

# **Management of Wapato Lake Quality**

## Interim Project Status Report

Metro Parks Tacoma  
August 2007

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## Glossary of Terms & Abbreviations

ha .....	hectare
ac.....	acre
m.....	meter
µg/L.....	micrograms per liter
TP.....	total phosphorus
mg/L.....	milligrams per liter
pH.....	hydrogen ion activity or measure of acidity

**Polymictic-** Lake that has its water column mixed multiple times per year, especially during the summer

**Alum-** Aluminum sulfate is a salt that when added to water produces aluminum hydroxide, which sorbs and inactivates phosphorus, making phosphorus unavailable as a biological nutrient

**Macrophyte-** Rooted green plant

**Chlorophyll-** Green photosynthetic pigment that captures light energy as chemical energy. Chlorophyll concentration is a measure of phytoplankton biomass and potential production.

**Phosphorus-** Essential nutrient for all living organisms and usually the most limiting nutrient in fresh water

**Transparency-** Water clarity, depth of visibility

## *Management of Wapato Lake Quality*

### Introduction

This is the initial phase of reexamining the water quality condition of Wapato Lake and recommending measures for restoration of the lake to a recreational-usable state. The Tacoma Park Board has recently (2005) approved the Wapato Park Master Plan to improve the lake quality. In response to this need, Tetra Tech, Inc. in cooperation with Tacoma Peirce County Public Health Department began a monitoring program at Wapato Lake in June 2006. This water quality monitoring will continue through the summer of 2007. This report is a brief summary of data analysis collected to date.

### Description

Wapato Lake is a natural lake with an area of 13.6 ha (34 ac), located at the south end of the City of Tacoma's 35 ha (87.5 ac) Wapato Park. The lake's watershed includes portions of I-5 and surrounding residential areas (Figure 1). The lake has maximum and mean depths of 3.5 and 1.5 m, respectively. The lake is polymictic, that is, it is too shallow to permanently stratify thermally during the summer. It is, therefore, subject to periodic complete mixing by wind.



Figure 1. Aerial view of Tacoma's Lake Wapato

## Management History

The lake has had three closures. The first in 1942, due to swimmer rashes, apparently resulting through effects of storm water inflow, and reopened in 1945. Recreational use was again curtailed for ten years in 1976 during which time bottom sediment was reconfigured in part of the lake that was separated off by a constructed dike to receive storm water diverted from the lake proper (Berschinski, 2006). Subsequent to that diversion, the lake received dilution city water for ten years. Low-nutrient city water was the main source for dilution for the first few years. However, drought conditions necessitated supplementing city water with high-nutrient well water during the remainder of the dilution period. During the initial two-year period when mostly low-nutrient city water was used, summer average total phosphorus (TP) was reduced by 47% from 86 to 46  $\mu\text{g/L}$  (Welch & Jacoby, 2001.)

The lake was treated with alum at 7.8 mg/L Al in 1984, because the higher nutrient concentration dilution water was no longer able to control internal P loading from sediments. However, TP increased by 24% to 58  $\mu\text{g/L}$  in spite of the alum treatment and a short-term (months) improvement of quality. The cause for failure of the alum treatment to control internal loading was at least partly due to a massive development of a non-rooted macrophyte, *Ceratophyllum*, which was probably responsible for a pH increase to 10.1 due to photosynthesis. At such a high pH, phosphate sorbed to Al and Fe is exchanged and solubilized, allowing it to be available to algae. The *Ceratophyllum* increase may have been due to increased clarity following the alum treatment.

Only one other shallow western Washington lake treated with alum, (South Patterson) was considered a failure (i.e., limited short-term water quality improvement) and it also had a high density of macrophytes (Welch and Cooke, 1999). However, South Patterson had an established macrophyte crop prior to the alum treatment, so the case of Wapato, developing a dense macrophyte crop after treatment that altered water quality (i.e., increase pH) that inhibited the alum treatment, was unique.

## Current Water Quality

Water samples were collected at the deepest point in the lake at a depth of 0.5 m twice monthly from June through September of 2006 and 2007. The total events will be 16. Samples will be collected by TPCHD. Water samples will be analyzed for SRP (soluble reactive phosphorous), TP (total P), chl *a* and abundance and biomass of individual phytoplankton taxa. Water transparency and profiles (0.5 m intervals) of DO and temperature will also be recorded on each occasion. As expected for such a shallow lake, there was no permanent thermal stratification, i.e., temperature profiles were for the most part uniform surface to bottom, except that a rather isolated volume existed below 2 m in midsummer (Figure 2). Despite no permanent stratification, very low DO (dissolved oxygen) water existed below 1.5 m in September (Figure 3).

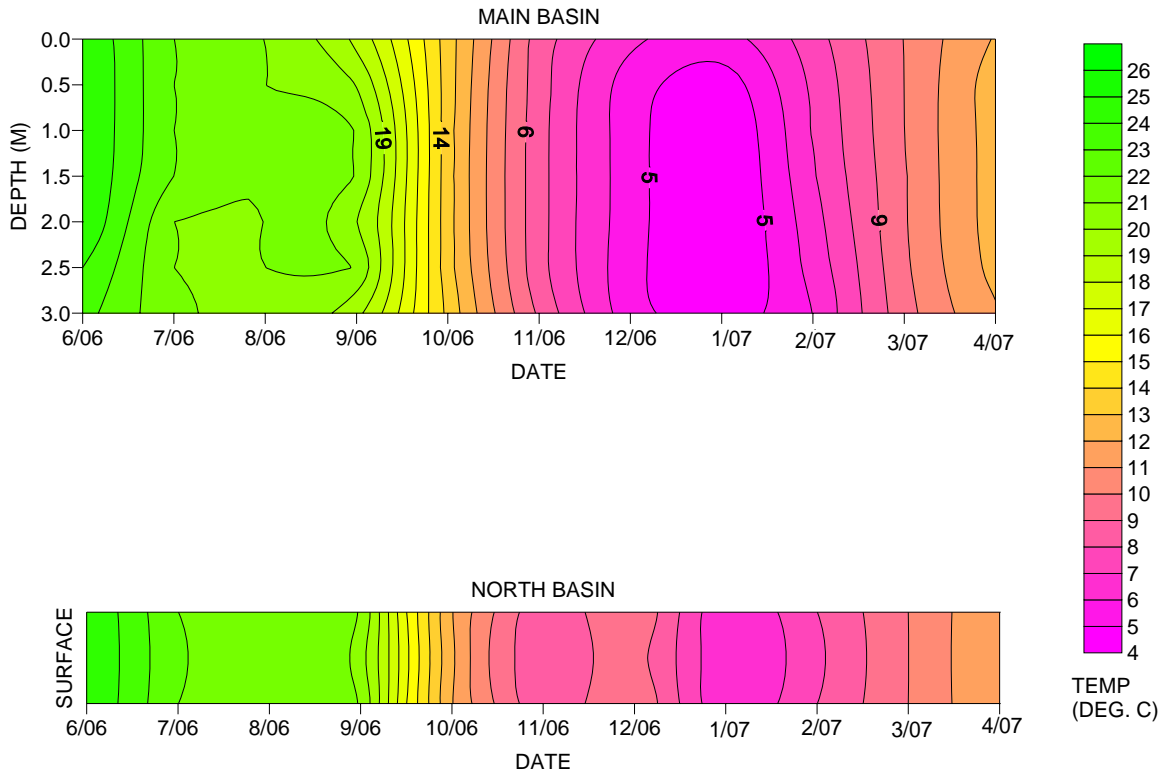


Figure 2. Temperature distribution in Wapato Lake 2006-2007.

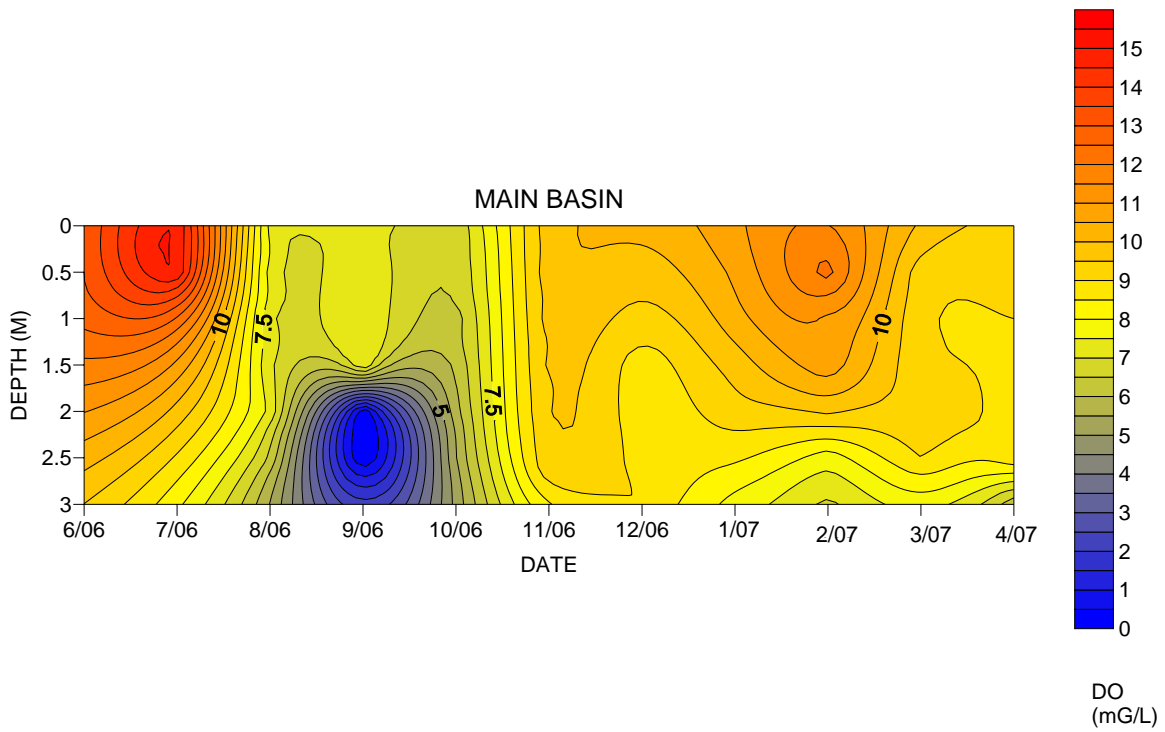


Figure 3. DO distribution in Wapato Lake during 2007.

Water quality, in terms of chlorophyll (chl), TP and transparency, was poorer in 2006 than prior to or after restoration activities during 1976-1985. The 2006 TP concentration was 28% greater than the pre-restoration level in 1979. Surface TP averaged 93  $\mu\text{g/L}$  and chl 52 $\mu\text{g/L}$  from June 2006 through April 2007 (Figures 4 & 5). Beginning in 2007 there was a significant drop in TP concentration from 255 to 34  $\mu\text{g/L}$ . TP content was consistently higher in bottom water (2.5 m samples), averaging 165  $\mu\text{g/L}$  (Figure 4). The general increase in TP at both depths during the summer low rainfall (resulting in low inflow) period indicates that; 1) a major source of P to the water column originates within the lake (bottom sediments), and 2) P release from bottom sediments to the overlying water at 2.5 m reached the surface water (0.5 m) due to the lake's polymixes.

Transparency averaged 1.08 m, a low value that characterizes the lakes highly enriched state and is due primarily to the high chl content.

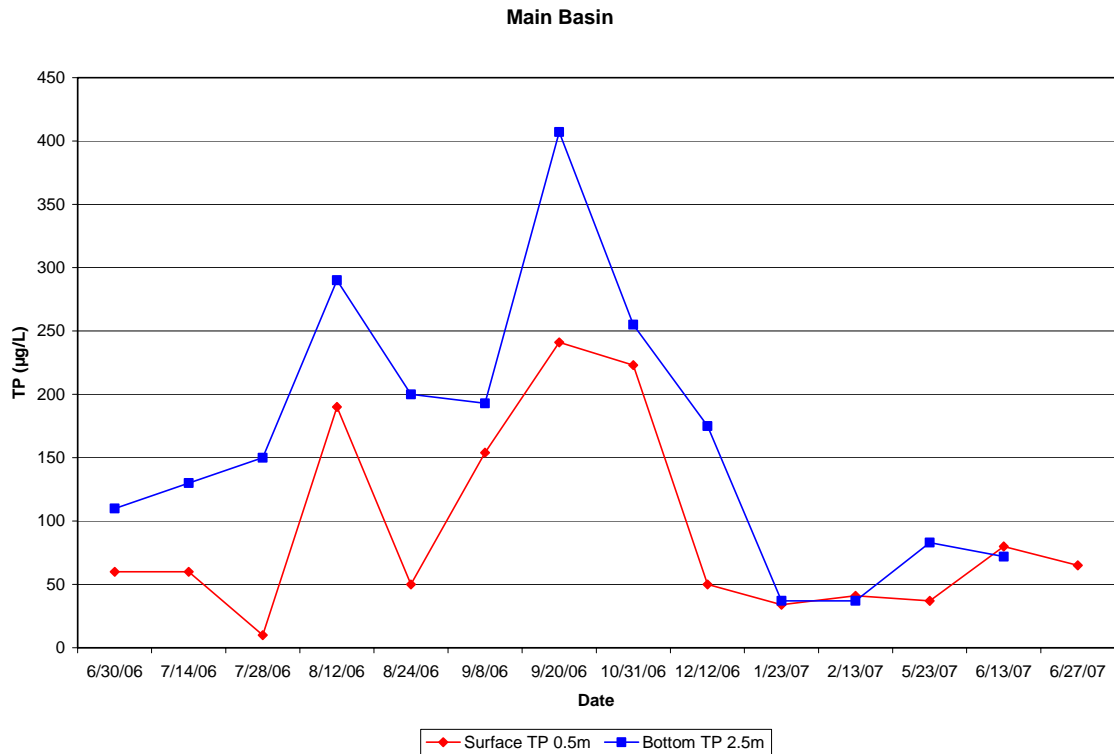


Figure 4. TP concentrations at two depths in the main lake during 2007.

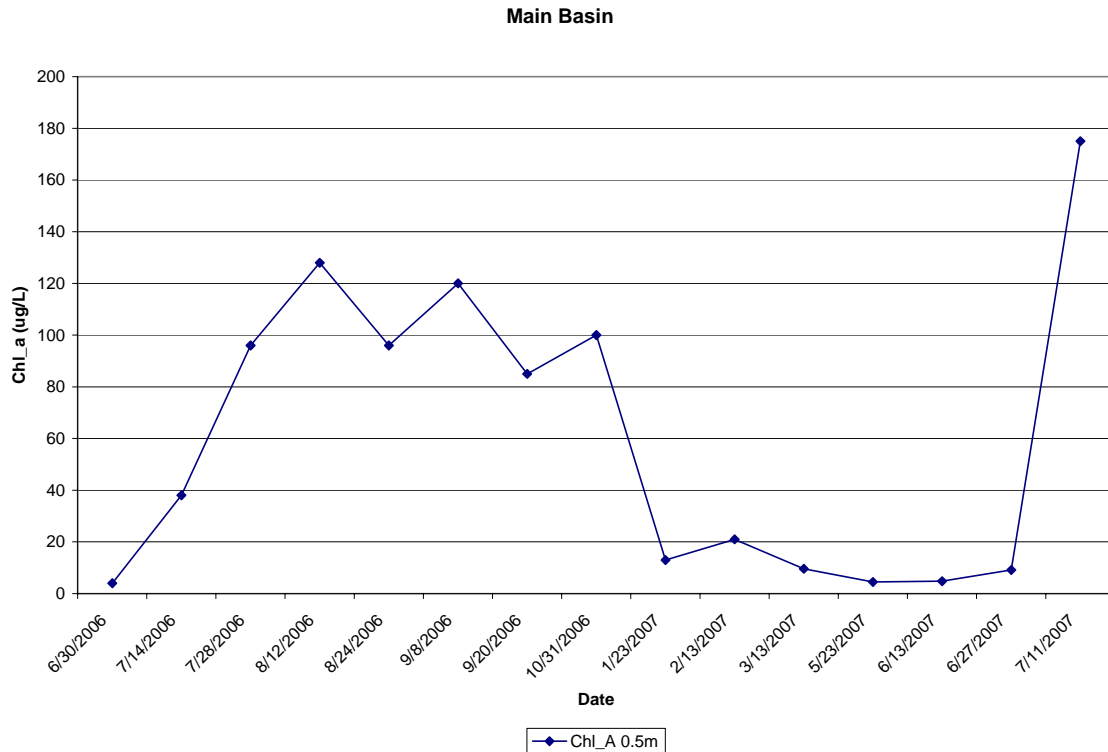


Figure 5. Chlorophyll at 0.5m in the main lake, 2006-2007.

Wapato Lake is clearly hypereutrophic. Such a state usually presents problems for recreationists. The goal for improving water quality should be at or below the boundary between mesotrophy and eutrophy which is an average of about 25 µg/L TP, 10 µg/L chl and 2 m transparency during summer. At these levels, the risk is very low for nuisance blue-green algae, or cyanobacteria, being dominant in the algal crop. With the risk of blue-green dominance, also comes the risk for algal toxicity.

The high summer TP content of 110 µg/L about equals the maximum in eleven western Washington lakes studied between the late 1970s and early 1990s. The mean TP in those lakes was 58 +/- 30 µg/L (Welch and Jacoby, 2001). The principal source (>50%) of summer P to 8 of those lakes was internal loading from sediments. Internal loading to Wapato during summer was 36% of the total which was lower than other lakes because storm water was still significant even after diversion of 53% of the external loading in summer (Welch and Jacoby, 2001). Summer storm water loading to Wapato was 3.6 times greater than the average of the nine other shallow lakes. TP in Wapato at that time was 58 µg/L – roughly half the level on 2006. Therefore, internal loading represented not only a larger share of total summer loading now than in 1982, but it was apparently the only source because water levels in both the north and main basins were below the levels of hydraulic connection between the basins. Although the north basin TP was about the same as that in the main basin (102 µg/L), that water did not pass to the main basin.

## Management Alternatives

Internal loading was the cause of poor lake quality in the mid 1980s, in spite of storm water diversion, and it is the main cause today. There are techniques that can have long-term benefit at reducing internal P loading, although their cost-effectiveness varies. These techniques along with case studies are reviewed in Cooke et al. (2005).

*Dredging and /or Capping:* Removing the uppermost layer of rich (high-P) sediment is the most permanent technique, but it is also the most expensive. Suction dredging is most often employed, but complete drainage of a small basin followed by removal by surface machinery (e.g., Mudcat dredge) has also been used.

Physically capping bottom sediment has been employed less often, because break through of dense material through the low density (~90 % water) bottom sediment readily exposes the rich sediment to continued P release. For example, ash from the 1980 Mt. St. Helen's eruption added ~8 cm of the highly dense material to Moses Lake sediment. Internal loading was curtailed for only 2 years before the material fractured and sank through the oozy sediment.

*Alum:* This has been the most cost effective means to reduce sediment internal P loading. Over 150 lake treatments have occurred in the world since the mid 1960s, and a large fraction have lasted 5-10 years, if summer external loading is not high. Several of these successful treatments were in shallow Washington lakes (Welch and Cooke, 1999; Welch and Jacoby, 2001). Aluminum -P complexes are not redox sensitive as is the case with iron, so they remain relatively stable over the long term.

*Calcium:* Phosphorus is sorbed by Ca forming long-term stable compounds, as is the case with aluminum. However, Ca complexes are soluble at the pH range in water, and especially sediment, in soft water lakes (low pH) as is the case in western Washington. Ca treatments have been successful in hard water (high pH) lakes in Alberta and Germany, although treatment longevity is unclear.

*Nitrate:* This technique has the potential of being the second most effective sediment treatment in the long-term. Liquid calcium nitrate is injected into sediment to 20 cm or so supplying the electron acceptor for denitrification. In that process, organic matter is removed (converted to CO<sub>2</sub>) oxygen conditions are improved (sediments are changed from anoxic to oxic), allowing iron to complex P. The machinery needed for injection and other considerations have led to infrequent use of this technique.

*Complete Circulation:* This technique of mixing water bodies is usually aimed at aeration of bottom water. That is, large water bodies can be destratified permanently during summer so that the whole water column is oxic. The technique has been used extensively for water supply reservoirs. In shallow lakes its use is primarily to mix the water column at a greater rate than that of the buoyancy rate of nuisance blue-green algae. While that has worked, it can also result in enhanced internal loading if mixing rate is not sufficient. Mixing a shallow lake like Wapato would probably reduce the buoyant blue-greens, but because P may or may not be reduced, due to the risk of enhanced internal loading, the total amount of algae may not decrease or may increase. The results of complete mixing are therefore, difficult to predict for shallow lakes.

*Dilution:* This technique has worked well to reduce (i.e., dilute) the internal supply of P from sediment in Green Lake and Moses Lake. However, the technique has not been employed often, due to the usual scarcity of large quantities of low-nutrient

water. It worked for a few years in Wapato, so long as most of the added water was low nutrient city water.

Adding low-nutrient water reduces the concentration in the lake and, therefore, results in lower nutrient concentrations in the outflow from the lake to downstream waters. While the mass of nutrient outflow is increased, the outflows concentration is less and concentration (mass/volume) is the unit expression that determines algal biomass and water quality. Adding more water to “flush” a lake will not work unless the nutrient concentration is much lower than the lake concentration. Algal cells can be “washed out” at a rate that exceeds their growth rate, but that would require a large quantity of water that would need to produce lake detention times of < 10 days, which usually is unrealistic.

The significance of the distinction between dilution and flushing is illustrated by the cases of Green and Moses Lakes. Before dilution-water additions, lake TP concentrations in the two lakes were 65 and 154  $\mu\text{g/L}$ , respectively. Diluting the lakes with water containing 6  $\mu\text{g/L}$  (Seattle City Water) and 25  $\mu\text{g/L}$  (Columbia River Water), ultimately brought lake concentrations down to 20  $\mu\text{g/L}$  and 43  $\mu\text{g/L}$ , with average summer water detention times of 150 and 33 days, respectively. In both cases, therefore, algal reductions were due to lowered TP concentrations, because water residence times, although shortened, were insufficient to compete with algal growth generation times, which were on the order of 2 days. Moreover, outflow water from the lakes contained markedly lower TP concentrations, which would have reduced, rather than increase, downstream effects.

*Other Management Activities:* The data clearly demonstrates that internal loading of P into the lake is the most significant problem to be addressed to produce immediate water quality improvements within Lake Wapato. However, it is still important to provide external nutrient control because it is the external sources of nutrients that led to the overenrichment of the lake in the first place. The successful long-term management of the lake will in part be determined by how aggressive external P control is pursued. Representative activities that would provide incremental water quality improvement include stormwater runoff best management practices, waterfowl control, shoreline vegetation enhancement, and shading of the water surface.

Stormwater runoff brings a significant amount of P to the lake each year. A portion of this P is deposited into the lake sediments. During the spring, summer, fall a fraction of this P can be “recycled” into the lake water overlying the sediments. This is internal loading. Hence, external P loading from stormwater runoff potentially in time can contribute to the internal loading of P into the lake. By reducing external P loading through stormwater management lake water quality can be improved by reducing long-term internal loading.

Waterfowl control will reduce both internal and external P loading into the lake by directing eliminating P introduction to the lake. There is no doubt that the resident waterfowl population is contributing to the poor water quality of the lake. However, the P concentration increase observed in the lake does not support that the waterfowl are by themselves the sole drivers in the excess P concentrations observed in the lake. Nevertheless, reducing P loading from waterfowl will have short-term and long-term positive benefits to the lake’s water quality, although that benefit may be very difficult to quantify.

Shoreline vegetation enhancement could potentially also reduce P loading by three paths. First, shoreline vegetation can discourage waterfowl; hence reduce P loading to the lake from waterfowl deposits. Second, vegetation would reduce shoreline erosion which also reduces P loading to the lake. Lastly, shoreline vegetation can help buffer overland stormwater runoff that can carry P to the lake.

Shading by trees around the shoreline provides two benefits to the lake. First, the shading directly reduces the availability of light to fuel photosynthesis in the lake. Second, the trees that provide the shade also reduce the wind energy that can in turn mix the lake potentially enhancing P availability to the phytoplankton.

## Discussion

Past and recent data strongly indicate that the major source of P during summer is internal loading from bottom sediments. Therefore, to improve water quality (i.e., greatly reduce algal abundance), internal loading should be reduced by as much or more than three fold in order to reach boundary levels for a mesotrophic state. The two most reliable methods to accomplish that are alum to inactivate P in sediments and the addition of low-P water to dilute the flux of P from sediments.

To estimate how much improvement can be expected, however, requires a better understanding of the contributions from both external and internal sources. That understanding can result only from monitoring those sources on an annual or semi-annual basis. However, regardless of how a loading estimate would turn out, internal would be the major source by far. So controlling internal loading is the appropriate step and a loading analysis would only establish the actual fraction and timing of the sources. While that information is important in most cases, it may be less important for Wapato, in view of the lake's history. Therefore, an alternative is to proceed with an alum treatment, thoroughly monitor the results, and determine the relative importance of internal loading afterward. The only other unknown is the expected effectiveness (i.e., what percent reduction) of the alum treatment, although that would not be known even with a loading analysis. An 80% effectiveness and longevity of at least ten years are usually assumed. Therefore an alum treatment is recommended without a pre-treatment loading analysis, because Wapato is considered a special case, i.e., there is little doubt that internal is the major source in summer. Sediment cores are recommended to determine the sediment content of mobile P, in order to determine an appropriate alum dose.

Judging the amount of dilution water to add without a loading analysis and mass balance model is more difficult. One could start the process on an experimented basis and raise the rate of input until monitoring results showed that the effect had been optimized, i.e., lake concentration had been decreased to within 80-90% of the inflow TP concentration. Treatment of dilution water may be necessary to lower TP concentration to 20 µg/L or so prior to entering the lake. That can easily be done, as was shown with the design of a treatment system to produce dilution water for Green Lake in the early 1990s, but it would be costly—much more so than an alum treatment.

## Alum Treatment Dose and Cost Estimate

Internal phosphorus cycling within Wapato Lake has been shown to be the most important factor in controlling phosphorus lake concentrations, which in turn, regulates the production of phytoplankton. Specifically, excess phosphorus concentrations in the lake allows over production of blue-green bacteria (Cyanobacteria) that impact the usability of the lake for humans as well as fish and other aquatic organisms. To manage the internal loading of phosphorus from the lake sediments it is recommended that this internal phosphorus be controlled by inactivation. Phosphorus inactivation is the process of making phosphorus unavailable to the biosphere. In lake management efforts to date the most successful management process for phosphorus control has been the addition of aluminum sulfate (alum). The aluminum in alum chemically combines with phosphorus forming an insoluble compound that is not bio-available in the sediments.

The dose of alum in terms of aluminum to inactivate the sediment phosphorus and water column phosphorus is 67.7 milligrams per liter as aluminum. This is a relatively high dose and will require a buffer to ensure environmental integrity. Sodium aluminate is the most common buffer used in alum treatments, for example, Green Lake (Seattle) in 2001 and Long Lake (Kitsap County) in 2007. The alum and sodium aluminate would be applied to the lake in liquid form in a ratio of 2:1 by volume. The required aluminum dose leads to the need for 23,227 gallons of alum and 11,614 gallons of sodium aluminate to be added to the lake in late winter or early spring for maximum effectiveness. The costs for the alum treatment are:

• Alum	\$46,454
• Sodium Aluminate	\$92,912
• Mobilization	\$13,184
• Tax at 8.6%	\$13,184
• Sub total Treatment Cost	\$166,487
• Engineering, Permitting, and Contingency 25%	\$41,622
• Total Estimated Cost of Alum Treatment	\$208,109

These costs are planning level cost and are based largely on the costs of the Long Lake treatment this last spring, which gives us a very good reference point for current costs.

## Summary

1. Historical and recent data indicate that the principal cause for the recent high TP concentrations and algal abundance in Wapato Lake is internal loading of P from bottom sediments.
2. To reduce internal loading, an alum treatment or dredging followed by alum is recommended, with dose based on the analysis of sediment cores. Thorough monitoring of lake conditions should be carried out to determine the effectiveness of the treatment.
3. Dilution is not recommended at this time, because of its greater cost than alum. If alum is not as effective as expected, dilution will be reconsidered along with periodic maintenance alum treatments.
4. Other management activities such as stormwater runoff management (including Best Management Practices and Low Impact Design for redevelopment), waterfowl control, shoreline vegetation enhancement, and increasing shading of the lake are encouraged to proceed as incremental steps toward a holistic lake management program.

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