

**Brief description of stormwater
monitoring studies not part of
Tacoma's Annual Stormwater
Monitoring Report**

Attachment B6.1

2011 Tacoma Stormwater Monitoring Studies

Thea Foss Stormwater Monitoring and Source Control Program

Under a Unilateral Administrative Order and a Consent Decree with EPA (AOC), the City of Tacoma implements the Thea Foss Post-Remediation Source Control Strategy, a stormwater monitoring and source control program for the municipal storm drains entering the Thea Foss and Wheeler-Osgood Waterways.

The monitoring program component evaluates the quality of stormwater discharges to the Thea Foss Waterway and the effect of those discharges on sediment quality. The monitoring results are being used in an ongoing evaluation of source loadings to the waterway to help identify and manage new or existing sources and to protect sediment quality in the years following the sediment remedial action. Chemicals predicted with the greatest potential to affect sediment quality in the years following cleanup action include polycyclic aromatic hydrocarbons (PAHs) and phthalates.

Over ten years (August 2001 - September 2011), stormwater, baseflow and stormwater suspended particulate matter (SSPM) were sampled at seven outfalls that discharge into Thea Foss Waterway. To date, 1,289 samples have been collected with (baseflow (322) and stormwater (709) and SSPM samples (62 outfall and 196 upline.) The whole-water and SSPM concentrations discharged to the waterway are dependent upon a number of factors.

The whole-water samples were analyzed for target analytes selected from the list of problem chemicals identified in the AOC, including selected semi-volatiles (PAHs and phthalates), total metals (lead, mercury and zinc), hardness, pH and TSS. The SSPM samples from the sediment traps and the sump were analyzed for the target analytes including semi-volatiles (PAHs and phthalates), total solids, grain size, TOC, selected total metals (lead, zinc and mercury), Pesticides/PCBs and NWTPH-Dx.

Tacoma Landfill Pervious Pavement Demonstration Project

The Surface Water and Solid Waste Utilities created a demonstration project at the Tacoma Landfill to study various types of pervious pavements and how each perform related to flow control, water quality treatment, maintenance and durability. The 36,100 square-foot paved area, which is used to provide employee parking, was constructed with equal sections of pervious interlocking pavers, pervious concrete, pervious asphalt and standard asphalt. Additionally, a grassy area adjacent to the site is used as a control and tested for water quality and flow control.

The project's prime location in a closed section of the Tacoma Landfill allows for complete collection of water infiltrating the pervious pavement sections due to the existing impermeable landfill liner beneath the pavement. The pervious pavements allow rainwater to infiltrate through the pavement and into the landfill cover layer, prior to entering the landfill cap primary drainage system. Infiltration through the pervious pavement and cover material provides a level of water quality treatment and reduces flow control requirements. Test results for both impervious and pervious pavement areas will be compared and results will be used for future stormwater modeling of the landfill cap and to evaluate the effectiveness of pervious pavements for flow control and water quality treatment.

Construction of the project was completed in April 2006. A report detailing the results of water quality sampling between March 2007 and October 2009 was completed in 2011

2011 Tacoma Stormwater Monitoring Studies

and is included in Appendix I of the Thea Foss and Wheeler-Osgood Waterways 2011 Source Control and Water Year 2011 Stormwater Monitoring Report which is in Attachment C-1.

A separate report detailing the results of continuous flow monitoring between June 2009 and June 2010 was completed in 2012 and is also included in Appendix I of the Thea Foss and Wheeler-Osgood Waterways 2011 Source Control and Water Year 2011 Stormwater Monitoring Report which is in Attachment C-1. The flow monitoring report is in support of Section S8.F.7 of the City's 2007 Phase I NPDES Permit (NPDES S8F). A report is included in Attachment C-4.

Wapato Lake Hydrology and Nutrient Monitoring

Storm event sampling was initiated by the City in April 2008 and continued through 2009, to determine nutrient and water budgets for the north and south basins of the lake. The City formalized and expanded this investigation with passage of Resolution 37864 on September 1, 2009. Water quantity and quality were measured through 2010. The City monitored groundwater and stormwater and provided laboratory work (except biological analyses, by UWT). UWT collected lake and sediment samples and any other samples from the park area. UWT also managed the volunteers assisting with the monitoring effort. All laboratory data went to UWT for analysis and reporting.

Results were reported in 2011 and are included in Attachment B6.2.

Volunteer Stream Team Water Quality Monitoring

In 2011, the Pierce Stream Team coordinated volunteers to collect water quality data for the following list of streams in Tacoma: Buckley Gulch Creek, Flett Creek, Garfield Gulch Creek, Leach Creek, Mason Creek, Titlow Park Creek, and Swan Creek. Monitoring parameters include pH, dissolved oxygen, nitrate, temperature, and turbidity. Qualitative observations of water appearance, visible discharges, stream bed coating, odor, weather, debris, or wildlife are also documented. Monitoring frequency varies from monthly to quarterly.

Hydrology and Nutrient Budget for Wapato Lake, Tacoma, WA

Attachment B6.2

Hydrology and Nutrient Budget for Wapato Lake, Tacoma, WA

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SUMMARY

Wapato Lake, a small, shallow urban lake in Tacoma, Washington, has a long history of water quality problems. Swimming beaches have been closed after high fecal coliform counts and the lake has been listed as impaired due to high total phosphorus concentrations. One reason for these ongoing water quality issues is the fact that the primary hydrological inflow into the lake is urban stormwater runoff. Stormwater acts as an ongoing source of new nutrients to Wapato. Thus, without addressing source control adequately, algae control efforts in the lake will be limited to short-term benefits. This study quantifies nutrient inputs and outputs to Wapato Lake in order to inform management decisions needed to effectively address nutrient source control in the future.

The separation of the North and South Basins of Wapato Lake in the early 1980s by the construction of a dike and stormwater bypass system effectively created two very different lakes. The water budget for the North Basin of Wapato Lake is dominated by entering stormwater runoff from a large urban area in South Tacoma, with all of this water leaving either through the bypass drain or evaporation. At least during water year 2010 none of this water entered the South Basin over the weir. Thus, all water entering the South Basin came from direct rainfall on the lake or overland runoff from the surrounding Wapato Park. As the contributing area is quite small compared to the South Basin volume, this results in a long flushing time (~8.5 years) and little movement of nutrients out of the South Basin. Moreover, during the summer with little rainfall evaporation in the South Basin results in the concentration of nutrients in the South Basin water column. Groundwater appears to have little influence on the hydrology of the South Basin.

A large flux of nutrients is associated with the stormwater flow into the North Basin. About half of the phosphorus influx leaves via the bypass drain while the other half is deposited in the North Basin sediments. In the South Basin, nutrients are added primarily via overland park runoff and waterfowl droppings. Sedimentation rates in the South Basin were high, but possibly affected by the alum treatment. Little phosphorus leaves the South Basin resulting in the net accumulation of phosphorus in the lake.

Water column measurements showed distinct correlations between chlorophyll *a* (from phytoplankton), Secchi depth (a measure of water clarity), and total phosphorus. All values were elevated in the summer of 2010, indicating mesotrophic (medium algae growth) to eutrophic (high algae growth) conditions in the lake. However, chlorophyll *a* values and Secchi depth collected by volunteers in 2009 and 2011 indicated strongly eutrophic conditions. The short-term improvement in 2010 is most likely due to the colder, wetter conditions during that water year. High phytoplankton biomass was also recorded in 2010, dominated during much of the summer by the cyanobacteria *Anabaena* sp. Release of phosphorus in the South Basin is much less than in the North Basin, although bottom water concentrations in the South Basin indicate some sediment release during the summer even after alum.

Other water column data showed that the impact of the 2008 alum treatment is still affecting the South Basin of the lake. Specific conductivity and pH both show evidence of continued adjustment throughout the water year as the slow flushing of the Basin clears the chemicals left from the treatment.

Overall, our study points to the need to address ongoing inputs of nutrients to the South Basin from overland park runoff and waterfowl as these appear to be the primary sources of new nutrients to this Basin. In addition, it appears that it may be necessary to control phosphorus release from the sediments using a regularly operating treatment system in conjunction with aquatic weed control to prevent the pumping of nutrients out of the sediment via plant uptake.

It is also suggested that the North Basin be actively maintained to maximize nutrient removal from stormwater, and that treated stormwater be used to decrease the flushing time for the South Basin. Although there was no overflow of the weir during the 2010 water year, it is known that overflow events occurred in water years 2008 and 2009 when rainfall intensity surpassed 1 inch in 24 hours. To prevent large additions of nutrients to the South Basin during these events it is recommended to increase sediment retention during high flow events, possibly through increased sinuosity, and possibly to use high flow events to feed stormwater to a treatment system to feed treated water to the South Basin.

BACKGROUND

Wapato Lake is a small, 23 acre lake located in the highly urbanized area of south Tacoma, Washington that has attracted visitors since the late 19th century. It has a long history of water quality problems and management activities. The lake has been closed four times of varying lengths to recreational use due to poor water quality.

Wapato Lake was first opened to the public in 1889 and in 1910 Tacoma's park board recommended that the Metropolitan Park District of Tacoma purchase the lake and surrounding area for recreational use (McGinnis 2005). The lake and surrounding area were finally purchased in 1920, which brought in more swimmers and visitors as well as continuous park development from 1926 to 1928 (McGinnis 2005). The first closure occurred in 1942 after swimmers reported rashes, which were thought to have been the result of overland sewage entering the lake (McGinnis 2005). A sewer improvement project was installed in 1945 and the lake was once again open to swimmers in 1948 (McGinnis 2005). Wapato Lake was closed again in 1957, after complaints to the Park Board of an unpleasant smell.

By 1966, the park was awarded an Urban Beautification Grant for lake rehabilitation and storm drain improvements. With this grant the Wapato Lake clean-up started in 1971 with the mechanical removal of aquatic plants covering more than 90% of its bottom. The aquatic plant removal was shown to have little effect in combating the continuous algal problems (Entranco 1986). In 1981 a diversion dam and storm water bypass system were constructed, creating two separate basins, north and south. The North Basin now has a surface area of 2.5 acres and a volume of 6.7 acre-ft (in addition there is approximately 6.5 acres of wetland) while the larger South Basin has an area of 20.5 acres and a volume of 107.2 acre-ft (Appendix A, Clean Lakes Inc. 2010). The bypass system diverts almost all storm water around the South Basin of the lake through storm drains, allowing only occasional overflows of the weir into the South Basin during significant storm events. In addition drinking water was injected into the South Basin in order to dilute P concentrations in the lake and an alum treatment was conducted in 1984 when results were less than hoped for (Entranco 1986). The dilution system was discontinued as it was found that the water used was often high in P.

The lake was again closed for recreational use in 1997 due to toxic algae and nicknamed 'Duck Poop Park,' by local citizens. An environmental study done by Tetra Tech in 2007, showed that phosphorus levels were double what they were in 1975 (Tetra Tech 2007). With few aquatic plants and reported deaths of turtles and waterfowl, it was shown that toxic algae blooms were causing serious problems in the lake (Tetra Tech 2007). In an effort to reduce the concentrations of toxic algal growth, an alum treatment was applied in July of 2008. Incorrect chemical concentrations used during the treatment resulted in a large pH drop and a massive fish kill. Algal blooms reappeared after the treatment.

This intensive study attempts to quantify more completely the hydrology and nutrient budget of Wapato Lake in order to better inform management decisions in the future. The study was conducted by volunteers and students and staff from the University of Washington Tacoma from 2008-2011, with a focus on water year 2010 (October 2009 to September 2010).

METHODS

UWT Water Column Monitoring

Water samples and water quality measurements were collected roughly biweekly from a boat by UWT students and staff at set locations in the North and South basins of Wapato Lake from October 2009 to November 2010 [Figure 1]. A multi-parameter water quality probe (HydroLab Quanta or MS5 Sonde) was used to measure temperature, specific conductivity, pH, dissolved oxygen, and chlorophyll *a* (MS5 Sonde only) at 0.5 m intervals (or less) throughout the water column. The probe was factory calibrated for temperature and specific conductivity in advance and then calibrated each day for dissolved oxygen and pH prior to transport to the field; depth was calibrated on site. Secchi depth was also recorded from the boat.



Water samples for nutrients (dissolved nitrate/nitrite, ammonia, and orthophosphate and total nitrogen and phosphorus) and alkalinity were collected by peristaltic pump with acid-washed tubing from surface (0.5 m) and near bottom depths at each sampling location and stored on ice. Samples for phytoplankton identification and chlorophyll were collected in the same manner from 0.5 m only at each station.

Nutrient samples were collected in triple-rinsed, one-gallon plastic cubitainers provided by the City of Tacoma and stored on ice in the dark. Samples were delivered to the City of Tacoma analytical laboratory in the Center for Urban Waters building the same day for analysis. Alkalinity samples were analyzed within 24 hours by UWT students or staff using the Gran titration method with daily calibration using a sodium bicarbonate standard. Samples for chlorophyll *a* were filtered immediately upon return to the UWT laboratories on glass fiber filters and stored in 90% acetone in the freezer in the dark prior to analysis. Cells were

disrupted by sonication, centrifuged and chlorophyll *a* was measured using a fluorometer.

Phytoplankton samples were collected in 250 mL dark Nalgene bottles and preserved in 1% Lugol's solution after collection. Zooplankton samples were collected using an 80 μ m mesh net tow from 5 ft below the surface. The contents of the net were transferred to 250 mL Nalgene bottles in 70% ethanol. All zoo- and phytoplankton samples were stored on ice for transport to the lab and later shipped to a contracted lab (ZP Taxonomic, Aquatic Analysts and EcoAnalysts) to be analyzed for taxonomy, abundance and biomass.

Volunteer Monitoring

Volunteer monitoring and sample collection was accomplished during alternating weeks from UWT sampling when possible. Volunteer sampling began in December 2008 and is still being conducted

currently (September 2011). The UWT Service Learning Coordinator (Kayomi Wada, Jennifer Guenther, or Christina Zinkgraf) or UWT project staff worked with citizen volunteers to measure Secchi depth, count waterfowl, and collect samples for nutrients, phytoplankton, and chlorophyll *a*. Water samples were collected from just below the lake surface using a telescoping sampler from the two docks in the South Basin (by the boathouse and at the south end of the South Basin) and from the weir spillway in the North Basin. Samples for chlorophyll and phytoplankton were handled as described above.

Nutrient samples were collected in acid-washed Nalgene bottles prepared by UWT students and staff. Samples for dissolved analysis were filtered in the field using 0.4 µm syringe filters. These and unfiltered samples were stored on ice and delivered to the City of Tacoma analytical laboratory in the Center for Urban Waters building the same day for analysis.

Waterfowl counts were accomplished from regular visual reference points around the South Basin to include birds in the South Basin or in the very near shore areas. Numbers of individuals were identified as geese, ducks, and seagulls.

Sediments

In August 2010, sediment cores were collected from each of the two basins using a hand-driven 2-inch core barrel (Wildlife Supply Company); the North Basin yielded a 56 cm long core, while the South Basin core was 80 cm in length. These cores were capped and carefully transported upright to UWT to minimize disturbance of the surface sediments. In the lab, the cores were sliced into 2 cm sections and placed in Nalgene jars. Core sections were then weighed, dried, homogenized (Wiley mill) and sent off for nutrient analysis. Sediments were analyzed for total nitrogen by CHN analysis and total phosphorus and metals by ICP-AES after nitric acid digestion (University of Washington School of Forest Resources Analytical Lab). Core sections were then sent to MyCore, Inc. for ²¹⁰Pb dating.

Since Wapato Lake has been subjected to various lake management treatments, it was decided that a core would be obtained from Wards Lake to be used as a background indicator. Wards Lake is an urban lake in the same watershed as Wapato Lake, actually receiving some of Wapato Lake's overflow, and has not been dredged or treated to our knowledge. A Wards Lake core was obtained in September 2010 and handled and analyzed in the same manner as Wapato Lake cores.

In July 2010, 34 samples of surface sediments were collected using a Ponar dredge (Wildlife Supply Company) from and boat and locations recorded using a GPS; 10 samples were collected from the North Basin and 24 from the South Basin. Nine samples were also collected by hand from the North Basin wetland in November 2010. The collected sediments were placed in Nalgene jars and stored on ice for transport to UWT. The samples were dried in an oven for one week at 80°C and homogenized in a Wiley Mill. The homogenized sediment was collected in plastic bags and stored in a dark place prior to analysis. Sediments were analyzed for nitrogen and phosphorus by the University of Washington School of Forest Resources Analytical Lab as described above for the sediment cores.

Benthic Flux

Estimates of benthic flux rates for nitrogen and phosphorus transport from the sediments to the overlying water column were conducted. A benthic flux chamber constructed by the Washington Department of Ecology was borrowed to carry out this work (see standard operating procedure http://www.ecy.wa.gov/programs/eap/ga/docs/ECY_EAP_SOP_036BenthicFluxChambers.pdf). The chamber was deployed from a boat in June-July 2010 in the deepest part of each basin for 2-5 days. The chamber was equipped with a HydroLab Sonde (borrowed from the Washington Department of Fish and Wildlife) and sampling port with the data cable and tubing extended to the lake surface and secured to an anchored buoy. Water samples for nutrients (dissolved nitrate/nitrite, ammonia, and orthophosphate and total nitrogen and phosphorus) were collected using a peristaltic pump and water quality measurements (temperature, dissolved oxygen, specific conductivity, and pH) were recorded during deployment without disturbing the chamber or the sediments.

Overland Flow

Estimates of overland flows to the South Basin and associated nutrient fluxes were carried out by UWT students. Flow rates were estimated by GIS. Using the contributing area map created by the City of Tacoma, land cover classes were assigned manually using aerial photos followed by ground truthing. Polygons were digitized and areas calculated. Runoff coefficients were assigned to the varying types of land cover using ASCE published values (http://www.dlr.enr.state.nc.us/TAC%20website/2008_06_Drafts_for_Public_Comment/Rational%20Method/New%20Rational%20Method.pdf). Local precipitation data was obtained for October 2009 to September 2010 from the City of Tacoma.

Student-collected overland flow samples were used to measure nitrogen and phosphorus concentrations. Samples were collected from six locations around the lake [Figure xxx] during rain events over a seven month period in 2010 and delivered the same day to the City of Tacoma analytical laboratory in the Center for Urban Waters building for analysis. By combining average sample concentrations, total rainfall, land cover areas, and runoff coefficients a mass flux into the lake was calculated.

City of Tacoma Data and Sample Collection

Lake and well water levels and storm drain flows were recorded and storm water samples collected by City of Tacoma Environmental Services staff. Data were received by UWT after validation by City of Tacoma staff. Methods used are described elsewhere.

RESULTS

General Climate Effects

Anecdotally it was apparent during the 2010 water year that the general climate was much different than in the preceding water years. To quantify this difference more concretely, we examined air temperature and precipitation patterns from McChord AFB in Tacoma (http://www-k12.atmos.washington.edu/k12/grayskies/nw_weather.html) for the 2008, 2009 and 2010 water years

[Table 1]. While average annual temperatures were not much different, average summer temperatures (June-Sept) were much lower (1.8-4.1°F lower) and annual precipitation was much higher (7.4-10.7 in higher) in the 2010 water year than in the 2008 and 2009 water years. These differences should be expected to affect some water quality parameters and may lead to decreased stratification, biological productivity and some dissolved concentrations.

Wind data for the 2010 water year [Figure 2] show higher winds in the early winter and early spring, with generally light winds in the summer. We have projected wind speeds along the N-S axis of maximum fetch in order to estimate the potential for sediment resuspension as a source of nutrients to the overlying waters. Wind speeds exceed 10 mph for only 62 hours of the year, corresponding to potential mixing depths of 2.9-4.2 ft. Thus sediment resuspension would only be an appreciable source in the very near-shore areas during most of the year, with the possibility of short-term resuspension during high-wind events, usually coinciding with storms and low-biological productivity potential in this region.

	WY 2008	WY 2009	WY 2010
avg annual temp (°F) =	48.5	48.7	48.8
total rain (in) =	33.1	36.4	43.8
avg summer temp (°F) =	60.0	62.3	58.2

Table 1: Climate data for water year 2008 through 2010 (http://www-k12.atmos.washington.edu/k12/grayskies/nw_weather.html).

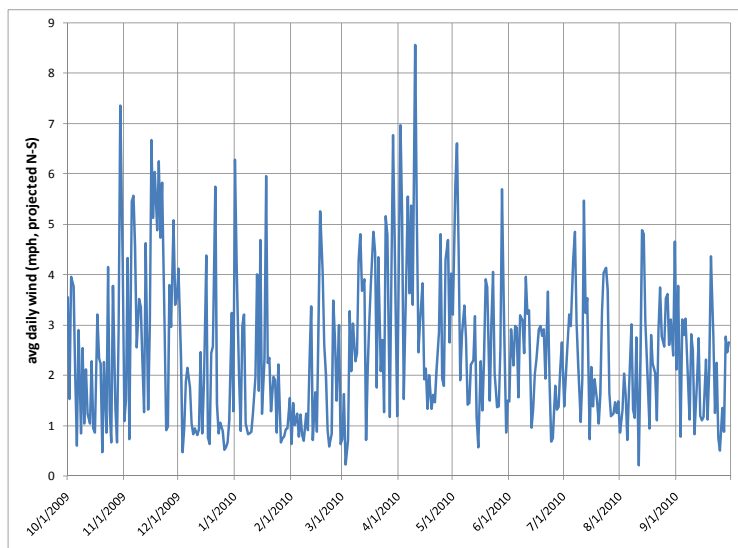


Figure 2: Average daily wind speed at Tacoma South L station projected onto north-south axis along maximum fetch direction for Wapato Lake for water year 2010.

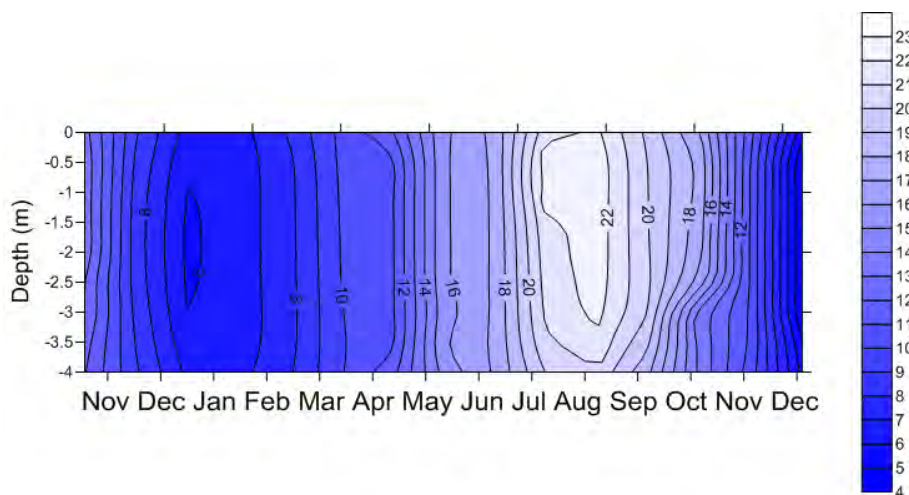


Figure 3: Temperature (°C) profile for the South Basin of Wapato Lake, 2009-2010, collected at station 1 in the deep end of the basin.

Temperature

Temperature profiles for Wapato Lake [Figure 3] show a relatively well-mixed lake throughout most of the year, as is to be expected with a shallow lake, with some weaker stratification established during the late summer and early autumn months (July-Oct).



Figure 4: Dissolved oxygen (mg/L) profile for the South Basin of Wapato Lake, 2009-2010, collected at station 1 in the deep end of the basin.

Dissolved Oxygen

Dissolved oxygen concentrations in the South Basin [Figure 4] reflect the stratified periods in the lake with lower levels in the bottom waters during the summer months and during the ice cover period in the winter, most likely attributable to aerobic respiration consuming organic matter in the sediments. Sub-surface oxygen maximums are also present at times during the late summer and early autumn months at about 1.5-2.0 m depths, most likely due to primary productivity (phytoplankton and possibly aquatic plants).

pH and Alkalinity

The pattern in pH in the South Basin water column [Figure 5] is correlated to dissolved oxygen concentrations during the summer and early autumn. This is supporting evidence for aerobic respiration in the bottom waters/sediments



Figure 5: pH profile for the South Basin of Wapato Lake, 2009-2010, collected at station 1 in the deep end of the basin.

(pH decrease) and enhanced primary production in the sub-surface (pH increase). However, another overall pattern is also evident; a gradual pH increase from 6.8 to 8.4 was measured in the entire lake over the water year, which may be due to continued equilibration of the lake following the incorrectly buffered alum treatment in 2008. Unlike pH, alkalinity [Figure 6] fluctuates during the water year but does not change appreciably from the start to the end.

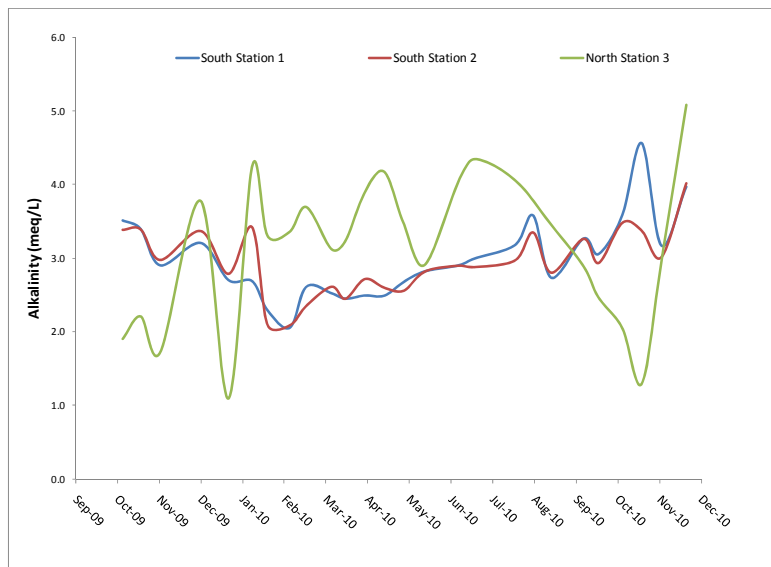


Figure 6: Alkalinity (meq/L) of surface waters (0.5 m) in the South Basin of Wapato Lake, 2009-2010.

Specific Conductivity

Further evidence for continued equilibration of the lake following the alum treatment is evident in the specific conductivity measurements in the South Basin [Figure 7]. Specific conductivity is relatively constant throughout the water column (evidence of little remineralization of sediment-bound ions) at all times during the water year, but the conductivity in the entire lake decreases from 0.130 to 0.070 over the course of the year. Thus, pH and specific conductivity data reflect slow continued equilibration of the lake water following the alum treatment due to slow flushing of the South Basin.

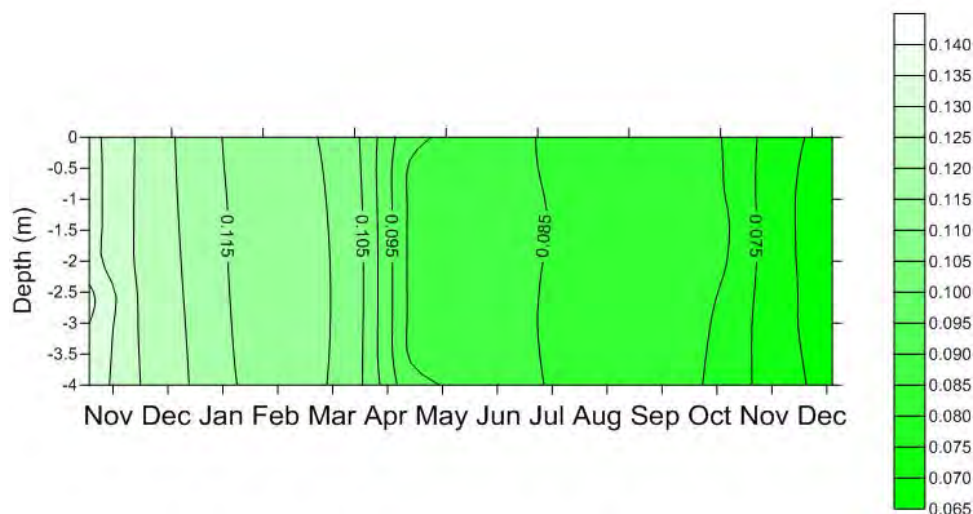


Figure 7: Specific conductivity (mS/cm) profile for the South Basin of Wapato Lake, 2009-2010, collected at station 1 in the deep end of the basin.

Secchi Depth

The Secchi depth recorded by volunteers and UWT staff from 2008-2011 [Figure 9] show a regular pattern of decreased water clarity due to phytoplankton productivity in the South Basin of Wapato Lake

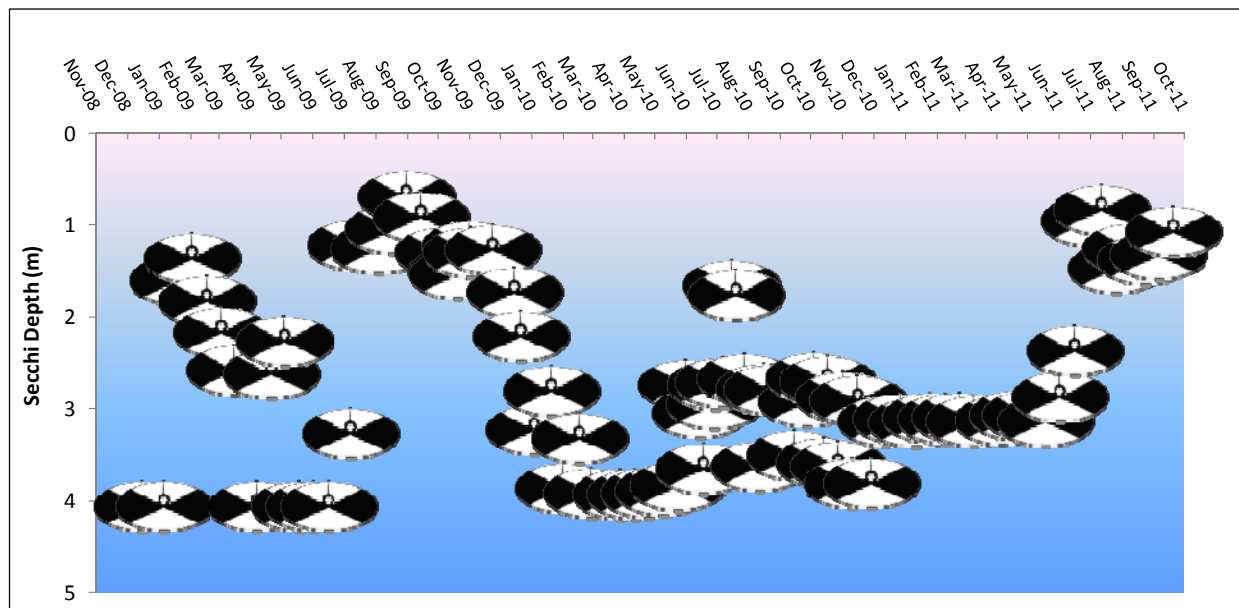


Figure 9: Secchi depth (m) recorded from 2008-2011 in the South Basin of Wapato Lake by UWT staff and volunteers.

every summer into early autumn. However, water year 2010 appears to have less productivity than 2009 and 2011, suggesting that the anomalous temperatures may have had a negative impact on phytoplankton production.

Chlorophyll

In the South Basin chlorophyll spikes to 35 $\mu\text{g/L}$ during the summer of 2009 [Figure 8] and again increases in late fall 2009 to 25 $\mu\text{g/L}$ at the start of the 2010 water year. This pattern

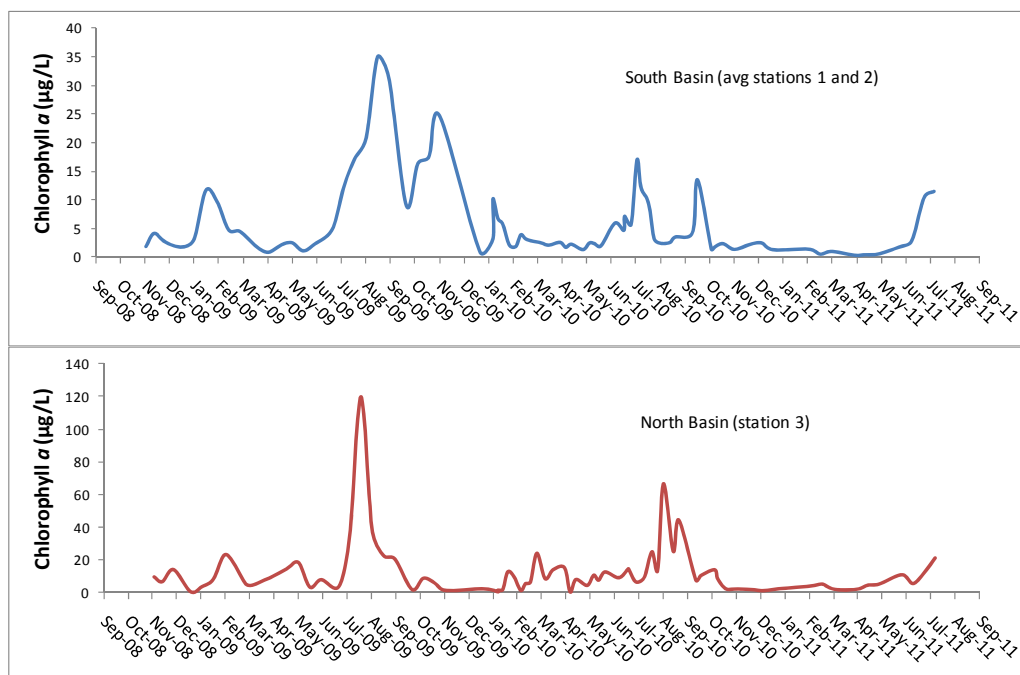


Figure 8: Chlorophyll *a* concentrations in surface waters of Wapato Lake (combined volunteer and UWT data) from 2008-2011.

repeats during the summer and autumn of 2010 but with lower maximum values (possibly due to the colder, wetter summer). Smaller chlorophyll spikes are witnessed in January of 2009 and 2010, possibly during short, sunny periods or ice cover-induced stratification.

Similar temporal patterns are witnessed in the North Basin [Figure 8], although maximum chlorophyll values reach over 120 $\mu\text{g/L}$ in the summer of 2009 and over 60 $\mu\text{g/L}$ in the summer of 2010.

Phytoplankton

Phytoplankton cell counts are correlated to chlorophyll concentrations in both the South [Figure 10] and North Basins [Figure 11] as might be expected during the late autumn of 2009 and the summer of 2010.

Waterfowl

Goose counts were much higher during the late spring and summer months (May-August) for the three years we have volunteer monitoring data at Wapato Lake [Figure 12]. Lower goose numbers in 2009

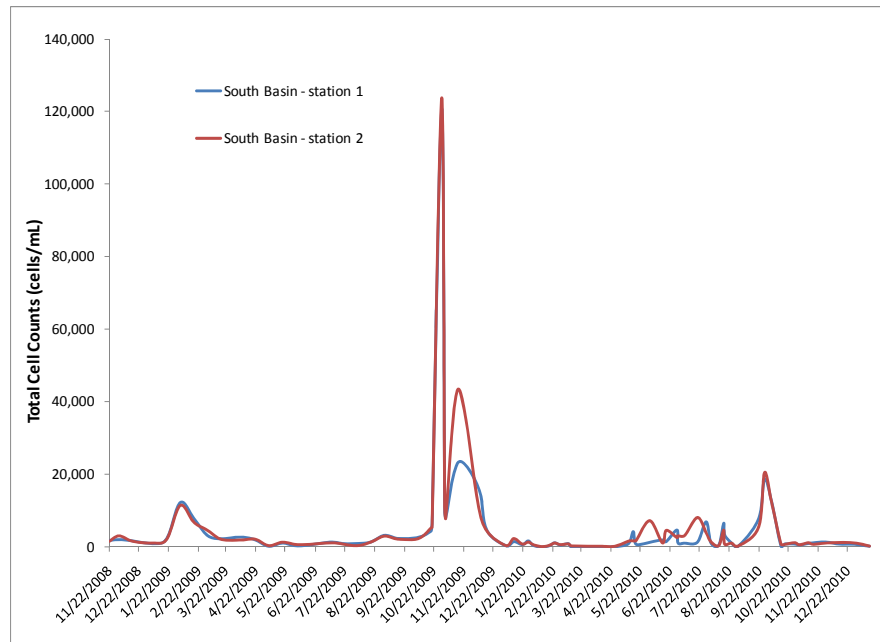


Figure 10: Phytoplankton cell counts (cells/mL) in the South Basin of Wapato Lake (combined volunteer and UWT data) from 2008-2010.

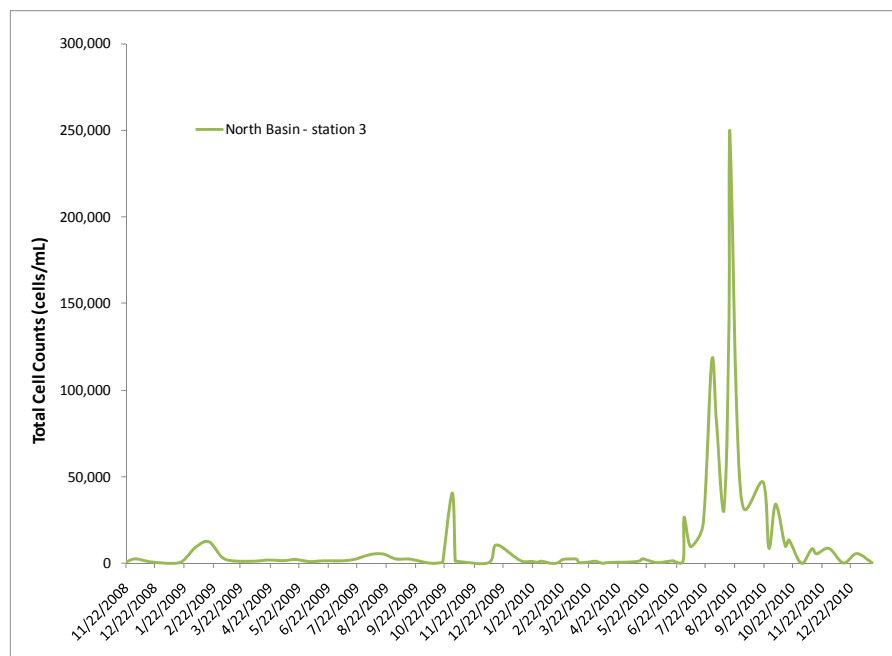


Figure 11: Phytoplankton cell counts (cells/mL) in the North Basin of Wapato Lake (combined volunteer and UWT data) from 2008-2010.

may be related to goose control activities funded during that time, but maximum counts in 2010 and 2011 are similar (200-250 individuals). Dabbling duck and seagull counts, which are highest during the fall to early spring, appear to have increased dramatically from 2008-2010.

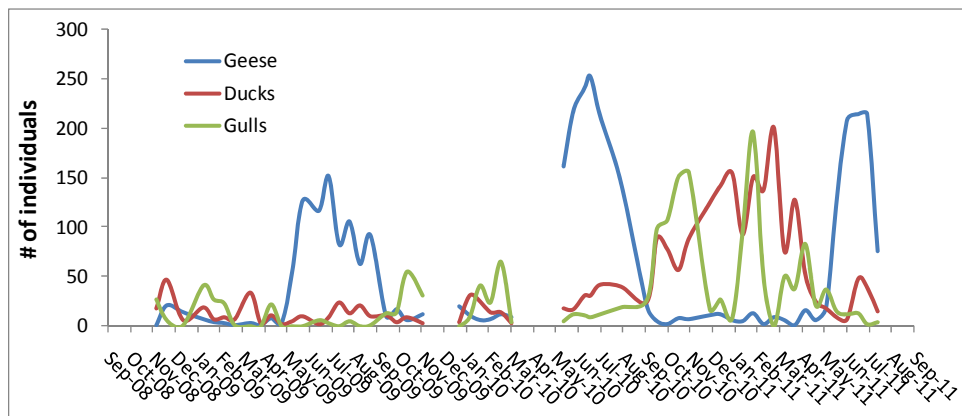


Figure 12: Waterfowl counts from the South Basin of Wapato Lake (data collected by volunteers with the UWT Service Learning Coordinator) from 2008-2011.

Sediment Core Record

Sediment core analyses in the North and South Basins show increasing N and P concentrations in sediments from the time of early development of the watershed in the late 1800s [Figure 13]. In the South Basin, this increase is interrupted by periodic short-term decreases in N and especially P, most likely due to management attempts including dredging, aquatic weed harvest, etc. In 1980, a major decrease in P in the South Basin marks the construction of the dike and bypass weir system and dilution with drinking water, whereas no concomitant decrease is witnessed in the North Basin. Thus it seems that this treatment system worked to decrease P concentrations in the sediments in the South Basin for close to 20 years. However, around 2002, P concentrations began to increase again in the South Basin coupled with decreasing P levels for the first time in the North Basin. The large spike in P at the top of the South Basin core is most likely the result of phosphorus removal to the sediments during alum treatment.

In addition, analysis of other elements in the sediment cores [Figure 14] clearly indicate the intensive alum treatment in 2008 in the South Basin, which deposited large quantities of Al, P, Si, S, As and other elements in the sediment. Also visible in the North Basin is a significant transition around the

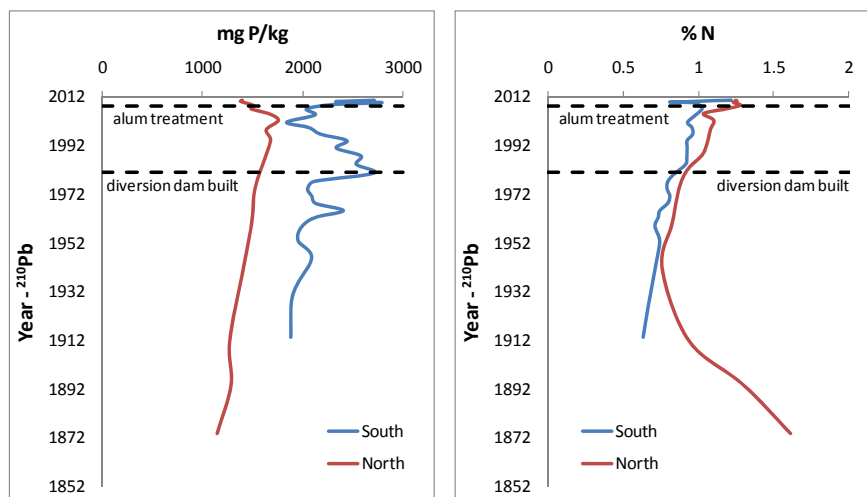


Figure 13: Phosphorus (mg/kg) and nitrogen (%) concentrations in sediment cores taken from the South and North Basins of Wapato Lake in 2010.

time of early development in the watershed [Table 2], corresponding possibly to a combination of increased erosion, land-use changes, and peat removal from the lake around the turn of the century.

Hydrologic Budget – North Basin

The hydrologic budgets for the North and South Basins of Wapato Lake

are detailed by month. Almost all water that enters the North Basin [Table 3] enters through the northeast and northwest storm drains (390 million gallons per year, or mgy) and exits via the North Basin bypass (301 mgy). The northeast drain (166 mgy) brings in less water than the northwest drain (224 mgy) annually. Monthly inflow through the northeast and northwest storm drains is proportional to rainfall in the watershed as expected [Figure 15]. Lake level measurements (recorded every 15 minutes) show no overtopping of the flashboards in the weir, thus indicating zero direct overflow from the North to the South Basin. However, it was noted that leakage does occur directly through the flashboards, but the estimate (based on head differences between the basins)

suggests weir leakage is responsible for a very small net annual flux (0.6 mgy) out of the South Basin into the North Basin, primarily during the spring and early summer when the lake level in the South Basin remains high. It was also determined by slug tests performed in shallow groundwater piezometers installed in the earthen dike between the North and South Basins that the dam itself may be somewhat permeable (average $K = 6.6 \times 10^{-3}$ cm/sec). A simple estimate of total annual flow through the dam results in 0.4 mgy flowing from the North into the South Basin. Evaporation losses from the North Basin are estimated to be around 7 mgy and direct rainfall into the

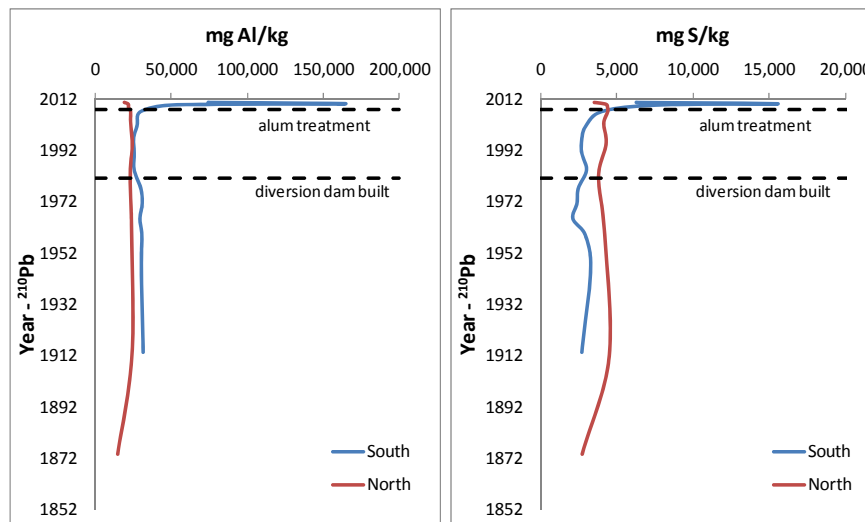


Figure 14: Aluminum and sulfur concentrations (mg/kg) in sediment cores taken from the South and North Basins of Wapato Lake in 2010.

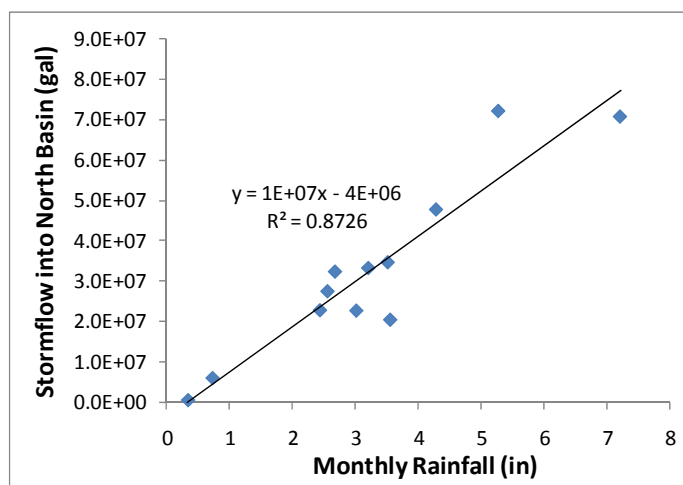


Figure 15: Correlation between monthly rainfall (in) and monthly storm flow (gal) into the North Basin of Wapato Lake during water year 2010.

NORTH BASIN	Year	Al	As	B	Ba	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	S	Se	Zn	Si
N_Wap 0-2cm	2010.7	19136	123	38.797	156	5039	5.86	55.4	150.2	19441	858	4796	310	33.3	316	75.1	1461	331	3544	100.2	353	1392
N_Wap 2-4cm	2010.3	21034	136	42.625	168	5413	6.98	61.7	115.9	21560	784	5396	336	37.1	286	83.6	1562	380	4045	66.0	405	849
N_Wap 4-6cm	2009.8	21880	140	43.198	173	5524	7.26	64.1	98.9	22543	867	5587	333	37.5	283	87.1	1633	416	4347	86.2	456	876
N_Wap 6-8cm	2008.7	21942	140	44.464	178	5591	7.36	65.5	103.5	22864	907	5738	331	38.8	299	87.9	1759	447	4412	88.0	519	776
N_Wap 8-10cm	2007.1	23294	151	46.914	186	5513	7.06	66.6	115.8	24587	917	6171	346	43.5	309	92.9	1575	453	4421	86.3	508	966
N_Wap 12-14cm	2002	23297	150	49.895	193	5315	8.43	74.5	141.9	26411	957	6775	337	43.9	349	93.1	1768	630	4159	76.1	749	737
N_Wap 16-18cm	1995	24375	156	52.104	198	5598	8.80	77.9	144.8	27818	1007	7194	362	45.5	361	97.8	1802	674	4312	106.5	769	799
N_Wap 20-22cm	1982	22990	150	48.158	179	5123	8.21	73.0	134.7	25745	906	6708	339	42.1	334	91.7	1602	688	3819	95.4	663	715
N_Wap 24-26cm	1960	23964	161	49.812	180	5301	8.73	76.5	128.5	26759	985	7066	361	44.9	340	96.6	1594	777	4208	94.7	629	754
N_Wap 28-30cm	1912	24151	157	46.584	177	4889	6.79	63.9	98.3	24835	862	6142	343	41.7	279	94.6	1309	322	4513	85.4	355	1043
N_Wap 32-34cm	1874	14723	82.042	21.238	117	4053	2.93	39.2	42.0	10906	402	3115	242	22.7	201	56.6	1151	134	2757	45.9	170	981
N_Wap 36-38cm	???	16700	86.354	21.72	132	4080	2.96	42.7	41.6	11124	461	3736	243	24.6	170	61.3	1178	144	2605	43.7	189	829
N_Wap 40-42cm	???	20479	103.37	24.628	149	3897	3.28	58.8	37.2	12725	607	4761	252	32.0	166	78.9	1275	118	2075	40.8	169	857
N_Wap 44-46cm	???	21343	99.028	22.456	141	3401	2.86	56.3	27.4	11721	516	4500	220	31.8	140	78.9	1488	78.7	1421	82.2	129	1060
N_Wap 48-50cm	???	18576	90.047	20.158	130	3393	2.62	48.0	25.7	10268	470	4026	211	30.3	135	70.4	1411	71.1	1598	52.1	133	743
N_Wap 52-54cm	???	17803	84.855	19.73	122	3264	2.49	41.8	23.8	9638.1	450	3714	198	26.0	134	61.1	1476	68.8	1506	28.7	111	839
SOUTH BASIN	Year	Al	As	B	Ba	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	S	Se	Zn	Si
S_Wap 0-2cm	2010.7	74367	264.87	66.277	80	2393	5.29	40.0	52.6	20663	699	3279	247	93.3	355	56.7	2598	290	6288	94.2	201	1946
S_Wap 4-6cm	2010.2	164310	591.2	44.54	97	2864	23.76	80.2	103.0	27178	ND	4852	310	212.0	667	102.2	3617	533	15612	167.0	332	9078
S_Wap 8-10cm	2009.7	50358	220.39	48.394	142	3854	6.34	56.0	76.4	26696	880	5120	410	71.8	329	82.3	2735	354	7836	90.4	272	839
S_Wap 12-14cm	2007	30163	181.98	52.889	180	4966	6.83	68.0	92.7	28992	928	6387	546	51.4	381	99.0	2172	376	4035	97.7	328	920
S_Wap 16-18cm	2002	27739	169.78	51.372	175	4785	6.81	69.9	92.1	27575	924	6444	477	48.7	361	99.1	1929	369	2983	115.5	323	1117
S_Wap 20-22cm	1997	25425	165.85	50.351	172	4560	6.81	68.2	91.2	27496	914	6256	464	46.6	346	96.4	2050	371	2715	111.9	318	878
S_Wap 24-26cm	1991	25847	167.38	50.359	179	4511	6.80	66.4	92.9	27496	945	6333	450	46.0	344	96.7	2028	383	2698	96.6	325	866
S_Wap 28-30cm	1984	25777	169.96	50.81	176	4358	7.10	66.7	92.9	28183	958	6301	451	47.8	337	96.1	2134	392	3018	83.9	322	801
S_Wap 32-34cm	1977	30125	191.24	55.841	198	4836	7.65	76.1	106.6	30605	1026	7124	462	52.8	370	107	2230	502	2481	77.3	342	1261
S_Wap 36-38cm	1971	31068	193	55.763	195	4736	7.28	75.8	113.0	30591	1105	7341	443	56.8	366	107	2043	516	2386	68.8	345	1316
S_Wap 40-42cm	1965	29576	184.51	52.281	191	4404	7.14	72.9	103.0	29069	1059	7040	408	52.5	344	103	2127	553	2124	71.3	335	1109
S_Wap 44-46cm	1959	30843	206.16	57.127	204	4904	8.28	82.0	113.8	31958	1200	7812	445	56.5	371	115	1860	643	2941	91.0	394	1250
S_Wap 48-50cm	1946	30491	215.63	59.244	212	4900	8.64	80.1	111.7	32990	1248	7949	465	56.7	388	114	1922	797	3295	69.5	400	1026
S_Wap 52-54cm	1913	31710	228.36	62.342	230	4872	9.21	81.3	106.7	34835	1224	8350	496	58.4	363	119	1983	728	2706	84.9	365	704
S_Wap 56-58cm	???	33336	224.18	63.663	239	5085	8.71	97.0	109.2	35658	1271	8535	496	61.6	358	129	1869	409	2193	112.0	304	950
S_Wap 60-62cm	???	30775	197.53	54.445	232	4696	7.48	76.0	94.8	30560	1100	7381	445	54.0	275	113	1806	254	2049	81.3	267	842
S_Wap 64-66cm	???	29031	190	51.493	232	4614	7.25	72.1	91.2	28495	1025	6749	430	50.3	246	112	1882	211	2552	68.6	261	1021
S_Wap 68-70cm	???	31387	196.2	52.704	258	5006	7.46	75.0	92.6	28667	1030	6386	451	52.5	236	114	2213	217	3053	68.9	273	1387
S_Wap 72-74cm	???	28929	171.11	46.657	227	4523	5.88	67.7	70.5	25517	927	5638	395	47.1	195	103	1963	159	3142	75.4	185	1099
S_Wap 76-78cm	???	18311	116.36	30.792	167	4174	4.10	43.4	45.7	16300	614	3547	316	33.4	156	67.3	1780	105	3235	58.3	138	1342

Table 2: Elemental concentrations (all in mg/kg) for sediment cores taken from the South and North Basins of Wapato Lake in 2010.

NORTH BASIN												
Year	Month	Rainfall (in)	Rainfall on Lake (gal)	NE Inflow (gal)	NW Inflow (gal)	Evaporation (gal)	North Bypass Outflow (gal)	Weir Overflow (gal)	Weir Leakage (gal)	Flow Through Dike (gal)	North Basin Volume Change (gal)	North Basin Balance (gal)
2009	October	3.55	8.68E+05	7.85E+06	1.26E+07	-3.13E+05	-1.84E+07	0	-6.67E+05	-2.93E+05	-9.44E+05	9.63E+05
2009	November	7.21	1.76E+06	3.33E+07	3.75E+07	-1.49E+05	-7.33E+07	0	-2.05E+06	-3.03E+05	-1.68E+06	-4.62E+06
2009	December	2.43	5.94E+05	1.05E+07	1.23E+07	0	-2.01E+07	0	-8.53E+05	-8.07E+04	2.31E+06	4.70E+06
2010	January	5.27	1.29E+06	3.42E+07	3.80E+07	0	-6.58E+07	0	2.81E+05	2.48E+04	-8.50E+04	7.88E+06
2010	February	3.2	7.82E+05	1.36E+07	1.96E+07	-1.74E+05	-2.67E+07	0	1.27E+06	9.62E+04	-3.40E+05	8.05E+06
2010	March	4.28	1.05E+06	1.86E+07	2.92E+07	-3.86E+05	-1.56E+07	0	4.98E+05	3.75E+04	-5.19E+06	2.81E+07
2010	April	2.67	6.53E+05	1.23E+07	2.00E+07	-6.01E+05	-2.23E+07	0	8.04E+05	6.60E+04	5.90E+06	1.68E+07
2010	May	3.51	8.58E+05	1.31E+07	2.15E+07	-9.70E+05	-2.29E+07	0	7.21E+05	6.26E+04	-2.55E+05	1.21E+07
2010	June	2.55	6.23E+05	1.05E+07	1.70E+07	-1.13E+06	-1.29E+07	0	7.53E+05	6.46E+04	6.13E+05	1.54E+07
2010	July	0.72	1.76E+05	2.75E+06	3.17E+06	-1.37E+06	-1.98E+06	0	1.00E+05	2.43E+04	1.10E+06	3.94E+06
2010	August	0.33	8.06E+04	1.24E+05	3.27E+05	-1.21E+06	0.00E+00	0	0	1.48E+04	9.77E+05	2.93E+05
2010	September	3.01	7.36E+05	9.38E+06	1.33E+07	-7.14E+05	-2.09E+07	0	-2.58E+05	-1.17E+05	-2.09E+06	-5.47E+05
	TOTAL	38.73	9.47E+06	1.66E+08	2.24E+08	-7.02E+06	-3.01E+08	0.00E+00	6.00E+05	-4.04E+05	3.14E+05	9.32E+07

Table 3: Monthly hydrology budget for the North Basin of Wapato Lake for water year 2010.

SOUTH BASIN											
Year	Month	Rainfall (in)	Rainfall on Lake (gal)	Weir Overflow (gal)	Weir Leakage (gal)	Flow Through Dike (gal)	Evaporation (gal)	Overland Flow (gal)	South Outflow (gal)	South Basin Volume Change (gal)	South Basin Balance (gal)
2009	October	3.55	1.98E+06	0	6.67E+05	2.93E+05	-7.13E+05	5.71E+05	0	-1.73E+06	7.72E+05
2009	November	7.21	4.01E+06	0	2.05E+06	3.03E+05	-3.40E+05	1.16E+06	0	-6.40E+06	4.85E+05
2009	December	2.43	1.35E+06	0	8.53E+05	8.07E+04	0	3.91E+05	0	-1.27E+06	1.33E+06
2010	January	5.27	2.93E+06	0	-2.81E+05	-2.48E+04	0	8.48E+05	-6.28E+03	-4.28E+06	-7.81E+05
2010	February	3.2	1.78E+06	0	-1.27E+06	-9.62E+04	-3.95E+05	5.15E+05	-5.46E+05	-7.41E+05	-6.58E+05
2010	March	4.28	2.38E+06	0	-4.98E+05	-3.75E+04	-8.80E+05	6.89E+05	-2.16E+06	-2.14E+06	-2.60E+06
2010	April	2.67	1.49E+06	0	-8.04E+05	-6.60E+04	-1.37E+06	4.30E+05	-1.42E+06	3.33E+06	1.65E+06
2010	May	3.51	1.95E+06	0	-7.21E+05	-6.26E+04	-2.21E+06	5.65E+05	-1.00E+03	8.62E+05	4.48E+05
2010	June	2.55	1.42E+06	0	-7.53E+05	-6.46E+04	-2.58E+06	4.10E+05	0	1.52E+06	1.63E+04
2010	July	0.72	4.01E+05	0	-1.00E+05	-2.43E+04	-3.12E+06	1.16E+05	0	3.60E+06	8.94E+05
2010	August	0.33	1.84E+05	0	0	-1.48E+04	-2.77E+06	5.31E+04	0	3.51E+06	9.84E+05
2010	September	3.01	1.68E+06	0	2.58E+05	1.17E+05	-1.63E+06	4.84E+05	0	-1.56E+06	-7.64E+05
	TOTAL	38.73	2.16E+07	0.00E+00	-6.00E+05	4.04E+05	-1.60E+07	6.23E+06	-4.13E+06	-5.29E+06	1.77E+06

Table 4: Monthly hydrology budget for the South Basin of Wapato Lake for water year 2010.

North Basin is estimated to be about 9.5 mgd. The decrease in lake volume in the South Basin accounts for 3.2 mgd of additional outflow for this water year.

Hydrologic Budget – South Basin

The South Basin may receive inflow from the North Basin over or through the weir.

However, no recorded events overtopped the weir and thus direct overflow from the North to the South Basin was zero [Table 4]. Leakage estimates through the flashboards and through the dike are as described above; on an annual net basis water moves from the South to the North Basin at 0.6 mgd through flashboard leakage and 0.4 mgd from the North to the South through groundwater flow through the dike, almost effectively canceling each other out.

Inflow from overland flow in the surrounding park is estimated at 6.2 mgd, while direct rainfall on the lake surface is 21.6 mgd. Evaporation removes water at a rate of 16.0 mgd, while the South Basin overflow drain is estimated to remove 4.1 mgd flowing primarily from January to April. The increase in lake volume in the South Basin accounts for 5.3 mgd of the inflow for this water year.

Groundwater head levels in the vicinity of Wapato Lake monitored by the City of Tacoma during the 2010 water year indicate that groundwater inflow is not a contributor to South or North Basin inflows [Figure 16]. As the water mass balance seems to almost completely balance without considering losses to groundwater in the South Basin, and as this is a perched lake sitting atop most probably some kind of aquitard, it is assumed that groundwater losses are negligible. As the South Basin lake volume is approximately 107.2 acre-ft, or 34.9 million gallons, and the outflow through the South Basin overflow drain is 4.1 mgd, we estimate the turnover time to be approximately 8.5 years for the South Basin, a very slow flushing rate.

Nutrient Budget – North Basin

Tying nutrient concentrations to hydrology we have assembled a nutrient budget with a monthly time step for the North and South Basins of Wapato Lake [Table 5]. In the North Basin, on an annual basis 96 kg of P and 634 kg of N enter through the northeast drain while 63 kg of P and 793 kg of N enter through the northwest drain. Total N in the two drains is correlated to total inflow and therefore watershed area, whereas total P is related to land use in the two drainage basins.

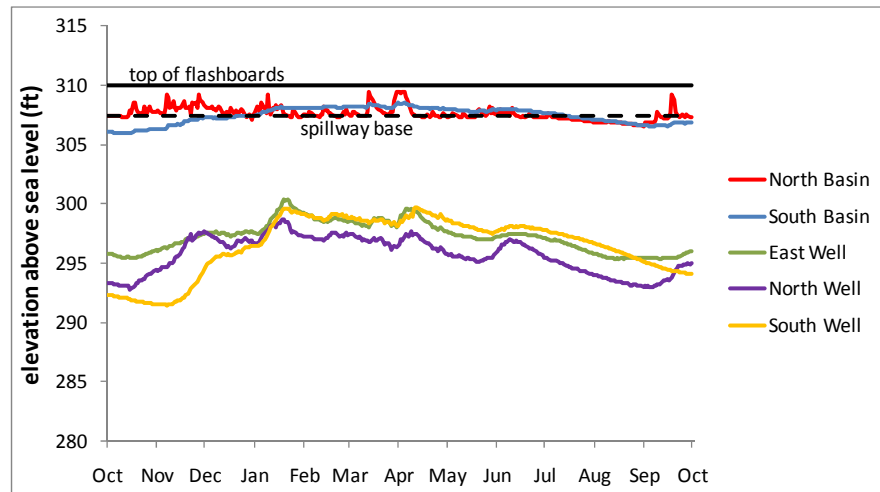


Figure 16: Water levels in the North and South Basins of Wapato Lake and nearby groundwater wells in water year 2010.

A small amount of P and N are added through weir leakage (0.5 kg P and 2.4 kg N) and groundwater flow through the dike (0.2 kg P and 2.2 kg N). Annual atmospheric inputs were not measured, but were estimated from USGS literature values for the Puyallup River watershed to be 1.1 kg P and 5.6 kg N (<http://wa.water.usgs.gov/pubs/fs/fs.009-98/table1.html>).

It is estimated that 61 kg of P and 595 kg of N leave the North Basin through the bypass drain, while sediment losses are estimated to remove 74 kg P and 490 kg N. The annual benthic flux of nutrients from sediments into the water column [Figure 17] is difficult to estimate as it is dependent on the prevalence of anoxia in the bottom waters. However, we did find that P release from North Basin sediments may be a significant source of P to the overlying waters during the summer [Figure 18]. No estimates of waterfowl contributions were carried out in the North Basin although anecdotally waterfowl were present in smaller numbers with geese noticeably absent.

Nutrient Budget – South Basin

Total phosphorus values in the South Basin of Wapato Lake in WY 2010 did show a significant improvement from pre-alum treatment values (Tetra Tech 2008), decreasing from a maximum value of 400 µg/L in WY 2007 to a maximum of 100 µg/L in WY 2010.

In the South Basin, the annual nutrient input via overland flow is estimated at 35 kg P and 69 kg N using field samples and runoff estimates based on rainfall and land use classification [Table 5]. This estimate is based on few measurements and limited locations due to theft and storm event timing. Additional monitoring of overland flow may be necessary to more accurately quantify this contribution. Annual atmospheric inputs estimated from literature values are 2.6 kg P and 12.7 kg N.

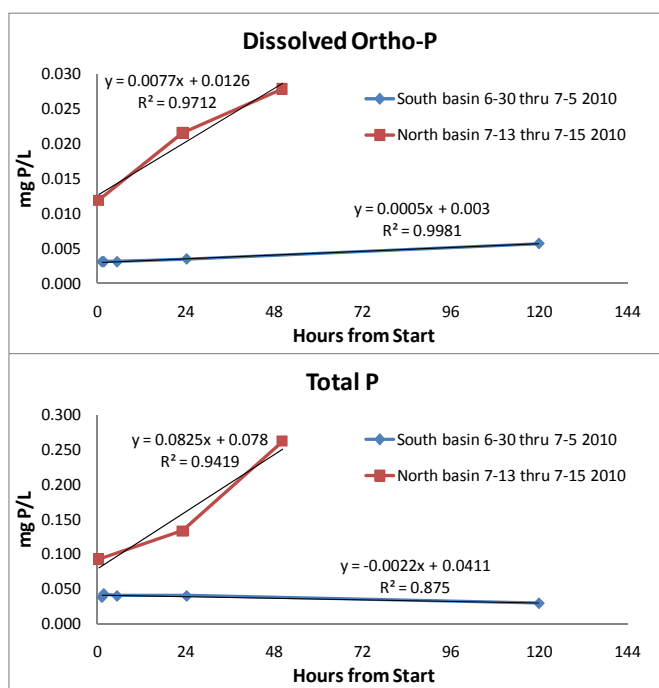


Figure 17: Benthic flux measurements in the North and South Basins of Wapato Lake in June-July 2010. A simple linear regression is fit to the data.

Waterfowl may also be a significant source of nutrients to the South Basin of Wapato Lake. Large summer and early autumn populations of geese and increasing winter and spring populations of dabbling ducks and seagulls are estimated to add 11 kg P and 37 kg N. It is difficult to know what percentage of waterfowl contributions are already included in overland flow estimates of nutrient inputs, but it may be that waterfowl numbers, pet waste, soil erosion and fertilizer use in the park (no estimates made for these latter three, although anecdotal experience suggests they may be important) all contribute to higher measured values of N and P in overland flow samples than calculated using

standard literature values. In fact, waterfowl contributions alone contribute enough P and N to account for the total reservoir of P and N in the waters of the South Basin [Table 5].

Removal of nutrients from the South Basin occurs only to a minor extent through the South Basin overflow drain (1 kg P and 10 kg N) and leakage through the weir (0.5 kg P and 2.4 kg N) and groundwater flow through the dike (0.2 kg P and 2.2 kg N). Losses to the sediments however are estimated to be 224 kg P and 1133 kg N. As these losses are much larger than the annual allochthonous inputs outlined above, it may be that a large portion of the nutrients added to these sediments are due to either the re-deposition of nutrients remineralized and transported up in the sediment column through benthic fluxes or plant uptake and senescence. Benthic flux measurements in the South Basin during the 2010 water year (following alum treatment) show little P release from the sediments at least in the deep areas of the lake [Figure 17], but summertime P concentrations do suggest that sediment release may still be occurring [Figure 18], possibly in shallow, nearshore areas where alum is less effective.

Trophic State Index (TSI)

The relative productivity level of Wapato Lake can be normalized using the trophic state index (TSI). This measure has been developed using chlorophyll, Secchi depth, total P, phytoplankton biovolume, and more. Using water year 2009 and 2010 data, the TSI for Wapato Lake is shown in Table 6. Although

TSI Parameter	TSI for Water Year 2009	TSI for Water Year 2010	2010 Trophic Category
Chlorophyll <i>a</i>	60	50	Eutrophic
Secchi depth	55	45	Mesotrophic
Total P	55	48	Mesotrophic
Biovolume	49	44	Mesotrophic

Table 5: Trophic state index (TSI) for the South Basin of Wapato Lake calculated using average summer data (July-September) for water years 2009 and 2010.

conditions seem to improve from 2009 to 2010, this improvement may just be an indicator of the lower average summer temperatures and higher rainfall. In 2011, Secchi depth again decreases [Figure 9], returning the TSI to the eutrophic range. These data show that the productivity in Wapato Lake remains elevated even after the 2008 alum treatment.

Phosphorus			N Basin Water Column	NE Inlet	NW Inlet	North Bypass	Weir Overflow	Weir Leakage	Dike Leakage	North Basin Balance	S Basin Water Column	S Basin Waterfowl	South Basin Overland Flow	South Outlet	South Basin Balance
Year	Month	Rainfall (in)	Total P (kg)	Total P (kg)	Total P (kg)	Total P (kg)	Total P (kg)	Total P (kg)	Total P (kg)	Total P (kg)	Total P (kg)	Total P (kg)	Total P (kg)	Total P (kg)	Total P (kg)
2009	October	3.55	2.11	5.0	4.2	4.8	0.0	0.2	0.08	4.1	1.75	0.24	3.24	0.00	3.8
2009	November	7.21	0.81	19.4	10.6	17.8	0.0	0.4	0.06	11.8	4.50	0.19	6.57	0.00	7.2
2009	December	2.43	0.63	6.1	3.5	4.9	0.0	0.2	0.02	4.5	10.32	0.35	2.22	0.00	2.7
2010	January	5.27	0.32	19.9	10.7	15.6	0.0	0.0	0.00	15.1	4.17	0.32	4.80	0.00	5.1
2010	February	3.2	0.41	7.2	5.2	6.2	0.0	-0.1	-0.01	6.4	2.90	0.20	2.92	-0.13	2.9
2010	March	4.28	0.51	11.2	7.8	3.8	0.0	0.0	0.00	15.2	4.16	0.23	3.90	-0.52	3.6
2010	April	2.67	0.34	7.3	5.6	5.1	0.0	-0.1	-0.01	8.0	6.29	0.11	2.43	-0.35	2.1
2010	May	3.51	0.57	7.2	5.9	5.5	0.0	0.0	0.00	7.7	1.69	0.11	3.20	0.00	3.3
2010	June	2.55	1.00	5.5	4.6	2.9	0.0	0.0	0.00	7.2	2.17	3.15	2.32	0.00	5.4
2010	July	0.72	0.67	1.6	0.9	0.5	0.0	0.0	0.00	2.0	4.36	3.73	0.66	0.00	4.4
2010	August	0.33	0.78	0.1	0.1	0.0	0.0	0.0	0.00	0.2	2.40	2.42	0.30	0.00	2.7
2010	September	3.01	1.20	5.4	3.6	5.1	0.0	0.1	0.06	3.7	8.80	0.42	2.74	0.00	3.4
	TOTAL	38.73		95.96	62.69	72.13	0.00	0.53	0.18	85.81		11.48	35.30	-1.00	46.49
									atmospheric	1.1				atmospheric	2.6
									sediment loss	-74.14				sediment loss	-224.24
									unaccounted P	12.77				unaccounted P	-175.15
Nitrogen			N Basin Water Column	NE Inlet	NW Inlet	North Bypass	Weir Overflow	Weir Leakage	Dike Leakage	North Basin Balance	S Basin Water Column	S Basin Waterfowl	South Basin Overland Flow	South Outlet	South Basin Balance
Year	Month	Rainfall (in)	Total N (kg)	Total N (kg)	Total N (kg)	Total N (kg)	Total N (kg)	Total N (kg)	Total N (kg)	Total N (kg)	Total N (kg)	Total N (kg)	Total N (kg)	Total N (kg)	Total N (kg)
2009	October	3.55	16.92	22.3	36.3	40.8	0.0	3.7	1.62	12.5	73.92	0.77	6.29	0.0	12.4
2009	November	7.21	8.78	130.6	135.3	175.8	0.0	4.6	0.68	84.8	65.61	0.62	12.77	0.0	18.7
2009	December	2.43	11.78	40.8	44.3	48.2	0.0	3.1	0.29	33.5	89.22	1.10	4.30	0.0	8.8
2010	January	5.27	5.92	131.9	140.0	157.1	0.0	-0.6	-0.05	115.4	114.73	1.01	9.33	0.0	9.7
2010	February	3.2	6.21	51.9	70.9	64.4	0.0	-2.9	-0.22	61.5	85.80	0.64	5.67	-1.3	1.9
2010	March	4.28	7.93	74.3	100.3	37.4	0.0	-0.7	-0.05	138.0	71.20	0.72	7.58	-5.2	2.4
2010	April	2.67	5.94	50.6	72.1	52.2	0.0	-1.7	-0.14	72.3	85.92	0.34	4.73	-3.4	-0.1
2010	May	3.51	16.36	48.6	75.4	54.0	0.0	-1.9	-0.16	72.0	89.44	0.36	6.22	0.0	4.5
2010	June	2.55	5.56	35.6	59.1	23.5	0.0	-2.0	-0.17	73.4	111.96	10.09	4.52	0.0	12.4
2010	July	0.72	4.86	10.7	11.4	4.8	0.0	-0.2	-0.04	17.6	64.09	11.95	1.28	0.0	13.0
2010	August	0.33	7.09	0.5	1.2	0.0	0.0	0.0	-0.04	1.7	88.64	7.76	0.58	0.0	8.3
2010	September	3.01	8.12	36.1	47.3	50.4	0.0	1.0	0.44	31.5	99.57	1.35	5.33	0.0	8.1
	TOTAL	38.73		634.05	793.45	708.60	0.00	2.42	2.15	714.32		36.72	68.60	-9.89	99.99
									atmospheric	5.6				atmospheric	12.7
									sediment loss	-489.88				sediment loss	-1133.11
									unaccounted N	230.04				unaccounted N	-1020.42

Table 6: Nutrient budgets for P and N for the North and South Basins of Wapato Lake for water year 2010.

RECOMMENDATIONS

North Basin Management

Currently the North Basin acts as a partial sink for storm water derived nutrients. During the 2010 water year we witnessed numerous days of very low oxygen concentrations (2 mg DO/L) in the surface waters of the North Basin and high potential P release rates from the sediments, suggesting that this basin may be a potential source of P during the warmer months. The North Basin should be actively managed to increase the trapping of particulate-bound nutrients and to prevent the North Basin becoming a significant source of nutrients due to sediment release and plant die-off. Catch basins at the storm drain inlets should be maintained as intended at the least. Other possible steps could include the periodic harvest of wetland plants to remove nutrients and organic matter possibly coupled with selective dredging of accumulated deposits around the plants. The re-engineering of the wetland to increase sinuosity and subsequent sediment retention may also be done with an eye toward making it easier to access plants and sediments for periodic removal.

Storm Water Bypass System

The storm water bypass system appears to be functioning well in its intended purpose to divert storm water-derived nutrients that make it through the North Basin around the South Basin. In fact, it seems that little or no North Basin water overflowed the weir flashboards to make it into the South Basin during the 2010 water year. While the flashboards and the dam itself are permeable to leakage, the net flux of water (and therefore nutrients) through the dam and flashboards was estimated to be quite small compared to other fluxes and probably could be ignored. However, this bypass system also prevents the vast majority of rainwater from contributing to the flushing of the South Basin. This results in a calculated flushing time for the South Basin of 8.5 years, with the majority of the water entering the South Basin coming from overland flows in Wapato Park, which we find have very high nutrient levels.

Cleaner Dilution Water

One possible method for delivering more water for dilution of the South Basin may be to treat the storm water from the North Basin and send it through the South Basin. Diverting some portion of storm water flow into perforated pipes below the park grounds could act to filter nutrients out of the water and increase localized clean groundwater flow into the South Basin, at least for part of the year. Increasing the baseline water levels in the North Basin (by raising the elevation of the inlet to the North bypass drain) may also provide some benefit by forcing more groundwater flow through the dam which may provide some similar P removal if leakage through the flashboards is halted. Finally, pumping local deeper groundwater into the South Basin may be an option, but total P concentrations measured in these nearby wells periodically had significantly higher P concentrations (> 100 µg/L) making this less likely to succeed without pretreatment.

Wapato Park Management

The majority of the nutrients entering the water column in the South Basin during water year 2010 are not from the North Basin, but rather they are locally contributed by waterfowl, overland flow and possibly sediment release and aquatic plant uptake and senescence [Table 5]. It is clear the 2008 alum treatment has decreased the flux of nutrients from the South Basin sediments [Figure 17], although it is not clear whether this is the case throughout the basin as our sampling was limited. However, elevated P levels in the South Basin during late summer and early fall 2010 suggest that sediment release may still be occurring to some degree [Figure 18]. Bottom water P concentrations correlate to chlorophyll concentrations and plankton numbers during the water year suggesting a link to sediment release. However, it should also be noted that geese populations are also contributing higher amounts of P during the summer [Figure 12]. Overland flow, on the other hand, is dependent on rainfall and therefore is lowest during the summer, but it may be a significant contributor to the addition of new P to the sediments overall [Table 5].

Therefore, we recommend that a management plan for the South Basin must include aggressive waterfowl deterrence (especially targeting geese, but with ducks an increasing issue possibly due to increasing aquatic plant growth), local park source control and runoff treatment, and some method of sediment P release reductions.

It has been our observation that abnormally high waterfowl numbers are supported by a lack of park user education and enforcement and by shoreline and park plantings that do not deter geese. Goose waste not only adds a significant load of nutrients to the South Basin, but it also decreases public access to the shoreline (no one wants to walk through or sit in the goose feces that accumulate there). Goose numbers can be decreased by education and enforcement by park staff already on location and through thoughtful shoreline plantings. Seagulls, on the other hand, roost on the roof of the boathouse and the abandoned dock protected from disturbance by the public. Repair of the dock and common pigeon deterrence devices may decrease their numbers. These may be particularly important to control as seagulls have been shown to be sources of fecal coliform bacteria, feeding at waste water treatment plants and the landfill before roosting elsewhere.

Park runoff may also be addressed through public education and thoughtful park plantings and design. We observed significant erosion of the shoreline due to the volume of overland flow in some areas and the potential for pet waste and bird feces to enter the lake in multiple locations. We even witnessed the

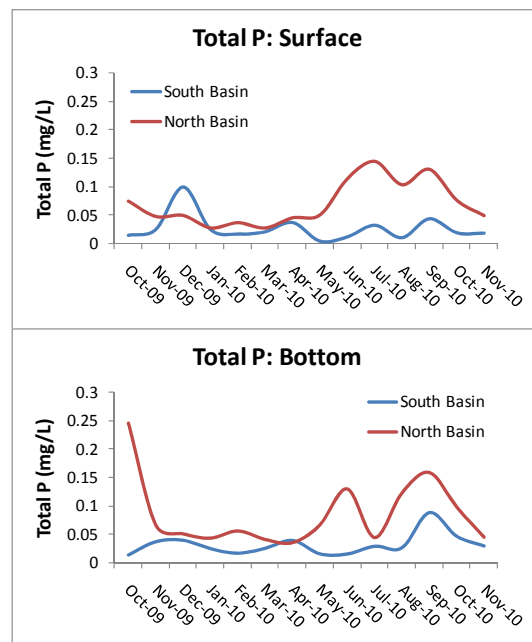


Figure 18: Total P concentrations in surface and bottom waters of the North and South Basins of Wapato Lake during water year 2010.

inappropriate use of TAGRO on steep slopes along parts of the lakeshore during planting, resulting in direct inputs to the lake. Shoreline plantings may provide a buffer strip to decrease erosion and nutrient retention, but it is also recommended that bioswales or rain gardens be incorporated as well. Pervious pavement around the boathouse and diversion of the roof drains into a rain garden would help decrease overland flow nutrient fluxes.

Finally, it will be necessary to develop an ongoing maintenance plan for keeping nutrients in the sediments. Alum treatment and/or oxygenation may be necessary to maintain P binding capacity in the sediments. However, it may also be necessary to control aquatic weed growth as well. After the 2008 alum treatment it appears that aquatic plants are exploding in coverage and density with the increased water clarity. These plants can pump P from the sediments and then release that P into the lake upon senescence.

Other Considerations

It should be noted that phytoplankton productivity was still elevated in the South Basin of Wapato Lake after the alum treatment, with the cyanobacteria *Anabaena* sp. dominating. Lake managers are more frequently turning to balancing nutrient inputs to dissuade toxic algae blooms and promote non-toxic species' growth, rather than attempting to remove P inputs entirely. In some cases this has even led to improved water clarity as zooplankton are able to respond by consuming larger plankton numbers. This may be a more logical choice for long-term lake management for a shallow urban lake.

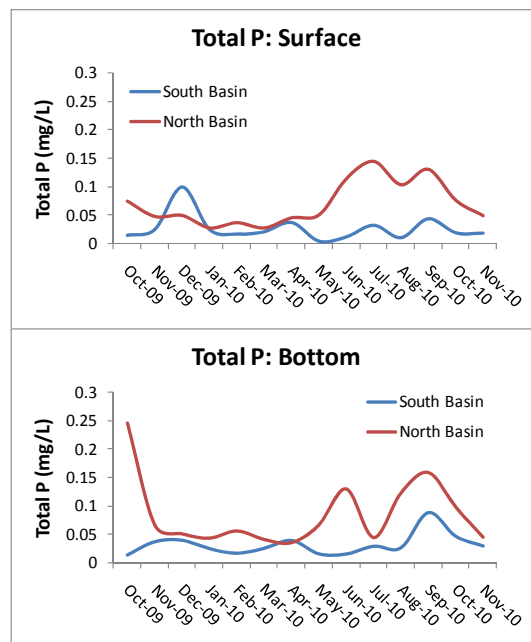


Figure 19: Total P concentrations in surface and bottom waters of the North and South Basins of Wapato Lake during water year 2010.

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