BROWN AND CALDWELL

Cherry Creek Basin
Water Quality Authority

Technical Memorandum

Conceptual Investigation of Reservoir Destratification For Cherry Creek Reservoir

May 4, 2004

1. INTRODUCTION

1.1. Problem Definition

The Cherry Creek Basin Water Quality Authority (Authority) has been implementing watershed-based, best management practices (BMP) and constructing pollution reduction facilities (PRF) for many years. However, the chlorophyll *a* standard (15 µg/l) and phosphorus goal (40µg/l) have not been met. The recent special study[1] of in-lake nutrient enrichment 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 water quality benefits are seen in Reservoir.

As a result, the Authority is considering in-lake management techniques that could be beneficial to reducing chlorophyll *a*, as well as nutrients and 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. However, watershed management is a necessary component of the Watershed Plan 2003[2] and both BMPs and PRFs will continue to be implemented.

1.2. Scope of Investigation

Investigations for this technical memorandum are limited to methodologies that address internal loading of the Reservoir, as the control of external loading is addressed by Watershed Plan 2003. The evaluation of destratification will provide sufficient information to include the project in the Authority's Capital Improvement Program (CIP), if appropriate, by using a similar level of analysis used for other PRFs included in the Authority CIP projections.

2. LITERATURE REVIEW

Information regarding destratification (i.e., mixing) was obtained and reviewed for applicability to Cherry Creek Reservoir. An annotated bibliography is attached to this Technical Memorandum. Some of the documents, which address lakes and reservoirs on the Front Range that use some type of in-lake management, are described further in Section 3 - Local Experience. Basic information about benefits and possible negative impacts of destratification are discussed below.

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[1] Lewis, Willam M. Saunders, James F III, and McCutchan, James H. Jr. January 22, 2004. *Studies of Phytoplankton Response to Nutrient Enrichment in Cherry Creek Reservoir, Colorado.*
[2] Cherry Creek Basin Water Quality Authority 2003. *Cherry Creek Reservoir Watershed Plan 2003.*

Important aspects of destratification are noted below:

- Lakes get much of their oxygen from the atmosphere through the process of diffusion. Destratification increases the volume of the Reservoir that is exposed to the atmosphere.
- The most common techniques for destratification are air injection or diffusion, which induces vertical mixing by slow currents.
- A second common method is mechanical mixing, which includes axial flow pumps, surface spray, impeller-aspiration, and pump and cascade.

Most of the effects of destratification and circulation are beneficial and include:

- Increase in dissolved oxygen through the water column, which improves fish habitat, benthic diversity, and reduces the solubulization of nutrients, ammonia, heavy metals, and other compounds from sediment, preventing them from causing "internal pollutant loads."
- Mixing reduces algal growth by either reducing its exposure to light,, by changing in-lake chemistry (i.e., pH, carbon dioxide), or by mixing of algae-grazing zooplankton to provide greater feeding opportunities.

Possible negative impacts from destratification:

- Increase in the bottom temperature of Reservoir, which can affect cold-water fishery.
- Increase oxygen demand at greater depths.
- Change in current balance of aquatic life and fish production.

3. LOCAL EXPERIENCE

More detailed information was obtained for three local lakes and reservoirs that either use or have investigated in detail the use of in-lake management to control water quality. These include Bear Creek Lake, McClellan Reservoir, and Standley Lake.

3.1. Bear Creek Lake

The following information was obtained from the annual report for Bear Creek Lake:[3]

> The City of Lakewood maintains an aeration system in Bear Creek Reservoir as a water quality enhancement, best management practice consistent with the Bear Creek Reservoir Control Regulation. This aeration system increases the amount of dissolved oxygen in the water column to protect the existing fishery.
>
> The original aeration system (1993) was designed to oxygenate the water column through a series of anchored towers at an estimated capital cost of $343,000 and O&M of $30,000. This hypolimnetic aeration system did not cause destratification of the water column. The system was supplemented with the Dura-Venturi system, which was installed in 1999.

[3] RNC Consulting June 2003. *Bear Creek Watershed Report 2002: Annual Report & Water Quality Summary Sheets.*

Beginning in 2002, the aeration system began to structurally fail from continued freezing in the winter, which resulted in minimal oxygen transfer efficiency. Consequently, the City of Lakewood bid and installed a new complete aeration system in early fall of 2002 by ASI (capital cost of $48,000). The ASI system has greater coverage throughout the reservoir and much high oxygen transfer potential. Key features of the ASI aeration system include:

- Eleven Air Diffusion Systems LTC Stainless Steel Modules
- Six Dura-Venturi aerators (From previous installation)
- 22 Million gallon per day per Module pumping rate
- Approximately one complete reservoir turnover every 3 days

The aeration system is expected to:

- Increase dissolved oxygen concentrations throughout the entire water column
- Increase availability of habitat for all fish species (warm and cold)
- Result in pH values that are homogenous and stabilized and cause water column temperatures to be more homogenous throughout the entire water column

3.2. McClellan Reservoir

The McClellan Reservoir is owned and operated by the Centennial Water & Sanitation District as a drinking water source. Mr.Paul Grundeman, Centennial WSD (303.791.7181) provided the following information:

- The mixing system using aeration was installed about 20-years ago. The reservoir is about 80-feet deep at the aeration point and contains 6,000 af. The problem was solubilization of pollutants due to reducing conditions in the anoxic hypolimnion that was suspending iron, hydrogen sulfide and manganese.
- The system consists of a single, 100 SCFM compressor, 2 or 3" diameter polyethylene feeder line anchored to the bottom with concrete blocks (and other means), and a 250-ft header with 1/8" diameter holes spaced at 5-ft to introduce air. It has been run 24/7/365 with minimal problems. A copy of the design drawings was provided to the Authority.
- Sampling has shown that the reservoir stays mixed.
- O&M is minimal, consisting of electricity, unit maintenance, and staff. No problems to date with the distribution system.

3.3. Standley Lake

In 1996, a nutrient control study was conducted for Standley Lake to evaluate methods for controlling the in-lake contribution of nutrients available for algal growth. The study recommended three aeration systems for preliminary design and further analysis. No system has been implemented to date.

Standley Lake, which provides water to Thornton, Northglenn, and Westminster, is believed to be co-limited by phosphorus and nitrogen (the maximum depth is 96 ft at the dam and the surface area is 135 acres). The study included an initial screening of 14 in-lake control strategies (e.g., aeration, alum, circulation, etc.) and 5 inflow control strategies (e.g., treatment wetlands, sedimentation pond,etc.). The study recommended the Speece Cone, diffuser line, and partial lift aeration systems be considered for preliminary design and further analysis. However, there was concern that if efforts were not made in the upper basin to reduce nutrients that the aeration would mask symptoms from nutrient impacts. The operating cities have since considered moving the lake intake to build wetlands and/or sediment detention ponds. However, there wasn't a large enough area for the wetlands needed and an evaluation of sediment ponds concluded that removing the sediments resulted in more algae growth, because of more light penetration. The operating cities are currently considering an option to route stormwater around Standley Lake.

4. ALTERNATIVES

Table 1 includes a list of in-lake management techniques and a brief summary of how they work and how they can improve water quality. This list, which is not exhaustive, is presented for consideration by the Authority to investigate other alternatives in more detail than presented in this Technical Memorandum.

5. CONCEPTUAL DESIGN AND COST ESTIMATE

Two vendors who provide consulting and products for lake and reservoir management were contacted and requested to provide conceptual level cost analysis to destratify Cherry Creek Reservoir. The following conceptual design and cost estimate is of similar detail as other PRFs that have been included on the Authority's CIP list.

5.1. Keeton Industries

Keeton Industries proposal (see Appendix A) uses the air-injection approach (bottom air-lift diffuser) as the technique to mix the Reservoir. The proposed system consists of four air compressors that deliver air through feeder lines to fine-bubble membrane diffusers. The system is anchored with concrete blocks. The feeder lines and diffusers are designed to be fish-hook resistant. The proposal by Keeton Industries has a projected capital cost of $360,000, which does not include power requirements.

Brown and Caldwell performed an additional cost-analysis to estimate probable cost per pound of phosphorus to install and operate the Keeton Industries system over a long period. The analysis included additional capital costs for power installation, annual operating and maintenance costs, and capital replacement costs.

The system was assumed to operate 24 hours a day from the middle of April through September (165-days). Capital replacement costs were based on the stated warranty periods for various components of the system and included the compressor, the feeder/diffuser system and the housing units.

To estimate the reduction in pounds of phosphorus, it was assumed that the system would reduce in-lake phosphorus concentrations from the current average level (i.e., 75-µg/l) to the phosphorus goal (40-µg/L). This assumption resulted in an annual reduction of about 1,320-pounds of phosphorus.

Calculations and assumptions are provided in Appendix A. A summary of the cost is presented in Table 2. The analysis assumes an interest rate of 7 % for a period of 35-years, which is the same as assumed for all other projects considered for the Authority's CIP. Note that there are additional costs anticipated, which are discussed in Section 5.3 below.

Table 1 – Alternatives for In-lake Management of Water Quality

In-Lake Management Strategy	Description	Mechanism for Water Quality Benefits
Air-injection (Diffuser) System	Uses an on-shore compressor that delivers air through lines connected to perforated pipes, barrels or pan diffusers placed in the deep area of the lake. Rising air-bubbles cause water in the hypolimnion to rise, pulling water from the hypolimnion to the epilimnion. The colder water than spreads out across the surface.	Increase in DO through water contact with the atmosphere caused by mixing.
Impeller-Aspirator	Consists of an electric motor-drive impeller at the bottom of a hollow shaft extending at an angle down into the water. The assembly floats on the surface. The rapidly turning impeller draws air down the shaft and propels water and air bubbles into the lake.	Increase in DO takes place through air bubble/water contact and at the agitated lake surface.
Mechanical Axial Flow Pumps	Use a "top-down" approach to set up circulation patterns. A flotation platform and frame support an electric motor, gearbox, drive shaft, and large propellers (6-16 foot diameter). The propeller is suspended a few feet below the surface. Its rotation pushes water from the lake surface downward, setting up a circulation pattern. The SolarBee® system is similar except it uses solar power to run the propeller and the propeller draws water up to the surface, rather than forcing water to the bottom.	Increase in DO through water contact with the atmosphere caused by mixing.
Side Stream Pumping Systems	Hypolimnetic water is pumped onto shore, injected with oxygen, then discharged back into the hypolimnion.	Increase in DO through oxygenation of hypolimnion
Deep Oxygen Injection System	Injection of pure oxygen through a network of diffusers at the lake bottom.	Uses the air-lift method to bring low DO water to the epilimnion, where it stops due to similar density and spreads out through the epilimnion. Also relies on oxygen transfer to increase DO.
Submerged Contact Chamber Systems	A rectangular chamber suspended in the hypolimnion from a raft. The chamber has baffle dividing it into two sides. On one side, oxygen is discharged at the base of the chamber from diffusers fed from an on shore liquid oxygen facility. Water is lifted up one side of the chamber, over the baffle, then discharged into the hypolimnion from an outlet at the bottom of the other side. One variation of this approach is referred to as the Speece Cone, which was investigated for Standley Lake. Another variation was initially used at Bear Creek Lake and replaced by the air-injection, bottom diffuser system.	Relies primarily on oxygen transfer to increase DO.
Periodic Alum Application	Alum is applied over the portion of the lake, which is 5-feet or greater in depth using a specially designed barge fitted with surface application, spray bars.	The floc reacts with phosphorus to form a relatively inert compound. As the floc settles, some particulate phosphorus is also removed in the water column. On the lake bottom, the floc forms a layer blocking release of phosphorus from sediment

Table 2 – Analysis of Probable Costs for Air-Diffuser System

Component	Capital Cost	Annual Cost
Compressor, feeder lines, diffusers, and unit housings, 4-each	$360,000	$27,700
Power, 4-locations	$40,000	$3,100
Operation and maintenance		$7,000
Capital replacement		$10,900
Subtotal		**$48,700**
Cost per pound of phosphorus		$37

5.2. Pump Systems Inc

A proposal by Pump Systems Inc., forthe SolarBee® mixing system, provides planning level costs for application at Cherry Creek Reservoir(Appendix B). Option 1 costs address the basic requirement for mixing and option 1A costs address requirement for both mixing, reduction in phosphorus and increase in dissolved oxygen concentration in a more direct manner. Option 1 costs were used for comparison.

The SolarBee® is a solar powered circulator that floats on the surface and requires no external electrical power. The machine is 16-foot in diameter and can draw up to 10,000 gallons per minute from below and spread the flow across the top in near laminar conditions. Each machine can circulate flow up to 50-acres of surface area. Due to recent improvements in the motor, the system can operate 24-hours a day, although it is solar powered.

The manufacturers information notes that installation is simple and does not require a contractor. Also, there is a two-year parts and labor warranty and the machines can be purchased, lease purchase or rent to own basis.

Brown and Caldwell performed an additional cost-analysis to estimate probable cost per pound of phosphorus to install and operate the SolarBee® system over a long period. The analysis included additional capital costs for power installation, annual operating and maintenance costs, and capital replacement costs.

The system was assumed to operate 24-hours a day from the middle of April through September (165 days). Capital replacement costs were based on the stated warrant periods for various components of the system and included the motor, impeller and housing unit.

To estimate the reduction in pounds of phosphorus, it was assumed that the system would reduce in-lake phosphorus concentrations from the current average level (i.e., 75-µg/l) to the phosphorus goal (40 µg/l). This assumption resulted in an annual reduction of about 1,320-pounds of phosphorus.

Calculations and assumptions are provided in Appendix B. A summary of the cost is presented in the Table 3. The analysis assumes an interest rate of 7 % for a period of 35-years, which is the same as assumed for all other projects considered for the Authority's CIP. Note that there are additional costs anticipated, which are discussed in Section 5.3 below.

Table 3 – Analysis of Probable Costs for Mixing System

Component	Capital Cost	Annual Cost
SB 10000Fv, 12-units	$495,190	$38,100
Operation and maintenance		$1,000
Capital replacement (25-yr)		$7,900
Subtotal		**47,000**
Cost per pound of phosphorus		$36

5.3. Additional Cost Considerations

In addition to the capital, operation and maintenance, and capital replacement costs discussed above, other costs to consider include the following:

Other Capital Costs. There may be other incidental capital costs, such as requirements to provide adequate boater-safety devices around each of the units place in the Reservoir.

Technical Feasibility. Additional investigation into other alternatives and a more comprehensive analysis, design and cost estimate may be appropriate before final design and commitment of funds is made. A technical feasibility scope and budget can be prepared, if requested, and could cost from $50,000 to $75,000.

Final Design. Depending on the system selected for implementation, final design and construction supervision could cost from 10% to 15 or as much as 20% of the capital costs.

Public Comment. Since any in-lake management system may impact recreation on the lake, a public comment process should be considered. The process could involve several meetings during the technical feasibility or final design phase to obtain and address comments and concerns. Cost for the public comment process can vary considerably, but a similar program for Cottonwood Creek was estimated at $15,000.

Agency Coordination. As part of the technical feasibility or final design process, coordination with state and federal agencies is required. The agencies include, but may not be limited to, Colorado Division of Parks, Colorado Division of Wildlife, the U.S. Army Corps of Engineers, and the U.S. Environmental Protection Agency. It is possible that some type of permitting will be required. Due to the sensitive nature of in-lake management for Cherry Creek Reservoir, a budget of 100 or more hours may be appropriate for conceptual-level, cost estimation purposes.

Project Administration. This is the cost to the Authority to administer feasibility studies, final design and construction supervision. For budget estimation purposes, a value of 3- to 5% of the capital costs is often used to address project administration.

Contingency. Contingencies are often added to cost estimates with the amount depending on the type of estimate (i.e, conceptual, preliminary, and final design based). Contingencies are meant to cover unanticipated costs, but also provide a margin for other “know” costs. Contingencies for conceptual level analysis are typically in the range of 20-to 25% or higher, depending on the level of confidence in the analysis.

Monitoring. It may be appropriate to increase the amount of sampling and monitoring to verify the results of specific in-lake management techniques. However, we believe the existing monitoring plan is sufficient to identify mixing, dissolved oxygen and phosphorus concentrations in the Reservoir.

6. FINDINGS AND RECOMMENDATIONS

In-lake management to control water quality is a technique that has been used for over 30-years in lakes of all sizes throughout the world. from a few acres to over several thousand acres. Destratification and aeration is used in local lakes (e.g., Bear Creek Lake, McClellan Reservoir, Coors lakes and Quincy Reservoir) with varying degrees of success and complexity of the systems. The simplest systems seem to perform with greater reliability than more complex systems.

We recommend the following actions because there is sufficient evidence that Reservoir destratification provides water quality benefits at a reasonable cost:

1. Review the possibility of using destratification with the staff of the Water Quality Control Division as one measure to achieve Reservoir standards, in conjunction with watershed management, to obtain their concurrence, suggestions and recommendations.

2. Include Reservoir destratification in the Authority's 3-year capital budget projections.

3. Include in the Authority's capital funds to conduct a feasibility analysis of methods for Reservoir destratification and prepare preliminary design and costs estimates. Suggested items for the scope of work include:

    a) Identify and evaluate design objectives for destratification, such as no-periods of potential stratification, reduction in chlorophyll *a* and nutrient concentrations, increased dissolved oxygen concentrations and others as appropriate.

    b) Identify and evaluate alternatives, including all costs for destratification.

    c) Coordinate with agencies directly impacted by the concept, including but not limited to the Colorado Division of Parks, Colorado Division of Wildlife, the U.S. Army Corps of Engineers, and the U.S. Environmental Protection Agency. Identify constraints and issues with destratification.

    d) Conduct public meetings to identify issues and constraints. Coordinate directly with various associations involved in recreation uses of the Reservoir.

    e) Prepare an economic analysis of 2 or 3 mixing alternatives that includes capital, operation and maintenance, capital replacement and other costs identified in the analysis.

    f) Recommend one alternative for consideration by the Authority. Work with the Authority to select an alternative for preliminary design.

    g) Prepare preliminary design, construction specifications, and final cost estimate for the selected alternative.

Annotated Bibliography
Conceptual Investigation of Reservoir Destratification

Aqua Sierra, circa March 2001. *ADS Aeration System Upgrade for Bear Creek Reservoir, Morrison Colorado*	Proposal to replace the hypolimnetic aeration system with an air diffuser system. 11 each, 4-ft diameter, ADS pan type diffusers 13,000 lf of feeder tubing. Turnover rate of 242 mgd results in one turnover every three days. Cost = $48,000
Arber, Richard P. and Associates, May 1992. *Bear Creek Reservoir In-Lake Treatment Plan and Conceptual Design.*	Water quality problems related to trophic status, algal blooms, decomposition and low O_2 Investigation of alternative in-lake treatment systems. Determination of best system for Bear Creek Reservoir Conceptual Design and estimate of costs. Due to need to increase O_2, both hypolimnetic aeration and destratification techniques were recommended. Objective of system also reduction of internal P loading. Total capital costs = $343,000, O&M $30,000
Beutel, Marc and Horne, Alex 1999. *A review of the Effects of Hypolimnetic Oxygenation on Lake and Reservoir Water Quality.*	Investigation into a wide range of system types and lake/reservoir sizes shows that hypo-limnetic, oxygenation results in numerous water quality benefits, including reducing of nutrients and other problem compounds from sediment.
CH2MHill ca 1996. *Standley Lake Nutrient Control Study.*	Identified and evaluated potential methods for controlling nutrient loading within Standley Lake, including watershed and in-lake techniques. In-lake techniques included Speece Cone and Diffuer Line Oxygenation, Full and Partial Air lift, and Alum Application. The recommendation was to install the Speece Cone Oxygenation system with a capital cost of $1,300,000 and O&M cost of $130,000.
Ecosystem Consulting, Inc., November 1993. *Bear Creek Reservoir Aeration System Aerator Operation and Maintenance.*	This firm awarded the contract to provide 3-hypolimnetic towers with oxygen diffuser chambers made from fiberglass. This is the O&M manual.
Illinois Environmental Protection Agency, Nov 1997. *Lake Aeration and Circulation.* <u>Lake Notes</u>	Two techniques for destratification are air injection and mechanical mixing, which includes axial flow pumps, surface spray, impeller-aspirator, and pump and cascade. During mixing, some algae species (e.g. diatoms) that tend to sink quickly will remain suspended, enhancing their growth.
RNC Consulting, June 2003. *Bear Creek Watershed Report 2002: Annual Report & Water Quality Summary Sheets*	*The City of Lakewood maintains a reservoir aeration program. This aeration system increases the amount of dissolved oxygen throughout the water column. The program helps support the fishery goal of the Association for the reservoir. This aeration effort has proven to be a successful management practice and the continued operation is necessary to maintain quality in the reservoir. The aeration system was replaced with a more efficient system that is designed to destratify the reservoir water column and introduce more uniform aeration within the reservoir main pool.*
Stenstrom, M.K. August 29, 2001. *2001 Oxygen Transfer Report Clean Water Testing.*	Laboratory testing of air diffusion systems (ADS) to determine O_2 transfer efficiency as a function of ADS submergence. Report provides basis for sizing ADS system recommended by Aqua Sierra (see below)

Appendix A
Keeton Industries Proposal

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

RESERVOIR DESTRATIFICATION CALCULATIONS

Keeton Industries – Air Injection (Diffuser) System

1. Other Capital Costs

- Power to four locations: 4-each at $10,000 = $40,000

2. Operations and Maintenance

- Power Requirements – 25-Hp motor x 0.746 = 18.7 Kw

- Summer Stratification Period

  - Run 24-hours/day during summer months where potential stratification can occur
  - Monitoring Data: Chadwick 2003 Annual Nutrient Monitoring Report.

  - At CCR-1:
    - End of May to end of August

Middle of August to end of September

  - At CCR-2
    - 2 weeks in later April to early May
    - June to 3rd week in July
  - At CCR-3
    - 2 week in later April to early May
    - June to 1st week in July
    - 2 weeks in later September

  - Critical Period: April 15 to October 1 = 165 days

- Demand: 18.7 kw x 165 d x 24 hr/d = 74,000 Kw-h

- Cost: 74,000 Kw-h x $0.08/Kw-h = $6,000/year

- Other O&M:
  - Labor, parts, materials to maintain building and operate system: $1,000

- Total O&M $6,000 + $1,000 = $7,000

3. Capital Replacement Costs

- Compressor Replacement

- 10-year warranty on compressor, four units
- Assume $10,000 each unit = $40,000
- Sinking fund factor at 7% for 10-years = 0.072
- Annualize cost: $40,000 x 0.072 = $2,900 (rounded)

■ Air Delivery System

- 5-year warranty, four systems
- Assume $10,000 for each system = $40,000
- Sinking fund factor at 7% for 5-years = 0.174
- Annualized cost = $40,000 x 0.174 = $7,000 (rounded)

■ Building and Other Appurtenance

- 25-year life, four buildings
- Assume $10,000 for each building = $40,000
- Sinking fund factor at 7% for 25-year = 0.016
- Annualized cost = $40,000 x 0.016 = $1,000 (rounded)

4. Estimate of Phosphorus Reduction

■ Average TP concentration over period of record: = 75µg/l.
■ TP goal of 40-µg/l
■ Reservoir Volume: 13,900 af
■ Phosphorus in Reservoir: 13,900 af x 0.075 mg/l x 2.72 = 2,840 lbs
■ Assume system reduce average TP to meet goal. Then pounds of phosphorus removed is Delta P = 13,900 af x (0.075 – 0.040 mg/l) x 2.72 = 1,320 pounds

5. Total Annualized Cost

Analysis of Probable Costs for Air-Diffuser System

Component	Capital Cost	Annual Cost
Compressor, feeder lines, diffusers, and unit housings, 4-each	$360,000	$27,700
Power, 4-locations	$40,000	$3,100
Operation and Maintenance		$7,000
Capital Replacement		$10,900
Sub-Total		$48,700
Cost per pound of P		$37

Keeton Industries

QUOTE #: 99315979

P O BOX 249, 13751 N. CR 11
Wellington, CO 80549
Phone: (970) 568-7754 www.keetonaqua.com
Fax: (970) 568-7795 www.keetonaquatics.com

DATE: 5/4/2004

BILL TO INFORMATION	SHIP TO	CONTACT
BILL RUZZO	CHERRY CREEK LAKE	**PHONE #** (303) 985-1091
6641 W. Hamilton Drive	850 ACRES	**FAX #**
LAKEWOOD CO 80227		**EMAIL** bill.ruzzo@attbi.com

PO NUMBER	TERMS	SALES PERSON
		RUSS JAMES

SUBSURFACE AERATION SYSTEM ROUGH ESTIMATE FOR CHERRY CREEK LAKE 850 ACRES---------4 INDEPENDENT SYSTEMS
WITH 40 DIFFUSERS OFF EACH SYSTEM

ITEM ID	DESCRIPTION	QTY	PRICE AMOUNT
CUSTOM	CUSTOM SUB-SURFACE AERATION SYSTEM---(4) MODEL LS100-25H ROTARY SCREW COMPRESSORS 106 ACFM CAPACITY 460-60-3, (160) FINE BUBBLE MEMBRANE DIFFUSERS --FISH HOOK RESISTANT		
	(4) 40 VALVE & FLOWMETERED MANIFOLDS FOR BALANCING AIR, (4) COMPRESSOR HOUSING SHEDS FULLY VENTILATED, 200000' SELF WEIGHTED FISH HOOK RESISTANT AIR FEEDER LINE, FULL FITTINGS PACKAGE, 5 YEAR WARRANTY--INSTALLED	1	$360,000.00

We are pleased to submit the above quotation for your consideration.
Should you place an order, be assured it will receive our prompt attention.
This quotation is valid for 30 days, thereafter it is subject to change without notice.

Sub Total:		$360,000.00
SalesTax:	0.00%	$0.00
Freight:		$0.00
Total		$360,000.00

Accepted by: Date:
Please return signed copy when ordering.

Appendix B
Pump Systems Inc. Proposal

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

RESERVOIR DESTRATIFICATION CALCULATIONS

Pump Systems Inc. – SolarBee® Mixing System

6. Other Capital Costs - None

7. Operations and Maintenance

- Inspection and minor repair of units: $1,000

8. Capital Replacement

- Life expectancy: 25 years
- Assume 100% replacement at 25 years
- Sinking fund factor at 7% for 25 years = 0.016
- Annualized costs: $495,190 x 0.016 = $7,900 (rounded)

9. Estimate of Phosphorus Reduction

- Average TP concentration over period of record: = 75μg/l.
- TP goal of 40 μg/l
- Reservoir Volume: 13,900 af
- Phosphorus in Reservoir: 13,900 af x 0.075 mg/l x 2.72 = 2,840 lbs
- Assume system reduce average TP to meet goal. Then pounds of phosphorus removed is Delta P = 13,900 af x (0.075 – 0.040 mg/l) x 2.72 = 1,320 pounds

10. Total Annualized Cost

Analysis of Probable Costs for Air-Diffuser System

Component	Capital Cost	Annual Cost
SB 10000Fv, 12-units	$495,190	$38,100
Operation and Maintenance		$1,000
Capital Replacement (25-yr)		$7,900
Sub-Total		47,000
Cost per pound of P		$36

May 5, 2004

Cherry Creek Basin Water Quality Authority

C/o Bill Ruzzo

6641 West Hamilton Drive

Lakewood, CO 80227-5335

Dear Bill,

We at SolarBee/Pump Systems are very pleased to present to the Cherry Creek Basin Water Quality Authority for your review our proposal for resolving many of the critical environmental problems identified for Cherry Creek Reservoir (CCR) through the application of the SolarBee solar-powered water circulator.

Background: Cherry Creek Reservoir (CCR) is a 850 surface acre flood control and recreational lake located in Denver, CO. CCR can be fairly characterized as a eutrophic, nitrogen (N)-limited lake. Summertime chlorophyll *a* concentrations routinely exceed 30 ug/L, soluble phosphorus (P) concentrations are relatively high, and Secchi depth transparency is typically less than 1 m. Although N-limited, the control of phosphorus (P) availability in CCR is critical for long-term control of algal growth. The fact algal growth is limited by N availability raises an additional concern for cyanobacteria (blue-green algae) blooms in CCR. Certain blue-green species (e.g., Anabaena, Aphanizomenon, and Microcystis species) are known for the intracellular toxins they produce which can render a water body dangerous for bodily contact.

Recommendation: Given the water quality issues identified for CCR and CCR's morphological characteristics, we recommend twenty (20) SB10000F solar powered circulators be installed to resolve the above problems. Thirteen (13) SolarBees would be required to eliminate blue-green algae blooms, while an additional seven (7) SolarBees would be necessary to maintain an oxic sediment-water interface in the hypolimnion while at the same time preventing blue-green algae blooms in surface waters. Please refer to the attached Excel spreadsheet we used to determine specific SolarBee requirements for CCR.

SolarBee Placement: The two main variables regarding SolarBee installations are locations of the units and the depth of the intake hose. For blue-green algae control, machines are placed at approximately 50 acre spacing and the intakes can be set so that only the upper portion of the water column is mixed. For hypolimnetic oxygenation, however, the intake hose is kept a few feet off the bottom (there is bottom plate to prevent sediment uptake into the SolarBee hose). SolarBee spacings for this application are closer together to accommodate the greater volume of water. In a situation like CCR where there may be multiple objectives, SolarBees can be strategically placed to accomplish multiple tasks wherever possible.

SolarBee Benefits specifically for Cherry Creek Reservoir: The SolarBee is uniquely capable of resolving the blue-green algae, internal P loading, and seasonal fish kill problems without the use of chemicals or land-based energy sources. The mechanisms and a summary of benefits are described below:

- Blue-green algae blooms can be eliminated by disrupting surface water stability – an important ecological requirement for blue-green bloom development. The surface water stability is disrupted by the physical transport (both vertically and horizontally) of water moved by the SolarBee. We have been successful in all 30+ lakes and reservoirs where SolarBees were installed for this purpose (including drinking water reservoirs for the Colorado cities of Thornton, Englewood, Conifer, Hotchkiss, Louisville, and Lafayette as well as other freshwater lakes including ones in Loveland, Longmont, and Pueblo). We would be happy to provide you contact information for these and other clients to remove any doubts that vertical mixing achieved by the SolarBee is indeed effective at eliminating blue-green algae blooms. This control mechanism has proven effective where bubblers, diffusers, and other means of lake aeration have been incapable of controlling blue-green blooms. The surface water turbulence created by such machines is both insufficient and too localized to impact the whole lake.

- SolarBees can be set to distribute and maintain high DO throughout bottom waters. They have proven effective at transporting photosynthetically-produced oxygen from surface waters down to the entire lake's bottom by whole-lake mixing. SolarBees can prevent the release of soluble phosphorus from lake sediments by facilitating natural adsorption and precipitation processes without the need for alum (aluminum sulfate) additions for binding soluble phosphorus. This mixing and hypolimnetic oxygenation would also prevent seasonal fish kills.

- Water clarity is typically increased through improvement of natural food web interactions.

- SolarBees require only solar power, eliminating the need for costly (for equipment, operation and maintenance) land-based energy sources or noisy power generators. The energy to drive the motor and impeller is generated with three 85 watt solar panels that operates from sun up to sun down. SolarBees have SCADA capability and additional battery backup.

- SolarBees circulation provides continuous surface renewal, thus exposing the entire water column to ultra violet (UV) rays that are known to destroy harmful pathogens that are often a public health issue in recreational lakes with body contact. Exposure to UV rays also destroys hosts responsible for swimmer's itch and swimmer's ear.

- SolarBees disrupt the surface tension in stagnant areas that are favorable habitats for mosquitoes, thus reducing their ability to survive and propagate.

Public Safety Issues: The SolarBees have been placed in lakes and reservoirs where there is heavy boat traffic, fishing, wind-surfing, sailing, kayaking and canoeing, and swimming. For example, we have 4 SolarBees in a 200 acre lake which has intense water skiing competition, as well as a 1 SolarBee in the middle of a 50 acre residential lake with a regulation competition water skiing course. In the 320 acre lake with 7 SolarBees in Palmdale, California, there are sea planes which land on the lake in addition to intense boating. We equipped the SolarBees in these lakes with state and federally approved buoy marker lights with variable intensities. There have been no accidents reported, and lake users are very happy to have improved water clarity without blue-green algae blooms.

The SolarBee is easy to maintain, requires little ongoing service and maintenance and it has a twenty-five (25) year life expectancy. Our certified installation crew will train your operator(s) with all aspects of the SolarBee at the time of installation and a toll free number is at your disposition for any questions regarding the SolarBees. We pride ourselves with excellent after sale service and we provide a 2 years parts and labor warranty on the SolarBees.

I thank you very much for your interest in the SolarBee. We believe that the Cherry Creek Basin Water Quality Authority as well as lake users will be very satisfied with the performance of the SolarBees by eliminating any threat of blue-green algae blooms, eliminating internal loading of P, increasing water clarity, and eliminating the threat of seasonal fish kills. We look forward to working with you on this project; please call at any time if you have questions.

Sincerely yours,

Harvey Hibl, Regional Sales Manager

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SolarBee®
Reservoir and Pond Circulators
"Cleaner Water at Less Cost"
http://www.solarbee.com

SOLARBEE BUDGET ESTIMATE

Date: 5-4-04

To: **Cherry**
Creek Basin Water Quality Authority

C/o Bill
Ruzzo

6641 West
Hamilton Drive

Lakewood,
CO 80227-5335

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

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1. PROJECT DESCRIPTION

a. Facility or Reservoir Name: Cherry Creek Reservoir, 850 surface acres X 26' max. depth.

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, the Problems to Solve:** Option 1: Control of cyanobacteria (blue-green algae) concentrations by circulating the upper waters (epilimnion) and improve water quality. Option 1A: Add additional units to also reduce the available phosphorus by oxygenating the lake bottom waters and sediments (hypolimnion) to prevent release of phosphorus (also prevent release of iron, manganese and H_2S) and prevent fish kills.

e. **Quantity of SolarBees Recommended and Brief Description of Recommended Deployment Method**: Option 1: Qty 13 SB10000Fv12 units are recommended(see the attached freshwater worksheet for more details). SB10000Fv12 features: new 25 life brush-less electric motor design that provides 24 hour operation with a solar charged battery backup system, 3,000 Gallons per minute (GPM) direct flow up the 36" diameter hose and 7,000 GPM induced flow, for 10,000 GPM total flow leaving the machine in full sunlight. 10 units to have a 15' maximum depth intake and 3 units to have 27' maximum depth intake**.** Option 1A: Add Qty 7 SB10000Fv12 units with a 27' maximum depth intake. All units to have coast guard approved solar beacons and increased visibility kit.

2. PROVISIONS FOR PURCHASING THIS EQUIPMENT

Cost, Option 1:

Quantity Purchase	Equipment Description	Purchase Cost each	Cost total
13	SB10000Fv12 units as described above	$ 36,256.00	$ 471,325.00

Delivery, installation, and startup cost	$ 23,865.00
Taxes	$ not included
TOTAL PURCHASE COST	$ 495,190.00

Cost, Option 1A:

Quantity	Equipment Description	Purchase Cost each	Purchase Cost total
7	SB10000Fv12 units as described above	$ 37,025.00	$ 259,175.00

Delivery, installation, and startup cost	$ 13,470.00
Taxes	$ not included
TOTAL PURCHASE COST	$ 272,645.00

If Option and Option 1A are both chosen, Total Cost: $767,835.00

Lease/Purchase Option:
5 year Municipal Lease Purchase Option is available from Wells Fargo or other leasing company, for the SolarBee equipment shown above: based on $768,000 x .02 rate factor = estimated monthly payment is $15,360.00/month for 5 years with a $1.00 buyout at the end of the 5 year term.

3. PROVISIONS THAT APPLY TO ALL PURCHASES:

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.

a. 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.

b. Delivery Time: Usual delivery time is 4-6 weeks from date of order.

c. 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

d. Payment Due Date: All payments are due 10 days after invoice date.

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

f. Add for Taxes and Governmental Fees. Except as indicated above, no taxes or tariffs or other governmental fees are included in the costs shown above, 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.

g. 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

h. 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.

i. 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 701-225-0320 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