the watershed. Removal of the anoxia would reduce some of the nutrient flux from the sediments to the algae.

Oxygen can be supplied to anoxic sediments in lakes by various means including addition of pure oxygen, air mixing, or mechanical mixing. There are various forms of each of these systems from underwater solution, bubble plumes, propellers and other devices. Not unexpectedly, the efficiency of delivery of the various devices varies considerably. The choice of technology varies with individual needs.

If sufficient dissolved oxygen (or oxygen-containing air or water) is supplied to the sediment-water interface, the flux of ammonia and phosphorus falls. *The world average from all kinds of literatures for all kinds of techniques is approximately 50% decrease for both N and P internal loadings.* The ranges are wide from almost no effect to ~ 90% reductions. The mechanism for P reduction is assumed to be the formation of an insoluble precipitate of ferric phosphate which is stable under oxygenated conditions. Ferrous phosphate forms quickly when the sediments become anoxic and is a soluble compound that released phosphate back to the water. The mechanism for N-reduction is less well understood, but is likely to involve increased growth of benthic biofilms on the sediments in the presence of oxygen. Since algae can use both nitrate and ammonia, the mere change of ammonia flux to nitrate would give no reduction in chlorophyll.

If mixing of Cherry Creek Reservoir is vigorous and focused, it is possible that oxygenated water from the surface will be mixed down to those areas with anoxic sediments. This will result in reduction in nutrients fluxing from the sediments. However, the concentration of oxygen, not merely its presence regulates, both phosphorus and ammonia releases. In general, by the time water from the surface actually gets within < 1 mm of the sediments in the deeper parts of “naturally” mixed systems it has lost most oxygen. Although probably containing enough oxygen to prevent fish kills and suppress malodors, the oxygen provided by natural mixing of the lake is not very effective at suppressing nutrient flux from the sediments. This loss of oxygen can be overcome by vigorously mixed systems that are continuously replenishing the oxygen in the deeper waters with well oxygenated water brought down from the surface.

Blue-Green Algae Successes and Lake Mixing

Blue-green algae (cyanobacteria) are common nuisance forms in lakes worldwide. There are many forms and species and each may need a different kind of control. However, in general, blue-green algae are warm-water forms that tend to form blooms (annual or irregular peaks in biomass) in the summer and fall. Specifically, blue-green algae are successful for three main reasons:

1) Blue-green algae contain **gas vacuoles** that enable them to control their buoyancy with very little expenditure of energy. They can make a regular up and down trips each day, being in the sunlight in the morning and sinking in

the afternoon to reach the higher nutrient concentrations at night. They float back up again for the morning sun. Larger colonial blue-green algae favor this strategy more than small or single filamentous species.

2) Blue-green algae are **not eaten** by zooplankton because they apparently “taste bad”. In addition, some are too large for the smaller zooplankton. Thus most blue-green algae are immune to grazing which controls most other algae.
3) Some forms can **fix atmospheric nitrogen gas** into protein if other sources of nitrogen (ammonia, nitrate) are scarce. Since Cherry Creek is probably limited by nitrogen, especially in the fall, this gives some species of blue-green algae an advantage.

Effect of mixing on blue-green algal buoyancy. Mixing of the lake can remove the first of these advantages (buoyancy regulation) since all kinds of algae will be stirred around together with no advantage to be gained from any diel cycle up and down. However, the amount of physical mixing required to stir buoyant blue-green algae varies; with small single celled forms or small filaments mixing through the water column is possible with enough stirring. *For larger colonial forms it is probably infeasible to add enough mixing power no matter which technique is used*. In fact, one of the drawbacks of physical mixing is the replacement of smaller nuisance species with larger scumming forms that are more readily seen by humans on calm mornings.

Effect of mixing on grazing of blue-green algae by zooplankton. Mixing of the lake will have no effect on grazing. Mixing may decrease or increase zooplankton depending on how it is done, but since blue-green algae are not eaten to any extent by zooplankton there will be little change in their numbers.

Effect of mixing on blue-green algal N_2-fixation. The effect on nitrogen gas fixation varies. If mixing also reduces ammonia flux then the balance of blue-greens could switch to a smaller amount of the larger colonial N_2-fixing species. Most importantly, Cherry Creek may actually be limited by iron since it has a large excess of phosphate. Iron is needed for nitrogen fixation in much greater amounts than for any other process (iron is a key co-factor in the enzyme nitrogenase that fixes N_2 and is also needed in the increased use of the cytochrome respiration system that provides the huge amount of additional energy needed to fix N_2). Thus if mixing reduces iron, the overall scum forming potential may decline.

Mixing and light limitation in blue-green algae. Much research and speculation surrounds this process. The wind is a very powerful force for lake mixing. Blue-green algae are found in the windiest lakes as well as calm ones. Lake mixing can change algae species composition and even favor diatoms over blue-green algae. Some species of *Oscillatoria* (a blue-green algae that normally grows as a singly filament) are easily mixed by stirring. Large colonial species such as *Microcystis* or *Aphanizomenon* are not easily stirred even by very vigorous artificial or natural mixing. So only smaller forms will be stirred by any feasible lake mixing.

Cherry Creek Reservoir is shallow (mean volumetric depth 8.5 feet, max depth ~ 25 feet). Most of the lake is less than 10 feet deep. Currently, the Secchi Depth transparency is less than 1 m (90 cm for summer 2004) with a photic zone (algae growth zone of 1-3 m (3-10 feet), assuming the 1% incident light defines the photic zone). However, the lower photic zone (< 10% incident light) will reduce algae growth relative to growth in the most favorable zone (~ 25% incident light). Unfortunately, the same mixing that sends algae into the gloomy depths also moves then out of the toxic surface zone (> 50% incident light) where photosynthetic inhibition reduces growth for much of the day.

Design of Lake Mixing and Oxygenation Systems

Cherry Creek Reservoir can be viewed as two separate systems:

1) That part that is less than 10 feet deep where mixing may already be relatively complete, the sediments are well oxidized, and light is available for the growth of algae at nearly all depths and
2) That part that is greater than 10 feet deep, where mixing is limited, the sediments are not well oxidized and the sediments are a source for internal releases of nutrients, and where light is not available at depth for the growth of algae.

The balance between the multiple phenomena caused by mixing that reduce algae by reducing light, reduce nutrients by reducing releases from sediments and make the residual nutrients more available in the photic zone will determine the extent of the water quality improvements in the reservoir as a result of oxygenation or mixing.

Conceptual Analysis of Alternatives

Reservoir Mixing

Mixing of the reservoir can potentially affect its water quality in many ways. The vertical circulation of the blue-green algae away from the surface and toward greater depths will decrease their growth potential due to light-limiting conditions at depth.

Without a change in the nutrient concentrations in the water column, however, the blue-green algae will likely be replaced by other types of algae. The other types of algae, however, will likely be more readily consumed by the zooplankton in the reservoir, thereby decreasing the overall concentration of algae and Chl *a*. There may also have a beneficial domino effect of less algal deposition on the bottom of the reservoir, less accumulation of nutrients in the sediments, and less subsequent releases of nutrients from the sediments back into the water column to feed the algal growth cycle.

Oxidation of Sediments

The water quality impacts and the reliability of this potential domino effect, however, are difficult to quantify and could be undermined by competing effects such as predation of zooplankton by the fish in the reservoir. The goal of reduced nutrient releases form the sediments, however, can be accomplished more directly by the recommended system by vertical mixing of the entire water column in those areas containing the most anoxic sediments (i.e. water depths greater than 16 feet).

The results form the special field tests completed as a part of this feasibility study and the monitoring data collected by the Authority from 200-2005 indicate that the critical periods of anoxia (less than 2 mg/L dissolved oxygen in the water column immediately above the sediments) can range from zero days per year to 60 days per year with a typical occurrence of 40 days per year. By eliminating these anoxic conditions, there will be a reduction in the release of nutrients from the sediments as discussed in Attachment A and summarized in Table 1.

Table 1: Nutrient Releases from Sediments due to Anoxic Conditions (350 Acre Active Zone greater than 16 Feet Deep)

Variable	Units	Typical	Minimum	Maximum
Days of Anoxia	days/yr	40	0	72
Ortho-P Release Rate	lbs/yr	810	0	1,460
Ammonia-N Release Rate	lbs/yr	1,140	0	2,052

There are ranges of uncertainty associated with these estimates due to the complexity of the environmental conditions which produce these releases. There are also multiple methodologies for estimating the rates of release. After carefully considering these complexities and alternative methods for estimation, the practical range for nutrient releases form the bottom sediments could be as high as 1,600 lb/yr for phosphorus and 3,600 lbs per year for ammonia nitrogen.

Although, at first glance, the release of nutrients from the sediments may seem small when compared with the annual loads on the reservoir (7,000 to 14,000 lbs per year for phosphorus), they can produce "shock loadings" of nutrients at crucial times in summer. Most of the annual loadings occur in the late fall, winter, spring, and early summer without affecting algae due to cold temperatures. In contrast, shock loadings in the summer cause an immediate increase in the in-lake concentrations of available phosphorus and ammonia nitrogen when the warmer temperatures will support the growth of algae and increase the Chl a in the reservoir. The potential ranges of nutrient loadings from the bottom sediments and the resulting increase in nutrient concentrations, and Chl *a* are summarized in Table 2. Since there is an overabundance of phosphorus already in the reservoir, the blooms will be most responsive to the increase (decrease) in ammonia releases from the sediments. These effects could range from 8 ug/L Chl *a* in typical years to 30 ug/l Chl *a* under worst conditions as calculated in Attachment B.

Table 2: Range of Effects of Controlling Nutrient Releases from Sediments

Variable	Units	Typical	Minimum	Maximum
Phosphorus Released from Sediments	Lbs/yr	810	0	1,600
Ammonia Released from Sediments	Lbs/yr	1,140	0	3,600
Increased Concentration of Phosphorus in Reservoir	ug/L	22	0	44
Increased Concentration of Ammonia in Reservoir	ug/L	31	0	98
Increased Concentration of Chl *a* in Reservoir	ug/L	8	0	30

Alternative Mixing/Oxygenation Systems

The AMEC team identified and evaluated three alternative concepts for achieving the program goals:

1) Lake-wide mixing of the upper layer of the lake (Upper Layer Mixing),
2) Focused mixing of the entire water column in the deepest part of the reservoir (Focused Mixing), and
3) Deep water oxygenation with a supersaturated oxygen/water solution and no mixing (Oxygenation Only).

The AMEC Team evaluated each of the three alternative concepts in terms of their likelihood to meet program goals and their anticipated environmental effects. The results of that analysis are summarized in Table 3.

The greatest emphasis in the ranking was placed on the achievement of the direct program goals. On that basis, the focused mixing alternative emerged as the recommended alternative. It was confirmed as the favored alternative after consideration of the secondary program goals and the environmental effects since no other alternatives were found to be superior in these secondary categories.

Table 3: Ranking of Conceptual Alternatives

Parameter	**Upper Layer Mixing**	**Focused Mixing**	**Oxygenation Only**
Direct Program Goals			
Reduction Chl *a*	1	2	1
Reduce blue-green algae	2	2	1
Mix water column	1	2	0
Deliver oxygen to sediments	0	1	2
Minimize interference with surface recreation	0	2	2
Life cycle costs	1	1	2
Subtotal Direct Program Goals	5	10	8
Indirect Program Goals			
Reduce internal nutrient loading	0	1	1
Consistent with Dr. Lewis advice	1	2	0
Risk of occasional equipment failure	0	0	0
Risk of loss of effectiveness of O_2 due to weak stratification	0	2	0
Minimize piping	1	2	0
Underwater devices (snags)	1	1	2
Subtotal Indirect Program Goals	2	8	3
Environmental Effects			
Noise	(SolarBee)2	0	2
Exposed Shoreline Equipment	(SolarBee)2	0	1
Lake visual effects	0	0	2
Enhance fishery	0	1	1
Enhance boating	0	1	2
Subtotal Environmental Effects	4	2	8
Total	12	20	19

Note: The ranking of the pros and cons for each alternative include a score of 2 for a clear advantage, 1 for a moderate advantage, and 0 for no relative advantage. The highest score is the preferred alternative.

Mixing System Conceptual Design

Introduction

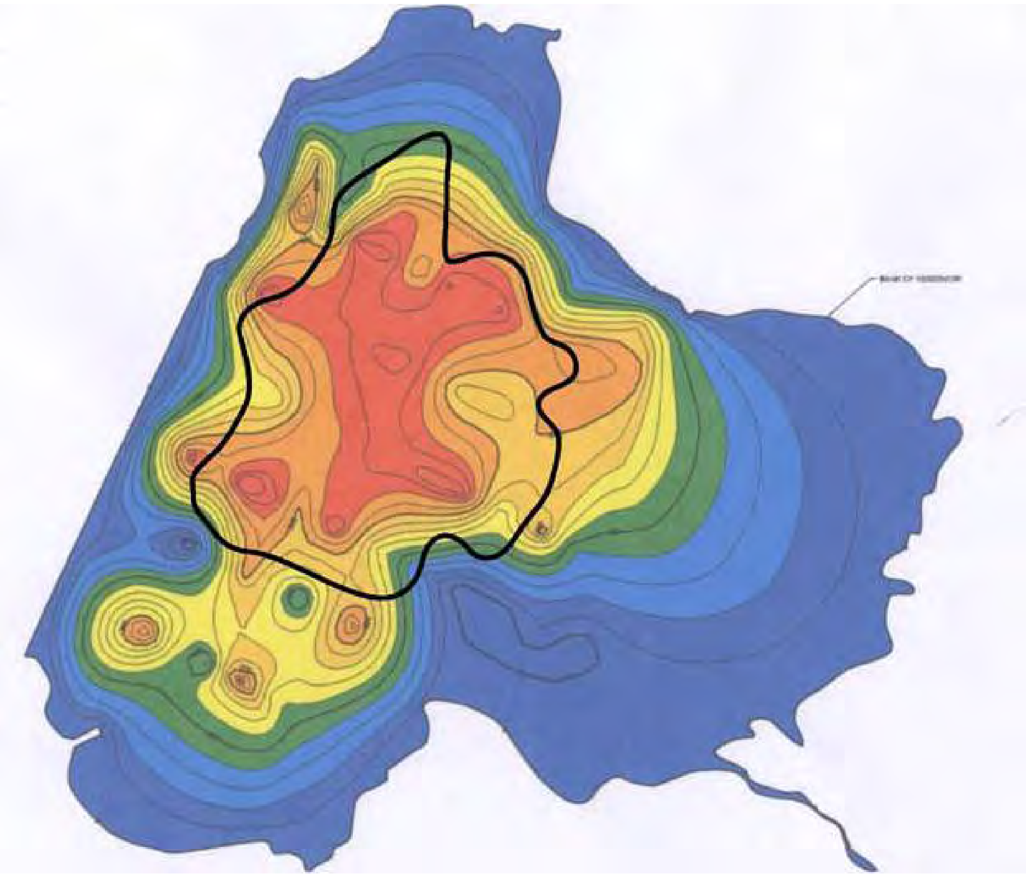
Artificial mixing or circulation of lakes and reservoirs is a widely applied technique to reduce thermal stratification and raise oxygen levels in the lower water column (see Brown & Caldwell 2004, Cooke et al 2005). In temperate climates, classic thermal stratification is established in the spring and disappears in the autumn. If the lake is deep, the thermocline will be present as a permanent summer feature. In eutrophic lakes low oxygen conditions can become established below the thermocline. Shallow lakes are usually well mixed, and do not show summer-long thermal stratification. Instead they show period of mixing alternating with periods of stratification each lasting days to weeks, and are known as polymictic. Cherry Creek Reservoir has limited periods of stratification and can therefore be considered to be polymictic (Heiskary & Lindon 2005)

Approach

Most established limnological literature relates to deep stratified lakes. These systems tend to function differently than shallow water bodies (Cooke 2001). This is becoming recognized and separate management techniques are being developed for shallow lakes (Scheffer 1997). Using Cooke's definition of a shallow lake, i.e. one with an average depth of less than 10 ft, indicates that Cherry Creek is just inside this category since the volume-weighted mean depth is 8.5 feet. Cook's definition, however, is not yet widely accepted (other workers consider 30 ft ~ 10 m to be the dividing line between shallow and deep lakes). Cook's work applies to temperate lakes mostly in the east of the US that are close to sea level. Cherry Creek Reservoir is at over 5,000 feet and is much cooler and thus more easily mixed by the wind than most eastern US and central European lakes. These factors tend to make Cherry Creek act as a "shallow lake" even in areas deeper than 10 feet.

In any case, the tools applicable to shallow lakes are the most appropriate and it may be best to consider this reservoir as essentially two different systems, the shallower end and the deeper end toward the dam in the development of management tools. This leads to the adoption of an approach that uses focused mixing in the areas where the sediment Oxidation Reduction Potential (ORP) measurements were the most negative (See Attachment C). This is essentially within the 20ft contour line as illustrated in Figure 1.

Figure 1: Sediment ORP and 20-ft Depth Contour Line



AMEC considered two separate options for mixing and oxidation. Both are consistent with the recommendations of Lewis *et al.* (2004):

1) Destratification plus mixing of the water column. This will increase the oxygen level in the bottom of the water column by mixing and removing the periods of stratification. If this results in oxygenation of the bottom sediments, it may reduce the release of nutrients (particularly phosphorus) from the sediments.
2) Vertical Circulation of algae. This reduces the potential for growth of large buoyant forms of blue green algae by mixing the cells and causing two effects: first, overcome the selective advantage that buoyant groups can have over less noxious algal groups in a stable water column and second, mix the algae into the darker deeper areas, thereby reducing the ability to photosynthesise and grow.

Option (2) likely require considerably more energy input than (1) ((Visser *et al.* 1996, Rybak 1985).

The most common method of achieving mixing is by the injection of compressed air (Illinois EPA, 2000). Other methods could include the use of jets, propeller mixers and similar equipment mounted on the water surface.

We have excluded from further consideration at this stage those methods of mixing that would require structures on the water surface due to serious public safety concerns for speed boaters, water skiers, jet skiers, and sail boats. Special consideration was given to the SolarBee circulation system due to its energy efficiencies using solar panels. We concluded, however, that the concerns for public safety precluded the use of this technology.

Destratification and Mixing of the Water Column Systems Designs

Continuous Linear Bubble Column. The most recent review of circulation/mixing has been provided by Cooke *et al.* 2005. They discuss in considerable detail the use of compressed air systems and a continuous linear bubble column produced an airline with drilled holes or slots located near to the bed in the deepest part of the reservoir. This system is described as the least expensive and easiest to operate.

There are two main approaches to the calculation of the main parameters required in the design of an effective continuous linear bubble column. The first is that of Lorenzen and Fast (1977) and the second is provided by Davis (1980). Examination of these two design models reveals apparent inconsistencies in the recommended design parameters. The Davis approach appears to require lower air input rates than that of Lorenzen and Fast. This may be a problem since Cooke *et al.* (2005) demonstrate that if the air input is not sufficient to attain the recommended value of 9.2 $m^3/km^2/min$ 1.5 $ft^3/Ac/min$ as recommended by Lorenzen & Fast, then successful destratification may not be achieved.

In order resolve this potential problem, we have used the Davis approach to calculate the required length of the diffuser but we have used the recommended air flow figure of Lorenzen & Fast. The area being considered for mixing is approximately 1.2 m^2 (300 Ac) and therefore a compressor supplying a free air volume of 660m^3/hr (370 ft^3/min) is recommended.

km^2

equals 1.23ft^3/ac/min. Calc error (?) should be 450 scfm. Final plans show 455-scfm compressor

The maximum depth of the reservoir is approximately 8 m (24 ft). According to Cooke, shallow water bodies may need more than the standard recommended airflow which can be up to up to 12.3 $m^3/min/km^2$ this would equate to an airflow of 888 m^3/hr (490 ft^3/min).

It is generally agreed that very little direct transfer of oxygen from the bubbles is achieved by air destratification techniques. The majority of the transfer is by uptake of oxygen at the air-water surface interface (Cooke *et al*. 2005). Therefore, the most important design parameter is the flow of water generated by the bubble plume.

calc error. Should be 522 scfm

The Davis approach does not identify a design parameter for water flow. The Lorenzen & Fast approach does. Because we have used a hybrid method to calculate the diffuser length and air flow, we have therefore used an alternative method to calculate the approximate water entrained. We have calculated the induced flow of water for the line diffuser by considering it to be a point diffuser. This appears to be valid because Ashton (1978 and1979 in Henderson-Sellers, 1984) has demonstrated that the values obtained for flow rates for a point and line source are of a similar order of magnitude. Using the equation provided by Smith *et al* (1982), a line diffuser in 6 meters of water depth supplied with 660 m^3/hr of air will move approximately 7,450 m^3 of water/hr and when supplied with 888 m^3/hr will move 8,350 m^3 of water/hr.

The direct application of the Davis methodology is difficult to do from the tables due to the shallow water depths of Cherry Creek Reservoir. As an approximation, we have used the example in Cook *et al*. (2005) which uses a 10 meter deep reservoir of similar area (1.2 km^2), even though the Cooke example had to overcome a greater temperature differential. This estimated a required perforated pipe length of 400 m (1,300 ft) with an air supply of 660 m^3/hr ~~(370 ft^3/min).~~ The estimated primary zone of influence for a 400 m long perforated diffuser line at a radial distance of 5x, 7x and 20x and an assumed water depth of 6m is shown in Figure 2.

One possible drawback use of a single continuous bubble column diffuser is the relatively small area of primary influence of flow in a shallow reservoir like Cherry Creek. Although the bubble plume sets up long vertical recirculation cells on either side of the diffuser, the distance the plume travels before it plunges back down will be related to depth. It would be possible to improve the operation of the diffuser by using several smaller lengths spreading them over a wider area. Such an approach was used by Visser *et al* (1996). That reservoir, however, was much deeper (max 100 ft) and we believe a multiple diffuser recommendation is more suitable in the shallow water depths of Cherry Creek. This is because the zone of influence, for sediment aeration purposes, is likely limited to 7x the depth because of the water circulation patterns that are set up by these systems (See later section).

We have included this alternative for illustrative purposes. If this option is pursued, a contractor could provide a more detailed design, but we have recommend the use of several smaller distribution lines rather than one single line to provide the necessary coverage. A quantity take-off for a linear diffuser system is provided at the end of this document.

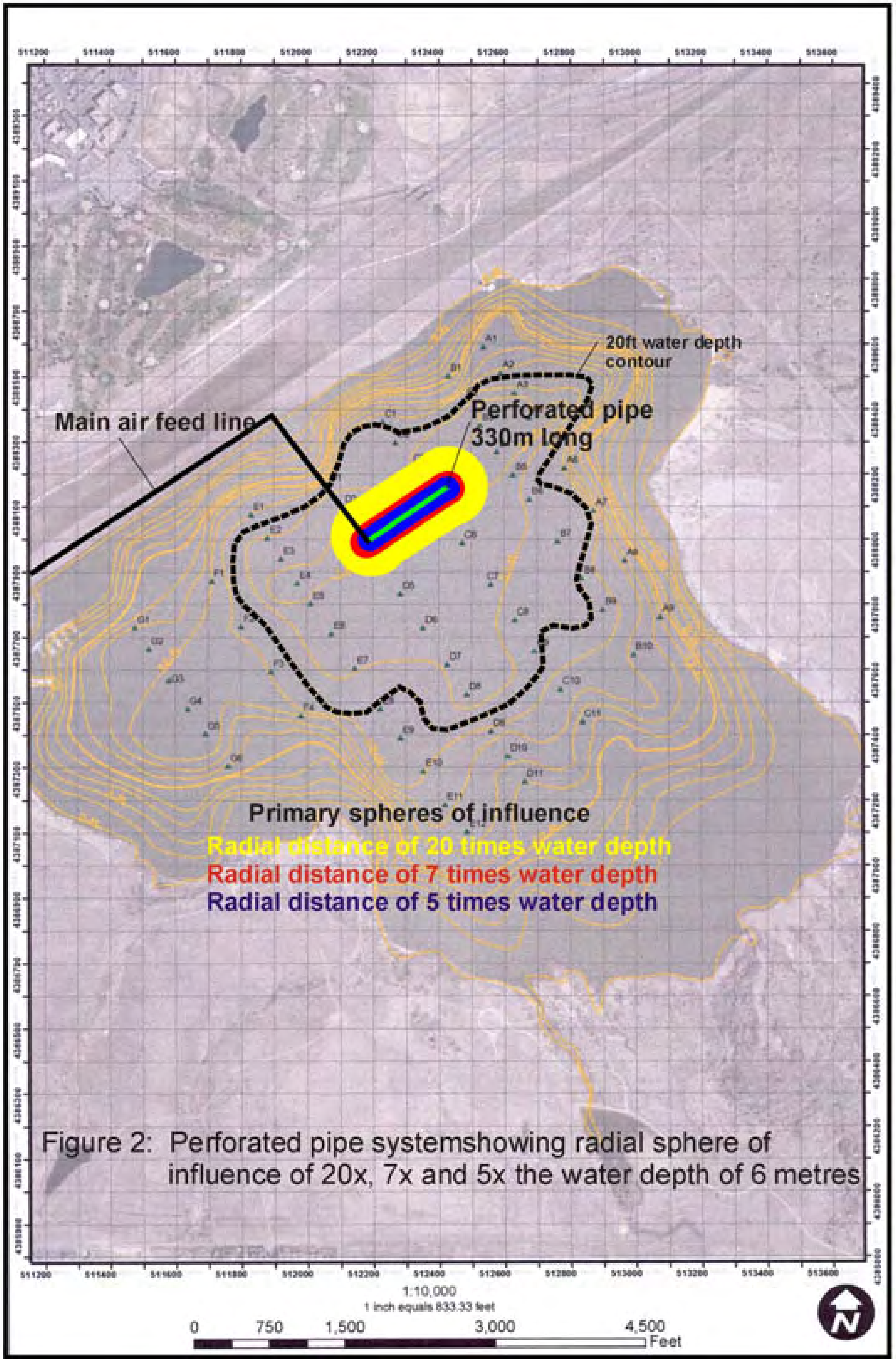


Figure 2: Perforated pipe systemshowing radial sphere of influence of 20x, 7x and 5x the water depth of 6 metres

Multiple Mixing Points. The potential for a linear diffuser system, or any other system to oxygenate sediments will be limited by the radius of the water circulation patterns that can be induced by the aeration system. The radius of the water circulation pattern is generally thought to be proportional to the depth of the reservoir.

Smith *et al*. (1982) suggest that irrespective of the volume of air passed through a diffuser, the primary sphere of influence is restricted by the depth. Increasing the air volume will increase the rate of water circulation and, therefore, the rate of oxygenation of the sediments, but it will not increase the zone of influence for this phenomenon. Thus, there is an apparent advantage to divide the required volume of air among as many diffusers as will be needed to provide coverage of the sediments to be oxidized based on the zone of influence for each diffuse.

There appear to be relatively few professional studies that compare the outcomes of mixing using multiple point source diffusers with line diffusers to destratify and mix reservoirs. The one exception to this is the study of a relatively small lake by Crowell *et al.* (1987). Visser *et al.* (1996) used a variation on the line diffuser approach by using 7 shorter line diffusers spaced throughout a reservoir rather than rather than one single long line diffuser. Meyer (1991) has suggested that on large lakes it may be better to spread the aeration system out over a greater area using multiple points of injection rather than just one location and a single diffuser. It is of interest to note that most commercially advertised aeration systems for lakes in the USA use multiple point source diffusers as their technique.

The number of diffusers required for Cherry Creek Reservoir, based on the different spacing criteria, is illustrated in Figures 3 and 4.

Intensive vertical mixing of reservoirs using diffusers has been well explained by Goosens (1979) and by Smith & Goosens (1982). They suggest that the primary cylinder of mixing yields a figure of radius equal to 5x -7x the depth for effective mixing to leave no quiescent areas or, more precisely, to provide a fully homogenized water column. If simple destratification, rather than homogenized mixing is the goal, it may be possible to space the diffusers at 20x depth as shown in Figure 3.

Using the 7x spacing criteria, approximately 113 point diffusers would be required for Cherry Creek Reservoir for the configuration shown in Figure 4. This configuration would directly impact approximately 300 acres of the most anoxic sediments. The overall concentrations of oxygen in the reservoir would also be improved and secondary mixing by winds and other lake circulation patterns could be expected to significantly oxidize other sediments within the reservoir.

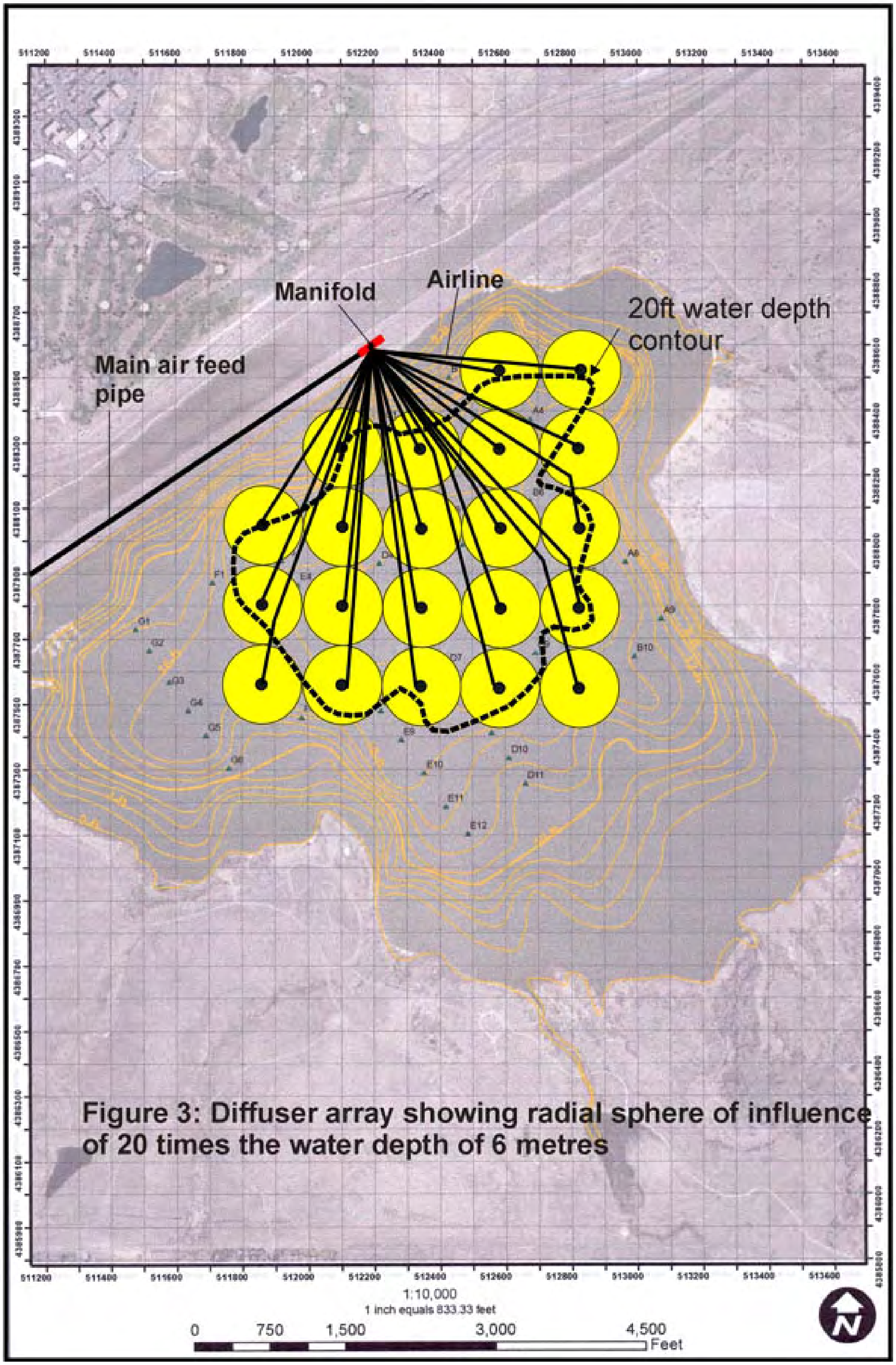


Figure 3: Diffuser array showing radial sphere of influence of 20 times the water depth of 6 metres

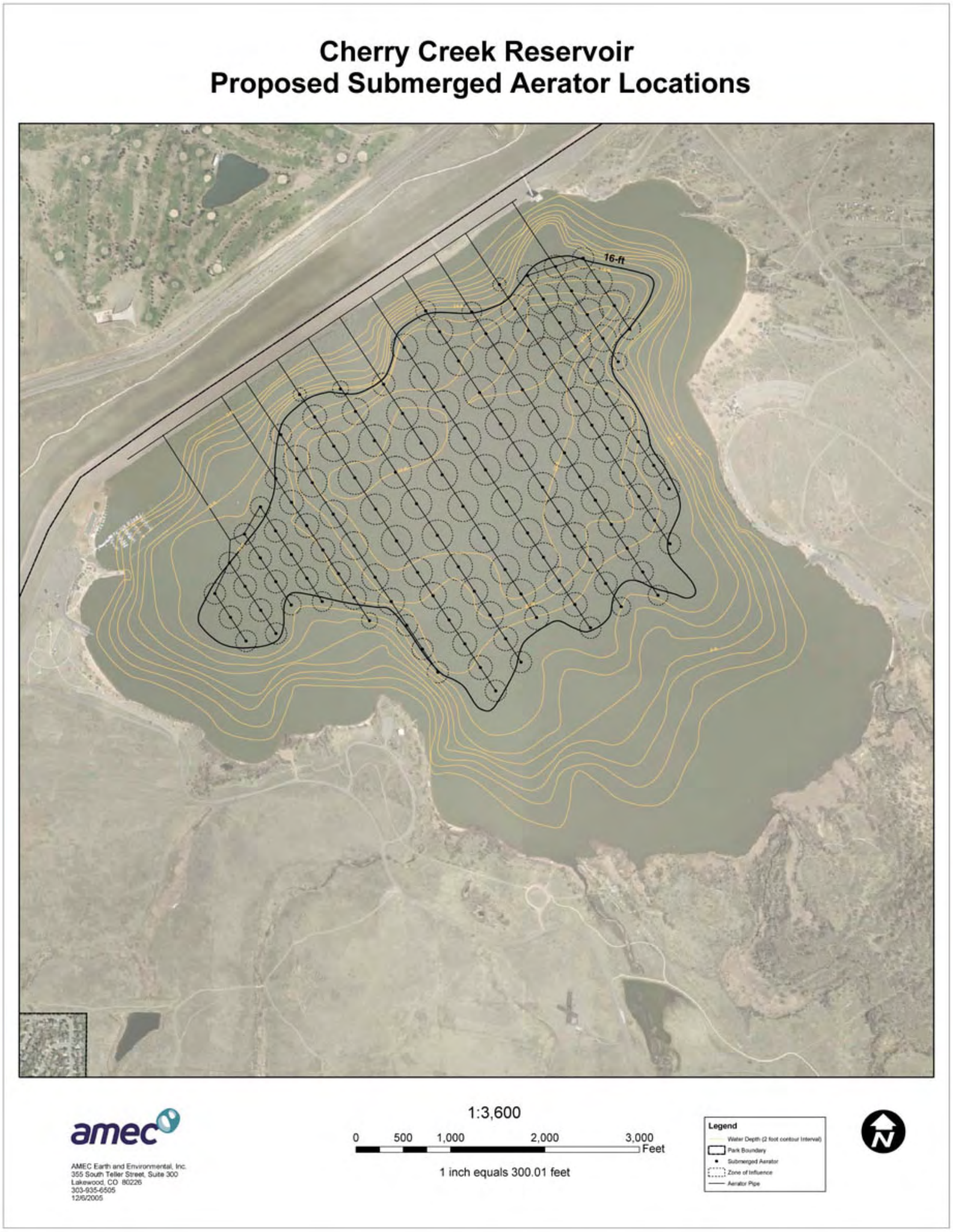


Figure 4: Diffuser array for 7x depth radial cone of influence

3.4 scfm

Using Lorenzen and Fast's (1977) recommended aeration rate of 9.2 m^3/km^2/min (1.5 ft^3/Ac/min), the total requirement would be 660 m^3/hr (~~370 ft^3/min~~). This would be the equivalent of 5.8 m^3/hr (3.3 cubic feet per minute (cfm)) for each of the 113 diffusers. This rate is reasonable for most commercial diffusers of the type recommended for treatment lagoons according to De Moyer et al (2001).

The amount of water moved by diffusers operating at 5.8 m^3/hr at various water depths based on De Moyer *et al*. (2001) is summarized in Table 4. This information confirms the diminished incremental value (at least in terms of volume of water circulated and hence potential reoxygenation of the water) of additional diffusers placed at shallower depths.

Table 4: Volume of Water Circulated by 5.8 m3/hr Diffusers

Number of Diffusers @5.8 m3/hr per Diffuser	**Volume of Water Moved (gal/min)**	
	20 ft Water Depth	**24 ft Water Depth**
20	180,000	290,000
30	270,000	430,000
113	1,000,000	1,600,000
150	1,300,000	2,100,000
200	1,800,000	2,900,000

Normally, there is little oxygenation of the water column arising from the dissolving of bubbles because the amount added is so small because so few diffuser are used to mix the water column. The majority of any oxygenation of the water will take place at the lake surface-air interface. It appears likely from Smith *et al.* that multiple injection points could be used to recirculate water within smaller cells. Similarly, by increasing air flow through diffusers, the recirculation rate can be increased and the turnover times reduced thereby bringing more oxygentated water down from the surface and into contact with the sediments. This vertical circulation of water can also help to control blue-green algae as discussed in the following sections.

Vertical Circulation of Algae. Examination on the literature on the subject of the use of artificial mixing to control blue green algae, or indeed to reduce the biomass of phytoplankton in general, reveals that this can be a somewhat hazardous target (see Cooke *et al.* (1995). In some instances, artificial circulation has increased the phytoplankton biomass although blue-green species have generally been reduced. They state explicitly that destratification of a lake with a mean depth of only 3m (10 ft), it is unlikely to be successful if light limitation is the proposed method of control. Reynolds (1993) has voiced similar concerns, concluding that there would appear to be little hope for inducing the required degree of environmental change on algae a 5m (16 ft) deep body of water were already isothermal to a depth of 4m (12 ft).

What is apparent is that in the 1.2 km^2 (300 Ac) mixing zone, sufficient multiple mixing points will render no areas quiescent making the area less suitable for buoyant blue-green species (Walsby, 1991). The vertical mixing in this deeper zone may also contribute to algal reduction of all species by light limitation. The potential success of this approach however, should be reviewed with guarded optimism. A problem not considered by most writers on blue-green algae is that they may increase their buoyancy in response to the mixing they experience. There is no published data on this phenonemnon, but studies carried out in Clear Lake California (a large shallow eutrophic lake) showed that only the very largest storms mixed large blue-green colonies. Typical afternoon winds or small storms had little effect overall (Rusk, Ph. D. Thesis under supervision of Prof. Horne ~ 1978). Thus, although mixing may reduce blue-green algae, the prediction that it will carries some risk.

The question of water velocity of water mixing is required to overcome the buoyancy of species such a *Microcystis* sp. was addressed by Visser *et al.* (1991) who used an estimate of the average floatation velocity of 0.11m/hr 0.07 in/sec. It may be even more difficult, however, to overcome their buoyancy. Horne and his students have recorded much higher floating velocities in California and Nevada. Some colonies rose at 3.6 m/hr (2.4 in/sec), while is about 30 times faster than the rate quoted above. Visser et al. (1991) noted that although there mixing system was not sufficient to entrain *Microcystis* sp. over the entire lake it was nevertheless sufficient to prevent blooming and scums.

Overall, it will be very difficult to provide sufficient mixing to stir down the large nuisance species of blue-green algae (*Anabaena, Aphanizomenon, Microcystis, Gleotrichia*) that are the main concern of Dr. Lewis. However, these algae often grow from small single cells (spores) or small over-wintering filaments. These are very much smaller than the large almost pea-sized or “grass clipping” size colonies that are common in summer. These smaller colonies could be mixed down by the recommended focused mixing method. This phenomenon would indirectly reduce the potential growth of the nuisance species by controlling their precursors.

There is probably some beneficial effects to be gained if a mixing system could be made sufficiently vigorous over a wide area and if it is focused on the deeper parts of the reservoir. Visser *et al.* (1996) have produced one of the few examples of a scheme designed to control blue green algae, in this instance *Microcystis* sp., that not only was said to be effective, but has been subject to proper appraisal via a professional peer review process. Their success appears to be due not only to the effective mixing into deep water of the algae, by using a sufficient volume of compressed air, but also because they used several mixing points rather than concentrating the line diffuser in only one area and that the zone of algae control extended beyond the 7x depth zone of influence of direct mixing.

Therefore, there is support for the premise that mixing Cherry Creek only within the deepest area may help to reduce the potential for excessive growths of large bodied buoyant blue green algae throughout the lake.

We propose therefore that the likely benefits of a multiple injection point system are sufficient to recommend this approach. It will satisfy the need to oxygenate the sediments in those areas with the greatest negative ORPs. It is apparent that there are companies who are willing to bid on such an approach if it goes out to tender.

At this stage, our recommendation is therefore to either:

1) Install several line diffusers located within the 16 ft contour with a minimum total aeration rate of 12.3 m^3/min/km^2 (2.0 ft^3/Ac/min)
2) Install 113 individual diffusers with a total aeration rate of 9.2 m^3/min/km^2 (1.5 ft^3/Ac/min) and a 7x depth radius cylinder of mixing for each diffuser.

We recommend that an invitation be issued for an competitive bidding process in which open bid process whereby contractors are invited to submit their proposals for a compressed air destratification / mixing system which is the measured against the criteria we have provided for the two alternative systems.

Additional refinements such as having the system operate in an intermittent manner can be built into the design consistent with Reynolds (1993) which may help to reduce the dominance of any algal group. Alternatively, a system such as that conceptualized and developed by Burns (1994), where the system switches on when a temperature differential develops between the top and the bed of the lake, could be incorporated or any other strategy that would emulate the alternating strategy of Steinberg & Gruhl (1991).

It would appear that these systems using individual diffusers would have enough flexibility to allow more diffusers to be deployed or greater volumes of air to be delivered.

Mixing only the Upper Portion of the Water Column

AMEC has also examined the possibility of limiting the mixing to only the upper portion of the water column to emphasize control of the buoyant blue-green species of algae. We have analyzed concepts that would be limited to the top 3m (10 ft) and in those areas greater than 16 ft deep to take advantage of potential light limiting conditions.

The decreased bubble lift distance associated with this concept above method would be applicable and would require much closer spacing of the diffusers than if they were located on the bottom of the reservoir. The effectiveness of the lift may be further compromised by the short vertical travel of the bubbles since the relatively large bubbles emitted from standard diffusers may not have sheared into smaller bubbles as they would with the longer vertical travel distances afforded by a deeper installation (De Moyer *et al*. (2001). The use of fine-bubble diffusers would therefore be preferable for this application. The nature of the diffuser material should be provided by the bidder. Two possible types would be a soaker hose material with multiple connection points from the supply manifold or the slotted tubing provided by Aqua Sierra, ASI, and others. Schematic diagrams of alternative systems are provided in Figures 5 and 6.

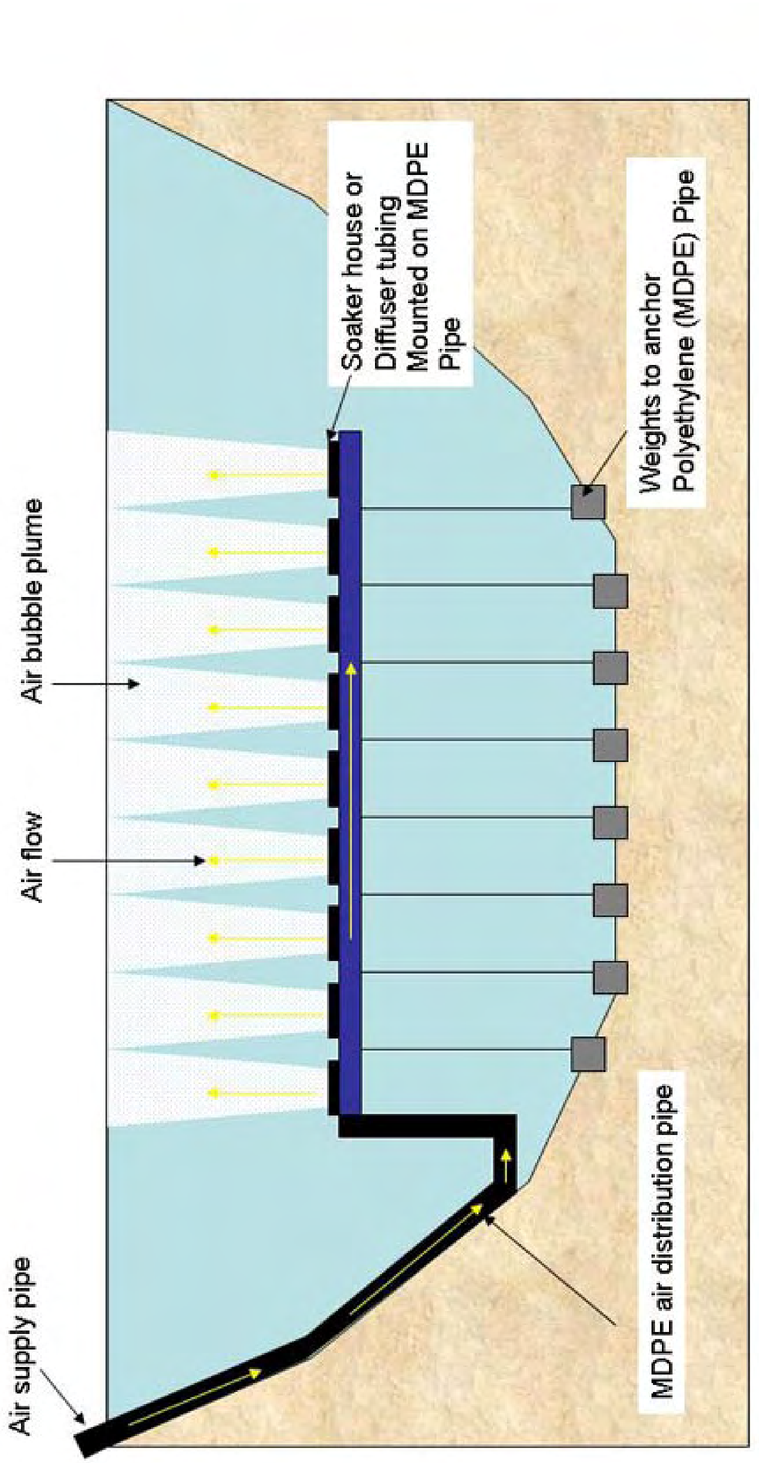


Figure 5: Diagrammatic representation of upper water column aeration system
Not to scale

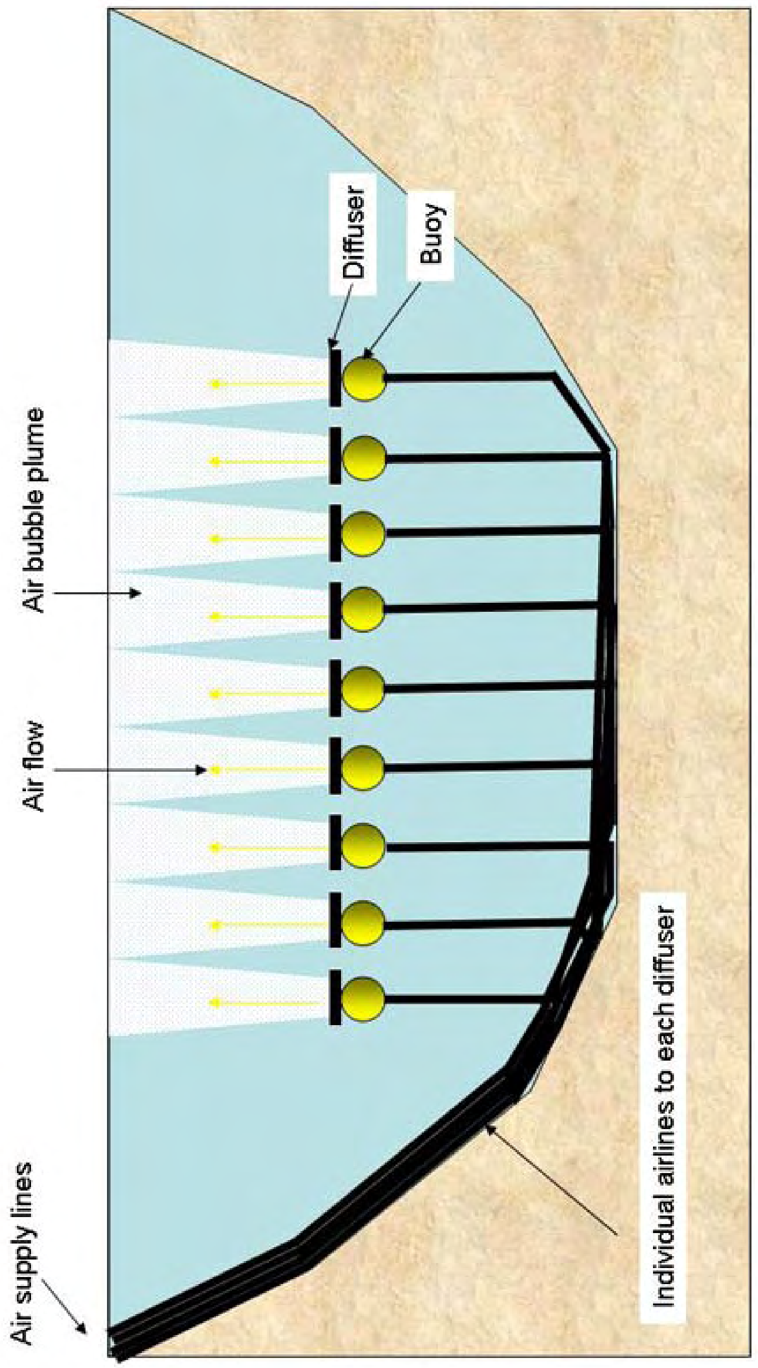


Figure 6: Diagrammatic representation of upper water column aeration system with buoyed diffusers from individual airlines
Not to scale

Both systems would be severely compromised by the smaller zones of influence for each diffuser. Thus, a larger number of diffusers would be required. The costs for installing such a system would be significantly greater than for bottom mounted diffusers due to the cabling systems required to suspend the diffusers at a constant depth below the surface. In addition, there would be substantially greater risk of boaters and fisherman to snag the aeration cables. For these reasons, we do not believe that such a system would be feasible or cost-effective. AMEC recommends that these systems receive no further consideration at this time.

As previously mentioned, AMEC also recommends against further consideration of the SolarBee near-surface circulation system due to the public safety risks associated with their equipment floating on the water surface.

Quantities Take-off

The estimated quantities of materials required for installation of the two identified types of aeration approach are summarized below:

Continuous Bubble Column System*. Compressor to deliver a minimum of 890m^3/hr (490 ft^3/min) of free air volume at a pressure of 9 bar. Compressor should be oil free.

Cabinet: Acoustic cabinet with electrical control panel, cooling fans and timer

Main air distribution line: Approximately 1,300m (4,300 ft) 110mm (4 inch) id MDPE pipe buried in northern bank of the lake. First section of pipe work, from compressor cabinet, to be in steel to allow for heat dissipation.

In-lake airline: Approximately 500 m (1,600 ft) of 50 mm (2 in) id for supply line to each linear diffuser. Pipe weighted with 10kg blocks at 2m intervals.

Multiple Diffusers: 33m (100 ft) long perforated pipe diffuser. Pipe perforated at 0.3m (1 ft) interval with 1mm (0.04 in) holes. Pipe weighted with 10kg blocks at 2 meter intervals or equivalent slotted tubing

Fittings: In-water fittings to be fabricated from brass or stainless steel

Multiple Mixing Points System. This system is based on a 113 diffuser array using a 7x radial distance for the primary cylinder of influence.

Compressor: Compressor to deliver a minimum of 660 m^3/hr (450 ft^3/min) of free air volume at a pressure of up to 1.6 bar. (e.g Reitschle Zephyr 500 which has an electricity requirement of 31 KW). Compressor should be oil free.

Cabinet or Compressor building: Acoustic cabinet with electrical control panel, cooling fans and timer

Main air distribution line: Approximately 1,500m (5,000 ft) of 110mm (4 in) id MDPE pipe buried in northern bank of the lake. Pipe to be fitted with 16 manifolds including control valves for airflow to each diffuser airline. First section of pipe to be to be steel to allow for heat dissipation.

In-lake airline: Approximately 82,000 m (270,000 ft) of self-sinking airline of 5/8" id. Airlines to be bundled together to create lanes of diffusers and placed in 6 inch PVC sleeves to protects the bundles against fish hooks and anchors.

Diffusers: 113 fine pore diffusers with 3mm bubble size

Fittings: In-water fittings to be fabricated from brass or stainless steel

* Guide only. Request should be made to the bidding contractor to provide a perforated pipe system design.

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Hypolimnetic Oxygen System Conceptual Design

Introduction

Another way to oxidize the deep sediments, and thereby reduce the internal loading of nutrients is to add a pure oxygen/water solution at the sediment/water interface. To be successful, the supersaturated oxygen solution would be distributed only during periods of stratification to prevent the too rapid dissolution of the solution into the entire water column rather than being concentrated at the sediment/water interface where it can accomplish the oxidation of the sediments.

Liquid Oxygen Design

Based on the limnology of Cherry Creek Reservoir over the past 5 years (2000-2005), the amount of oxygen to be added to the deep waters during temporary thermal stratification to meet the presumed highest past oxygen demand from water and sediment combined was estimated at 1.1 tons/day. The range of values depends on the depth of the temporary summer thermocline which itself depends on the weather in the immediate past. At full pool (el, 5,550 ft.) with the minimum thermocline depth (10 ft.) and thus maximum hypolimnion volume, the oxygen requirements are estimated at 1.08 tons/day. At maximum thermocline and minimum hypolimnion pool the oxygen requirement averages 0.25 tons/day. After the initial few weeks and certainly after system has been operating for 2 years the oxygen demand will probably be 0.25 to 0.5 tons/d.

It is concluded that a submerged Down-flow Contact Oxygen system (SDCO or Speece Cone) was the only practical oxygenation device to meet the needs of the project in shallow warm polymictic Cherry Creek Reservoir. Based on bathymetry, location of the cone near the deepest point optimizes cost efficiency since it will operate under almost an additional atmosphere of pressure which will improve the efficiency of dissolving oxygen in the water. Most importantly, a cone in the deeper zone will provide the vital cool, dense bubble-free plume flowing in the ideal horizontal direction over the oxygen-demanding and nutrient-generating sediments (bubbles plumes are buoyant and rise vertically away the problem area they need to contact).

The option of on-site liquid oxygen (LOX) deliveries to the site would provide a totally silent operation and is recommended in this case as superior to on-site generation of oxygen using pressure swing absorption oxygen generator. The pressure swing units require substantial energy inputs for the compressor that drives the unit and would be a potential source of noise.

The LOX system consists of the Speece Cone and water pump (silent and invisible underwater), a large propane-like LOX evaporator and tank ~ 12 ft high, a small control panel, and some small electric and oxygen pipes connecting the above ground and submerged parts.

Installation of the submerged cone and water pump can be made by assembling on land near shore, floating it to the site, and sinking the entire unit and flexible lines using SCUBA divers if needed (a bathymetric survey will be needed prior to sinking the cone). It may be possible to use a crane to install the system directly in one of the deepest points near the dam.

Life Cycle Cost Estimates

We have prepared conceptual level opinions of probable life cycle costs for each of the three conceptual alternatives. Those opinions are summarized in Table 5.

Table 5: Conceptual Level Opinion of Life Cycle Costs

Parameter	**Upper Layer Mixing (2)**	**Focused Mixing**	**Oxygenation Only**
Capital Costs	$768,000	$520,000 - $700,000	$370,000
Operation, Maintenance and Replacement			
Replacement	$23,000	$15,600 - $21,000	$10,500
General Maintenance	$1,000	$1,000	$1,000
Power	$0	$11,100	$500
Liquid Oxygen	$0	$0	$20,600
Subtotal O&M and Replacement	$24,000	$27,700 - $33,100	$32,600
Equivalent Annual Costs (1)	$85,000	$69,000 - $88,700	$62,000
Effective Phosphorus Load Reduction (lbs/yr)	810	810	810
Unit Costs ($/lb P removed)	$105	$85 - $109	$77

(1) Equivalent annual costs based on a capital recovery factor = 0.0794 (7%, 35 years)
(2) Based on SolarBee

The most cost effective alternative is the Oxygenation Only System. It, however, does not have as high of an overall ranking as the Focused Mixing System as described in a previous section. The SolarBee system in the upper range of equivalent annual cost and has been eliminated from further consideration due to the concerns for public safety associated with the operation of these units on the water surface.

Attachment A

Memorandum Re:
Internal Loading Estimates for Cherry Creek Reservoir

MEMORANDUM

TO: Bob McGregor
FROM: Jean Marie Boyer, Hydrosphere
SUBJECT: Internal Loading Estimates for Cherry Creek Reservoir
DATE: October 14, 2005, REVISED October 25, 2005
CC: Alex Horne, Ken O'Hara

This memo summarizes the effort to estimate the internal loading of phosphorus and ammonia in Cherry Creek Reservoir.

1. The theory we are working with is that SRP and ammonia are released from the sediments during periods of anoxia at the sediment-water interface. These nutrients are biologically available to phytoplankton and are a concern in Cherry Creek Reservoir.

2. For phosphorus, the Einsele / Mortimer model is widely accepted to explain internal loading (Bostrom et al, 1988). This model assumes a chemical mechanism -- that redox conditions at the sediment-water interface are the principal factor regulating P release and that P is released under reducing conditions following reduction of Fe^{3+} to Fe^{2+}. Results from numerous studies have been consistent with this model. However, some studies have shown that it does not apply for all lakes (see for example, Driscoll, et al., 1993) and that other mechanisms, such as biological processes, may play a role in sediment releases (Kalff, 2002).

3. Less is understood regarding the mechanisms for ammonia release. It has been shown that the amount of ammonia released by the sediments is controlled by the presence or lack of oxygen in the overlying waters (Beutel, 2003).

4. Releases of phosphorus and ammonia under oxic conditions have been reported. It is widely accepted that oxic releases are much lower than anoxic releases but there have been some studies that show significant releases during oxic conditions.

5. The basis for this analysis is if oxygen were applied to the sediment-water interface, internal loading of phosphorus and ammonia during what are now anoxic periods, would be eliminated. Thus, this analysis only deals with anoxic release rates.

6. This notion is not accepted for all situations however. Note that Driscoll, et al. (1993) suggest that the addition of oxygen at the sediment-water

interface may enhance P release based on their work on Onandaga Lake, a calcareous hypereutrophic lake. They state that pH will decline with the introduction of oxygen (due to increased aerobic mineralization) and more $CaPO_4$ will become soluble as a result.

7. For Cherry Creek Reservoir, DO concentrations at the bottom decrease in the summer months (Figure 1). In general, concentrations decrease to around 2 mg/l in early June with a rapic increase in mid-August. The exception is 2005 where the lowest concentration is 3.11 mg/l. Due to the polymictic nature of the reservoir, DO concentrations typically rise and fall during the summer months. During 2001 and 2004, concentrations bounced up to above 7 mg/l in mid-summer.

8. Figures 2 and 3 show concentrations of nutrients at the bottom of CCR along with dissolved oxygen concentrations. Rapid increases of phosphorus occur each summer. The relationship with low DO is most clearly seen for 2002, 2003, and 2004. The bottom also experiences ammonia spikes during the summer but the relationship between low DO and ammonia concentrations isn't as clear. For example, in 2005, the bottom had the highest summertime DO concentrations yet had the highest spike in ammonia.

9. Methods to quantify the existing release of nutrients from the sediments during periods of anoxia include:

    A. Direct laboratory measurements using intact sediment cores;

    B. Backing out the internal loading using an annual mass-balance approach whereby all other sources and sinks are determined independently;

    C. Use published release rates from other lakes;

    D. Estimate release rates based on empirical relationships developed from similar lakes based on sediment TP concentrations;

    E. Estimate based on the changes in hypolimnetic concentrations during periods of anoxia (in situ);

10. None of these methods are very precise. Each has shortcomings.

11. Note that the release of phosphorus from the sediments has been investigated much more so than nitrogen. There is little in the literature for nitrogen release estimates

12. The five methods listed under number 9 above are discussed below for Cherry Creek Reservoir.

Method A: Direct Laboratory Measurements Using Sediment Cores

Several procedural shortcomings have been identified for this method: These include 1) obtaining an undisturbed core, 2) achieving experimental conditions in a lab that reflect ambient conditions, and 3) extrapolating the results to lake-wide conditions (Effler, et al., 1996).

This method is often used on lakes and reservoirs, but sediment cores have not been collected and analyzed for Cherry Creek Reservoir.

Method B: Backing Out Internal Loading Using a Mass Balance

This method is often seen as being the least desirable since it depends on the accuracy of the other inputs into the mass balance (Effler, et al., 1996). There is often a high degree of uncertainty associated with the quantifying the other inputs.

This method is similar to developing a mechanistic model and using the internal loading as a calibration parameter. Again, the exercise is dependant on the accuracy of the other inputs.

Note that a dynamic model was developed for the reservoir in 2000 (LaZerte and Nurnberg, 2000). Internal loading of phosphorus was quantified at 4,000 pounds / year (Nurnberg and LaZerte, 2000). A large portion of the P budget during the summer months was attributed to coprecipitation of phosphorus with $CaCO_3$. There are few data for Cherry Creek Reservoir to support this contention. If this mechanism was overestimated, a greater amount of internal loading would be needed to make the budget balance. In addition, groundwater contributions to the reservoir have been specifically studied and quantified subsequent to the development of the model (Lewis et al., 2005). Thus, there may be a significant level of uncertainty associated with the modeling results.

A mass balance analysis has not been conducted for the reservoir using the results from the Lewis et al. (2005) effort.

Method C: Use Published Rates from Other Lakes and Reservoirs

Phosphorus Release Rates:

Phosphorus release rates measured in other lakes have been compiled by Nurnberg (1988). For eutrophic lakes listed in her compilation (N = 26), phosphorus release rates range from 0.8 mg/m^2/day to 32 mg/m^2/day. The median value is 10.5 mg/m^2/day.

If one considers the eutrophic lakes with sediment phosphorus concentrations similar to Cherry Creek Reservoir in the areas of anoxia (0.7-0.9 mg/gm dry weight), the release rates range from 6.6 to 10.5 mg/m^2/day. A value of 8.5 mg P/m^2/day is assumed using this method for Cherry Creek Reservoir. (Note that sediment TP concentrations for eutrophic lakes in Nurnberg's compilation ranged from 0.630 to 4.72 mg/g dry weight with a median value of 1.5. Sediment TP concentrations in Cherry Creek Reservoir are on the low end of the compiled values.)

Nitrogen Release Rates:

There is less literature published on the release of ammonia than the release of phosphorus. The following rates were reported by Beutel, 2001:

Table 1: Summary of Literature Review of Ammonia Release Rates

Ammonia Release Rate	**Notes**	**Source**
12-50 mg N/m^2/day	- 4 Wisconsin Lakes - Anoxic conditions - Incubation Results	Graetz et al., 1973
80 mg N/m^2/day	- A Danish Lake - Anoxic Conditions - Incubation Results	Rysgaard, et al., 1994
6-13 mg N/m^2/day	- A Swiss Lake - Hypolimnetic Accumulation before Oxygenation	Hohener and Gachter, 1994
18.1 - 20.6 mg N/m^2/day	- Walker Lake, CA - Anoxic Conditions - Incubation Results	Beutel, 2001
16.5 mg N/m^2/day	- Walker Lake, CA - Anoxic Conditions - Hypolimnetic Accumulation	Beutel, 2001

A value of 19 mg N/m^2/day is assumed for Cherry Creek Reservoir. This is the median of the mid-point results and is in line with the recent work conducted by Beutel on a western reservoir.

The mass of nutrients released are estimated in Table 2 attached at the end of this section. In order to compute the mass of a nutrient released to the water column, one needs to estimate not only the release rate but also 1) the area of sediments actively releasing, and 2) the days of anoxia per year. In addition, a temperature correction (Q10) should be used since the temperature at the sediment - water interface of Cherry Creek Reservoir is warmer (T ~ 20 degrees) than most reservoirs.

The values listed in the 'baseline' column of Table 2 are based on a review of the data and the literature. Minimum and maximum values (also based on a review of the data) are listed also in order to bracket the estimates.

The Q10 value is based on results from Kelton and Chow-Fraser, 2005. The active area is based on the area below 5 meters deep (elevation 5530.3 feet). The min are based on an area below 6.5 meters deep and the max is based on one-half of the reservoir surface water area. Note that Nurnberg used the area below 6 meters deep in her modeling analysis.

The days of anoxia were estimated based on a review of the dissolved oxygen data 2000-2005. For this analysis, it is assumed that anoxic conditions exist when DO at the CCR-2 7m location is at or less than 2 mg/l. At this location, dissolved oxygen tends to drop to less than 2 mg/l in the summer (typically June) and bounces between anoxic and oxic conditions until sometime in August. Then it stays in an oxic state. Thus, the number of anoxic days is less than the number of days in the overall period due to mixing on windy days.

A potentially anoxic period was determined for each year based on the first time the DO was <= 2 mg/l at CCR-2 7m and the last time this occurred. The percentage of data points in this period that were at or below 2 mg/l was computed and translated into a number of anoxic days for each year as shown in Table 3.

Table 3: Estimated Periods of Anoxia in Cherry Creek Reservoir

Year	Potentially Anoxic Period in Days	% of Data in the Potentially Anoxic Period ≤ 2 mg/l	Computed Number of Days of Anoxia
2000	78	54%	42
2001	57	43%	25
2002	72	100%	72
2003	29	67%	19
2004	73	50%	37
2005	0	0%	0

There is considerable variation between years and the range for days of anoxia is from 0 - 72 days. The mean is 33 days and the median is 37 days. The value of 40 days was used for the baseline computation.

The estimated phosphorus release, based on baseline values, is **1,590 pounds P/year**. The range is 0 to 2,870 pounds P/ year. For ammonia, the baseline estimate is **3,560 pounds N/ year**. The range is 0 to 9,370 pounds N/ year. The range is very large for ammonia due to the wide range in the few rates published in the literature.

Method D: Use Empirical Relationships

An empirical relationship between sediment TP concentrations and P release rates was formulated by Nurnberg (1988). The regression is based on lakes world wide (N = 63) and has an r^2 of 0.21. Using a sediment TP concentration of 830 mg/kg dry weight, the predicted TP release rate is 5.5 $mg/m^2/day$.

Using this rate and the remaining baseline variables in Table 2, the computed amount of P released is **1,030 pounds P/ year**.

Empirical relationships for ammonia were not located in the literature.

Method E: Estimate based on Hypolimnetic Concentrations

This approach is often considered to provide the best estimate of internal P loadings and has been found to be in agreement with results from laboratory experiments (Nurnberg, 1987). It is complicated, however, by failing to isolate sediment releases from other sinks and sources from and to the hypolimnion (e.g., diffusion to epilimnion, settling decaying P from epilimnion) (Effler, et al., 1996).

The application of this method to Cherry Creek is less straight forward than it is for a typical dimictic lake due to periodic mixing during the summer months. An analysis of the profile data indicates that the reservoir is probably stratified between 7/7/04 and 7/21/04. During this period, the epilimnion nutrient concentrations were relatively constant, the tributary inflows were constant, and there were no stormwater events. Also, DO levels at the bottom (CCR-2 7m) were low (< 1 mg/l).

Using area-capacity relationships described in Morong, 1989, and assuming that the top of the hypolimnion is at 5534 feet (based on profile data), the phosphorus release over these 14 days is approximately 6.5 $mg/m^2/day$. Conducting the same analysis for SRP results in an SRP release rate of 6.8 $mg/m^2/day$ which is close to the TP estimate, as expected. A P release rate of 6.5 $mg/m^2/day$ translates to **810 pounds P/year** for Cherry Creek Reservoir for 40 days of anoxia and a 350 acre active area.

For ammonia, the calculation results in a value of 9.1 mg/m^2/day. This result is within the values measured for other lakes (Table 1). An ammonia release rate of 9.1 mg/m^2/day translates to **1,140 pounds N/year** for Cherry Creek Reservoir for 40 days of anoxia and a 350 acre active area.

Other years may have similar conditions upon which to make estimates. The year 2004 was the only one analyzed for this effort. Note that 2004 experienced higher than average nutrient spikes in the hypolimnion (See Figures 2 and 3 attached to the end of this section).

Summary of Release Computations

Results from the computations described above are summarized in the Table 4. Of the various methods, the one that is most closely based on actual conditions in Cherry Creek Reservoir is the method using hypolimnetic concentrations.

Table 4: Summary of Estimates for Releases of Nutrients from Sediments

Method	Internal Loading of Phosphorus (# / yr)	Internal Loading of Ammonia as N (# / yr)
Lab Measurements	-----	-----
Mass Balance	-----	-----
Published Release Rates	1,590	3,560
Regression Equation	1,030	-----
Hypolimnion Concentrations	810	1,140

Additional Data Review

The data were also briefly analyzed for overall relationships between hypolimnetic DO concentrations, hypolimnetic nutrient concentrations, and chlorophyll *a*. The relationships weren't always clear. In 2005, the reservoir experienced higher than normal dissolved oxygen concentrations in the hypolimnion (all values above 2 mg/l) and the chlorophyll *a* concentrations were the lowest in the period 2000 - 2005. Yet, there were large spikes of nutrient concentrations in the hypolimnion (see Figures 2 and 3 -- the ammonia spike was the highest for the six years). In 2002, the chlorophyll *a* concentrations were low (July-Sept mean = 18.8), yet the dissolved oxygen concentrations in the hypolimnion were also low and for a longer period of time. A relationship between hypolimnetic dissolved oxygen concentrations and chlorophyll *a* concentrations in Cherry Creek Reservoir was not found. This analysis was brief however, and additional data analysis may uncover more information.

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Table 2:
Method C: Use Release Rates from the Literature

Computations

Variable	Units	Baseline	Min	Max
Q10	----	1.5	1.2	2
Active Area	Acres	350	200	420
Days of Anoxia	days/year	40	0	72
P Release Rate	mg/m^2/day	8.5	4	12
N Release Rate	mg/m^2/day	19	9	50

Conversion Factor:
0.00892163

*Computed Nutrient Release (pounds / year)***

Nutrient	Baseline	Vary Release Rate		Vary Active Area		Vary Days of Anoxia		Vary Q10	
		Min	Max	Min	Max	Min	Max	Min	Max
Phosphorus	1,593	749	2,248	910	1,911	0	2,867	1,274	2,123
Ammonia	3,560	1,686	9,368	2,034	4,272	0	6,408	2,848	4,746

** Min / Max computations assume baseline values for all variables except for the one in the column heading.

Figure 1: DO (mg/l) in Cherry Creek Reservoir
SIte CCR-2 7m

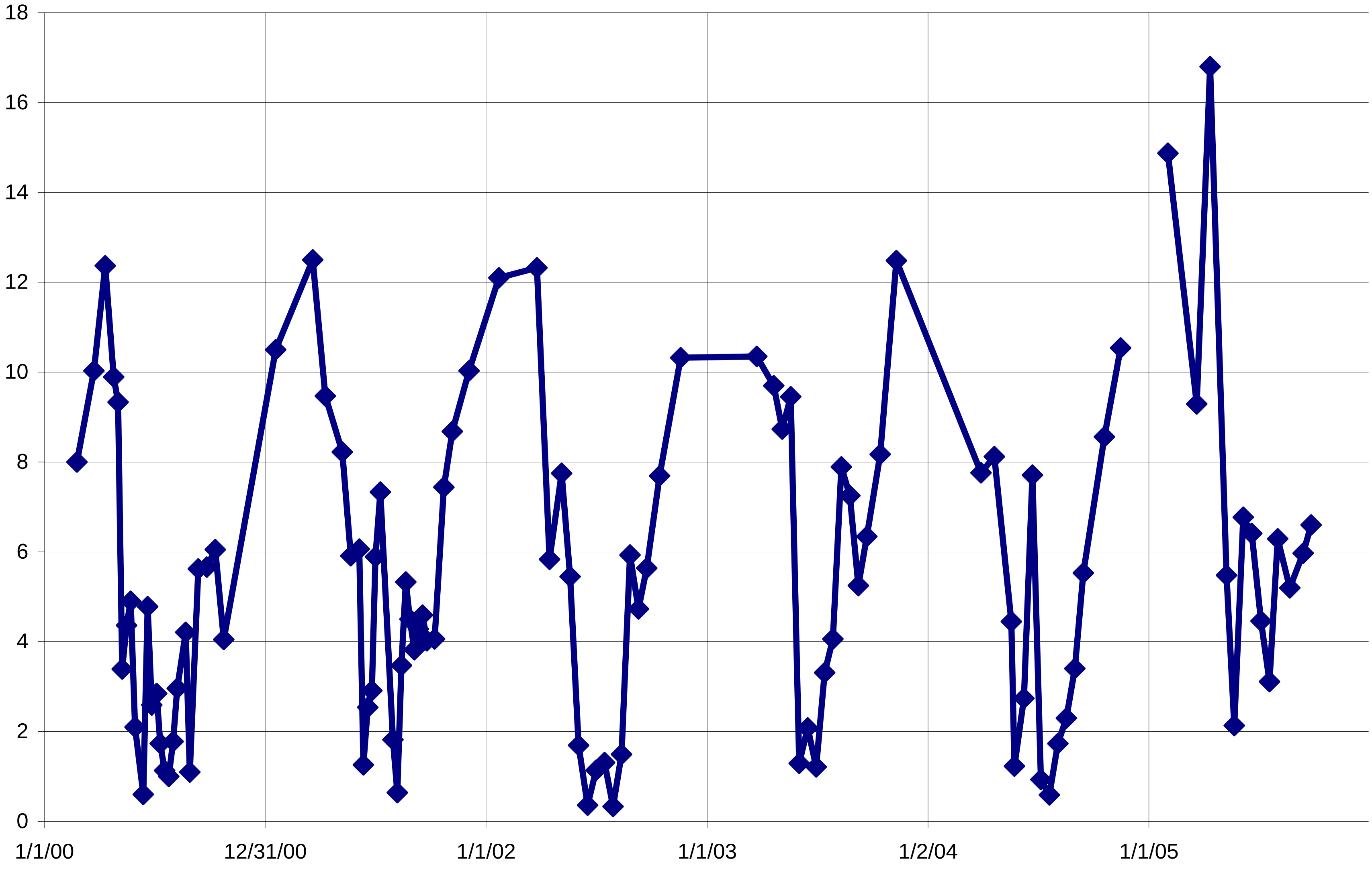


Figure 2: DO (mg/l) and Orthophosphate (ug/l) Concentrations
Site CCR-2 7m

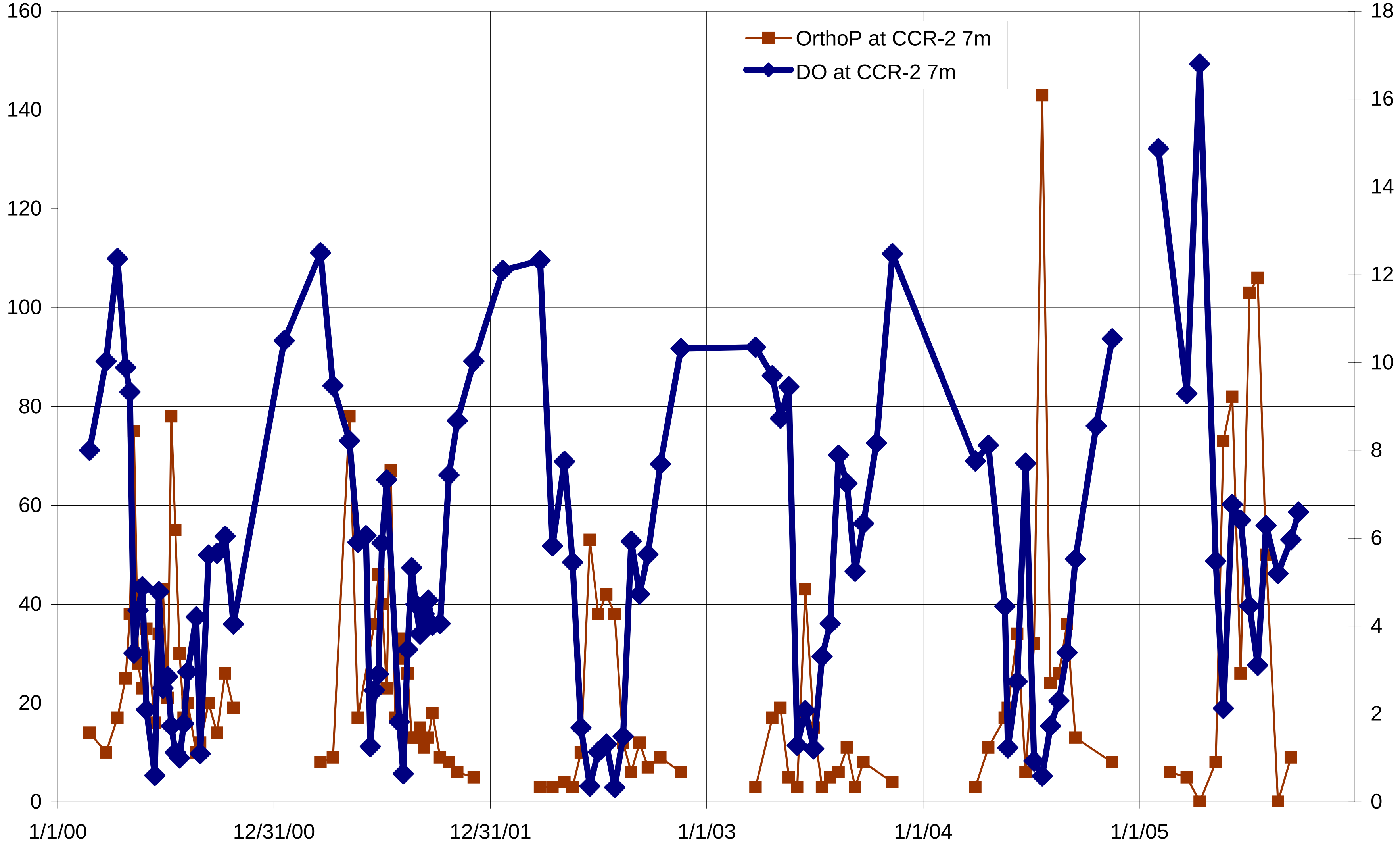
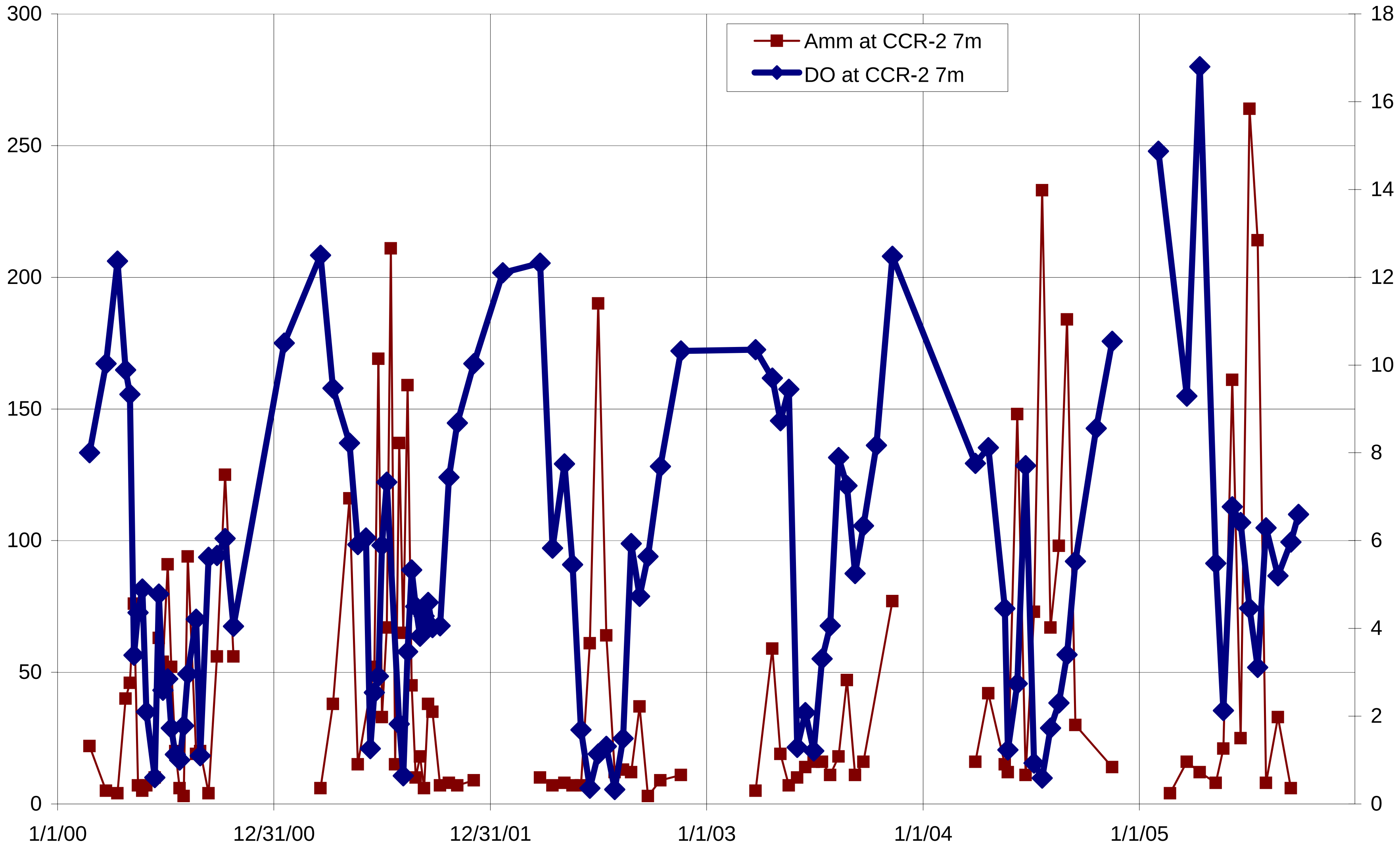


Figure 3: DO (mg/l) and Ammonia (ug/l) Concentrations
Site CCR-2 7m



Attachment B

Memorandum Re:
Cherry Creek Reservoir: Calculation of Internal Loading Effects on Chl *a* Production by Aeration/Mixing/Oxygenation

Memo to: Robert McGregor
From: Alex Horne
Re: Cherry Creek Reservoir: Calculation of internal loading effects on chlorophyll a production by aeration/mixing/oxygenation
Date: 26 October 2005; Revised 05 December 2005

SUMMARY. Effective delivery of oxygen to the bed of Cherry Creek Reservoir by any method during periods of anoxia is predicted to reduce the chlorophyll *a* concentration in summer. Two methods were used (i) a simple empirical bottom-up model and (ii) a direct lake observation. The first method showed a most likely range of reduction of 18-32 ug/L (extreme range of 9-64 ug/L) depending on the assumptions used in a simple empirical model. These values can be compared to most likely values of the second method that showed a reduction of 8-13 ug/L (maximum range 8-33 ug/L) estimated from using direct observations of reservoir deep ammonia and algae fluctuations in the period 2000-2004.

The two methods of prediction are quite close and more importantly the error spread strengthens the validity of the predictions. If the most likely values are averaged the overall prediction is ~ 10 ug/L for the effect of the aeration-oxygenation reduction during the period of anoxia. Since this period typically begin sometime after the start of the July-September regulatory season, the net reduction of Chl a during the regulatory season will be approximately 8 ug/L when averaged over the entire regulatory season.. The value seem realistic especially in the light of this year's (2005) results where the chlorophyll *a* values remained at ~ 19 ug/L rather than 40 ug/L in blooms and no anoxic sediments or internal loading was seen.

The calculations and assumptions are shown below. The effect can only be attributed to the suppression of ammonia released; the calculation for P is invalid due to the large amounts of P present already. However, the aeration-mixing-oxgyenation methods proposed will reduce both N and P fluxes from the sediments so the assumption of N as a limiting element does not affect the results.

GIVEN: The best average estimates of internal loading for Cherry Creek Reservoir were 1,140 pounds of ammonia-N and 810 ponds of phosphate-P released during typical irregular anoxic summer sediment events (team member Jean Marie Boyer). Team member Ken O'Hara has estimated that it is possible to deliver oxygen > 2 mg/L to the deeper parts of the lake bed using aeration-mixing. Horne has determined that pure oxygen additions at the lake bed would also achieve > 2 mg/L at the lake bed. Thus anoxia can be prevented in Cherry Creek Reservoir.

QUESTION: What decrease in algae would suppression of this nutrient flux by aeration/oxygenation provide during the critical July-September period?

CALCULATIONS

CALCULATION #1. BOTTOM UP MODEL USING ESTIMATED NUTRIENT FLUXES FROM THE SEDIMENTS

Preamble. Most algae in lakes in summer are limiting in their ability to grow by a shortage of nutrients. Although grazing by zooplankton, sinking to the mud, parasitism, disease and natural death reduce algae numbers, their initial growth is usually controlled by one or more limiting nutrients. The limiting nutrient can and does change over the day and from week to week and may be different for different algal species. Obviously at night, early morning and evening light restricts growth. Carbon dioxide probably limits algal growth in the afternoon in Cherry Creek Reservoir but the deficit is made up overnight by respiration and ingress from the atmosphere. Other likely limiting nutrients such as phosphate, ammonia & nitrate, silica and iron are not supplied from the atmosphere and only small amounts are recycled from excretion during respiration. Thus in summer when inflows of water from outside the lake are small, any fluxes of nutrients that come from the sediments will have a direct, shock loading on the algae present. The amounts of nutrients can be estimated from the length of anoxia above the sediments and a model of how the nutrients transform into algae. This is the basis of calculation #1.

Limiting nutrient. Phytoplankton growth in the reservoir has been shown by Professor Lewis's bioassays to be strongly limited by N. Confirmation of this N-limitation of algae growth is found in the almost total absence of bioavailable-N (nitrate) in the lake. A small amount of presumably bioavailable ammonia is present. Other forms of N in the reservoir as shown by the non ammonia + nitrate part of Total Nitrogen (TN) are not bioavailable and consist of rather inert organic-N compounds. In contrast, there is ample immediately bioavailable phosphate and even more potentially bioavailable TP. Unlike most TN, most TP is not inert and can be degraded to bioavailable phosphate by the alkaline phosphatase enzyme which is produced by algae in response to P-starvation. Alkaline phosphatase cleaves the bond between the inorganic phosphate molecule and the (usually) organic compound to which it is attached. There is no similar enzyme for TN, although a few species of blue-green algae can respond by inducing the nitrogenase enzyme. These N_2-fixing species such as *Anabaena* or *Aphanizomenon* are normally rare in Cherry Creek Reservoir. In addition, algae have a very effective P-storage mechanism (polyphosphate granules) that can last for 6-20 generations while there is no equivalent non-toxic easily available N-storage other than a small amount of storage as amino acids or as the N-component of chlorophyll a.

Thus the appropriate limiting nutrient for this calculation is nitrogen (= ammonia released). However, a similar calculation for the phosphate released is also made.

Ammonia released from the sediments under anoxic conditions in Cherry Creek = 1,140 pounds of ammonia-N = 1,140/2.2 = 518 kg N
When replete with nitrogen algae contain N equal to 5% of the dry wt of algae.
Therefore 518 kg of N (as nitrate or ammonia) will grow:
= 518/0.05 (5%) = 10,400 kg algae dry wt.
Chlorophyll *a* is ~ 1% of dry wt (range ~ 0.5-2%). Assuming a 1:1 conversion of nutrient to algae (see below for modification) 10,400 kg of algae will contain 104 kg of chlorophyll *a*
Thus the ammonia flux from the sediments could theoretically produce
~ 1.0 x 10^2 kg of chl a or **1.0 x 10^{11} ug chl a**

Reservoir volume (constant recreational pool at elevation 5,555.4 feet amsl) is 13,659 af x 1.23 x 10^6 = 16.8 x 10^9 L (liters)
From Secchi disc depth assume photic zone is 2.5 m (7.5 feet or 5,547.9 ft amsl)
From hypsographic (volume-depth) curve 7.5 feet (5,542.9 ft) occurs at 7,489 af.
Thus volume of photic zone = 5,659 af (13,148-7,489)
= ~ 5.7 x 10^3 x 1.23 x 10^6 = 7.0 x 10^9 L (liters)

Theoretical concentration of Chl *a* from the added N =
1.0 x 10^{11}/7.0 x 10^9 = ~ 14 ug/L Chl *a* in photic zone

Empirical evidence from nearby Standley Lake Reservoir (see Appendix) is that added bioavailable N produces only 50% of the theoretical algae derived from a 1:1 conversion. Reasons for the difference are primarily inefficiencies in transport and uptake of N combined with grazing, sinking, disease and natural death processes (see Appendix below). Thus likely chl a in the photic zone = 14/2 = ~ 7 ug/L chl a in photic zone

The addition of oxygen using pure oxygen or air mixing will suppress internal loading at the time by 50 to 90% for ammonia releases (based on world average = 50% and best results ~ 90%).

Initial model prediction of effect of the air/oxygen treatment =
Range 7 x 0.5 & 7 x 0.9 = 3-6
= ~ 3 to 6 ug/L chlorophyll a reduction in the July-September period due to ammonia suppression

Phosphate released. 810 pounds of phosphate-P = 810/2.2 = 368 kg P
P is 0.3% of the dry wt of algae so using the same format as for N.
Most likely effect of the air/oxygen treatment =
= ~ 860 ug/L chlorophyll a reduction in the July-September period due to the suppression of phosphate releases from the anoxic sediment. Obviously, this

is an unlikely result and is due to the excess of P already present in the reservoir. Thus this result using P should not be used to predict the effects of aeration/mixing/oxygenation on algae biomass.

Further refinement of estimate (1) Percent N in organisms in N-limited situations

In an N-limited system, the percentage of chlorophyll a in algae is reduced from 5% since chlorophyll a itself is used a major N-storage item. Thus a more realistic estimate for N-limited systems is approximately 2.5%. This refinement has the effect of doubling the value of the chlorophyll a reduction generated by aeration/oxygenation to 6-12 ug/L. A similar correction cannot be made for P since the reservoir contains and excess of P in the water.

Further refinement of estimate (2) Percent chlorophyll in N-limited situations

As the N-supply declines chlorophyll a also declines as a percentage of dry weight. The range measured in blue-green algae is 0.5-2% and 1% was used in the initial calculations. Using the lower end of the estimate (0.5%) the effect is once again to double the value of the chlorophyll a reduction generated by aeration/oxygenation to 12-24 ug/L. A similar correction cannot be made for P since the reservoir contains and excess of P in the water.

REDUCTIONS IN CONCENTRATIONS OF ALGAE (AS CHLOROPHYLL A) PRODUCED BY SUPPRESSION OF INTERNAL LOADING OF NUTRIENTS (AMMONIA IN THIS CASE) BY AERATION/OXYGENATION USING A BOTTOM UP MODEL.

MOST LIKELY RANGE = 6-12 ug/L CHLOROPHYLL A (bottom up model)
(Maximum range = 3-24 ug/L)

CALCULATION #2. MIDDLE LEVEL MODEL USING OBSERVED NUTRIENT AND CHLOROPHYLL CHANGES BETWEEN 2000-04

Preamble. Fluxes of nutrients from the sediments grow algae in summer (bottom up assumptions see calculation # 1). The empirical model used makes several important assumptions as shown by the calculations above (%N as dry wt, % chlorophyll a, losses to other factors such as grazing or sinking, % reduction of internal loading expected from aeration-oxygenation). The range produced by the variation in these estimates is considerable 3-24 ug/L. Thus a second calculation would be useful to see if it fit the same region as the bottom up estimates. Examination of the record of internal loading fluxes and chlorophyll a changes in Cherry Creek Reservoir are available for 2000-2004. These can be used to estimate the effects of internal loading and thus the effects on Chlorophyll a in the reservoir itself.

Nutrient fluxes. When DO in the deeper water drops below ~ 1.5 mg/L there is a surge in ammonia (and to a lesser extert, phosphate). Since Cherry Creek Reservoir is polymictic (mixes frequently and then stratifies then mixes again) in the summer the nutrients are quickly transferred to the surface photic zone where they stimulate algal growth. For example ammonia at 7 m depth at station CE-2 ranged around 200 ug/L immediately following the onset of anoxic periods (> 1.5 mg/L D at 7 m) in 2002 and 2004. For comparison the levels of nitrate or ammonia in the lake surface water were usually in the 5-10 ug/L range in summer. In addition, the concentrations of ammonia in the deep water was low when the conditions were oxygenated.

Increases in surface nutrients from a benthic internal loading pulse are not usually seen since the nutrients are used up as fast as they are supplied following a mixing event. Thus the deep water concentrations act as an indication that nutrients have risen and are available for the surface algae following mixing.

Chlorophyll a responses to ammonia fluxes from the sediment. In Cherry Creek Reservoir the chlorophyll a values follow the typical temperate lake cycle of a spring and fall bloom with a “Clearwater” phase in between. In Cherry Creek Reservoir the mid-summer clear phase is short and not very clear. Nonetheless the chlorophyll values im summer range from 10-20 ug/L. Occasionally this range is interrupted by a short algae bloom which is often correlated with an increase in ammonia in deep water within the three weeks prior to the bloom (e.g. the bloom of 80 ug/L chl a on 24 July 2001 and rise in deep ammonia at the CCR-2 site at 7 m from 33 to 67 then 211 ug/L in the three weeks prior to the 24 July. A similar rise in ammonia occurred in the 6 m depth from 40 to 116 ug/L).

Other rises in chlorophyll have been lower than the 80 ug/L example cited above. These blooms have been ~30 - 40 ug/L (e.g. 41.6 ug/L on July 15 2003, 31.5 ug/L on 9 September 2003). Given that these increases come on a base of 10-29 ug/L, assume 15 ug/L as an average, the actual increase over background is 15 (30 – 15 ug/L) to 25 (40 – 15 ug/L to the maximum of 65 ug/L (80-15 ug/L).

Thus the approximate effect of internal loading releases seems to be from 15 to 25 ug/L with a maximum of 65 ug/L of chlorophyll a over the background. Thus if these loadings were reduced by 50-90% by aeration-oxygenation, the resulting most likely declines in chlorophyll a would be ~ 8-13 ug/L (max range ~ 8-33 ug/L).

MOST LIKELY RANGE CHLOROPHYLL A REDUCTION
= 8-13 ug/L
(Maximum range = 8-33 ug/L)

COMPARISON BETWEEN THE TWO METHODS AND A FINAL AVERAGE

These values can be compared with the bottom up model prediction estimates of declines in chlorophyll a of 6-12 ug/L (extreme range 3-24 ug/L). The two methods of prediction are quite close and if the most likely values are averaged the overall prediction is ~ 10 ug/L for the effect of the aeration-oxygenation reduction. The value seem realistic especially in the light of this year's (2005) results where the chlorophyll a values remained at ~ 19 ug/L and no anoxic sediments or internal loading was seen.

APPENDIX.

SIMPLE LAKE MODELS

Standley Lake analysis of algae produced for N and/or P added. (From University of California, Berkeley. Civil & Environmental Engineering CE course 113 (spring 2003) and Extension Service Course on Lakes & Lake Management October 2005. Section # 15 - Simple lake models). See also chapter 12 in Horne & Goldman, *Limnology*, McGraw-Hill Publishers NY 2nd ed. 1994.

The concentration of chlorophyll *a* in a lake should be predictable since the elemental composition of algae is known (~ 50% carbon or silica; 5% N, 0.3% P as dry weight) and chlorophyll a ranges from 0.5 – 2% dry weight). Thus knowing the concentration of the limiting nutrient(s) in the lake water should allow a simple calculation of the amount of algae.

Similarly, if a little more complex, the rate of growth of algae should be found from an equation of the form:

$$dC/dt = dP/dt\ .C - (S + G + Pa + D)$$

Where the positive terms are:
C is the amount of algae,
P is net primary production (photosynthesis minus respiration).
Thus dC/dt is the net rate of rise or fall of the algae bloom &
dP/dt .C is the gross growth rate where P (photosynthesis) depends on available light, nutrients, the growth rate of each algal cell (for example diatoms will normally out compete all other phytoplankton if silica is available since it takes less than 10% of the energy to make a silica frustule compared with a normal algal cellulose cell wall).
The negative terms are:
S is sinking out of the photic zone (to the lake bed where they usually remain, die or are eaten by benthic invertebrates or decomposed by bacteria); usually occurs after a few days of calm weather and is most important for the spring bloom of diatoms which are heavy due to their silica cell walls.
Pa is parasitism (fungi, bacteria, other diseases; is little known and not reported at all for Cherry Creek Reservoir), &
D = natural death (~ 6% for the few cases measured).

Table 1. Simple Lake Models. Calculation of chlorophyll *a* based on nutrients present in spring before algal growth occurs assuming all lake nutrients were expressed at one time as algae. TIN was assumed to become 5% of the dry weight of algae, TP to become 0.3% of the dry weight of algae and chlorophyll a to be 1% of algal dry weight. Data from Standley Lake in 1993.

Nutrient	**Conc. in late winter (Feb 1993) (ug/L)**	**Calculated summer chlorophyll a peak (ug/L)**	**Actual chl a ug/L**	**Factor error**
Nitrate	135	27	4.3	~6
Ammona	40	8	4.3	~2
TIN (nitrate + ammonia)	175	35	4.3	~8
Total phosphorus	13.5	45	4.3	~10

What is happening? Primarily, there are other factors at work in between the nutrient and its expression in as algae. These factors are:

1. Primarily algae are not 100% efficient at converting nutrients to algal biomass
2. Not all algae will peak at once (but there is a peak when the limiting nutrient declines to a critical level).
3. Algae cannot take all the nutrients out of the water (think of the lower part of the Monod, substrate-growth curve which will be below ~ 10 -20 ug/L for the smaller algae in Cherry Creek Reservoir, probably more for larger phytoplankton)
4. Some algae will grow but will be eaten by zooplankton or parasitized so you will not see their offspring which must all grow at once in the simple model
5. Some algae will sink to the lake bed and not produce young in the log growth phase. In Cherry Creek Reservoir the benthic chironomid grazers in the mud will eat algae as soon as they reach the sediments.
6. Some algae will not get the optimum light they need. Cherry Creek Reservoir is quite turbid with Secchi depths of ~ 1 m (photic zone ~ 2.5 m). With an average depth of ~ 3.5 m this means that during the frequent holomixis (top-to-bottom wind stirring) most of the algae will spend daylight hours in total darkness or at light levels < the optimum 24% of incident light (Io). Production will still occur but will be spread out and there will then be more time for the other factors listed as 1-5 & 7-8 will reduce the standing crop of chlorophyll a as measured for the purposes of regulation and meeting water quality standards.
7. Some algae may be more efficient at using nutrients so the chlorophyll a = 0.5 – 2% is a big spread. Think how green your parent’s lawn is after addition of nitrogen fertilizer and how yellow it became when fertilizer was not applied. The only way algae can store nitrogen is as the amino group ($-NH_2$) in a limited way in the cell or as green pigments. This is a toxic molecule and can only be stored in a non toxic form when attached to some other large molecule. Only chlorophyll and proteins are suitable and there is only a limited amount of these available. In contrast phosphorus can be stored harmlessly and in large amounts (many generations of growth) in polyphosphate granules. In the case of Cherry Creek Reservoir, N is limiting so the algae will be a bit pale green with nearer 0.5% chlorophyll than the 1% used in the calculations.

Attachment C

2005 Feasibility Study Field Test Program

Test Protocol
Cherry Creek Reservoir Mixing Feasibility Study
August 20, 2005

Probable Dates
August 23-25, 2005

Water/Sediment Interface
Parameters: Dissolved Oxygen (DO) and Oxidation Reduction Potential (ORP)
Sites: 63 sites along 7 transects
    A1-A9
    B1-B10
    C1-C11
    D1-D11
    E1-E12
    F1-F4
    G1- G6
Depth: Sediment/water interface
Time of Day: anytime

Water Quality Profiles
Parameters: DO, Temperature, Specific Conductance, pH, ORP, Secchi Disk
Sites: 13 sites
    A3
    B4, B7, B9
    C2, C4
    D3, D8
    E2, E4, E7, Ell
    G3
Depth: 2-ft intervals throughout water column to sediment/water interface
Time of Day: 4 AM to 8 AM

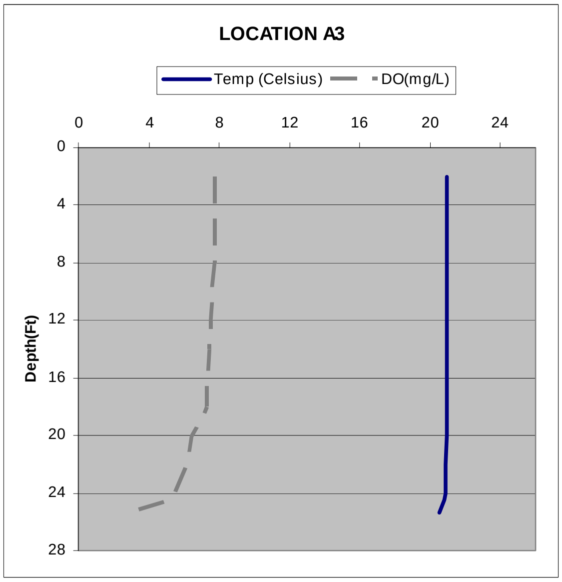
Sediment
Parameters: Total Organic Carbon, pH, Total P, Soluble Reactive P, TKN, Nitrate-N and Ammonia-N
Sites: 5 sites
    B4, B9
    D3, D8
    G3
Depth: Sediment
Time of Day: anytime

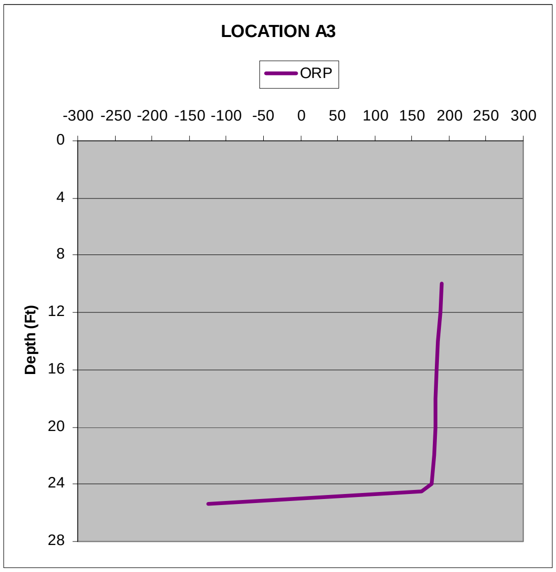
Attachments: Sampling Locations Map

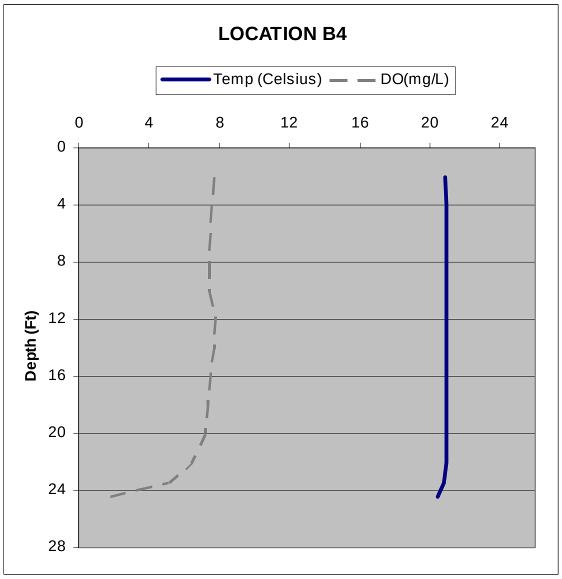
W:\5271009031CherryCreekDestratification\Test Program\Test protocol 050820.doc

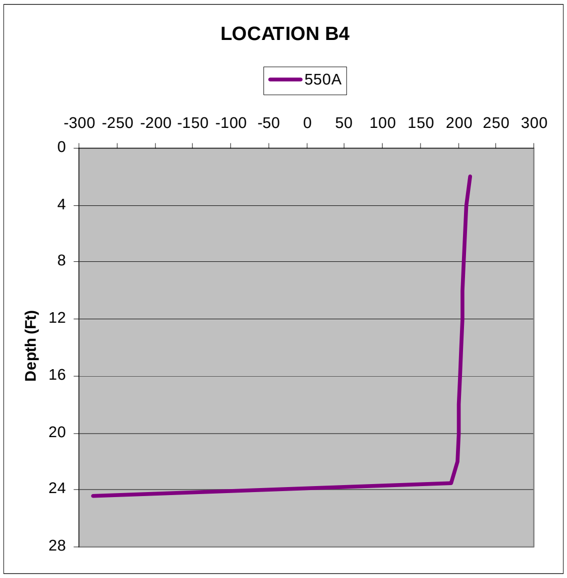
www.amec.com
AMEC Earth & Environmental, Inc.
355 S. Teller St., Suite 300
Lakewood, CO 80226
Tel   +303-935-6505
Fax +303-935-6575

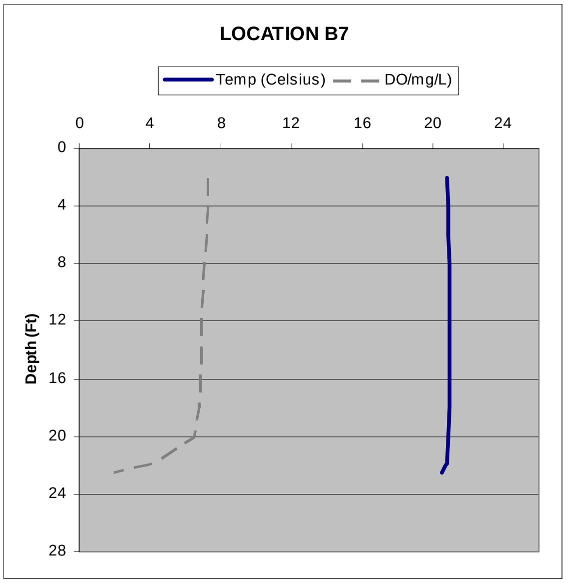
Cherry Creek Reservoir Profiles
August 23-25, 2005







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20
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16
20
24
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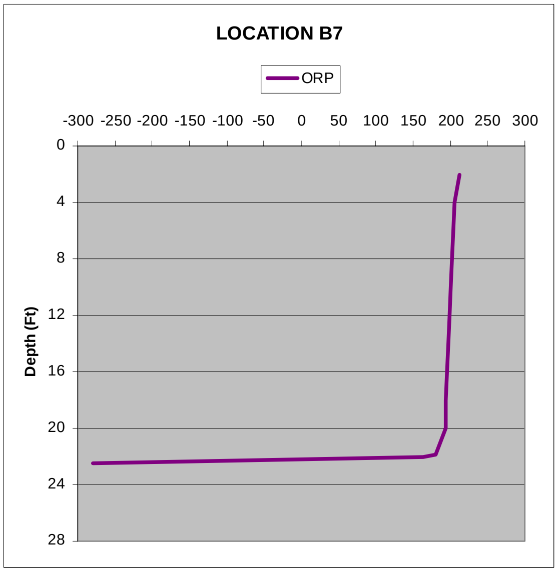
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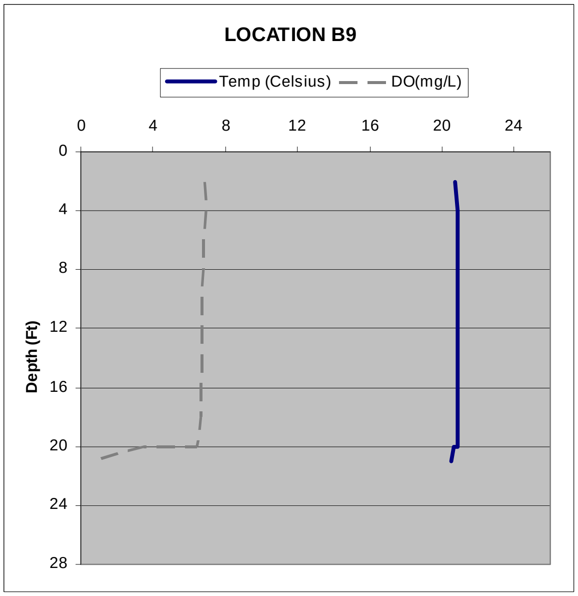
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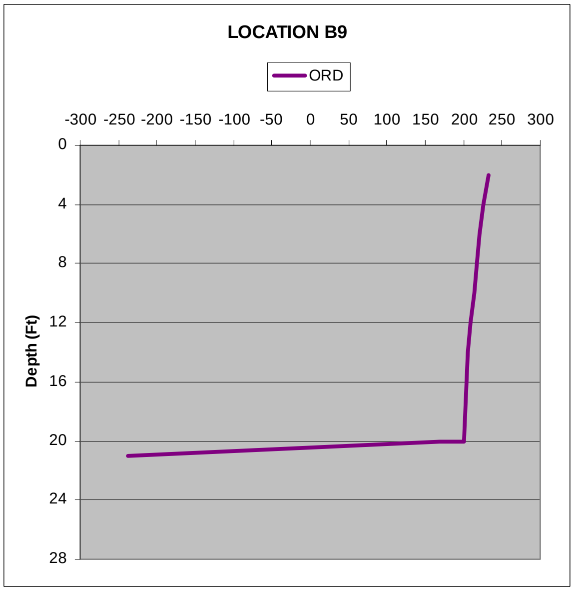
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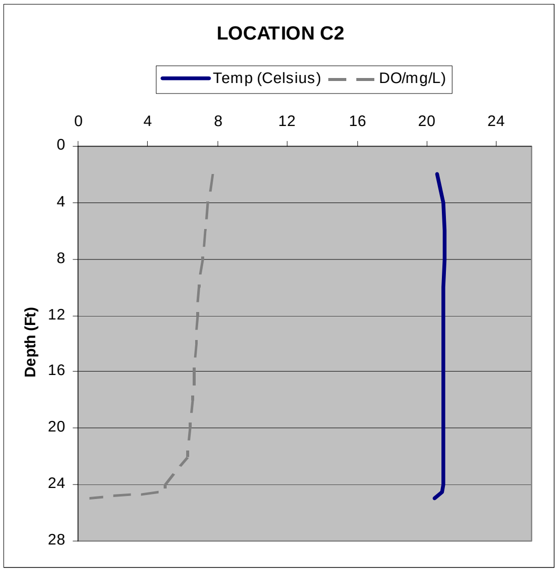
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DO/mg/L)
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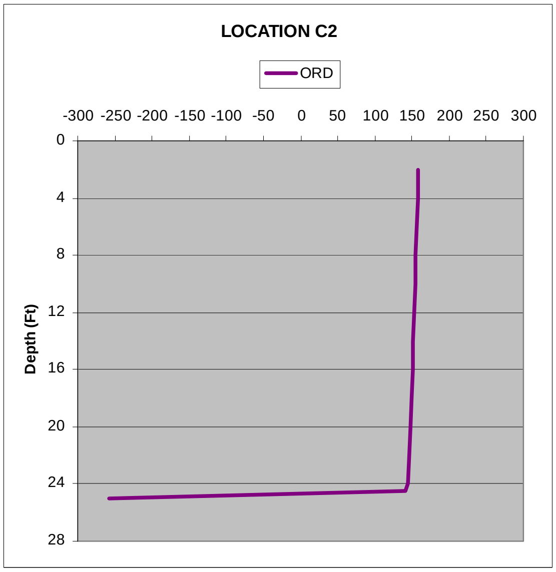
Depth (Ft)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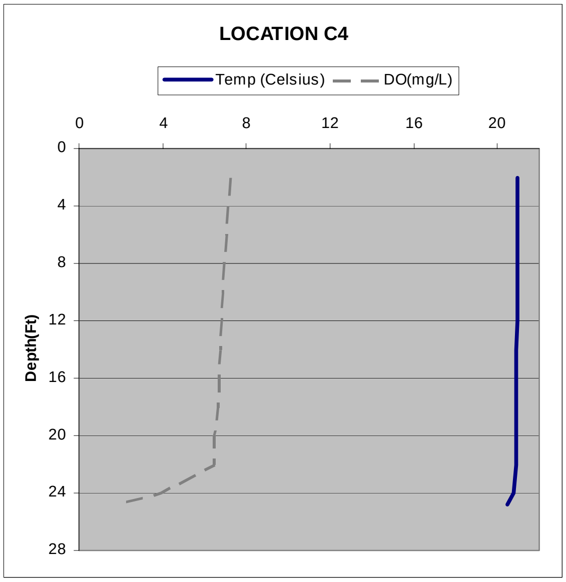
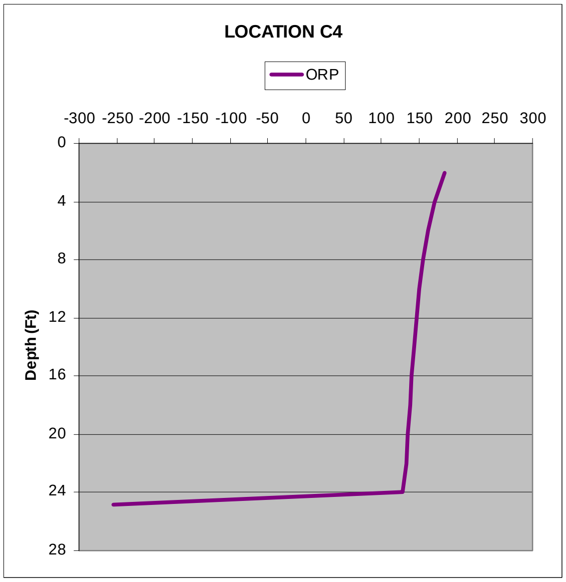
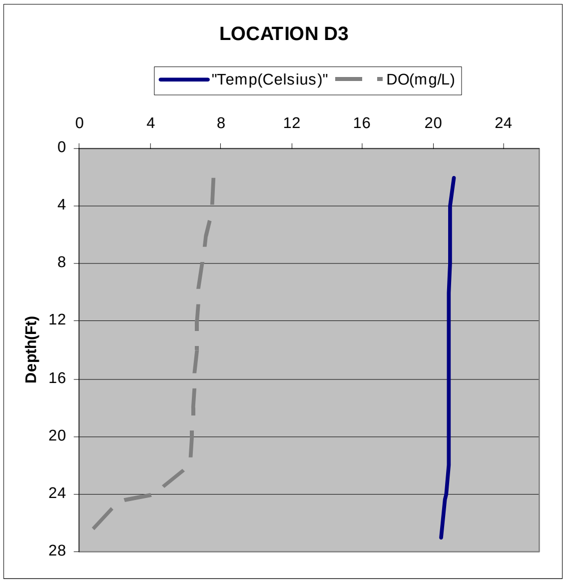
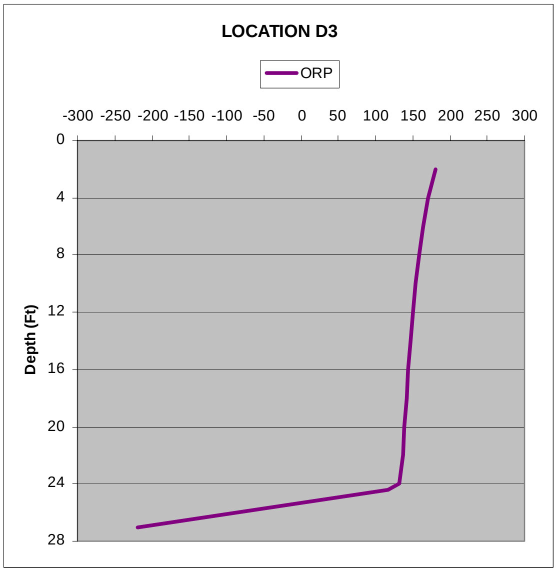
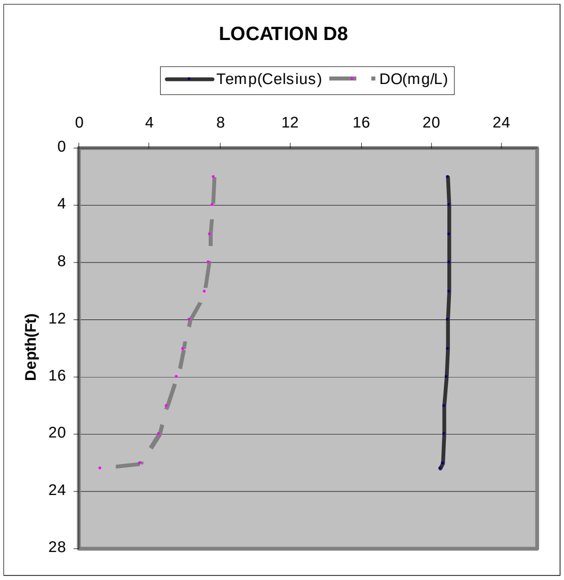
8
12
16
20
24
28
Depth (Ft)


LOCATION C4
Temp (Celsius)
DO(mg/L)
0
4
8
12
16
20
0
4
8
12
16
20
24
28
Depth(Ft)


LOCATION C4
ORP
-300
-250
-200
-150
-100
-50
0
50
100
150
200
250
300
0
4
8
12
16
20
24
28
Depth (Ft)


LOCATION D3


LOCATION D3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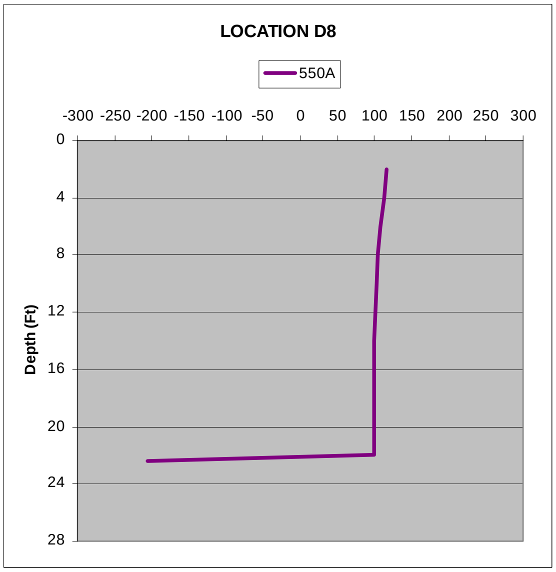
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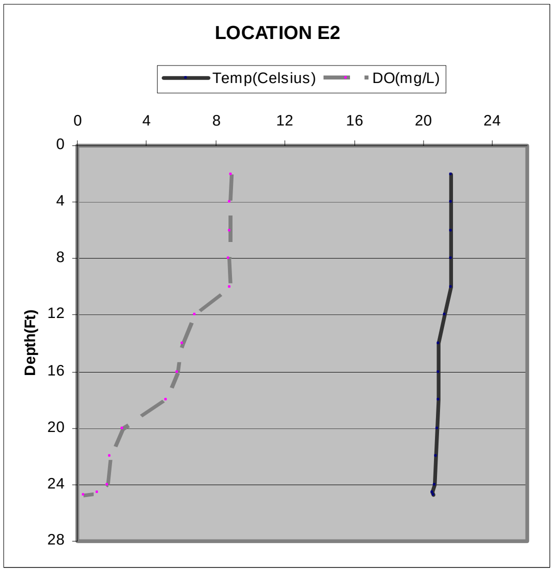
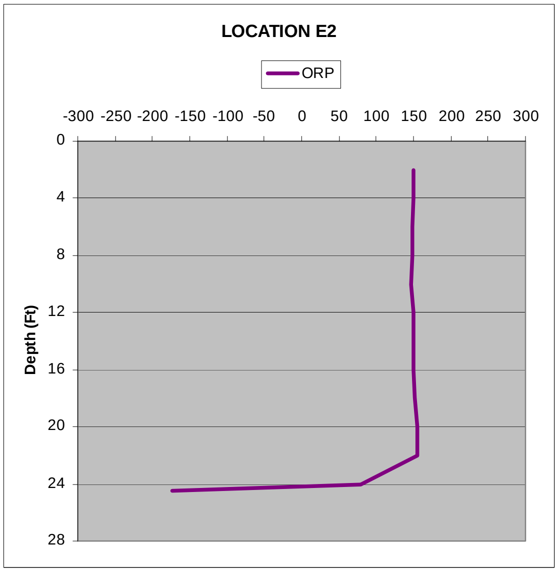
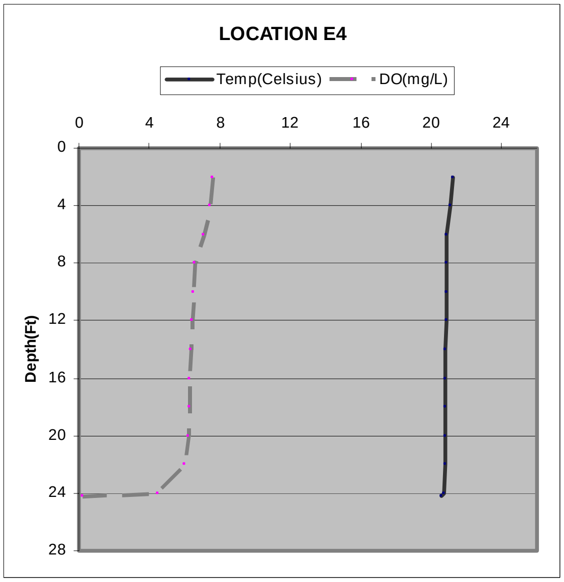
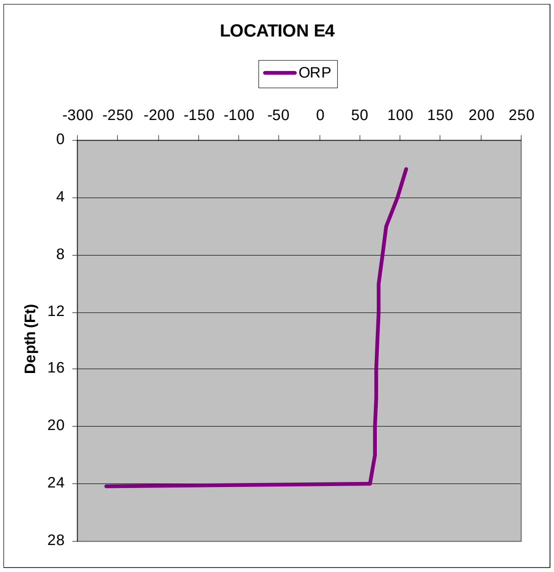

LOCATION E2
Temp(Celsius)
DO(mg/L)
0
4
8
12
16
20
24
Depth(Ft)
0
4
8
12
16
20
24
28


LOCATION E2
ORP
-300
-250
-200
-150
-100
-50
0
50
100
150
200
250
300
Depth (Ft)
0
4
8
12
16
20
24
28


LOCATION E4
Temp(Celsius)
DO(mg/L)
0
4
8
12
16
20
24
Depth(Ft)
0
4
8
12
16
20
24
28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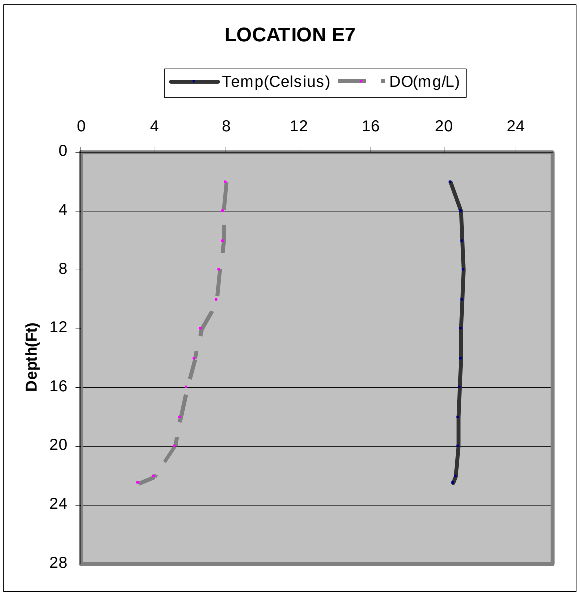
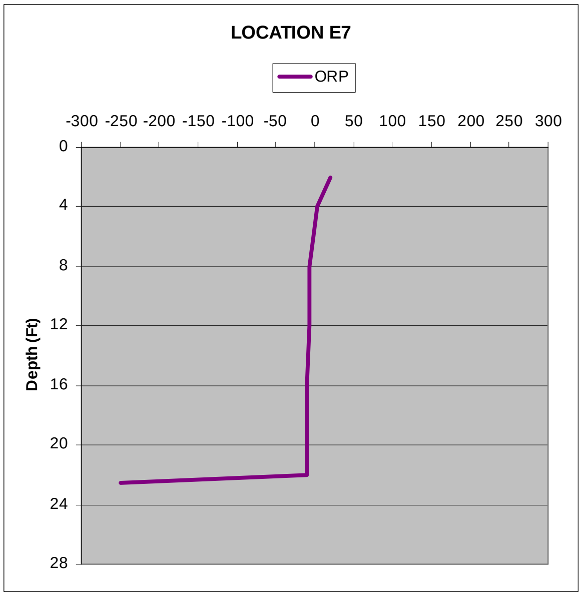
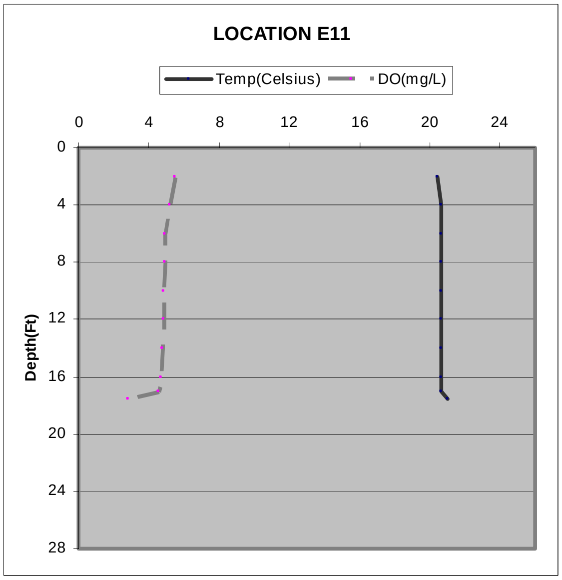
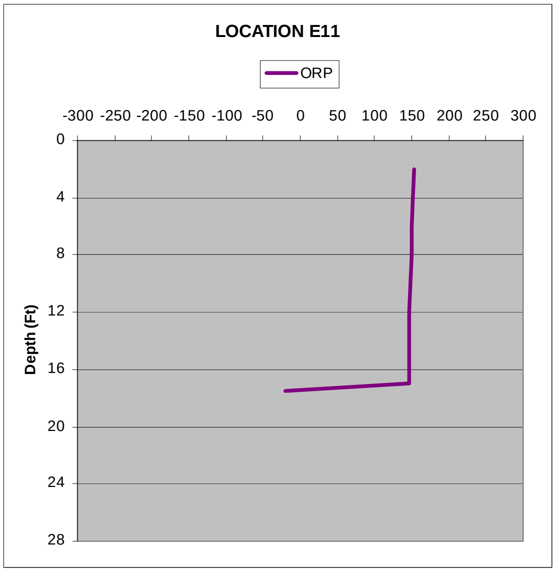
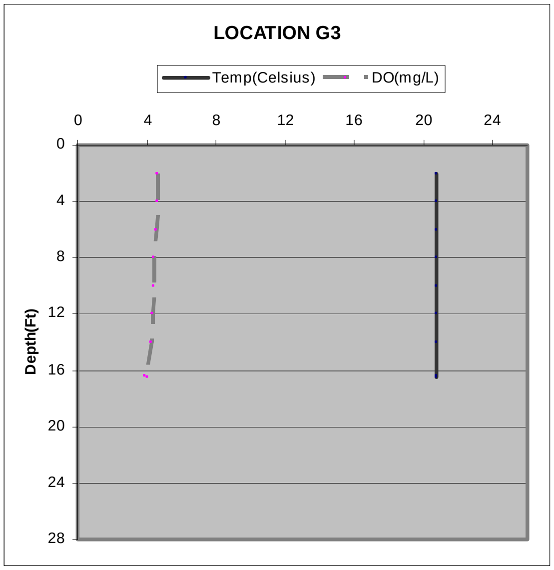
ORP
-300
-250
-200
-150
-100
-50
0
50
100
150
200
250
Depth (Ft)
0
4
8
12
16
20
24
28

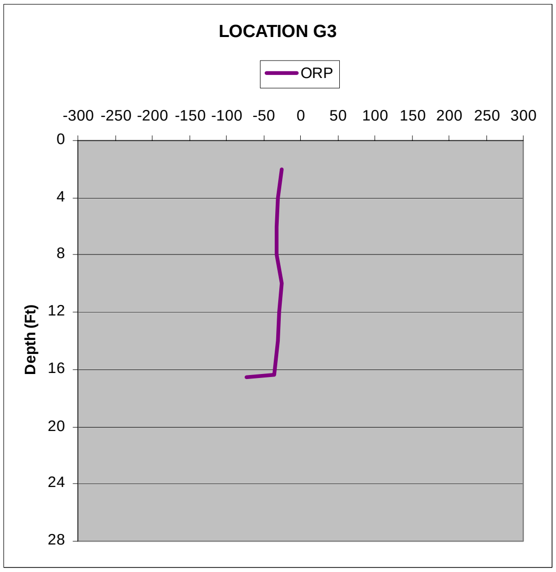

LOCATION E7


LOCATION E7


LOCATION E11


LOCATION E11


LOCATION G3
Temp(Celsius)
DO(mg/L)
0
4
8
12
16
20
24
0
4
8
12
16
20
24
28
Depth(Ft)


LOCATION G3
ORP
-300
-250
-200
-150
-100
-50
0
50
100
150
200
250
300
0
4
8
12
16
20
24
28
Depth (Ft)

Cherry Creek Reservoir
Bottom of Lake Sediment Interface Testing

Location	Date	Time	Lake Bottom (Feet)	Meter Depth (Feet)	Temperature 556MPS (Deg. C)	Temperature 550A (Deg. C)	DO 556MPS (mg/L)	DO 550A (mg/L)	ORP 556MPS	pH 556MPS	Conductivity 556MPS (uS/cm)	Secchi Depth (Inches)
A-1	08/24/2005	10:28	24.5	24	20.66	21.1	5.6	4.9	30	8.32	782	
A-1	08/25/2005	7:18	25.5	25		20.6		3.54				
A-1	08/25/2005	7:18	25.5	25.5	20.39		0.29		-200	7.43	773	33.5
A-2	08/24/2005	10:38	24.6	24.1	20.72	21.1	5.76	5.31	40	8.33	784	
A-2	08/25/2005	7:25	25.3	24.8		20.9		2.78				
A-2	08/25/2005	7:25	25.3	25.3	20.53		3		-59	7.94	767	35
A-3	08/25/2005	7:30	25.4	24.9		21		2.53				
A-3	08/25/2005	7:30	25.4	25.4	20.55		2.57		-125	7.83	766	
A-4	08/24/2005	10:50	24.4	23.9	20.47		5.96	5.52	70	8.33	779	
A-4	08/25/2005	7:38	24.4	23.9		21		1.75				
A-4	08/25/2005	7:38	24.4	24.4	20.5		0.27		-239	7.45	762	34
A-5	08/24/2005	11:05	24.2	23.7	20.3	20.7	5.56	5.2	55	8.25	779	
A-5	08/25/2005	7:45	24.2	23.7		20.51		1.9				
A-5	08/25/2005	7:45	24.2	24.2	20.9		2.57		-234	7.63	766	
A-6	08/24/2005	11:15	23.8	23.3	20.56	20.9	5.99	5.5	55	8.29	782	
A-6	08/25/2005	7:50	23.9	23.4		20.9		2.05				
A-6	08/25/2005	7:50	23.9	23.9	20.4		0.22		-226	7.22	760	36.5
A-7	08/24/2005	11:24	22.8	22.3	20.75	21.1	5.7	5.4	97.5	8.27	786	
A-7	08/25/2005	7:57	23.1	22.1		21		2.62				
A-7	08/25/2005	7:57	23.1	23.6	20.56		0.24		-225	7.37	767	
A-8	08/24/2005	11:38	21.5	21	20.8	21.1	5.55	5.09	140	8.23	786	
A-8	08/25/2005	8:05	21.6	21.1		20.9		2.3				
A-8	08/25/2005	8:05	21.6	21.6	20.59		2.68		-75	7.67	768	33.5
A-9	08/24/2005	11:48	19.6	19.1	20.81	21.1	4.69	5.04	158	8.2	786	
A-9	08/25/2005	8:12	19.7	19.2		20.7		2.33				
A-9	08/25/2005	8:12	19.7	19.7	20.5		2.22		-180	7.37	767	
B-1	08/24/2005	14:15	25.0	24.5		21.2		5.33				
B-1	08/24/2005	14:15	25.0	25.0	20.56		0.22		-236	7.47	796	
B-1	08/25/2005	8:25	25.0	24.5		20.8		3				
B-1	08/25/2005	8:25	25.0	25.0	20.41		3.3		-280	7.58	769	32
B-2	08/24/2005	13:48	25.0	24.5	20.59	20.9	5.09	3.3	48	7.91	782	
B-2	08/24/2005	14:04	25.0	24.5		21.6		5.25				
B-2	08/24/2005	14:04	25.0	25.0	20.58		5.82		-167.3	7.91	881	
B-2	08/25/2005	8:33	24.9	24.4		21		2.04				
B-2	08/25/2005	8:33	24.9	24.9	20.45		2.5		-105	7.84	768	
B-3	08/24/2005	13:35	24.5	24	20.52	20.9	5.45	5.27	160.6	8.24	781	
B-3	08/25/2005	8:40	24.7	24.2		20.9		1.44				
B-3	08/25/2005	8:40	24.7	24.7	20.48		1.62		-285	7.47	764	
B-4	08/24/2005	13:23	24.4	23.9	20.49	20.8	5.38	4.8	162.8	8.19	781	38
B-4	08/25/2005	8:48	24.4	23.9		21		1.56				
B-4	08/25/2005	8:48	24.4	24.4	20.48		1.83		-282	7.2	769	32
B-5	08/24/2005	13:14	25.0	24.5	20.6	21.1	5.17	4.7	155	8.17	782	
B-5	08/25/2005	8:54	25.0	24.5		21		1.76				
B-5	08/25/2005	8:54	25.0	25.0	20.45		0.27		-196	7.49	769	
B-6	08/24/2005	13:08	23.4	22.9	20.75	21.4	5.68	5.44	202.1	8.2	783	
B-6	08/25/2005	9:03	23.5	23		20.9		2.01				
B-6	08/25/2005	9:03	23.5	23.5	20.45		0.24		-280	7.27	766	33
B-7	08/24/2005	13:00	22.5	22	20.74	22.3	3.86	3.29	163.7	7.85	784	
B-7	08/25/2005	9:10	22.5	22		21		1.98				
B-7	08/25/2005	9:10	22.5	22.5	20.49		1.3		-280	7.55	765	
B-8	08/24/2005	12:15	21.4	20.9	20.68	21.3	3.64	3.39	168.1	8.1	784	
B-8	08/25/2005	9:18	21.7	21.2		21		1.92				
B-8	08/25/2005	9:18	21.7	21.7	20.45		0.23		-216	7.28	762	
B-9	08/24/2005	12:04	20.5	20	20.62	20.9	3.5	3.13	168	8	783	
B-9	08/25/2005	9:24	20.4	19.9		21		1.71				
B-9	08/25/2005	9:24	20.4	20.4	20.5		0.6		-237	7.39	755	41
B-10	08/24/2005	11:55	19.0	18.5	20.78	21.1	3.8	3.54	181	8.15	786	
B-10	08/25/2005	9:32	19.0	18.5		21		2.5				
B-10	08/25/2005	9:32	19.0	19.0	20.56		2.81		-212	7.46	756	
C-1	08/25/2005	9:43	25.3	24.8		21		3.25				
C-1	08/25/2005	9:43	25.3	25.3	20.44		0.22		-286	7.28	769	
C-2	08/25/2005	9:53	25.0	24.5		21		2.52				
C-2	08/25/2005	9:53	25.0	25.0	20.44		0.67		-258	7.23	779	41
C-3	08/25/2005	10:02	24.8	24.3		21		1.77				
C-3	08/25/2005	10:02	24.8	24.8	20.5		1.82		-257	7.68	771	
C-4	08/25/2005	10:08	24.8	24.3		21		2.06				
C-4	08/25/2005	10:08	24.8	24.8	20.49		1.77		-255	7.49	771	
C-5	08/25/2005	10:13	24.5	24		21		2.15				
C-5	08/25/2005	10:13	24.5	24.5	20.46		0.5		-288	7.36	770	42
C-6	08/25/2005	10:22	24.2	23.7		21		2.55				
C-6	08/25/2005	10:22	24.2	24.2	20.5		2.5		-284	7.38	759	

By: THA
Checked By:____
Date Last Updated:10/30/2005

C-7	08/25/2005	10:28	24.0	23.5		20.9		2.4				
C-7	08/25/2005	10:28	24.0	24.0	20.5		2.75		-168	7.76	768	41
C-8	08/25/2005	10:35	25.1	24.6		21		2.45				
C-8	08/25/2005	10:35	25.1	25.1	20.47		0.24		-168	7.36	765	
C-9	08/25/2005	10:45	22.5	22		21		2.97				
C-9	08/25/2005	10:45	22.5	22.5	20.52		0.39		-203	7.42	743	39
C-10	08/25/2005	10:53	19.5	19		21.1		3.04				
C-10	08/25/2005	10:53	19.5	19.5	20.67		2.28		-189	7.49	769	
C-11	08/25/2005	11:05	17.7	17.2		21.1		2.32				
C-11	08/25/2005	11:05	17.7	17.7	20.65		2.62		-155	7.44	755	37.5
D-1	08/25/2005	11:25	26.0	25.5		21.1		0.87				
D-1	08/25/2005	11:25	26.0	26.0	20.56		1.3		-140	7.88	770	40
D-2	08/26/2005	8:35	25.3	24.8		20.9		1.59				
D-2	08/26/2005	8:35	25.3	25.3	20.61		0.77		-135	7.72	772	34
D-3	08/25/2005	11:43	27.0	26.5		21		2.14				
D-3	08/25/2005	11:43	27.0	27.0	20.42		0.28		-220	7.4	806	
D-4	08/25/2005	11:47	25.0	24.5		21		1.83				
D-4	08/25/2005	11:47	25.0	25.0	20.45		0.24		-238	7.31	774	39
D-5	08/25/2005	11:54	26.0	25.5		20.9		2.05				
D-5	08/25/2005	11:54	26.0	26.0	20.53		1.48		-268	7.45	766	
D-6	08/25/2005	12:03	24.3	23.8		21.1		3.03				
D-6	08/25/2005	12:03	24.3	24.3	20.49		0.31		-280	7.29	814	39
D-7	08/25/2005	12:12	23.7	23.2		21		2.27				
D-7	08/25/2005	12:12	23.7	23.7	20.48		0.29		-281.4	7.35	781	
D-8	08/25/2005	12:20	24.0	23.5		21		4.39				
D-8	08/25/2005	12:20	24.0	24.0	20.66		4.75		-137	7.99	768	41
D-9	08/25/2005	12:27	24.5	24		21		5.23				
D-9	08/25/2005	12:27	24.5	24.5	20.55		0.24		-202	7.37	754	
D-10	08/25/2005	12:36	16.0	15.5		21.1		5.37				
D-10	08/25/2005	12:36	16.0	16.0	20.66		5.55		-87.3	8.12	770	38
D-11	08/25/2005	12:45	13.5	13		21.1		5.91				
D-11	08/25/2005	12:45	13.5	13.5	20.65		6.07		-72	8.13	773	
E-1	08/25/2005	13:03	25.2	24.7		21.2		2.46				
E-1	08/25/2005	13:03	25.2	25.2	20.52		0.47		-277	7.47	816	43
E-2	08/25/2005	13:08	25.2	24.7		21.1		0.05				
E-2	08/25/2005	13:08	25.2	25.2	20.58		0.35		-216	7.56	771	
E-3	08/25/2005	13:15	24.9	24.4		21.1		0.4				
E-3	08/25/2005	13:15	24.9	24.9	20.53		0.2		-299	7.35	778	36
E-4	08/25/2005	13:22	24.7	24.2		21.1		0.14				
E-4	08/25/2005	13:22	24.7	24.7	20.59		0.22		-265	7.46	798	
E-5	08/25/2005	13:33	25.4	24.9		21.1		0.67				
E-5	08/25/2005	13:33	25.4	25.4	20.6		1.04		-196	7.68	771	40
E-6	08/25/2005	13:42	23.9	23.4		21.2		1.73				
E-6	08/25/2005	13:42	23.9	23.9	20.62		1.88		-275	7.51	771	
E-7	08/25/2005	13:48	25.5	25		21.1		3.2				
E-7	08/25/2005	13:48	25.5	25.5	20.69		3.6		-140	7.98	771	37
E-8	08/26/2005	6:23	21.6	21.1		21		2.15				
E-8	08/26/2005	6:23	21.6	21.6	20.71		2.58		-36.9	7.88	770	37
E-9	08/26/2005	6:33	18.4	17.9		21		2.32				
E-9	08/26/2005	6:33	18.4	18.4	20.71		2.6		13	8.01	770	
E-10	08/26/2005	6:40	19.1	18.6		21		2.1				
E-10	08/26/2005	6:40	19.1	19.1	20.64		2.56		13.1	7.96	770	34
E-11	08/26/2005	6:49	16.6	16.1		21		2.85				
E-11	08/26/2005	6:49	16.6	16.6	20.76		3.02		-19.7	7.89	771	
E-12	08/26/2005	6:58	14.1	13.6		21.3		6.27				
E-12	08/26/2005	6:58	14.1	14.1	21.21		6.77		10.5	8.15	773	31
F-1	08/26/2005	7:10	22.7	22.2		20.8		4.58				
F-1	08/26/2005	7:10	22.7	22.7	20.76		4.95		12	8.2	770	35
F-2	08/26/2005	7:18	24.5	24		21.1		1.8				
F-2	08/26/2005	7:18	24.5	24.5	20.54		0.22		-210	7.48	778	
F-3	08/26/2005	7:28	23.4	22.9		21.1		1.82				
F-3	08/26/2005	7:28	23.4	23.4	20.73		2.43		-84	7.78	772	35
F-4	08/26/2005	7:37	22.1	21.6		21		1.41				
F-4	08/26/2005	7:37	22.1	22.1	20.53		0.73		-245	7.4	753	
G-1	08/26/2005	7:48	20.1	19.6		20.8		3.5				
G-1	08/26/2005	7:48	20.1	20.1	20.61		0.6		-267	7.44	786	32
G-2	08/26/2005	7:55	20.5	20		20.6		2.76				
G-2	08/26/2005	7:55	20.5	20.5	20.72		3.05		-145	7.76	771	
G-3	08/26/2005	8:02	16.5	16		20.8		3.65				
G-3	08/26/2005	8:02	16.5	16.5	20.72		4.03		-73	7.92	770	37
G-4	08/26/2005	8:07	21.1	20.6		20.9		2.55				
G-4	08/26/2005	8:07	21.1	21.1	20.53		0.27		-265	7.35	739	
G-5	08/26/2005	8:14	23.4	22.9		20.9		1.82				
G-5	08/26/2005	8:14	23.4	23.4	20.63		2.1		-134	7.77	771	38
G-6	08/26/2005	8:24	20.8	20.3		20.9		0.81				

By: THA
Checked By:____

G-6	08/26/2005	8:24	20.8	20.8	20.63		0.99		-104	7.69	768	32

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: A3
Date: 08/24/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS	
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)
5:26	2	21.18		7.83	7.4	183.2	8.42	787	39
5:28	4	21.18	21.3	7.79	7.43	179.5	8.41	787	
5:31	6	21.19	21.3	7.71	7.39	177	8.4	788	
5:32	8	21.2	21.3	7.56	7.3	175.6	8.39	788	
5:34	10	21.22	21.3	7.48	7.2	173.7	8.37	789	
5:50	12	21.1	20.9	7.4	7.13	176	8.46	787	
5:55	14	21.09	21	7.47	7.29	175.1	8.46	787	
5:57	16	21.11	21.1	7.46	7.32	174.6	8.46	787	
5:59	18	21.1	21.1	7.15	7.03	174.1	8.45	787	
6:03	20	21.07	21.1	6.99	6.9	173.4	8.44	787	
6:05	22	20.93	21	5.55	5.46	173.4	8.34	786	
6:08	24	20.88	21	5.2	4.75	171.1	8.28	786	
6:10	26.6	20.8	21	4.92	4.65	163.5	8.23	786	

Date: 08/24/2005

8:05	2	20.95	20.5	7.74	7.2	205.5	8.15	785	37
	4	20.96	20.6	7.74	7.22	198.2	8.22	785	
	6	20.97	20.8	7.69	7.07	194.1	8.29	785	
	8	20.97	20.9	7.7	7.12	192.1	8.32	785	
	10	20.98	21	7.53	7.05	189.5	8.33	785	
	12	20.98	21	7.47	7.09	188.2	8.35	785	
	14	20.98	21.1	7.45	7.1	185.8	8.36	785	
	16	20.98	21.1	7.3	6.91	183.9	8.36	785	
	18	20.98	21.1	7.24	6.86	182.2	8.37	785	
	20	20.96	21.1	6.4	6.17	181.4	8.35	785	
	22	20.9	21.1	6.11	5.6	179.6	8.31	786	
	24	20.87	21	5.4	5.1	177	8.26	786	
8:20	24.5	20.82	21	5.16	4.8	163	8.22	786	
7:30*	25.4	20.55		2.57		-125	7.83	766	

* Tested interface 8/25/05.

Date: 08/25/2005

7:30	24.9		21		2.53				
7:30	25.4	20.55		2.57		-125	7.83	766	

By: THA
Checked By:____
Date Last Updated:10/30/2005

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **B4**
Date: 08/23/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
11:23	12	2098		6.31		-17.1	8.26	789	50	
11:27	14	20.88		5.2		-19.1	8.16	789		
11:28	16	20.77		3.85		-19.5	8.07	789		
11:30	18	20.72		3.6		-110	7.69	784		
11:31	20	20.74		2		-160	7.32	780		
11:33	21	20.71		2.6		-186	7.33	780		
11:34	23	20.7		2.5		-214	7.37	782		
	25	20.5		0.15		-275	7.04	808		

Date: 08/24/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
7:30	2	20.87	19.9	7.75	7.82	216	8.44	784	40	
	4	20.92	20.2	7.61	7.42	211.6	8.43	785		
	6	20.96	20.5	7.5	7.19	209.2	8.43	785		
	8	20.96	20.7	7.47	7.08	207.9	8.43	785		
	10	20.96	20.8	7.42	7.09	206.5	8.43	785		
	12	20.96	21	7.8	7.14	205.3	8.44	785		
	14	20.96	21	7.71	7.02	203.4	8.43	785		
	16	20.96	21.1	7.5	6.83	202.4	8.43	785		
	18	20.96	21.1	7.34	6.77	201.3	8.43	785		
	20	20.96	21.1	7.22	6.43	200	8.42	785		
	22	20.96	21.1	6.4	5.6	199.7	8.39	786		
7:45	23.5	20.83	21.1	5.1	4.75	190.7	8.28	786		
8:48*	24.4	20.48		1.83		-282	7.2	769	32	Interface

* Tested interface 8/25/05

Date: 08/25/2005

8:48	23.9		21		1.56					
8:48	24.4	20.48		1.83		-282	7.2	769	32	Interface

By: THA
Checked By:____
Date Last Updated:10/30/2005

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **B7**
Date: 08/24/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
7:12	2	20.79	19.6	7.29	7.26	212.5	8.42	783	40	
	4	20.85	19.9	7.3	7.09	206.4	8.39	730		
	6	20.9	20.3	7.2	6.8	203.8	8.39	785		
	8	20.91	20.5	7.05	6.67	202	8.4	785		
	10	20.91	20.7	7.03	6.54	200.3	8.4	785		
	12	20.91	20.8	6.94	6.52	198.5	8.4	785		
	14	20.91	20.9	6.93	6.47	197.9	8.4	785		
	16	20.91	20.9	6.87	6.54	195.8	8.4	785		
	18	20.91	21	6.79	6.44	194.4	8.39	785		
	20	20.9	21	6.5	5.3	193	8.39	785		
7:20	22.4	20.83	21	4.2	3.4	180	8.24	787		
9:10*	22.5	20.49		1.3		-280	7.55	765		Interface

* Tested interface 8/25/05.

Date: 08/25/2005

9:10	22		21		1.98					
9:10	22.5	20.49		1.3		-280	7.55	765		Interface

By: THA
Checked By:____
Date Last Updated:10/30/2005

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **B9**
Date: 08/24/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
6:41	2	20.75	19.4	6.89	6.88	233	8.39	784	21	
	4	20.88	20.1	6.95	6.66	226	8.39	785		
	6	20.89	20.4	6.8	6.56	221	8.38	784		
	8	20.89	20.7	6.79	6.37	216.7	8.39	784		
	10	20.87	20.8	6.74	6.49	214.1	8.39	784		
	12	20.86	20.9	6.69	6.33	209	8.39	784		
	14	20.87	20.9	6.69	6.42	206.2	8.38	785		
	16	20.88	21	6.62	6.26	204.4	8.38	785		
	18	20.88	21	6.61	6.37	202.7	8.38	785		
7:00	20.5	20.87	21	6.41	5.99	199.8	8.38	785		
9:24*	20.4	20.5		0.6		-237	7.39	755	41	Interface

* Tested interface 8/25/05.

Date: 08/25/2005

9:24	19.9		21		1.71					
9:24	20.4	20.5		0.6		-237	7.39	755	41	Interface

By: THA
Checked By:____

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **C2**
Date: 08/24/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
8:30	2	20.61	20.1	7.7	6.72	157.8	8.39	785	41	
	4	20.98	20.8	7.47	6.58	157.7	8.37	786		
	6	20.99	20.9	7.26	6.43	156.4	8.38	786		
	8	20.99	21	7.12	6.4	155.3	8.38	786		
	10	20.98	21	6.9	6.32	154.2	8.38	786		
	12	20.98	21.1	6.86	6.28	153.4	8.38	786		
	14	20.98	21.1	6.76	6.28	151.8	8.38	787		
	16	20.97	21.1	6.61	6.11	150.7	8.37	787		
	18	20.97	21.1	6.55	6.14	150.1	8.37	787		
	20	20.97	21.1	6.42	6.01	148.4	8.36	787		
	22	20.96	21.1	6.28	5.79	146.2	8.36	787		
	24	20.93	21.1	5	4.71	145.1	8.3	787		
8:50	24.5	20.88	21.1	4.99	4.68	140.3	8.24	787		
9:53*	25	20.44		0.67		-258	7.23	779		Interface

* Tested interface 8/25/05.

Date: 08/25/2005

9:53	24.5		21		2.52					
9:53	25	20.44		0.67		-258	7.23	779	41	Interface

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **C4**
Date: 08/24/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
9:00	2	20.95	20.3	7.25	6.77	184	8.26	786	36	
	4	20.97	20.8	4.16	6.56	171	8.34	785		
	6	20.95	20.9	7.09	6.54	161.5	8.35	786		
	8	20.95	21	6.94	6.24	155	8.36	786		
	10	20.94	21	6.91	6.31	150.4	8.35	786		
	12	20.93	21.1	6.81	6.34	147	8.35	786		
	14	20.93	21.1	6.78	6.35	143.3	8.35	786		
	16	20.93	21.1	6.7	6.25	140.1	8.35	786		
	18	20.93	21.1	6.62	6.23	137.4	8.35	786		
	20	20.92	21.1	6.47	6.11	135.4	8.34	786		
	22	20.92	21.1	6.44	6.14	133.2	8.34	786		
9:20	24	20.77	21.1	3.9	3.55	128.3	8.13	787		
10:08*	24.8	20.49		1.77		-255	7.49	771		Interface

* Tested interface 8/25/05.

Date: 08/25/2005

10:08	24.3		21		2.06					
10:08	24.8	20.49		1.77		-255	7.49	771		Interface

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **D3**
Date: 08/24/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
9:30	2	21.14	21.4	7.57	6.75	180.5	8.41	787	38	
	4	20.98	21.3	7.46	6.65	170.1	8.38	785		
	6	20.98	21.2	7.15	6.42	163.3	8.37	785		
	8	20.93	21.2	6.92	6.35	158.3	8.36	785		
	10	20.91	21.1	6.7	6.08	154	8.34	785		
	12	20.9	21.1	6.65	6.09	150.8	8.33	785		
	14	20.9	21.1	6.6	6.16	147.5	8.33	785		
	16	20.89	21.1	6.45	6	144.1	8.32	785		
	18	20.88	21.1	6.43	6.07	141.4	8.32	785		
	20	20.87	21.1	6.35	5.98	138.7	8.31	785		
	22	20.87	21.1	6.28	5.25	136.6	8.31	785		
	24	20.77	21	4.2	3.5	131.2	8.18	786		
9:42	24.4	20.67	21.9	2.4	2.05	116	8.02	787		
11:42*	27	20.42		0.28		-220	7.4	806		Interface

* Tested interface 8/25/05.

Date: 08/25/2005

11:43	26.5		21		2.14					
11:43	27	20.42		0.28		-220	7.4	806		Interface

By: THA
Checked By:____
Date Last Updated:10/30/2005

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **D8**
Date: 08/25/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
6:50	2	20.94	20.4	7.63	7.38	116.6	8.27	769	35.5	
	4	21.02	20.8	7.56	7.14	112.1	8.28	770		
	6	21.03	21	7.47	7	107.6	8.29	770		
	8	21.03	21.1	7.4	6.99	104.7	8.29	770		
	10	21.03	21.2	7.12	6.62	103	8.28	770		
	12	20.93	21.2	6.29	6.01	100.8	8.22	770		
	14	20.95	21.2	5.92	5.32	99.7	8.21	769		
	16	20.88	21.2	5.55	4.85	99.1	8.17	769		
	18	20.76	21.1	5	4.45	98.7	8.12	768		
	20	20.71	21.1	4.52	4.02	99.1	8.06	767		
	22	20.66	21	3.5	3.02	99.8	7.99	767		
	22.9		21		2.77					
6:58	23.4	20.48		1.2		-205	7.36	766		Interface

Date: 08/25/2005

12:20	23.5		21		4.39				41	
12:20	24	20.66		4.75		-137	7.99	768		Interface

By: THA
Checked By:____

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **E2**
Date: 08/25/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
5:40	2	21.6	21.9	8.89	8.23	150	8.39	775	32	
	4	21.6	21.9	8.81	8.32	149.5	8.39	776		
	6	21.62	21.9	8.8	8.23	148.8	8.38	776		
	8	21.61	21.9	8.77	8.22	148.3	8.38	776		
	10	21.58	21.9	8.8	8.23	147.4	8.39	775		
	12	21.22	21.6	6.8	6.1	149.6	8.28	770		
	14	20.9	21.4	6.1	5.5	150.4	8.2	769		
	16	20.89	21.4	5.8	5.11	150.6	8.15	769		
	18	20.87	21.3	5.13	4.66	152.5	8.09	770		
	20	20.78	21.2	2.6	1.87	155	7.9	770		
	22	20.71	21.2	1.9	1.71	154.8	7.8	770		
	24	20.66	21.1	1.7	1.25	80	7.68	769		
	24.5		21		0.97					
5:55	25	20.52		1.12		-174	7.42	770		Interface

Date: 08/25/2005

13:03	24.7		21.1		0.05					
13:03	25.2	20.58		0.35		-216	7.56	771		Interface

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **E4**
Date: 08/24/2005

Time	Meter Depth (Feet)	Temperature 556MPS (Deg. C)	Temperature 550A	DO 556MPS (mg/L)	DO 550A	ORP 556MPS	pH 556MPS	Conductivity 556MPS (uS/cm)	Secchi Depth (Inches)	Note
9:50	2	21.25	21.3	7.6	6.7	108	8.41	789	38	
	4	21.09	21.2	7.45	6.55	96	8.43	785		
	6	20.9	21.1	7.11	6.18	83	8.39	785		
	8	20.86	21.1	6.6	5.99	78	8.37	785		
	10	20.85	21.1	6.5	5.85	74	8.36	785		
	12	20.84	21.1	6.43	5.89	73.3	8.34	785		
	14	20.83	21.1	6.39	5.85	71.1	8.33	785		
	16	20.81	21.1	6.29	5.87	70.6	8.34	784		
	18	20.8	21	6.25	5.82	70	8.33	784		
	20	20.8	21	6.24	5.91	69.3	8.33	784		
	22	20.78	21	6	5.42	68.8	8.31	785		
10:00	24	20.72	21	4.48	3.99	63	8.21	785		
13:22*	24.2	20.59		0.22		-265	7.46	798		Interface

* Tested interface 8/25/05

Date: 08/25/2005

13:22	24.2		21.1		0.14					
13:22	24.7	20.59		0.22		-265	7.46	798		Interface

By: THA
Checked By:____
Date Last Updated:10/30/2005

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **E7**
Date: 08/25/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
6:05	2	20.4	19.5	7.97	8.09	20	8.27	765	34	
	4	20.97	20.7	7.86	7.64	3	8.34	768		
	6	21.05	21	7.84	7.47	-2	8.35	768		
	8	21.07	21.2	7.67	7.1	-6.3	8.35	768		
	10	21.06	21.3	7.48	6.85	-6.5	8.34	768		
	12	20.97	21.2	6.6	6.11	-7.4	8.29	768		
	14	20.93	21.2	6.28	5.68	-8.8	8.26	768		
	16	20.88	21.2	5.8	5.21	-9.3	8.23	768		
	18	20.84	21.2	5.48	4.93	-10.5	8.19	767		
	20	20.81	21.2	5.15	4.54	-10.1	8.15	767		
	22	20.69	21.1	4.01	3.21	-10.6	8.06	766		
	22.5		21		2.64					
6:18	23	20.53		3.17		-250	7.76	763		Interface

Double Check
Date: 08/25/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
7:05	2	20.88	20.4	7.95	7.43	-35	8.24	768		
	8	20.98	20.8	7.65	7.18	-24	8.27	769		
	14	20.98	21	7.53	6.89	-20	8.28	769		
7:10	20	20.82	21.1	5.35	4.8	-15.4	8.18	770		

Date: 08/25/2005

13:48	25		21.1		3.2					
13:48	25.5	20.69		3.6		-140	7.98	771	37	Interface

By: THA
Checked By:____
Date Last Updated:10/30/2005

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **E11**
Date: 08/24/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(mg/L)				(uS/cm)	(Inches)	
6:20	2	20.45	18.4	5.5	5.13	154.2	8.25	780	30	
	4	20.62	19.6	5.2	4.85	152.5	8.2	780		
	6	20.66	20.2	4.93	4.55	150.3	8.18	781		
	8	20.66	20.5	4.88	4.48	149.2	8.18	781		
	10	20.65	20.5	4.85	4.5	148.7	8.17	781		
	12	20.67	20.7	4.82	4.47	147.4	8.16	781		
	14	20.67	20.7	4.75	4.48	146.9	8.16	781		
	16	20.67	20.7	4.72	4.34	146.5	8.16	781		
6:28	17	20.66	20.8	4.58	4.11	145.8	8.16	781		
6:49*	16.6	20.76		3.02		-19.7	7.89	771		Interface

* Tested interface 8/26/05.

Date: 08/25/2005

6:49	16.1		21		2.85					
6:49	16.6	20.76		3.02		-19.7	7.89	771		Interface

By: THA
Checked By:____

Profiles:

Cherry Creek
Reservoir Destratification Testing

Location: **G3**

Date: 08/25/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(%)				(uS/cm)	(Inches)	
5:15	2	21.65	21.9	105.4	97.3	152.8	8.26	776		
	4	21.66	22	102	94.7	150.5	8.29	776		
	6	21.67	22	105	95.9	149.9	8.3	776		
	8	21.41	21.8	91.4	84.7	149.9	8.27	772		
	10	21.07	21.6	78.7	71.5	151.3	8.18	770		
	12	20.9	21.4	73.5	65	152.6	8.11	769		
	14	20.92	21.4	55	49.5	154.6	7.97	770		
	14.5		21.3		24.7					
5:30	15	20.8		36.4		140.5	7.8	770		Interface

Date: 08/25/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(%)				(uS/cm)	(Inches)	
6:35	2	21.4	20.2	8.71	8.74	160	8.05	776		
	4	21.59	21.3	8.77	8.44	150.4	8.25	776		
	6	21.59	21.4	8.68	8.4	146.5	8.27	776		
	8	21.3	21.4	7.2	6.69	142.5	8.22	770		
	10	21.1	21.3	6.6	6.16	139.6	8.18	768		
	12	20.96	21.2	6.18	5.41	138.4	8.14	768		
	14	20.91	21.2	5.7	5.29	136.5	8.11	768		
	15		21.2		3.68					
6:48	15.5	20.85		4.2		135.8	8.02	769		Interface

Date: 08/26/2005

Time	Meter	Temperature		DO		ORP	pH	Conductivity	Secchi Depth	Note
	Depth	556MPS	550A	556MPS	550A	556MPS	556MPS	556MPS		
	(Feet)	(Deg. C)		(%)				(uS/cm)	(Inches)	
8:48	2	20.74	20.9	4.63	3.92	-26	8.04	770	32	
8:50	4	20.76	21	4.58	3.94	-30	8.03	770		
8:52	6	20.76	21.1	4.55	3.95	-31.4	8.03	770		
8:54	8	20.74	21.1	4.37	3.8	-32.6	8.03	770		
9:05	10	20.73	21	4.4	3.99	-26	8.01	770		
9:07	12	20.74	21	4.3	3.87	-28.3	8.02	770		
9:09	14	20.73	21.1	4.22	3.81	-30.5	8.02	771		
9:11	15.9		21.1		3.58					
9:11	16.4	20.73		3.87		-34.8	8.02	770		Interface

Date: 08/26/2005

8:02	16		20.8		3.65				37	
8:02	16.5	20.72		4.03		-73	7.92	770		Interface

By: THA
Checked By:____
Date Last Updated:10/30/2005

Attachment D

SolarBee Technical Information

SolarBee
Englewood, Colorado

SolarBee
Solar-Powered Reservoir Circulator
"Quality Water, Naturally"
http://www.solarbee.com

Christopher F. Knud-Hansen, Ph.D., CLM
Limnologist and Certified Lake Manager
11853 Pecos St., Westminster, CO 80234
(866) 469-9606 • (303) 469-9606 • Fax (303) 469-4701

Main Office and Service Center
SolarBee Division of Pump Systems, Inc.
530 25th Ave E, PO Box 1930, Dickinson, ND 58602
(866) 437-8076 • (701) 225-4495 • Fax (701) 225-0002

MEMORANDUM

To: SolarBee Personnel

From: Christopher F. Knud-Hansen, Ph.D., CLM

Date: March 18, 2005

Re: Ecological benefits associated with preventing blue-green algae blooms through SolarBee circulation: A new approach for controlling eutrophication in lakes.

Preface:

The essay below is an initial summary of the ecological relationships in lakes and ponds associated with the control of blue-green algae (cyanobacteria) through SolarBee circulation. These relationships reveal a new paradigm for eutrophication control. Rather than trying to limit overall algal growth through reductions in nutrient (primarily phosphorus) availability, SolarBee circulation prevents blooms of blue-green algae through habitat disturbance. This form of bio-manipulation selects against bloom-forming blue-green algae while favoring non-blue-green algae. The sustainable benefits to overall lake ecology through SolarBee circulation are contrasted against traditional in-lake management approaches dealing primarily with the symptoms of eutrophication.

This essay represents the framework of a more formal manuscript currently in preparation to be submitted to an international, peer-reviewed journal later this year. As such, *this memo should be viewed as a "draft" document and used/distributed for informational purposes only*.

Introduction:

Eutrophication refers to the enrichment of available food in aquatic systems, with algal productivity (i.e., the rate of algal production) representing the cornerstone of the aquatic food web. Algae will grow as long as they have sufficient dissolved inorganic phosphorus (DIP; e.g., phosphates), dissolved inorganic nitrogen (DIN; e.g., nitrates and ammonia), light energy for photosynthesis, and suitable temperatures. The availability of dissolved inorganic carbon (DIC; e.g., carbon dioxide, bicarbonate) and micronutrients (e.g., silica, iron) can limit algal productivity, but DIP and/or DIN are typically the limiting nutrient(s) in freshwater lakes and reservoirs. So, algal productivity typically increases as more DIP and DIN enter a lake.

However, all algae are not functionally or ecologically equal. Blue-green algae (cyanobacteria) are both morphologically and functionally different from non-blue-greens, such as diatoms, greens, and flagellates. Blue-greens have gas vesicles that allow them to regulate their buoyancy in the water column. During the day in calm waters, blue-green algae can come near the surface in order to give them a competitive advantage over non-blue-greens for light, atmospheric carbon dioxide, and atmospheric nitrogen (N_2, for those blue-greens capable of incorporating or "fixing" N_2 directly). Many species of blue-green algae also contain a variety of cyanotoxins. One significant ecological implication of these cyanotoxins is that zooplankton, macroinvertebrates, and fish do not like to eat them. So when blue-greens die, they tend to sink to the bottom of the lake where their decomposition can deplete bottom waters of dissolved oxygen (DO). Anoxic bottom waters are not only detrimental to fish, but these conditions have other undesirable consequences characteristic of eutrophication (described below).

In contrast to the inedible blue-greens, however, non-blue-green algae can and do get consumed by aquatic organisms, thus moving energetically (and materially) up the food chain – improving water clarity while increasing biodiversity. It is not that all algae are bad, just primarily the toxic, non-edible blue-green algae. Edible algae help sustain a vigorous fish community, while toxic blue-green blooms can harm fisheries and degrade the entire lake ecosystem.

Thus, this new paradigm for controlling eutrophication is based on the recognition that food enrichment goes into two different directions depending upon whether algal productivity is dominated by blue-green algae or by non-blue-green algae. When dominated by toxic blue-green algae, food enrichment remains at the microbial level cycling between blue-green blooms and microbial decomposition. When algal productivity is dominated by non-blue-green algae, however, both biomass and energy move up the food web into zooplankton, other invertebrates, and fish. When the latter happens, even with nutrient enrichment and relatively high algal productivity, the lake ecology is enhanced and the consequences of eutrophication minimized.

Problem identification:
Perhaps the most visible indicator of lake eutrophication and impairment are blue-green algae blooms during summer months. These blooms are typically a result of high nutrient inputs (i.e., soluble inorganic nitrogen and phosphorus) and warm, stagnant waters. Because blue-green algae are not readily consumed by zooplankton, other invertebrates or fish due to their intra-cellular cyanotoxins and relatively large size, they often remain on the water's surface upon death causing unsightly scums and noxious odors. When they die, uneaten blooms eventually settle to the lake sediments where microbial decomposition depletes DO from bottom waters (i.e., the hypolimnion). Anoxic bottom waters promote the sediment release of soluble iron (Fe) and manganese (Mn), causing taste and odor problems in drinking water reservoirs, as well as hydrogen sulfide (H_2S) and soluble P. Hydrogen sulfide and anoxic waters are both detrimental to fish and other aquatic animals. Soluble P released from anoxic sediments into overlying waters can become available again for algal uptake following lake mixing events (e.g., fall turnover). This process is called "internal P loading", and has been major focus for many lake managers in their efforts to mitigate eutrophication (discussed more below).

In addition to the ecological consequences (i.e., lake eutrophication) caused by uneaten blue-green algae, the intra-cellular toxins themselves can create a very unhealthy situation. Not all blue-green algae possess toxins, but bloom-forming blue-green algae typically contain neurotoxins, hepatotoxins, and/or dermatoxins. When these toxic blooms dominate the algal community, the rest of the lake biota suffers and biodiversity diminishes. Unfortunately, lake biota can also include humans and pets, and reported instances of severe illness and death from both groups have been attributed to accidental consumption of toxic blue-green algae. Although animal illness and deaths have been reported worldwide since the late 1800s, it has only been since 1998 that the drinking water industry and the general public have begun to really appreciate the importance of cyanotoxins to public health. Controlling toxic blue-green algae, therefore, and not necessarily the edible non-blue-green algae, is really the critical lake management issue.

Traditional in-lake management approaches:

Traditional in-lake approaches for managing eutrophic lakes focus primarily on the ecological consequences of blue-green algae blooms, rather than directly preventing the blooms in the first place. For example, hypolimnetic oxygenation through supplemental aeration or hypolimnetic withdrawal can improve fish habitats and inhibit soluble P release from the sediments, but the underlying problem of blue-green algae blooms will persist. The same is true for alum and iron applications designed to keep soluble P chemically fixed in the sediments. However, summer blooms are typically fueled by nutrients brought in from summer stormwater runoff and tributary inputs – the soluble P released from anoxic sediments is usually unavailable for algal growth until after fall turnover. Hypolimnetic aeration and alum blankets are not effective at consistently preventing blue-green algae blooms – these approaches attempt to deal primarily with the consequence of the blooms.

Nevertheless, it is useful to examine more a bit closely the concepts and practical experience associated with alum applications, since that is perhaps the most common in-lake approach for reducing P availability to control eutrophication. First, there is an underlying assumption that algal productivity in a given lake is limited by the availability of soluble P, and so limiting P availability will reduce algal productivity. Without confirming data or conducting algal bioassays, this belief is not necessarily a given. In part because P can recycle in lakes more efficiently than N, algal productivity in eutrophic lakes are increasingly becoming more N (or co N+P or light) limited. However, since even under N-limiting conditions it is still better to promote P-limitation when trying to reduce algal growth via nutrient control, the focus on P is still appropriate.

So, let’s assume hypothetically that summertime algal productivity in the neighborhood lake is P-limited, and that the entire lake bottom has been effectively capped with alum. Also assume that some of the undesirable “trade-offs” (e.g., unbalanced buffering, unintended fish kills and other aluminum toxicity issues) associated with alum applications did not occur. So, what are reasonable expectations for this lake?

The effectiveness of alum treatments to reduce algal growth is in great part related to the relative P loading from the watershed versus internal recycling. For this hypothetical lake, let’s assume that internal P recycling represents 50% of annual total P inputs. However, because lakes are typically strongly thermally stratified during the warm summer months, most if not all of this soluble P accumulating in bottom waters is not brought back into upper waters until fall turnover.

Although this internal P input can stimulate a fall – and perhaps even a spring – algal bloom, there is likely not much impact on summertime algal productivity.

But for this hypothetical, let’s assume that the approximately 50% reduction in P inputs to surface waters due to alum applications did in fact cause a 50% reduction in summertime algal productivity. This would make, hypothetically, the summer blue-green algae blooms only half as severe. In many waters, reducing toxic blue-green algae blooms even by 90% would still leave sufficient algal biomass to restrict waters for human contact according to World Heath Organization’s guidelines on exposure to blue-green toxins. Furthermore, improved water clarity associated with reduced algal productivity may allow existing infestations of rooted aquatic weeds to spread into new areas or deeper waters.

More realistically, however, external P inputs (e.g., from tributaries and stormwater runoff) are likely responsible for stimulating algal blooms during the summer months. P recycled from the sediments typically has a minimal impact on summer blooms because thermal stratification separates anoxic, nutrient-rich bottom waters from surface waters where algae utilize nutrients for photosynthesis and growth. Therefore, the probability that an alum treatment would have a significant impact on summertime blue-green algae blooms is relatively small for two reasons: 1) reductions in P availability do not necessarily have an impact on algal speciation – blue-green algae would likely still dominate, though perhaps with reduced severity, and 2) summertime algal productivity is likely controlled by summertime nutrient inputs from external sources not necessarily impacted by alum treatments.

Furthermore, the probability that any observable benefits to water quality associated with an alum application are sustainable is even smaller. Because alum only addresses the *symptom* of P accumulation in anoxic bottom waters, and not the underlying *problem* of blue-green algae blooms (which transport P to the sediments when they die and settle to the bottom), it is only a question of *when* the next alum application would be necessary, not *if*. Depending upon the amount of external P loading, presence of bottom feeding fish (e.g., bullheads), invertebrate activity in the sediments, and other factors that may reduce the effectiveness of alum treatments, the frequency of applications may be sooner than anticipated.

However, P availability from anoxic sediments is NOT the true source of the problem – it is just a symptom/consequence of the real problem, which are typically blue-green algae blooms. The paradigm shift described in this paper changes the focus from nutrient availability for all algae to directing available nutrients into “good”, edible algae that actually enhance the food web and improve the overall health of the lake. Therefore, the problem is NOT too much phosphorus. Phosphorus is not toxic to aquatic life – in fact, it is an essential food for all plants and a necessary component for nucleic acids and other life-supporting molecules. For effective lake management, the goal should not necessarily be to reduce phosphorus concentrations or overall lake productivity, but instead keep nutrients/energy moving up the food web and not remain stuck in a blue-green algae-bacterial decomposition loop. In other words, help P (and N) inputs become incorporated into edible algae rather than into toxic, inedible blue-green algae. This goal can be uniquely achieved through the long-distance horizontal and vertical circulation induced by SolarBee water circulators.

The SolarBee Approach for Improving Lake Ecology

The SolarBee is a solar-powered up-flow water circulation machine capable of bringing water up from a desired depth and transporting it horizontally long distances across the lake surface. Water brought up to the surface is moved radially in all directions away from the SolarBee. This circulation is fundamentally different from wind mixing, which tends to move water in shallow, vertical vortices with limited (and more unidirectional) long-distance transport. Generally speaking, the SolarBee can be deployed in two different manners to improve water quality and enhance lake ecology.

One method of deployment is a form of hypolimnetic oxygenation, where the SolarBee intake hose is set deep, near the bottom of the lake, in order to transport oxygenated surface waters down to the sediments and effectively seal them with regards to the release of soluble P under otherwise anoxic conditions. However, if too few of machines are deployed for the actual sediment oxygen demand, then there is a risk of bringing up P-rich waters from an anoxic hypolimnion. This could have the unintended consequence of actually increasing P loading to surface waters and possibly exacerbating the blue-green algae problem. Uncertainties about lake-specific P dynamics notwithstanding, and because limiting P availability does not specifically eliminate blue-green algae blooms, this is NOT the approach we recommend for blue-green algae control.

With the second, preferred method of deployment for blue-green algae control, the SolarBee intake hose is set shallower so as to circulate just the epilimnion. The effect is to physically disturb the favored habitat (i.e., calm, quiescent surface waters) of bloom-forming blue-green algae so they are unable to out-compete the edible, non-blue-green algae. Usually the SolarBee intake hose is set at or above the thermocline (where water temperatures and densities are more uniform) but below the photic zone, usually about 8-15 feet from the surface. Water from this depth is brought up and spread radially from the machine. The SolarBee's patented distribution dish allows water to flow away from the machine in a near-laminar flow, enabling it to reach long distances (1,000 feet or more). Surface waters then move downward along the lake's margins and back to the machine at the intake depth. Each SolarBee SB10000v12 pumps over 10,000 gallons per minute and can prevent blue-green blooms in a 50-acre circle (830 ft radius) surrounding the machine. Since the effect is additive, more units can be installed for controlling blue-green blooms in larger lakes (this issue is discussed further below).

This SolarBee-induced water movement has shown to be consistently effective at preventing blue-green algae blooms in over 80 fresh and saltwater bodies throughout North America since first introduced for this application in 2002. Without any changes to nutrient loading, typical results include significantly improved water clarity, lower pHs, reduced chlorophyll *a* and total P concentrations, increased biodiversity, increased secondary production (both zooplankton and fish), and reduced biochemical oxygen demand (BOD) to bottom waters. This epilimnetic circulation also keeps DO concentrations high throughout the water column above the thermocline, thus improving the fish environment. It is important to remember that these water quality improvements are unrelated to nutrient concentrations – the elimination of blue-green algae blooms is by habitat manipulation which impairs their ability to out-compete non-blue-greens, and *not* by limiting their nutrient availability. For example, these results have been noted in a drinking water reservoir receiving secondary effluent from domestic sewage. Even with soluble P concentrations reaching 0.5 mg/L and ammonia-N and nitrate-N concentrations exceeding several mg/L, blue-green algae blooms were eliminated, water clarity remained about 3-4 meters, chlorophyll *a* concentrations averaged 2-3 ug/L, and no unusual taste and odor problems were reported (MIB and geosmin, organic chemicals that cause taste and odor problems in drinking water, are typically associated with blue-green blooms). In fact, blue-green bloom control through SolarBee-induced circulation has been consistently reliable even in wastewater reservoirs, where BOD and total suspended solids were significantly reduced as a consequence.

In addition to controlling blue-green algae blooms, SolarBee-induced circulation has also proven effective at improving fish spawning habitats in littoral (near shore) sediments as oxygenated surfaces waters move down along the sediments and back to the machine. By directing nutrients into edible algae and enhancing the overall food web, increased fish productivity, spawning, and vigor have been viewed very positively in at least 10 lakes where SolarBees have been installed for blue-green bloom control.

Furthermore, this same oxygenated return flow that has benefited fish spawning has also been effective at eliminating several species of invasive submerged macrophytes (e.g., Eurasian watermilfoil, EWM). Similar to many invasive aquatic weeds, EWM strongly favors ammonia-N over nitrate as their nitrogen source. SolarBee circulation moving oxygenated water along littoral sediments apparently oxidizes sediment ammonia to nitrate, creating N-limitation of EWM growth. The few remaining plants often have a sickly, yellowish look typical of N deficiency. Lightly rooted invasive species like EWM are affected, but native plants tend to be more deeply rooted and not similarly impacted. The elimination of blue-green blooms further promotes nitrogen limitation by reducing the amount of algae settling to the sediments that would otherwise release ammonia-N through their decomposition. We have seen EWM disappear in over a dozen lakes, even as water clarity significantly improved due to the elimination of blue-green algae blooms. We are currently designing a research program for 2006 together with the US Army Engineer Waterways Experiment Station (Vicksburg, MS) and the Eau Galle Aquatic Ecology Laboratory (Spring Valley, WI) to investigate actual nitrogen dynamics behind the observed ammonia-limitation of invasive weed growth with SolarBee-induced circulation.

Proposed applications of SolarBees in large lakes do raise the issue of the scope of SolarBees' influence. There are units deployed in several lakes > 500 acres, though the focus in those lakes is on treating specific coves, marinas, and high value areas rather than the whole lake. Even very large lakes like Clear Lake (CA, 40,000 acres) or the Salton Sea (CA, 240,000 acres) can benefit by targeting specific "hotspots" that suffer localized impacts from algal blooms. We also know that we can eliminate blue-green blooms from the entire lake if sufficient units are installed. We have been consistently successful from water bodies less than 1 acre up to the 234-acre Lake Palmdale (CA), where 7 SolarBees have eliminated blue-green blooms since 2003. We have every reason to believe that the observed, additive SolarBee effect on disrupting blue-green algae habitats extends beyond 7 machines. The negative ecological impact on individual blue-green algae cells is not a function of lake size. There is no reason to believe that a 3,000-acre lake with sufficient SolarBees would not experience the same ecological benefits as documented in Lake Palmdale and all the other lakes similarly treated.

The SolarBee technology is relatively new. Although the company (Pump Systems, Inc.) has been in the water movement business since 1978, the SolarBee was first invented in 1998 primarily to distribute photosynthetically-produced DO more efficiently in wastewater lagoons. Lake applications began in 2002 with the development of the larger machine capable of moving 10,000 gpm. Original lake applications also focused on facilitating oxygen distribution to deeper waters. However, the observed lake benefits of blue-green bloom prevention, fish habitat improvement, and submerged macrophyte control were originally unknown and unintended – we learned of these benefits from lake and reservoir owners reporting their observations and data.

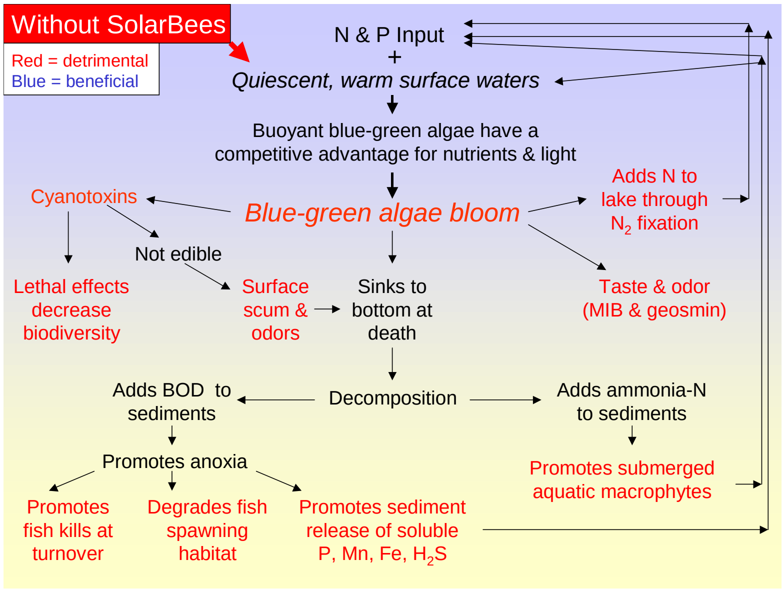
Although SolarBees have successfully and consistently eliminated blue-green algae blooms in more than 80 water bodies, lake owners have also helped identify some of the limitations of this application. Experience has shown that SolarBees will not be effective for blue-green bloom control if: 1) if SolarBees are placed in only part of the lake while blue-green algae are blooming in an "upstream" and untreated part of the lake, and 2) if the photic zone extends significantly below the intake hose depth (which happened twice when the water clarity dramatically improved). Even though the exact physiological mechanism(s) behind blue-green algae bloom control through habitat disturbance is still somewhat uncertain, we have a very reasonable and reliable expectation of success when the above limitations are accounted for.

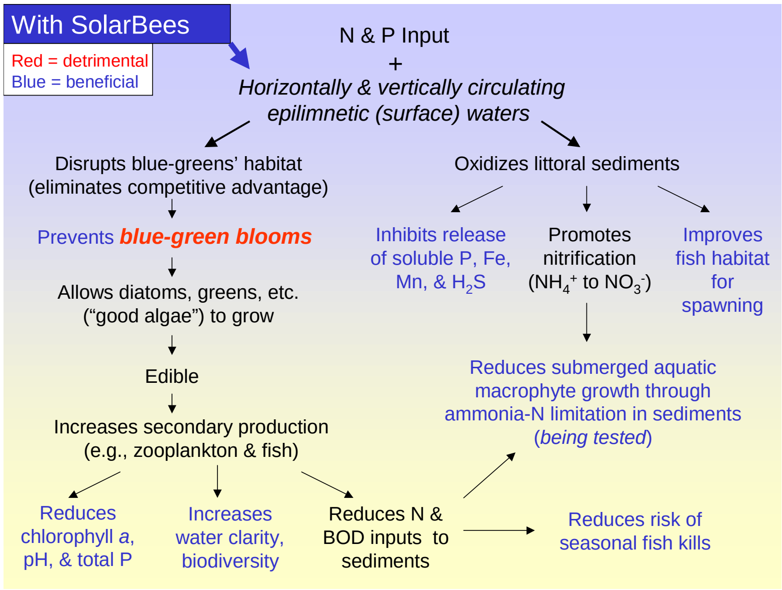
Summary:

Metaphorically, traditional lake management approaches can be thought of as a lake physician. The "physician" approach often uses chemicals and invasive techniques to quickly treat the symptoms of a problem rather than the problem itself. For example, hypolimnetic aeration and alum additions are used to treat the symptoms of oxygen depletion and sediment P release caused by the death and settling of blue-green algae blooms. As long as the blooms continue each year, hypolimnetic oxygen depletion will also occur.

In contrast, the SolarBee approach is more like a lake therapist. The SolarBee "therapist" approach addresses the whole lake by eliminating the principal cause of the problem – blue-green algae blooms – while also eliminating the need for symptomatic treatments such as alum or hypolimnetic aeration (but if desired, SolarBee intake tubes can be set off the bottom to circulate naturally oxygenated surface waters down into the hypolimnion). Phosphorus that would have otherwise gone into blue-greens now go into edible "good" algae (e.g., diatoms, greens, etc.) that do get consumed by aquatic animals - the result: lower algal biomass, no toxic algal blooms, greater secondary production (i.e., zooplankton and fish), lower pH, improved water clarity, and reduced organic loading to bottom waters. In fact, simply eliminating stagnation is very beneficial to a lake. This is all accomplished using only solar energy without toxic chemicals or land-based energy sources, making the SolarBee eco-friendly, energy efficient, and economical for long-term, sustainable benefits.

The implications and ecological benefits of controlling blue-green algae blooms through bio-manipulation rather than P control are just recently becoming better appreciated. The two flowcharts below summarize the ecological relationships associated with this evolving concept as described above. The first flowchart illustrates that the negative ecological consequences associated with blue-green blooms will occur regardless if the bloom dies naturally or killed by copper sulfate additions. It also shows that even if hypolimnetic oxygenation and/or alum were applied (eliminating the bottom left part of the flowchart), both blue-green blooms and most negative ecological consequences would still persist, albeit with reduced severity. The second flowchart shows that by eliminating blue-green algae blooms through habitat manipulation, not only are the negative symptoms of eutrophication minimized, the entire lake ecology significantly improves.





Appreciating these ecological linkages is the key to understanding how SolarBees can prevent eutrophication without controlling nutrient inputs. Although watershed management is very important for a large number of reasons, controlling P inputs to reduce eutrophication does not necessarily have to be one of them. In fact, many lake fisheries will actually benefit from P inputs directed into edible, non-blue-green algae. The SolarBee enhances natural ecological processes in lakes through horizontal and vertical circulation, benefiting the lakes, benefiting those who utilize the lakes, and benefiting those who would otherwise have to pay for expensive short-term treatment costs to mitigate the symptoms of eutrophication.

SolarBee®
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"Quality Water, Naturally"
http://www.solarbee.com

Christopher F. Knud-Hansen, Ph.D., CLM
Limnologist & Certified Lake Manager
SolarBee Division of Pump Systems, Inc.
11853 Pecos St., Westminster, CO 80234
(866) 469-9606 • (303) 469-9606 • Fax (303) 469-4701

Main Office and Service Center
SolarBee Division of Pump Systems, Inc.
530 25th Ave E, PO Box 1930, Dickinson, ND 58602
(866) 437-8076 • (701) 225-4495 • Fax (701) 225-0002

MEMORANDUM

To: SolarBee Personnel

From: Christopher F. Knud-Hansen, Ph.D., CLM

Date: October 5, 2005

Re: Relationship between algal biomass (chlorophyll *a*) and corresponding depletion of dissolved oxygen in the bottom waters of Cherry Creek Reservoir (Denver, CO) during the summers from 1987 – 1999.

Introduction

We have long understood the logic behind the premise that if inedible cyanobacteria (blue-green algae) blooms are eliminated in surface waters, then the amount of biochemical oxygen demand (BOD, represented by decomposing blue-green algae) accumulating in bottom waters is consequently reduced. By reducing the amount of BOD settling into bottom waters, the rate and amount of dissolved oxygen (DO) depletion in these bottom waters is also reduced – paralleling the concept of "a penny saved is a penny earned". Unfortunately, we have been missing a good data set to examine that relationship empirically. However, access to an excellent data set from Cherry Creek Reservoir has now filled that missing empirical link.

Below are charts describing data collected from Cherry Creek Reservoir (860 acres surface area, maximum depth about 30', located in Denver, Colorado) between 1985-1999. Data were collected by USGS and independent consultants contracted by the Cherry Creek Basin Water Quality Authority. Each point represents the seasonal (July-September) average of bi-weekly samples collected at up to three in-lake stations. During this period, increased urbanization in the watershed caused CCR to become increasingly more eutrophic.

Data Analysis

The graphs below show the steady and statistically significant ($P < 0.01$) increase in chlorophyll *a* over the period from 1987 to 1999 (Figure 1). Algal speciation data confirm that cyanobacteria (blue-green algae) dominated the summer algal community in Cherry Creek Reservoir.

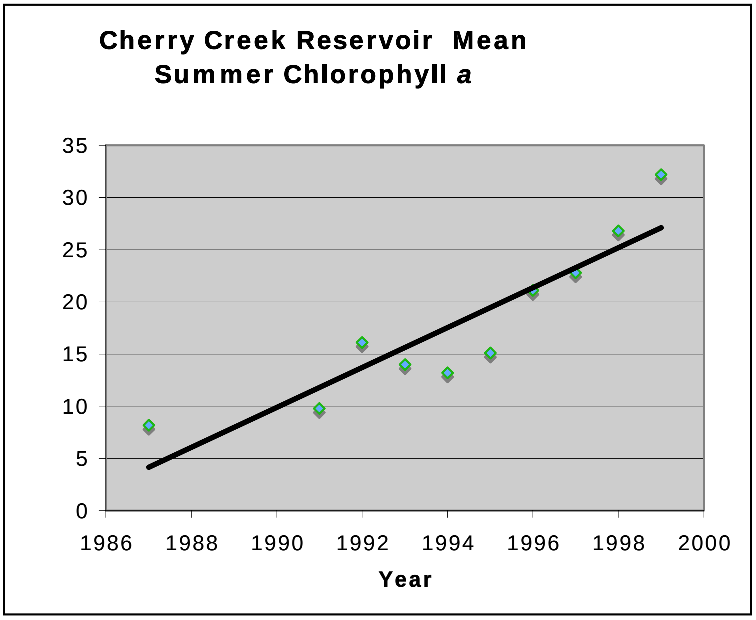

Figure 1. Statistically significant regression relationship ($r^2 = 0.60$, $P < 0.01$) of mean summer chlorophyll *a* concentrations in Cherry Creek Reservoir from 1987 – 1999.

Because blue-green algae are not readily edible by zooplankton and fish because of their intracellular toxicity and relatively large size, they settle to the bottom of the reservoir uneaten and are decomposed by bacteria and fungi. Figure 2 shows the corresponding decrease in DO concentrations in the bottom waters (1 m off the reservoir bottom) of Cherry Creek Reservoir during the summer months when the reservoir is thermally stratified.

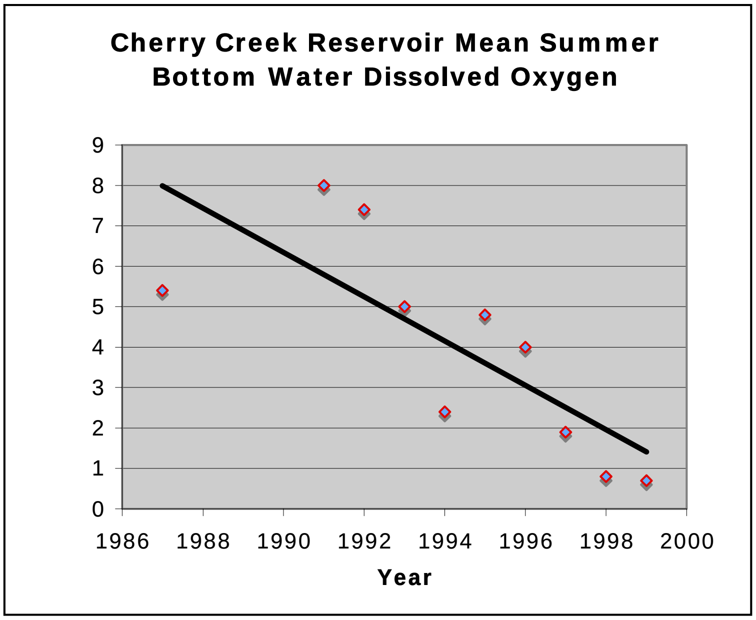

Figure 2. Statistically significant regression relationship ($r^2 = 0.77$, $P < 0.01$) of mean bottom water DO concentrations during July - September in Cherry Creek Reservoir from 1987 – 1999.

If in fact sedimenting blue-green algae are the primary source of BOD in the bottom waters of Cherry Creek Reservoir, then there should be a strong statistical correlation between mean chlorophyll *a* concentrations in the upper waters and bottom water DO concentrations. Figure 3 shows that there is a highly significant relationship ($P < 0.001$) between the two independently-measured variables. This means that there is less than a 1 out of a 1000 chance that the relationship below just happened by chance.

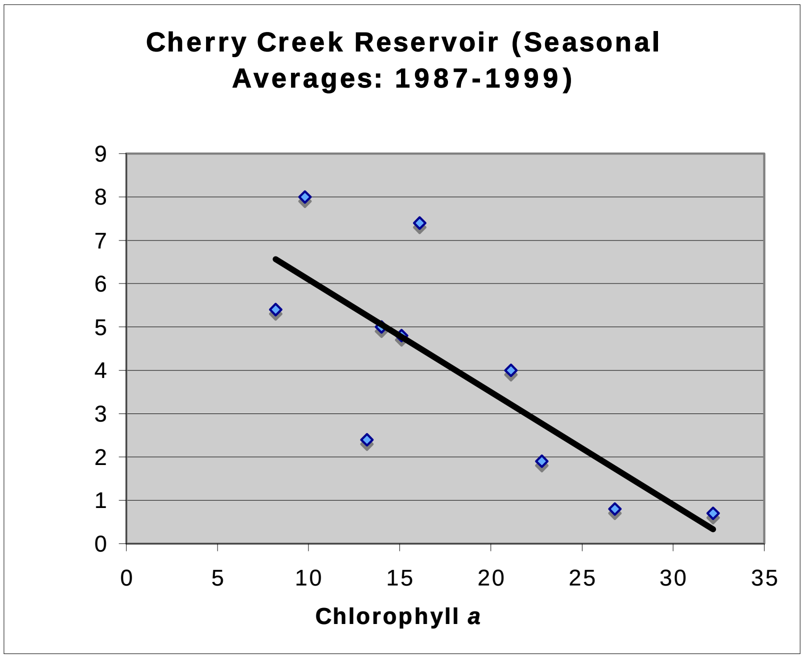

Figure 3. Statistically significant correlation relationship ($r^2 = 0.81$, $P < 0.001$) of mean summer chlorophyll *a* concentrations versus mean summer bottom water DO concentrations in Cherry Creek Reservoir from 1987 – 1999.

Therefore, the elimination of blue-green algae blooms should naturally improve bottom water DO concentrations in Cherry Creek Reservoir. There are other benefits as well. By eliminating blue-green algae's competitive advantage through habitat disturbance via circulation (see sample references below), nitrogen and phosphorus (algal nutrients) go into edible algae (e.g., chlorophytes, diatoms, etc.). These edible algae get eaten by zooplankton and fish, thus moving up the food chain and enhancing secondary productivity. Typical results include significant increases in water clarity, zooplankton populations, and fish vigor, while chlorophyll *a* and total phosphorus concentrations go down because of the decrease in algal biomass. As an example, Lake Palmdale, a 234-acre raw water and recreational lake in Palmdale, CA, had 7 SolarBees installed in 2003. Average chlorophyll *a* concentrations dropped from 13.5 ug/L to 6.6 ug/L, while average Secchi depths improved from 3 ft (maximum of 4 ft) to 6 ft (maximum of 14 ft). They also report significant increases in zooplankton (cladocera and copepods), fish spawning, and fish vigor. The Palmdale Water District is also saving about $60,000 per year by not having to use copper sulfate on the lake to combat blue-green algae blooms.

It is also useful to quote a section (page 1-6) from an Executive Summary written by Brown and Caldwell in 2000 on behalf of the Cherry Creek Basin Water Quality Authority:

"*Blue-green algae were consistently the most abundant algal group in the Reservoir. Zooplankton populations (which serve as grazers of algae) were comprised primarily of protozoans and rotifers during much of the summer. During late summer, periods of low zooplankton densities often correlated to periods, when phytoplankton densities and chlorophyll a concentrations were generally high. The fish community in the Reservoir has historically been dominated by gizzard shad, an effective zooplanktivore.*"

The gizzard shad fishery would greatly benefit from the elimination of blue-green algae blooms in Cherry Creek Reservoir because 1) increased zooplankton production would provide more food, and 2) the reduction of BOD inputs to bottom waters would keep these waters well-oxygenated as they used to be in the 1980s and mid-1990s. In fact, reductions in nutrient loading to Cherry Creek Reservoir since 1999 have helped stop the steady increases in chlorophyll *a* as seen in Figure 1. Consequently, bottom water dissolved oxygen concentrations have improved somewhat. In 2002, less that 9% of the lake's volume was below 5 mg/L. 2004 data show that bottom water DO concentrations remained above 2 mg/L and often around the 5 mg/L threshold. Since only 8% of the lake's volume is below 18' and DO concentrations are typically above 5 mg/L in waters above 18', there would be little benefit by mechanically adding DO in this lake – particularly if blue-green algae are still blooming unabated. SolarBee-induced circulation not only eliminates blue-green algae blooms, and thus the source of BOD to bottom waters, it has an additional benefit of keeping inshore sediments well-oxygenated and consequently improving fish spawning habitats. There is also empirical evidence that total coliform counts are reduced through constant exposure of circulated water to the sun's ultraviolet radiation.

Conclusion

Bottom water anoxia is often a consequence of blue-green algae blooms in surface waters that ultimately settle and decompose in the bottom waters. Data collected at Cherry Creek Reservoir since 1987 have provided a unique opportunity to empirically demonstrate that relationship. Recent improvements to the reservoir's watershed management and data collected since 1999 clearly show some improvements to both chlorophyll *a* concentrations and bottom water DO concentrations. Mechanically adding DO to bottom waters would have negligible benefits to the lake ecosystem, and would still not address the overriding problem of toxic blue-green algae blooms. However, by eliminating blue-green algae blooms through circulation, the reservoir would have 1) reduced chlorophyll *a* concentrations (likely below the 15 ug/L standard), 2) improved bottom water DO concentrations (likely maintaining concentrations above the 5 mg/L threshold), 3) increased zooplankton populations, 4) improved fish health and spawning, 5) and possible reductions in total coliform counts. By using SolarBees to create the necessary circulation, all the above benefits would happen without any land-based energy or unwanted chemical additions.

References related to the effect of circulation on blue-green algae bloom control:

Bailey-Watts, A.E. et al. (1987), An experiment in phytoplankton ecology and applied fishery management: effect of artificial aeration on troublesome algal blooms in a small eutrophic loch. *Aquaculture and Fisheries Management*, 18:259-276.

Harris, G. P. and G. Baxter (1996). Interannual variability in phytoplankton biomass and species composition in a subtropical reservoir. *Freshwater Biology*, 35: 545-560.

Huisman, J., et al. (2004), Changes in turbulent mixing shift competition for light between phytoplankton species, *Ecology*, 85(11): 2960-2970.

Reynolds, C.S. et al. (1983), Some effects of artificial mixing on the dynamics of phytoplankton populations in large limnetic enclosures. *J. of Phytoplankton Research*, 5: 203-234.

Visser, P.M. et al. (1996), Artificial mixing prevents nuisance blooms of the cyanobacterium Microcystis in Lake Niewe Meer, The Netherlands. *Freshwater Biology*, 36: 435-450.

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SolarBee®
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SOLARBEE PROPOSAL

Date: 10-6-05

To: **Bob McGregor**
Amec Earth and Environment
355 South Telller
Lakewood, CO 80226

From: Harvey Hibl, Regional Sales Manager, 303-469-4001

1. PROJECT DESCRIPTION

a. Facility or Reservoir Name: Cherry Creek Reservoir, 850 surface acres

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TIFF (LZW) decompressor
are needed to see this picture.

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b. Address or Location of Facility or Reservoir: 1 mile from the City of Centennial

c. Type of project, Wastewater, Fresh water, or Salt Water or Other: Fresh water, Reservoir for Flood Control and Recreation.

d. SolarBee Objectives:

- Decrease mean chlorophyll a concentrations
- Decrease peak chlorophyll a concentrations
- Increase dissolved oxygen concentrations at all depths
- Reduce nutrient concentrations at the bottom of the reservoir during the summer
- Reduce the fraction of blue-green algae
- Improve fish habitats

We are confident all of the above can be done without harming the existing uses of the lake and that the SolarBee system would compliment the Watershed based control measures to reduce the nutrient loadings to the reservoir.

e. Quantity of SolarBees Recommended and Brief Description of Recommended Deployment Method:

Qty 19, SB10000v12 units are recommended, units to be spaced on an approx. 45 acre spacing layout to minimize any surface impact, (units spaced approx. 0.28 miles apart from each other).

<u>SB10000v12 features:</u> 25 life brush-less electric motor design that provides day and night operation with a solar charged storage system, 3,000 Gallons per minute (GPM) direct flow up the 36” diameter x 12’ max depth intake hose and 7,000 GPM induced flow, for 10,000 GPM total flow leaving the machine in full sunlight. All units to have coast guard approved solar beacons and increased visibility kits.

2. PROVISIONS FOR PURCHASING THIS EQUIPMENT

a.1. Cost:

Quantity	Equipment Description	Purchase Cost each	Purchase Cost total
19	SB10000v12 units as described above	$ 37,900.00	$ 720,100.00
	Delivery, installation, and startup cost		$ 49,000.00
	Taxes		$ to be determined
	TOTAL PURCHASE COST		**$ 769,100.00** **+ tax**

Other options to be quoted at a later date:

- Wireless handheld monitor system for reading motor RPM, battery voltage, motor current and battery charging current.
- Service Contract to provide periodic checkups on the equipment.

b.0. Rental Provisions:

b.1. Monthly Rental Cost:

Rental cost for the SolarBee equipment shown above, per month	$ 19,900.00
Sales or other tax, per month:	$ to be determined
TOTAL RENTAL COST PER MONTH	$ 19,900.00 + tax

b.2. One-Time Delivery, Installation, and Startup Cost. The renter's cost for delivery, installation and startup is $ 49,000.00, plus any applicable state or local sales taxes. At the end of the rental period, if this rental is not converted to purchase, there is no charge for the factory retrieval of the equipment.

b.3. Monthly Invoices. The equipment rental cost will be invoiced in advance on the monthly anniversary of the installation for each month.

b.4. Length of Rental Period. The minimum rental term for this equipment is twelve (12) months. At the end of that period, this rental agreement shall continue on a month-to-month basis until either party cancels it according to the provisions found in this paragraph. The renter may cancel this agreement by notifying the owner in writing, or by fax, 30 days prior to the requested termination date. Rent will continue until the end of the 30-day notice period. The owner reserves the right to cancel this agreement by 30 days written or faxed notice to the renter. Furthermore the renter hereby authorizes the owner to re-possess the equipment at any time, without notice to the renter, if the renter becomes delinquent in rent payments.

b.5. Maintenance of the Equipment. The owner (PSI) is responsible for parts and labor costs caused by normal wear. The renter is responsible for all other parts and labor costs, including those caused by Acts of God. The renter is also responsible for relocating the machine(s) after wind events or ice movements, for unplugging any clogged strainer or impeller, or for making minor adjustments or repairs to the equipment as needed to maximize its effectiveness.

b.6. Rent Reduction Because of Equipment Malfunction. Malfunction of the equipment will result in a rent reduction if (1) the malfunction involves a mechanical failure of some component on the machine that causes the impeller of the machine to fail to rotate, and (2) the renter gives the owner notice of the parts needed to make the mechanical repair, and (3) the owner fails to repair the problem or supply the parts and a labor allowance to the renter within 7 business days of the notice from the renter. If a reduction of rent is allowed based on this provision, the owner shall issue a rental credit invoice showing the amount of the reduction according to these calculations: (a) the reduction shall apply only to that machine in need of repair and (b) the reduction shall be calculated based on the number of days that passed from when notice was received by the owner to the time when parts were supplied to the renter.

b.7. Option to convert the rental to a purchase at a later date. The purchase price of the rented equipment is shown above in the section on purchasing the equipment. If the renter desires to convert this rental to a purchase, the renter should request that the owner, at least 30 days before the desired purchase date, supply a firm quotation to convert the rental to a purchase. Title to rental equipment never passes to the renter unless and until all outstanding rental invoices and the actual purchase price for the equipment is received by the owner. If the conversion to a purchase is made within twelve (12) months of the date the equipment was installed, then sixty percent (60%) of the prior rental payments pertaining to this agreement will be credited to the purchase price. If the conversion to a purchase is made after twelve (12) months of the date the equipment was installed, then forty percent (40%) of the prior rental payments pertaining to this agreement will be credited to the purchase price.

b.8. Prorated Warranty if rental is converted to purchase. For any rental machines converted to a purchase, the prorated warranty remaining after the purchase is calculated as follows: Prorated Warranty Remaining = (Conversion Purchase Price / Original Purchase Price) X New Machine Warranty Period as shown in the owner's manual.

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3. ADDITIONAL PROVISIONS THAT APPLY TO ALL PURCHASES AND RENTALS:

a. Assumptions. This quotation may be based on worksheets and calculations which have been provided to the customer, either previously or else attached to this quotation. The customer should bring to our attention any discrepancies in data used for the calculations.

b. Length of time this offer is open. This quotation is valid for 60 days. The salesperson shown above can verify prices in effect after that time.

c. Delivery Time: Delivery time varies, but is usually within 6-10 weeks from order.

d. Delivery Method and Installation: PSI sends a team of at least two trained factory representatives to deliver, install, and place into operation each SolarBee unit. Additionally, the team will provide training to customer personnel on the operation and maintenance of the SolarBees

e. Payment Due Date: For governmental entities, and for homeowners associations that have pre-approved credit, payments are due 10 days after invoice date, and invoicing occurs upon completion of installation. For private individuals, payment is due by credit card or cashier's check before the machine is shipped.

f. Currency. All prices shown are in US Dollars, and all payments made must be in U.S. Dollars.

g. Add for Taxes, Governmental Fees, and Special Insurance Requirements. Except as indicated above, no taxes or tariffs or other governmental fees are included in the costs shown above, nor are any cost of special insurance coverage the customer may require. All local, state, and federal taxes, including, sales and use taxes, business privilege taxes, and fees of all types relating to this sale, whether they are imposed on either PSI or the customer, are the customer's responsibility to pay, whether these taxes and fees are learned about before or after the customer orders the equipment. The customer's purchase order should indicate any taxes or fees due, on equipment and services, and whether the customer will pay them directly to the governing body or else will pay them to PSI for PSI to send in to the governing body. Regarding insurance, the company maintains adequate liability and workman's compensation insurance to generally comply with its requirements for doing business in al fifty U.S states and will provide, at no charge, certificates of insurance when requested. However, if additional insurance or endorsements, beyond the company's standard policy, are required by the customer, then the costs of those additional provisions and/or endorsements will be invoiced to the customer after the costs become known.

h. Maintenance and Safety. The customer agrees to follow proper maintenance instructions regarding the equipment as contained in the safety manual that accompanies the equipment or which is sent to the customer's address, or which is available to the customer on the internet. If the customer uses the SolarBee circulator in an area where any water or ice recreation exists, or may occur, the customer takes all responsibility for operating the SolarBee machines in a manner that creates conditions which are safe for such traffic

i. Government Regulatory Compliance. In wastewater systems the customer must comply with applicable governmental wastewater regulations. In fresh water lakes, there may be local, state, and/or federal (such as the USCG and USACE, in the US) guidelines and regulations pertaining to safety, proper placement, marking, and maintaining of aids to navigation and to the ecology, such as the SolarBee. It is the customer's sole responsibility to inquire about such regulations and ensure that SolarBees are deployed and maintained so as to remain in compliance with these regulations and guidelines, and to hold PSI harmless from any liability caused by non-compliance with these regulations and guidelines.

j. Warranty and Liability. The parts and labor warranty for each machine is in the owner's manual, which can be provided upon request and which, in most cases, is also available on the internet at solarbee.com. There is no liability to PSI for any consequential damages of any kind, nor is there any warranty of fitness of purpose, or warranty of merchantability, and there are no other warranties, express or implied.

k. Method of acceptance of this quotation. To accept this quotation, please issue a purchase order to Pump Systems, Inc., Box 1940, Dickinson, ND 58601. The purchase order can be mailed, or it can be faxed to 701-225-0002 at the home office, or it can be faxed to the salesperson listed at the top of this quotation. The purchase order should refer to the date of this quotation, and will be assumed to include this entire quotation by reference.