Opportunities Created by Engineered Solutions to the Capitol Lake / Budd Inlet 303 d Water Quality Dilemma

Introduction

Nutrients discharged from agricultural operations, non point sources, waste management, and bioenergy processing facilities create significant environmental problems adversely affecting over 30% of our nations waters. The Deschutes River drainage basin is no exception. Soluble phosphorus and nitrogen are the primary water quality concerns of our time. Those nutrients fertilize the aquatic environment increasing aquatic phytoplankton, macrophyte, and fixed film cyanobacteria production. The increased primary production causes toxic algae blooms and upon respiration the consumption of oxygen and release of CO_2 resulting in aquatic oxygen depletion and pH fluctuations that adversely impact higher forms of aquatic life. In freshwater environments phosphorus is the rate limiting chemical constituent for biomass primary production. However, arguments have be made that nitrogen is the rate limiting chemical constituent given nitrogen's perturbation of most geochemical cycles. The National Academy of Engineering recently published the "Grand Challenges for Engineering" http://www.engineeringchallenges.org/cms/challenges.aspx. One of the 14 challenges was "Manage the Nitrogen Cycle". The "nitrogen issue" is the result of twice as much nitrogen being introduced into the world through anthropogenic sources as introduced through natural sources. The ability to produce reactive nitrogen through the Haber-Bosch process has enabled man to feed the world. However, that engineering miracle has totally distorted the nitrogen cycle leading to significant environmental and public health problems (SAB, n.d.).

Nitrogen (N) may be the limiting nutrient for biomass production in estuaries and the ocean but phosphorus (P) is considered the limiting nutrient in freshwater ecosystems since freshwater cyanobacteria can fix nitrogen. Soluble nitrogen can also be volatilized as ammonia, NO_x gas, N_2O gas, fixed from atmospheric N_2 gas ,

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incorporated in organic biomass, or precipitated in any of a number of organic and inorganic compounds. Consequently it is difficult to perform a mass balance on Total Nitrogen.

Phosphorus appears to be the limiting nutrient in the lakes of Western Washington. Phosphorus is a critical nonrenewable resource necessary to support global food production. Consequently, P must be recovered and reused. In the words of Isaac Asimov (1974) “life can multiply until all phosphorus is gone, and then there is an inexorable halt which nothing can prevent...We may be able to substitute nuclear power for coal, and plastics for wood, and yeast for meat...but for phosphorus there is neither substitute nor replacement.” Capitol Lake receives high inflows of phosphorus from the rivers and it’s sediments and as a result supports high levels of total phosphorus and orthophosphate, the form of phosphorus used for phytoplankton growth. Eventually, phosphorus will be recovered from the Deschutes River, out of necessity, at some point in man’s evolution.

Regardless of the available nutrients, temperature, light, and CO_2 also limit photosynthesis and the creation of organic matter that can be degraded with the consumption of oxygen. The atmospheric temperature and CO_2 concentration are expected to increase substantially over the next few decades due to global warming. Nutrient availability, with increased temperature and CO_2 concentrations will enhance phytoplankton growth, toxic cyanobacteria blooms, and low dissolved oxygen levels in our lakes, rivers, and estuaries. Light availability may in fact end up being the limiting factor controlling phytoplankton growth given the current nutrient loads and large stores of nutrients available in the sediments for growth.

The Deschutes River, Capitol Lake, and Budd Inlet aquatic system is a typical system adversely impacted by dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus or orthophosphate. The Deschutes River basin produces substantial quantities of dissolved and particulate nitrogen and phosphorous. During the summer, large quantities of dissolved nitrogen and phosphorous are taken-up by fixed film cyanobacteria and benthic algae attached to the Deschutes River stream-bed. The cyanobacteria, and suspended sediment, containing both nitrogen and phosphorus, are then discharged to Capitol Lake during wet weather high stream flow periods that occur during the winter and spring. During warmer low flow conditions the particulate matter settle and undergo anaerobic decomposition liberating their nutrients as soluble inorganic nitrogen and phosphorus. The soluble nutrients are rapidly consumed by hydrophytes and phytoplankton thereby producing water column plant material measured as “total organic carbon” (TOC). Capitol Lake is highly productive during warm sunlit summer and fall months. However, during cold cloudy days the phytoplankton and hydrophytes die, settle to the sediments and undergo decomposition wherein the organic nutrients are converted to dissolved organic and inorganic soluble forms that further fertilize the water column. With essential light, and CO_2, the nutrient rich waters produce more phytoplankton as the waters flow through Capitol Lake, until discharged with the organic-rich fine sediment to Budd Inlet, where the nutrient rich organic carbon (biomass) is mineralized to produce CO_2 and organic acids while consuming oxygen.

In summary the Deschutes River produces large quantities of nitrogen and phosphorus nutrients that are discharged to Capitol Lake producing a highly eutrophic lake susceptible to toxic algae (cyanobacteria) blooms and aquatic toxins. The nutrient rich Lake produces sufficient organic biomass, TOC, from atmospheric CO_2 and sunlight that when discharged to Budd inlet lowers the dissolved oxygen concentration to values below Budd Inlet’s water quality standards. The central issue is **Nutrient Enrichment.** Nutrient enrichment is responsible for the following adverse ecosystem consequences in the Deschutes Drainage Basin including Capitol lake and Budd Inlet:

1. Algae Blooms, toxic algae and their toxins; Saxitoxin, Microcystin, Anatoxin-a
2. Low dissolved oxygen in Capitol Lake and Budd Inlet that adversely impacts fish passage and the aquatic life.
3. Significant GHG emissions such as N_2O, CH_4, CO_2, H_2S from the anaerobic decomposition of organic material created through photosynthesis from light, CO_2 , and Lake nutrients.
4. Fertilization of the aquatic environment to support invasive plant species by providing nutrients in the form needed (organic debris for New Zealand Mud Snail).
5. Visual impairment of the Lakes appearance and restriction of recreational opportunities.

Eliminating the nutrient enrichment of Capitol lake will eliminate those “adverse consequences”.

Available Technologies

Technology is required to economically remove soluble nitrogen and phosphorus nutrients discharged from numerous point and non point sources such as agricultural waste management, food processing, wastewater treatment, and renewable energy production through anaerobic digestion where a majority of the particulate organic nutrients are converted to soluble inorganic ammonia and phosphate.

A large number of expensive technologies have been developed to remove both soluble nitrogen and phosphate from wastewater streams. Phosphate removal by chemical precipitation, biological assimilation, or crystallization (MAP aka struvite) precipitation is expensive, having a cost several times greater than the value of the product produced. Ammonia nitrogen removal by stripping, biological nitrification / denitrification, ammonia oxidation (Anammox) or precipitation as ammonium sulfate, nitrate, or phosphate is also expensive. (Recently Green Lake, a small lake in King County Washington used chemicals to precipitate phosphorus and thereby rid the lake of toxic algae at a cost exceeding $2,000,000. Typically, the frequency of lake chemical treatment is seven years.) Wetlands or constructed marshes are the least expensive technology but occupy large tracts of land where nutrient accumulation may not be sustainable.

Capitol Lake Farm Analogy

Capitol Lake can be visualized as a highly productive 261 acre farm with unlimited water, nutrients, and topsoil. The Capitol Lake Farm is capable of producing 4,000 ± dry tons of crop biomass each year (based on a low phytoplankton yield of 20 g/m^2/d over a 6 month production season). Biomass for renewable fuel is typically valued at $60.00 per dry ton. Six months of production would have a value of $240,000. Year-round production would have a value twice that amount.

At this time the Capitol Lake Farm’s “crop” is not wanted since it is used to feed bacteria that lower the dissolved oxygen of Budd Inlet. The reason for removing

__the Capitol Lake dam is that Capitol Lake grows a toxic "crop" and without the dam and Lake there would be no "crop".__

However, the Lake should be looked on as an aesthetic and recreational resource. In addition the Lake could be an economic resource if one harvested the Deschutes river fine particulate matter inputs and the lake sediments as a nutrient laden topsoil. The lake macrophytes and phytoplankton can also be harvested to produce bioenergy transportation quality fuel (biomethane), and certified organic phosphorus and nitrogen fertilizer, in an inorganic form. In addition, if the phytoplankton is grown and harvested prior to respiration the Lake will provide large quantities of oxygen to the lower Budd Inlet and thereby prevent DO depletion.

__In short to solve the Capitol Lake dilemma engineered systems must be installed to: 1) harvest sediments and fine particulate matter before they are polluted with bio-toxins, and 2) install a separate system to harvest nutrients and organic biomass from the lake to produce bioenergy and certified organic food nutrients. The topsoil, energy, and organic nutrients should be sold to produce income for Lake operation and maintenance. One should be able to obtain bioenergy grants to pay the Capitol cost of the nutrient recovery systems.__

This paper discusses the technology for nutrient harvesting. Suspended solids separation and sediment harvesting are well developed known technologies[1] that can be discussed in a separate paper. Recent articles on the subject describe submerged Lamella separators that remove fine particulate matter from storm runoff flow detention ponds[2] and the continuous hydraulic removal and concentration of consolidated sediments[3]. One can envision submerged Lamella separators removing suspended solids from the Deschutes river upon its entrance into Capitol Lake and hydraulically removing those suspended solids followed by

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[1] One-Dimensional Modeling of Suspended Sediment Dynamics in Dam Reservoirs, Guertault, Lucie, et.al., ASCE J. Hydraulics Eng. 040160331

[2] Perez, M , Methodology and Development of a Large-Scale Sediment Basin for Performance Testing, ASCE J. Irrigation & Drainage Eng. 04016042

[3]Ke, Wun-Tao, Influence of Sediment Consolidation on Hydrosuction Performance, ASCE J. Hydraulic Eng. 04016034

dewatering and drying in geotubes on rail cars for export as top-soil along the existing rail lines adjacent to Capitol Lake.

Nutrient Harvesting

Conversion of soluble nutrients to harvestable particulate matter, such as macrophytes and phytoplankton is an attractive method for removing nutrients. However, the limited productivity, ammonia toxicity, and cost of harvesting have prevented widespread adoption. Algae or cyanobacteria growth is limited by the turbidity that such growth imparts to the liquid, referred to as self shading. Light penetration is reduced in direct proportion to the phytoplankton biomass concentration. Pond or lake surface area also limits CO_2 gas transfer to the growing algae thereby limiting productivity. Variable depth and energy consuming CO_2 gas injection photobioreactors have been proposed to overcome such limitations while maintaining stable pH values. Finally, harvesting a highly concentrated biomass containing the recovered nutrients is very expensive and in some cases disruptive. Phytoplankton biomass separation and concentration is the most expensive unit process in algae production and recovery systems. Biomass nutrient separation and concentration equipment increases the Capitol and O and M cost considerably.

In most cases It is desirable to limit the phosphorus concentration to less than 20 ug/L to maintain healthy lake water quality. The eutrophic lakes of Western Washington have phosphorus concentrations exceeding 50 ug/L. Many contain cyanobacterial toxins. In most cases maintaining low 20 ug/L phosphate concentrations are sufficient to prevent toxic cyanobacteria blooms.

To overcome the nutrient removal limitations associated with conventional autotrophic organism growth and nutrient harvesting in ponds and lakes, the Rotating Photo-Bioreactor was developed.

The Rotating Photobioreactor

The Rotating Photo Bioreactor RPB[4] is a suspended or attached growth reactor wherein a culture of autotrophic or phototrophic microorganisms is grown on

[4] The RPB is a patented process and device covered by US Patents 8,637,304; 8,895,279; 9,328,006 and pending application 14/544,078

rotating media or plates mounted on a rotating shaft that is partially submerged and exposed to the atmosphere as shown in Figure 1. The photobioreactor maximizes light exposure to the growth surface as well as low pressure CO_2 gas transfer to and from the growth surface. Light and CO_2 (if required) is provided between the plates but above the water surface of the RPB. To minimize light inhibition, light exposure intensity is controlled by rotation speed. Biomass harvesting is performed by vacuum suction of the plate surface, as it rotates, by an automatic disc suction system that collects concentrated biomass at a concentration exceeding 10% dry solids, after it has been drained (high point of rotating disc). The bioreactor is capable of providing high surface to volume ratios (S/V) for maximum light exposure, photo-autotrophic growth, gas transfer, and oxygen production. Turbid liquids can be processed since light transfer to the retained organisms is not hindered by liquid turbidity or organism growth density.

Figure 1
The Rotating Photobioreactor

The RPB is a low pressure gas transfer apparatus that produces oxygen, while consuming CO_2 or dissolved bicarbonate. The RPB enables efficient harvesting of concentrated nutrient laden biomass through vacuum removal of excess growth from the plate surface. Those attributes make the RPB an attractive, simple, economical, and scalable method for removing soluble nutrients (NPK) from waste streams and harvesting those nutrients with the biomass. The RPB is a nutrient waste treatment technology that incorporates an economical method to concentrate and separate the nutrient laden biomass for use as a fertilizer or renewable energy source.

The Rotating Photo Bioreactor (RPB) is an improved method of producing aquatic biomass for energy production, as well as removing and concentrating nutrients from waste streams and/or eutrophic waters. Given its beneficial attributes, biomass grown in the RPB can out-compete resident biomass production. The RPB operation consists of taking lake water containing nitrogen and phosphorus, pumping that water to the Rotating Photo-Bioreactor from some location in the lake (preferably the lake surface) through a submerged intake line. After nutrient removal the highly oxygenated treated water is returned to the lake. Alternatively the covered RPB's can be floated on the lake surface such that 50% of the plate surface lies below the lake surface and 50% above. A large population of cyanobacteria is grown on the rotating plates as a dense fixed film. Those organisms grow while consuming the lake's nitrogen and phosphorus. The cyanobacteria $\{(CH_2O)_{106} + (NH_3)_{16} + (H_3PO_4)\}$[5] consume carbon dioxide and nitrogen and phosphorus nutrients found in the lake to produce fixed film or attached biomass and oxygen.

Optimum growth, leading to rapid uptake of nutrients, requires a) light, b) carbon dioxide, and c) adequate water temperature in addition to the nutrients. The uptake of nutrients is highly dependent on light since the specific growth rate of the organisms ($u = [(dX/X)\ dt]$ or $[\ln (X_t / X_0) / t] = 1.0\ d^{-1}$) has been shown to be a function of light intensity and wavelength. The required light is approximately 2.14 kWh per kilogram of dry biomass containing 8.9 grams of phosphate as P.

Photosynthesis
Reaction Calculations Used (mole basis)

Input: $106\ CO_2 + 16\ NO_3^- + HPO_4^{2-} + 122\ H_2O + 18\ H^+$

Plus Light: 5.4 MJ hv @20% = 27 MJ = 7.71 MJ/Kg = 2.14 kWh / Kg dry solids

Output Yields: (3.5 Kg biomass, 31g P)
$\{C_{106}\ H_{263}\ O_{110}\ N_{16}\ P_1\}_{\text{cyanobacteria}} + 138O_2$

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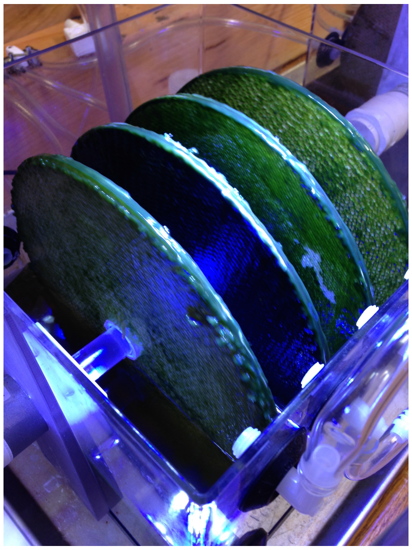
[5] Ecological Stoichiometry; Sterner and Elser, 2002 , Page 30

A 2012 video of the pilot operation can be seen at (http://www.youtube.com/watch?v=pD5MTx88FJE). Published papers can be found at http://www.extension.org/67578 and http://www.extension.org/pages/67578/economical-recovery-of-ammonia-from-anaerobic-digestate#.



OVER THE PAST TWO YEARS A NUMBER OF STUDIES HAVE BEEN PERFORMED TO DOCUMENT THE CYANOBACTERIA GROWTH RATES UNDER VARIOUS CONDITIONS. THOSE STUDIES BY E3 HAVE USED THE SMALL LABORATORY SCALE REACTORS SIMILAR TO THE ONE SHOWN.

The RPB was originally developed[6] as a method to increase the pH of anaerobic digestate without the use of chemicals for the stripping and recovery of ammonia nitrogen. It was known that autotrophs consume bicarbonate and thereby increase the liquid pH when the amount of carbon dioxide present is low enough to be growth limiting. However, growing algae or cyanobacteria presented a number of problems. Ammonia is toxic to autotrophs and significantly reduces their specific growth rate. Consequently, it was necessary to develop a large biomass for sufficient growth to occur and thereby consume the bicarbonate to provide an increased pH at low specific growth rates. The development of a large cyanobacterial mass required a large surface to volume ratio (S/V). But developing a large surface to volume ratio was hindered by the color and turbidity of the digestate as well as turbidity produced through autotrophic growth. The color, turbidity, and autotrophic concentration reduced the euphotic zone in which autotroph growth occurs. All of those deficiencies can be overcome by using attached autotrophic growth apparatus, i.e., the RPB.

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[6] The RPB was first demonstrated under a US Department of Agriculture Small Business Innovative Research (SBIR) grant at the City of Tacoma Wastewater Treatment Plant in 2012. A full scale RPB is expected to be demonstrated at the LOTT wastewater treatment plant in Olympia, WA once the WA State Department of Commerce Phase 2 Clean Energy Funds are approved. It is also expected to be demonstrated in early 2017 at Lake Hicklin in King County to remove cyanobacterial toxins under the King County WaterWorks grant program.

Growth occurs on rotating solid or semisolid surfaces constructed of a variety of materials upon which organisms attach and form a biofilm, in a manner similar to attached cyanobacterial growth on the rocks lining most streams. The process uses natural or genetically engineered organisms that attach to a rotating support media upon which autotrophic organisms grow. The media consists of a series of plates or plate-shaped discs that maximize light exposure and gas exchange within an enclosed or open reactor. The attributes of the process are as follows:

A) Surface to Volume Ratio (S/V). The apparatus provides a very large surface to volume ratio for light exposure as well as gas transfer. The rotating photobioreactor is truly three dimensional since the biomass growth surface is proportional to twice (i.e., both sides) the square of the plate diameter. Providing a rough or contoured surface will increase that surface area. Turbid liquids can be processed since the liquid depth over the biomass growth surface is very low, permitting adequate light utilization. The diameter and distance between the plates controls the S/V ratio. That distance between the plates can be low if artificial light sources (e.g., light-emitting diodes) are placed between the plates. A lake surface exposed to natural sunlight would provide an exposed surface equal to its length times its width (diameter). The RPB will provide an area equivalent to the length divided by the spacing (s) times the width (diameter d) squared times 1.57; $((L/s)*2*pi*d^2/4)$.

B) Light Exposure-Light penetration is hindered in conventional photobioreactors since the euphotic zone, that is a function of turbidity imparted by biomass and particulate matter, is commonly less than 4 inches. In the RPB, exposure to light is independent of liquid depth and turbidity. Light can be supplied by natural or artificial means. Light exposure is controlled by the surface area of the rotating growth plates, the radiant flux of light provided, and the speed of rotation. The rotation speed can be controlled to maximize light exposure, organism shading, light inhibition, and gas transfer. The rotation speed in an enclosed reactor provide a means to control temperature and exposure to predation, thereby minimizing any adverse environmental effects. Light increases the temperature of the growth surface. The artificial light source can be easily accessed for repair and maintenance since it can be located in the wall or top cover of the photobioreactor above the water level. Typically the lights are above or between the plates and above the water surface for ease of maintenance and reduced expense.

In most cases light is the the limiting variable in photosynthesis. Normal photobioreactor operation is 12 hrs per day over 365 days per year. Two units, each operating 12 hours per day, are required to provide complete coverage of liquid flow in a river or stream over 365 days per year.

C) Water Losses The loss of water vapor may also be minimized by condensing water vapor (in cooler lake or river water) from the gases exiting the enclosed rotating photobioreactor.

D) Solids Retention Time Most importantly, the reactor maximizes the solids retention time of the organisms that remove chemical constituents from the liquid or generate gases. The reactor can produce a non-turbid effluent since the growth occurs on the rotating plates. No matter the application, the RPB will produce energy-yielding biomass or gases from the supplied $C0_2$. The biomass can be recovered at a rate to maximize yield.

E) Biomass Harvesting. Harvesting algae or cyanobacteria is typically an expensive unit process representing 20 to 30% of the total cost of algae biomass production. Commonly used processes include centrifugation, flotation, flocculation (with a variety of flocculants), sedimentation, membrane filtration, ultrasonic separation, froth flotation, and electrolysis. The attached biomass can be easily harvested in the RPB. The concentrated solids can be removed from the rotating plates through any of a variety of means such as periodic scraping or partial scraping with a blade to discharge the aggregated solids to the liquid media for removal through settling. Concentrated biomass is preferably removed from the rotating surface of the growth plates with a vacuum suction device that periodically removes a portion of the biomass from different sections of the rotating surface like a record player stylus. Concentrated biomass at 10% plus is accumulated in a vacuum receiver. That biomass can be delivered to an energy producing process to recover the energy value as an oil, sugar, or biomethane gas. The biomass may also be further dried to produce a fertilizer in a powder or pellet form. After anaerobic digestion the nutrients can be recovered as a concentrated inorganic fertilizer for organic food production.

F) Nutrient Harvesting. Autotrophic organisms can harvest soluble nutrients in direct proportion to their growth rate. The growth rate is generally controlled by the limiting nutrient light that is provided above the water surface between the plates. The nutrients can be economically harvested with the biomass.

G) Gas Processing. In waters with low bicarbonate alkalinity it may be necessary to supply $C0_2$ for maximum autotrophic organism growth while removing the inhibiting oxygen. Unlike conventional photobioreactors, the gas containing $C0_2$ is delivered at low atmospheric pressure to the RPB, at relatively low cost. The $C0_2$ can be obtained from a variety of combustion sources or biomass conversion processes such as composting.

H) pH Control- The process can also control the pH of the liquid through cyanobacterial consumption of bicarbonate. An optimal pH of 8.3 can be maintained or the pH may be increased to control predation by other organisms or for stripping gases by simply adjusting $C0_2$ inputs in the form of a gas or as bicarbonate. The unhindered light exposure and ability to control the pH will provide a degree of disinfection and predation control.

I) Process Integration-The process produces large quantities of oxygen that can be used for a variety of purposes. The effluent liquid is fully saturated and can be supersaturated with oxygen. The growth of autotrophic organisms will convert soluble nutrients to solid biomass for removal. The oxygen generated can be used for a variety of purposes such as wastewater treatment or stabilization and biogenic drying of processed biomass solids. The compost / drying process can be integrated with the RPB process that produces oxygen for composting while the composting process produces the $C0_2$ for the RPB process. Such an arrangement reduces the discharge of gases, including any odorous compounds to the environment.

In energy terms the simplest equation describes photosynthesis as an endothermic reaction that requires 2.8 MJ of radiant energy to synthesize one molecule of glucose from six molecules of $C0_2$ and H_2O.

A more realistic black box description is as follows: 106 CO_2 + 90 H_2O + 16 NO_3 + PO_4 + mineral nutrients + 5.4 MJ of radiant energy = 3,258 g of new protoplasm (106C, 180H, 46O, 16N, 1P, 815 g of mineral ash) + 154 O_2 + 5.35 MJ of dispersed heat.

Input: $106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+$

Plus Light: 5.4 MJ hv = 2.14 kWh / Kg @ 20% efficiency

Yields: $\{C_{106}H_{263}O_{110}N_{16}P_1\}_{cyanobacteria} + 138O_2$

J**) Toxicity Reduction.** It is expected that the light exposure in conjunction with the high rate of oxygen production will significantly reduce any cyanobacterial toxins found in the lake water.

Application of the RPB to Capitol Lake

Capitol Lake is a 9,800 foot long, 260 acre lake. Table 1 presents the relevant data from DOE Reports.

	Existing Lake	Dredge Lake	I-5 to RR Bridge
Surface Area (sf)	11,369,160	11,369,160	4,250,000
Length (ft)			5,000
Width (ft)			900
Depth	10.4	13	13
Cross Section (sf)			11,700
Volume (cf)	118,637,000	147,799,080	58,500,000
Flow $Q_{7–10}$ (cfs)	64.1	64.1	64.1
$Q_{7–10}$ Detention Time (d)	21.42	26.69	10.56
$Q_{7–10}$ Velocity (ft/hr)			19.7
$Q_{7–10}$ Distance in 12 Hours (ft)			236.7

	Existing Lake	Dredge Lake	I-5 to RR Bridge
Mean Annual (MA) Flow (cfs)	396	396	396
MA Detention Time (d)	3.47	4.32	1.71
MA Velocity (ft/hr)			121.8
MA Distance in 12 Hours (ft)			1,462.2
$Q_{7–10}$ Orthophosphate (mg/L)			0.014
$Q_{7–10}$ Total Phosphate (mg/L)			0.4
$Q_{7–10}$ DIN (mg/L)			0.65
$Q_{7–10}$ Ortho-P Load (Kg/d)			2.20
$Q_{7–10}$ DIN Load (Kg/d)			102
MA Orthophosphate (OP) (kg/d)			
MA Total Phosphate (Kg/d)			75
Model Sediment OP Release (Kg/d)			10.89
Model Sediment DIN Release (Kg/d)			480
Ratio DIN to OP (weight basis)			44

The Department of Ecology studies indicated that phosphorus is the controlling nutrient for Capitol Lake phytoplankton production. Under the Q_{7-10} (seven day low flow once in 10 years) water quality modeling low flow through the Lake, the total daily phosphorus load is 2.2 Kg/d. That load is low when compared to the sediment release of 10.89 Kg/d of orthophosphate. The sediment release of nutrients is apparently the controlling factor for the production of the Capitol Lake “crop”; that in turn is the controlling factor in the depletion of dissolved oxygen in Capitol Lake and Budd Inlet. The release of soluble reactive phosphorus from the sediments is directly related to the phytoplankton deposition history. As soluble reactive phosphate and dissolved inorganic nitrogen enter the Lake the existing phytoplankton consume the soluble nutrients thereby converting the nutrients from the soluble to the particulate organic (new phytoplankton) form that are transported down the Lake to eventually settle to the Lake sediments where they undergo anaerobic decomposition (again) producing soluble nutrients that are again transported further down the Lake. The growth, death, and transport of phytoplankton through the Lake is a function of lake flow, location in the lake, light, temperature etc. at any instant as well as the history of previous deposition and sediment transport. It is highly likely that the winter high flow rates will essentially clear out most of the previous years settled organic matter. An accurate Lake physical and biochemical sediment transport model is required to interpret any proposed solution to the water quality deficiencies short of removing the dam and Lake. That model is required in order to further develop this proposal. It is the essential technical element, which at present appears to be a “black box”.

We propose to use the RPB to continuously remove soluble reactive phosphate and dissolved inorganic nitrogen and some particulate nutrients[7] from the waters flowing through Capitol Lake. Removal of the soluble nutrients will starve downstream organisms of the nutrients required for growth, essentially ending the growth and death cycle once sediment nutrient reserves are depleted.

Many alternative arrangements exist for the transport of Lake waters through the RPB. The waters can flow perpendicular or parallel through the rotating plates. We are currently proposing that the waters flow parallel to the rotating disks. The disk spacing will be sufficient to allow fish passage upstream through the plates. Table 1 presents the lake water velocities under the various flow conditions presented in the DOE reports (a 365 day mean flow function is required).

In order to remove 13 kg of orthophosphate per day utilizing a specific growth rate of 1.0 (or a 1 day doubling time) it will be necessary to harvest 1,300 Kg of dry biomass per day containing 1% orthophosphate. The harvest at 10% dry solids concentration will be 13,000 Kg or 13 metric tons per day (1.5 truck loads). The RPB disks can support a 43.4um thick layer of active autotrophic organisms or approximately 20 g per m^2 of dry matter. Twenty foot diameter plates (10’ above water and 10’ below water) will provide 628 ft^2 or 58.5 m^2 of surface area capable of producing 1,150 grams of dry solids having a 1.0% phosphate concentration or 11.5 grams of P per day. One thousand 20 foot diameter plates will be required to harvest 11.5 Kg of orthophosphate per day. The number of plates required at a one foot spacing will be 1,000 over 1,000 feet.. As can be seen from the attached sketch, Capitol Lake has a width of approximately 900 feet over most of its length (the pan handle). The spacing would have to be modified slightly to accommodate

[7] The RPB is an excellent surface skimmer capable of capturing suspended particulate matter.

the RPB or the surface area of each disk would have to be increased by contouring or texturizing. This will have to be done in any case to prevent light inhibition.

If two rows of RPB,s are used and set apart by 12 hours of travel time between rows each having lights on 50% of the time (12 hours on and 12 hours off) the required number of discs per row would be 500. With a safety factor of 20% the required number of discs would be 600 per row times two rows or 1,200 discs each being 20 feet in diameter. The spacing between each row of plates is equal to 12 hours at the Lakes $Q_{7\text{-}10}$ water flow velocity. The lighting cycle time can be varied to accommodate minor changes in lake velocity. The intent is to process the entire flow of water through a "lights on" RPB. The most economical arrangement will be to use covered but floating RPB supported by piles driven adjacent to the 40 foot long RPB modules. The adjacent figure shows the two RPB assemblies just south of the existing RR Bridge / walkway. The covered RPB will extend 12 feet above the water surface. The existing top rail of the RR Bridge crossing is 13 feet above the water surface. Consequently, the RPB assembly will be below the top of the RR Bridge and will not be seen by observers north of the RR bridge.

The RPB will require power for the lighting system, rotation motors (a compressed air bubble system will be used to drive rotation), and vacuum solids handling system.The photosynthesis lighting required is 2.14 kWh per Kg of biomass removed (see previous discussion). The system will remove 1,300 Kg or 2,860 pounds per day of dry solids or 28,600 pounds per day of 10% dry solids (1.5 truck loads per day). The power required for lighting is estimated to be 2,782 kWh /day (1,300 Kg x 2.14 kWh / Kg). At a cost of $0.15 per kWh, the daily lighting cost will be $417 / day. The total electrical cost will be less than $800 $d^{-1.}$ The estimated cost of the RPB system is expected to be less than $4,000,000.

Benefits of the RPB System

The proposed RPB System will meet the water quality objectives by harvesting nitrogen and phosphorus nutrients from Capitol Lake, hereby eliminating the dissolved oxygen deficiencies in Budd Inlet and Capitol Lake. Removal of the nutrients will also eliminate toxic algal blooms and minimize the growth of invasive plant species. Fish habitat will be improved. Ecosystem function will be enhanced along with improved wildlife habitat. The system will not adversely impact fish passage. Swimming, boating, and other recreational opportunities will be provided by the proposed improvements. In addition to the public and ecological benefits the proposed system may provide substantial economic benefits through the harvest of nitrogen, phosphorus, bioenergy, and topsoil. Most importantly the system will be far less expensive than any of the demolition alternatives proposed to date.

A realistic mathematical model of the sediment, nutrient, and an hydraulic flows through Capitol Lake is required in order to fully quantify the expected economic benefits (net income) of the proposed system.