Kalamalka Lake Water Quality Study

Microflora, Water Chemistry & Thermal Profiles

2010

Wind row on Kalamalka Lake Spring 2010

Prepared for: Greater Vernon Water and District of Lake Country

Larratt Aquatic Consulting Ltd. 3025 Ensign Lane, West Kelowna, B.C. V4T 2Z4

Phone: 250.769.5444 Fax: 250.769.3233 Email: heather@larratt.net

Key Findings of 2010 Study

Wood Lake

- In August 2010, Wood Lake marled (calcite precipitation) and that protected against a fall cyanobacteria bloom until the fall overturn was complete in November.

Kalamalka Lake

- The injection of nutrient from a manure spreading operation that washed into Coldstream Creek during a rain storm in January 2010 triggered a complex algae bloom in the North Arm of Kalamalka Lake in late winter and a very strong *Cyclotella* diatom bloom in the spring. Nutrient injections tend to affect several years because only 2% of the water exchanges in Kalamalka Lake each year.

- Overall 0 – 20 m Kalamalka Lake algae production was moderate to high in summer 2010, with 0 – 3465 cells/mL potentially toxin-forming cyanobacteria and 75 – 3785 total cyanobacteria. Cyanobacteria numbers were highest in August samples. A surface flagellate *Dinobryon* bloom occurred again in 2010, causing a fishy taste and odor in the shallow E-Kal intake but no problems for the deeper N-Kal intake. Since *Dinobryon* filter-feed on minute particulates such as bacteria, their prevalence suggests a significant load of bacteria in the North Arm.

- Both the North and South ends of Kalamalka Lake are subject to significant turbulence; the multi-year thermal data shows more intense seiche activity during warm autumns (seiches are the main transport mechanism for surface contaminants to the intakes).

- Turbidity and mild odor events usually coincide in Kalamalka Lake and are induced by algae growth and seiches. A significant water quality benefit would be realized if intakes were positioned >3 m off the substrate.

- Raw water *E. coli* are usually a concern during the fall at the north end of Kalamalka Lake but not at the south end. Since the sediments contained viable *E. coli* in the north but not the south, Coldstream Creek is implicated (Coldstream Creek *E. coli* = 180 to 11,000 cfu/100 mL during 2010). In the past three years, *E. coli* spiked in the narrow window of October 13 – 20. At both ends of the lake, 40 m samples did not contain measurable *E. coli during 2010.*

- In the N Arm, four turbidity spikes exceeding 5 NTU occurred in 2010, however, the overall annual turbidity has declined from 2000 – 2010.

- From 2004 to 2010, growing season average total organic carbon has increased throughout Kalamalka Lake by (6-7 mg/L) and Wood Lake by (5.6-16.2 mg/L).

The following table summarizes the averaged 2010 water quality data:

Average Water Quality Change with Current and Potential Intake Depths – 2010

Kalamalka Lake	South 20 m	South 30 m	South 40 m	North 20 m	North 30 m	North 40 m
Distance to pumphouse* m	550	755	1810	315	680	1590
# of seiches over 2 ^{o}C/yr	20	8	5	10	4	1
Max seiche temp. fluct'n ^{o}C	14	3.2	3.0	11.7	9.9	4.0
Total organic carbon mg/L	7.0	6.3	6.2	6.6	6.3	6.1
Chlorophyll-a ug/L	1.8	1.7	1.2	2.0	1.6	1.2
Turbidity NTU (IHA limit =1)	0.8	0.5	0.5	0.7	0.5	0.5
UV Transmissivity %	90.2	90.4	90.1	91.5	91.3	91.5
Avg algae counts (cells/mL)	1460	1180	1170	1470	1090	550
E. coli cfu/100 mL	<1-1	<1-2	<1	<1-270	<1-40	<1-1
Total coliforms cfu/100mL	<1-OG	<1-8	<1-3	<1-270	<1-59+	<1-OG

*Minimum possible distance from pump house to depth, actual engineered intake locations may vary
OG = overgrown

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1.0 Introduction
1.1 Goals of the Kalamalka Lake Water Quality Study

Ministry of Environment data from 1971 through 1998 measured increasing phosphorus and chlorophyll-a concentrations in Kalamalka Lake. After an offensive taste and odour problem in 1999, a jointly-funded study involving MoE, Greater Vernon Water, Regional District of North Okanagan (RDNO-GVW) and District of Lake Country (DLC) was launched to:

- Define the physical and biological impacts on water quality at the existing GVW and Lake Country intakes, particularly those that impact aesthetics and potability
- Determine ideal depth for a North Kalamalka Lake intake and a South Kalamalka Lake intake to obtain the best water quality using thermistors, dissolved oxygen/temperature profiles, water chemistry and water current drogues
- Provide baseline water chemistry for future additional water treatment
- Study fluctuations in nutrients and algae production in Kalamalka Lake and Wood Lake
- Co-operate with MoE in tracking long-term nutrient and productivity changes in Kalamalka and Wood Lakes, and the implications of those changes for water resources

This study is now in its 12th year and this report includes several graphs that summarize the entire data set for parameters that demonstrated statistically significant trends over the study period.

Over the twelve years of study, many trends and influences on intake water quality have been clarified and refined. The research has been evaluated and re-directed on an annual basis by the participants. Increasing concern over water quality in the Coldstream Creek inflow has prompted MoE to resume detailed nutrient sampling as of 2009. A detailed twice monthly monitoring of bacterial concentrations and water chemistry profiles will be conducted from April 2011 to April 2012.

Other groups including BC Ministry of Environment, Agriculture Canada and UBC-O are conducting valuable research within the Kalamalka and Wood Lake watersheds. Their work is referenced in this study.

1.2 Background on Kalamalka Lake and Wood Lake

Kalamalka Lake

Hydrology Kalamalka Lake is the largest source of potable water in the North Okanagan (A. Cotsworth, pers. comm.) Kalamalka Lake is deep for its size. It has a maximum depth of 142 m, contains 1520 million m^3 and has a residence time of 55 – 65 years. About 20% of its annual inflow comes from Wood Lake and 80% from Coldstream Creek and groundwater. The main body of Kalamalka Lake is oligotrophic with phosphorus and occasionally nitrogen controlling algae growth (Nordin et al, 1988). In general, nutrient concentrations are greater at the North and South ends of Kalamalka Lake and they move in concert, indicating whole-lake influences are more important than localized inputs. Kalamalka Lake is a marl lake and has elevated concentrations of calcium and sulphate.

Coldstream Creek Coldstream Creek imports nutrients and *E. coli* bacteria to Kalamalka Lake. From Noble Canyon downstream, 45% of its riparian area needs restoration. Agricultural impacts on Coldstream Creek include stream bank erosion, surface discharge of nutrients and horse/cattle/avian fecal material as well as nitrate-enriched groundwater discharge. In the 1970's, MoE estimated that the Coldstream area donated 47% of the total cultural N and 43% of the total cultural P loading to the Kalamalka-Wood Lake Basin (Nordin et al., 1998). In the downstream urban areas, the most obvious impacts stem from direct discharge of untreated storm water. In MoE research, Coldstream Creek is far more impacted than Mission Creek or Shingle Creek in terms of nitrates and bacterial counts (Nordin et al., 1998).

Wood Lake Inflows Water generally moves northward from Wood to Kalamalka Lake through the Oyama Canal. Wind action and lake seiching frequently cause oscillations in the flow through the canal. In late summer and particularly in dry years, a net southerly flow occurs (MoE, 1975). When the Hiram-Walker plant was operating, its cooling water forced nutrient-rich water from Ellison, through Wood and into Kalamalka Lake. MoE estimated that 20-30% of the nutrients entering Kalamalka Lake came from Wood Lake during that time (MoE, 1975). These flows were discontinued in 1992.

Limnology Every year, Kalamalka Lake begins to stratify during late March. Stratification is firmly re-established by mid-May. Thermal/turbidity disturbances at the intakes caused by seiches (internal waves) tend to cluster in early June. The thermocline gradually drops as Kalamalka Lake heats up over the summer. During the fall, the thermocline oscillates deeper into the lake. These oscillating periods (Aug/Sept/Oct) are marked by mild taste/odor and turbidity events. Nutrients released from the sediments may stimulate algae growth by mixing into the water column during seiches.

Without summer seiches, water temperatures at the GVW N-Kal and DLC S-Kal intakes would be stable near 8 – 10^{o}C. With seiches, 20^{o}C water penetrates to 10-15 m at the North end, while at the South end, 20^{o}C water travelled down to 11-13 m. At the intake depths, seiches bring warm surface water with increased turbidity, alternating 1-2 times a day with cool bottom water. They last for several days with diminishing intensity until the next storm triggers another seiche.

After October, both the RDNO N-Kal and Lake Country S-Kal intakes withdraw water from the cooling surface layer as it thickens down to the intake depth. Mixing continued as the thermal stratification became increasingly fragile until storms break down the water layers during November. Thermal mixing is complete by early December (Bryan, 1990). After December, the entire lake cools as a unit until very subtle inverse stratification sets up in January. In cold winters, partial ice cover develops in sheltered bays.

Productivity Chlorophyll-a concentrations increased over 1971–1998 (MoE database), paralleling an increase in phosphorus concentrations. Phosphorus adheres to soil particles, explaining why P trends are linked to the size of freshet. Phosphorus concentrations are also affected by the timing and intensity of the marl precipitation. The highest phosphorus loading to Kalamalka Lake comes from Coldstream Creek (Bryan, 1990). Nitrogen inputs also increase with large freshets both as particulates and as dissolved nitrate donated by groundwater. Nitrogen cycling is also affected by bacterial activity in Kalamalka Lake sediments.

Marl Precipitation Kalamalka Lake experiences summer marl precipitation events because of its naturally high calcium and sulphate concentrations. The timing and intensity of the annual marl precipitation varies from year to year due to fluctuations in water chemistry, water temperature and algae growth. It normally occurs between mid July to early August. Marl precipitation helps Kalamalka Lake because it co-precipitates phosphorus. As soon as the marl precipitation occurs, usually in July, nutrient concentrations drop and algae production declines to an annual low. Marl also co-precipitates the made-by-bacteria B vitamins and they are required for the growth of many algae (Larratt, 2007). The carbonate/marl cycle in Kalamalka Lake protects this lake from nutrient enrichment and raises its sedimentation rate to 2.9 mm/yr (Dill, 1972). It also probably explains why Kalamalka has lower algal production than Okanagan Lake despite their similar nutrient concentrations.

Water Quality Although Kalamalka Lake has enviable water quality on the global scale, there are indicators of both positive and negative change. Since all lakes undergo water chemistry fluctuations, the challenge before us is to preserve Kalamalka Lake water quality.

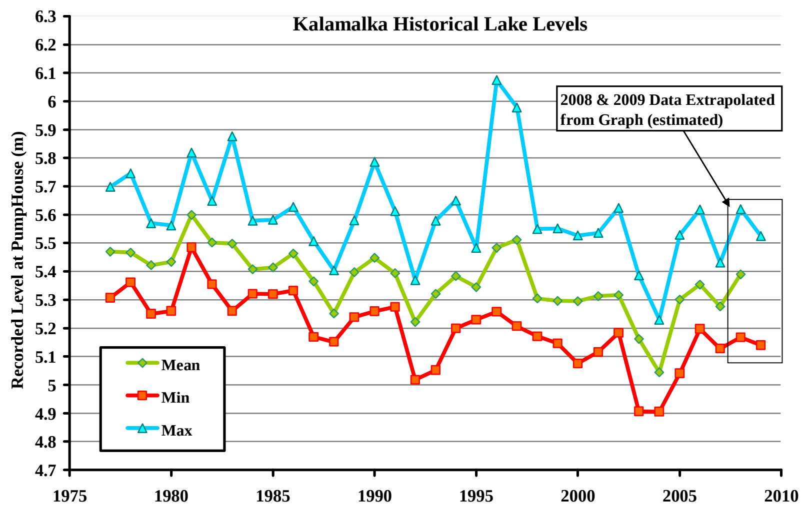
Kalamalka Lake

NEGATIVE CHANGE

- Farming practises and storm water outfalls import nutrients and bacteria via Coldstream Creek and via Wood Lake. *E. coli* in the N-Kal intake raw water are currently higher than the historic norm.
- Dissolved sodium and chloride (salt) ions may be increasing in Kalamalka Lake, pointing to a measurable human impact on the lake as opposed to climactic factors (MoE).
- Kalamalka Lake has fluctuating pH that could affect the intensity of the marl precipitation that restricts phosphorus availability.
- Kalamalka Lake water levels are trending lower and may relate to precipitation, consumption or releases to Lower Vernon Creek (Figure 1.1).

Figure 1.1

(After Clark, 2009)



POSITIVE CHANGE

- In 2000, wastewater treatment replaced septic systems on Wood Lake and progressively lowered nutrient loading from Wood to Kalamalka Lake.
- Algae samples collected in the 1930's – the last series of hot, dry summers, contained large numbers of blue-green algae (cyanobacteria) that produce toxic alkaloids. These algae require high nutrient concentrations and warm water temperatures. Several of these undesirable species are no longer found in Kalamalka Lake but are common in smaller lakes in the region. Some of these blue-green algae are occasionally seen in Okanagan Lake.
- Commencing in 1971, the Hiram Walker plant pumped cooling water from Okanagan Lake into Upper Vernon Creek. Its drainage included Ellison (Duck) Lake to Middle Vernon Creek to Wood Lake and ultimately to Kalamalka Lake. This influx temporarily shortened Kalamalka Lake's flushing rate to 37 - 45 years. The plant closed in 1992, and the extra flushing stopped. Kalamalka Lake reverted to its original 55 – 65 year flushing time (MoE 1985). Normally, lowering a lake's flushing rate increases nutrient concentrations but in this case, nutrient-rich Duck Lake water accelerated algae production in Wood Lake with a ripple effect on Kalamalka Lake. MoE estimated that 20-30% of the nutrients entering Kalamalka Lake came from Wood Lake during that time (MoE, 1975). Kalamalka Lake is apparently better off without the increased flushing of high nutrient water through its drainage system (MoE 2005; J. Allingham, pers. comm. 2008).
- Lead concentrations in sediments from the impacted North end have declined since the era of unleaded gas began and the use of lead arsenate pesticides ended.

Wood Lake

Hydrology/Limnology Wood Lake is shallower than Kalamalka Lake with a maximum depth of 34 m and a volume of 200 million m^3. Wood Lake's inflow comes from eutrophic, shallow (5 m deep) Duck/Ellison Lake via Vernon Creek. Because the volume of water in the hypolimnion is small relative to Wood Lake's surface area, there is considerable oxygen depletion in the summer. A net transfer of phosphorus from the sediments to the Wood Lake water column results during the summer stratified months (Bryan, 1990). Generally, Wood Lake discharges to Kalamalka Lake but occasionally the balance between releases and evaporation and inflows cause Wood Lake to be lower than Kalamalka Lake. In this case, Kalamalka water enters Wood Lake and helps restore Wood Lake's hardness to the point where marl precipitation can occur (as it did in 2010). Because water exchanges between the two lakes, replacing the old septic systems on Wood Lake with sewer lowers nutrient loading for both lakes. Wood Lake still receives untreated storm water outfalls, as does Kalamalka Lake.

Figure 1.2: Vernon Creek Plume into South Wood Lake April 27, 2006

Water Quality Wood Lake is productive with an excellent kokanee fishery. It was classified as eutrophic in the 1980's with average phosphorus concentrations of 0.075 mg/L (Nordin et al, 1988). About 57% of the total nitrogen loading and 35% of the total phosphorus loading to Wood Lake originated from cultural sources (MoE 1975). Replacing the septic tanks surrounding Wood Lake with the completion of the Lake Country sewer in 2000 caused significant water quality improvements in Wood Lake. Current water quality would place Wood Lake in the mesotrophic category – a considerable achievement.

Wood Lake

NEGATIVE CHANGE

- Farming practises and storm water outfalls import nutrients and bacteria to Wood Lake
- There was a severe cyanobacterial bloom in May 2008 that closed beaches and a moderate one in spring 2009; these blooms are induced by nutrients and warmer water
- Developers are proposing large dock/marina facilities on Wood Lake to accommodate power boats. Marinas increase hydrocarbon pollution and boating promotes shoreline disturbance to both lakes
- Wood Lake is vulnerable to any increase in the flushing rate from Ellison (Duck) Lake

POSITIVE CHANGE

- In 2000, wastewater treatment replaced septic systems on Wood Lake and progressively lowered nutrient loading into Wood Lake
- Wood Lake nutrient concentrations have declined from its 1980's eutrophic status to mesotrophic status in 2007 to 2009 – a return to the nutrient regime Wood Lake enjoyed in the early 1900s (based on sediment samples, Dr. I. Walker, UBC)
- The Hiram Walker plant pumped cooling water ($0.142 m^3/s$) from Okanagan Lake into Upper Vernon Creek. Its drainage included Duck Lake to Middle Vernon Creek to Wood Lake. This influx temporarily doubled Wood Lake's flushing rate. The plant closed in 1992, and the extra flushing stopped. Normally, lowering a lake's flushing rate increases nutrient concentrations but in this case, nutrient-rich Duck Lake water accelerated algae production in Wood Lake. Wood Lake is probably better off without the increased high nutrient inflow from its drainage system (J. Allingham, pers. comm. 2008).
- Anecdotal evidence shows that the frequency of Wood Lake marl events has increased since 2000 and may occur to a minor degree in September most years.
- The re-location of HWY 97 away from the current dangerously narrow roadway that traverses Wood Lake within meters of the shoreline, provides an excellent opportunity to plant native willow as a riparian filter between the roadway and the lake.

1.3 Definitions

The following terms are defined as they are used in this report.

ALGAE BLOOM: A superabundant growth of algae. Many species are capable of covering the surface of a pond or lake.

ANAEROBIC or ANOXIC: Devoid of oxygen.

ANTHROPOGENIC: Human-caused of an effect of human activity

BENTHIC: Organisms that dwell in or are associated with the sediments.

BLUE-GREEN ALGAE (CYANOBACTERIA): The family of bacteria-like algae having cyanochrome as the main photosynthetic pigment and chlorophyll as a secondary pigment. Many members reproduce rapidly and some cause algae blooms.

CONDUCTIVITYY: Electrical *conductivity* of *water* samples is used as an indicator of how salt-free, ion-free, or impurity-free the sample is; the purer the *water*, **the lower its conductivity.**

DIATOMS: The family of algae containing chlorophyll as the primary photosynthetic pigment and having hard, silica-based "shells" (frustules). Diatoms affect filtration and produce a range of taste and odors.

DROGUE: Float used to track current paths at a depth below the water surface determined by the position of vanes (or other surface to intercept currents) suspended beneath the float.

EUTROPHIC: Refers to a nutrient-rich, biologically productive water body where the concentrations of mineral and organic nutrients has reduced dissolved oxygen, producing environments that frequently favor plant over animal life.

FALL OVERTURN: In fall, surface waters cool and sink, eroding the thermocline until a wind storm mixes the entire water column.

GREEN ALGAE: The large family of algae containing chlorophyll as the primary photosynthetic pigment.

INFLOW PLUME: When a creek flows into a lake, its water seeks the layer of matching density in the receiving water, mixing and diffusing as it travels. Suspended and dissolved solids add to water density while increasing water temperature decreases water density.

LIMITED, NUTRIENT LIMITATION: In any environment, a nutrient or other growth requirement will limit or restrict the potential growth of organisms. For example, phosphorus usually limits algae production in lakes; if there is an increase in all of the other nutrients, no increase in algae growth will result because phosphorus is the bottleneck. Conversely, even a small increase in the phosphorus supply will result in increased algae growth.

LIMNOLOGY: **The study of freshwater; physical and chemical considerations such as lake thermal behavior, nutrient cycling, basin morphology, sediment structure, etc.**

MARL: **A marl event involves the precipitation out of solution of calcium carbonate, magnesium carbonate and calcium sulphate (gypsum) when the water warms or pH increases; sometimes referred to as calcite precipitation.**

MACRONUTRIENT: **Macronutrients are the major constituents of cellular protoplasm and usually limit biological production. They include nitrogen, phosphorus, carbon, hydrogen and sulphate.**

MICRONUTRIENT: **Relatively minute amounts of a micronutrient are required to maintain plant growth within its environmental constraints. These include; Mn, Fe, Co, Zn, Cu, Mo etc.**

MICROFLORA: The sum of microscopic algae, bacteria, fungi, actinomycetes etc. that are photosynthetic.

MYXOTROPHIC: Refers to organisms that can be photosynthetic or can absorb organic materials directly from the environment .

NANNOPLANKTON: **Minute algae that pass through the mesh of fine (No. 20) bolting cloth. Most are less than 5 microns in their largest dimension.**

PHYTOPLANKTON: **Algae that float, drift or swim in standing water.**

PHOTIC ZONE: **The zone in a water body that receives sufficient sunlight for photosynthesis.**

PLANKTON: **Those organisms that float or swim in water. Phytoplankton refers to plants; zooplankton to animals.**

RIPARIAN: A riparian zone or riparian area is the interface between land and a stream or lake. Plant communities along the river margins are called riparian.

SECCHI DEPTH: **The depth to which a 20 cm disk with alternate black and white quadrants can be seen through the water column**

SEICHE: Wind-driven tipping of the water layers during the summer. Seiches cause the water layers to oscillate for days after a wind storm.

THERMOCLINE: **The zone of greatest change in water temperature with depth (> 1^{o}C/m) that separates the surface water (epilimnion) from the underlying cold hypolimnion.**

ZOOPLANKTON: **Minute animals that graze algae, bacteria and detritus.**

List of Sample Site GPS Co-ordinates:

Kal N 40 m	251	N 50 12.977	W 119 16.896
Kal N 30 m	171	N 50 13.421	W 119 16.459
Kal N 20 m	11	N 50.13.628	W 119 16.499

Kal N 10 m	10	N 50 13.454	W 119 15.899
Kal S 20 m	12	N 50 07.005	W 119 22.350
Kal S 30 m	252	N 50 07.110	W 119 22.463
Kal S 40 m		N 50 .127	W 119.374

Definition Reference Tables:

Lake Classification by Trophic Status Indicators

Trophic Status	Chlorophyll-a ug/L	Total P ug/L	Total N ug/L	Secchi disc m	Primary Production mg C/m^2/day
Oligotrophic	0 – 2	1 – 10	<100	> 6	50- 300
Mesotrophic	2 – 5	10 – 20	100 – 500	3 – 6	250 – 1000
Eutrophic	>5	> 20	500 - 1000	< 3	>1000

After Nordin 1985

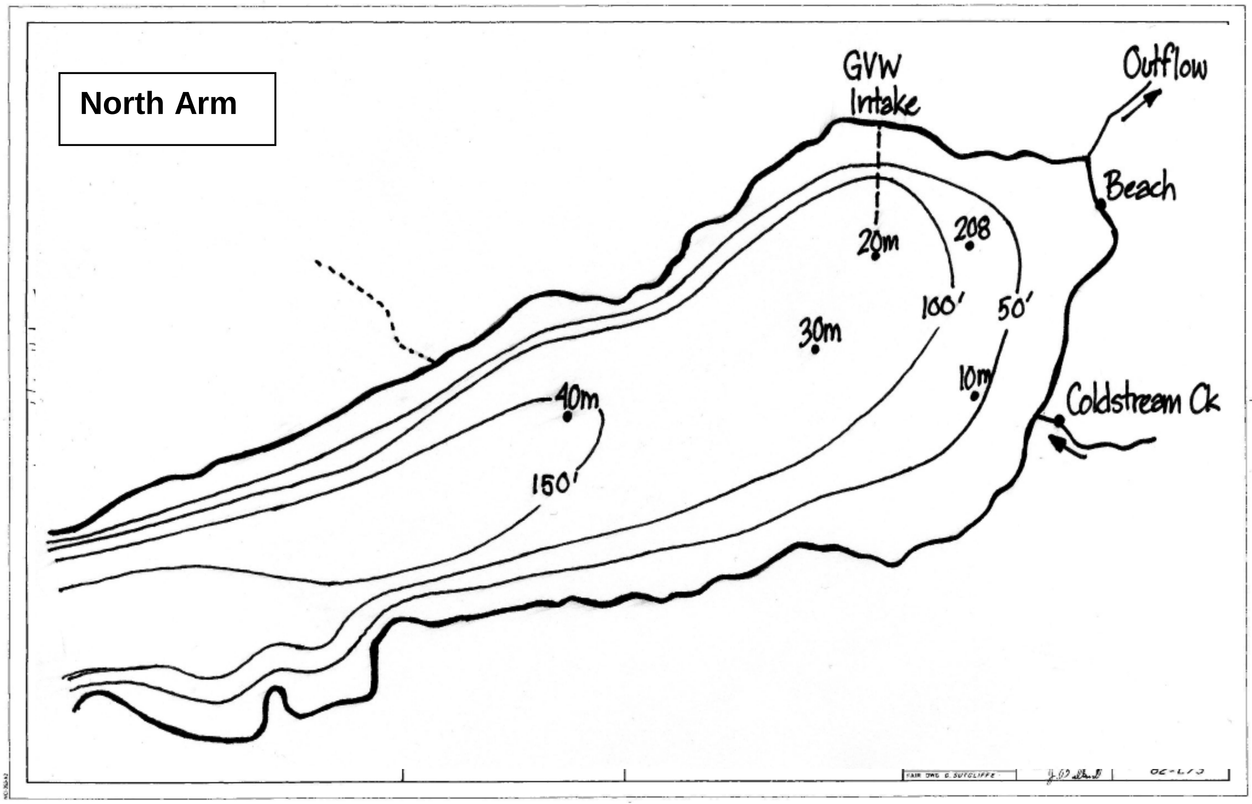
Nutrient Balance Definitions for Microflora (Dissolved Inorganic N : Dissolved Inorganic P)

Phosphorus Limitation	Co-Limitation of N and P	Nitrogen Limitation
>15 : 1	<15 : 1 – 5 : 1	5 : 1 or less

After Nordin 1985

Report Abbreviations: *DLC = District of Lake Country; GVW = Greater Vernon Water MoE = Ministry of Environment: LAC = Larratt Aquatic Consulting: GEID = Glenmore-Ellison Irrigation District; C of K= City of Kelowna: UBC-O= UBC Okanagan campus IHA=Interior Health Authority*

FIGURE 1.3: Bathymetry of Kalamalka Lake, North Arm and South End



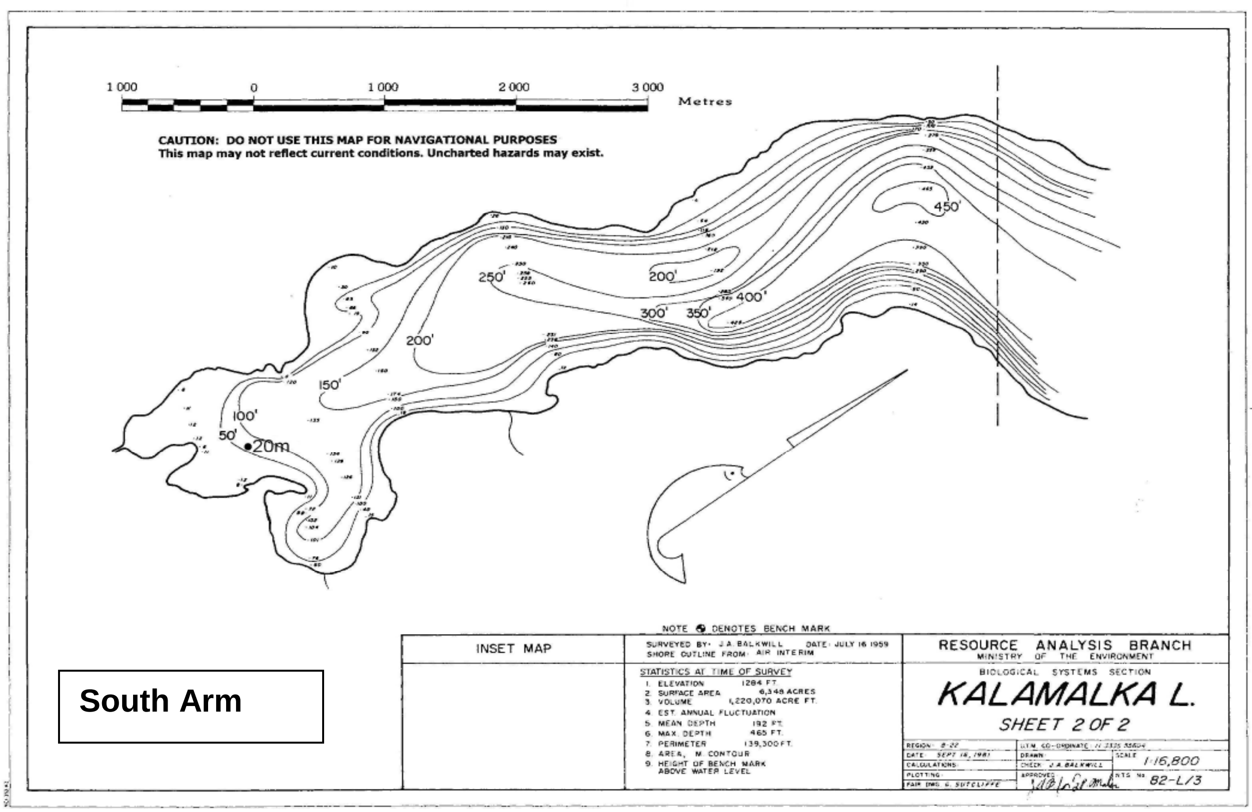
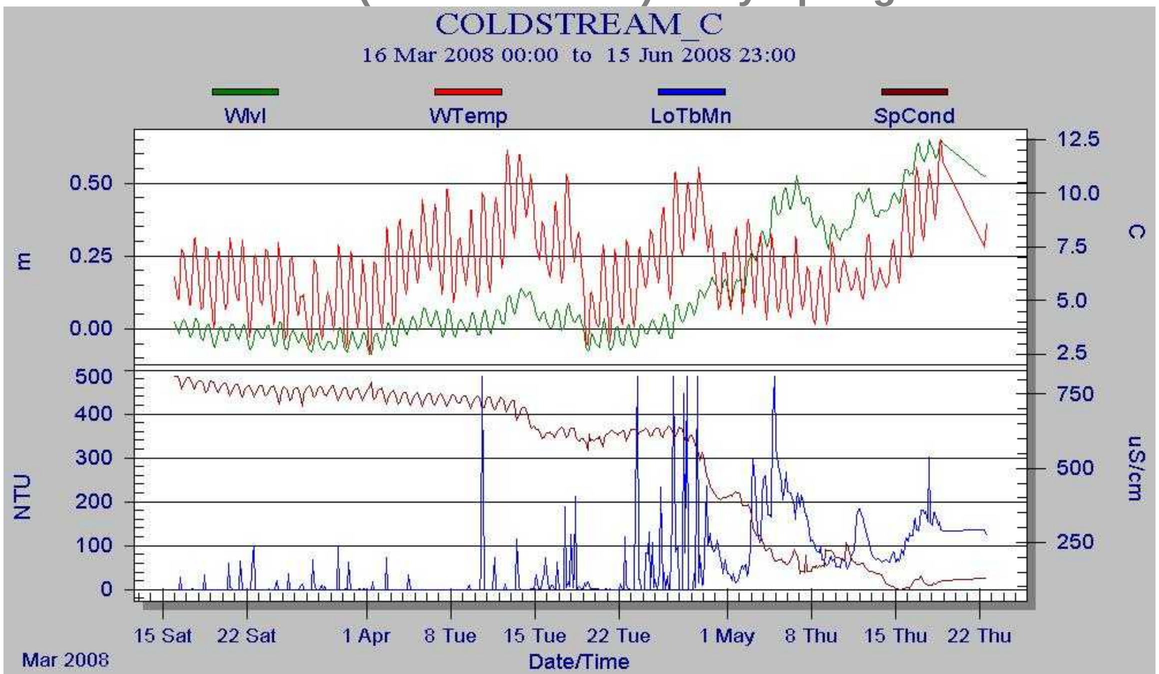
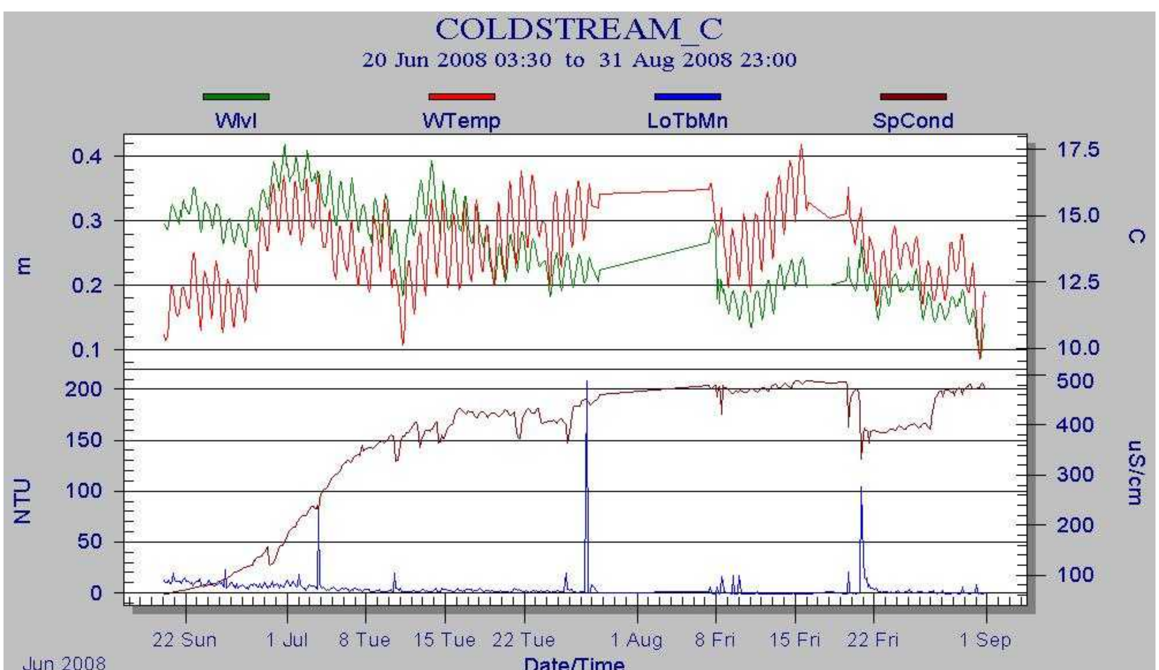


FIGURE 1.4: Example of Flows and Water Quality in Coldstream Creek (MoE Recorder) early Spring and Summer



Wlvl=water level Wtemp=water temperature LoTbMn=turbidity SpCond=specific conductivity

NOTE: These graphs show early freshet from a large freshet year (2008) Turbidity peaks of 500 NTU occurred during high flows that reached 0.55 m^3/min. The Coldstream Creek watershed has hydrologic impacts from riparian damage, extensive farming and storm water inflows from the lower urbanized area. Note the inverse correlation between flow/turbidity and conductivity.



Wlvl=water level Wtemp=water temperature LoTbMn=turbidity SpCond=specific conductivity

FIGURE 1.5: Kalamalka Lake: North Sample Sites

Kalamalka Lake South and Wood Lake Sample Sites

2.0 Results & Discussion

2.1 Coldstream Creek Freshet

The snow pack in 2010 was extremely low, particularly in Vernon's watershed. A very cool, wet spring 2010 brought water stores into the normal range. 2010 freshet was gradual. It peaked in late May and concluded by mid-June. Usually 80% of the annual inflow to Kalamalka Lake is from Coldstream Creek and the remaining 20% is from Wood Lake. The size of the groundwater component is not known but will be substantial.

During freshet and summer storms, Coldstream Creek responds within 24 hours with higher flows and turbidity spikes of up to 180 NTU above base flow (Figure 1.4). Storm drain water from the urbanized lower area and agricultural damage to riparian areas in the Coldstream Valley contribute to this rapid response to storms. A forestry road failure in the Noble Creek Canyon in 1996 exposed marine clays and temporarily increased Coldstream Creek freshet conductivity from 350-400 to 900 uS/cm (MoE). Since 2008, the conductivity has returned to normal and ranged from 100 - 400 uS/cm during freshet. The surface plume is also pushed around by storms, causing turbidity of >10 NTU along Kalamalka Beach during freshet (Figure 2.1).

Coldstream Creek Freshet Plume Behaviour

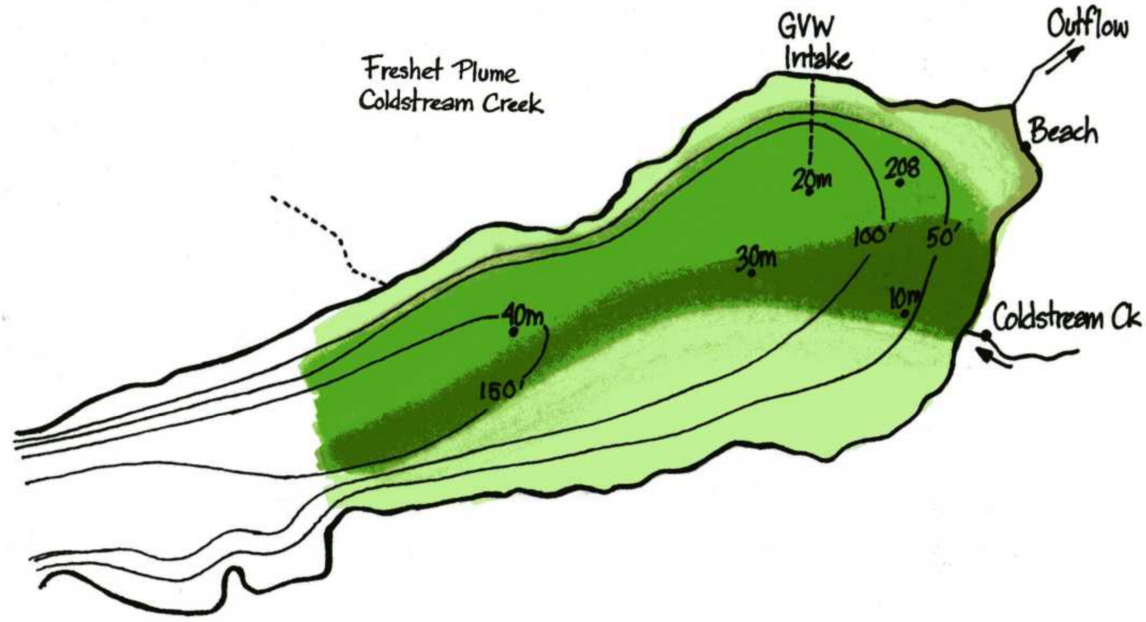
The thermal behaviour of the Coldstream Creek plume varies from year to year and particularly within each freshet.

A dock constructed in 2005 at the mouth of Coldstream Creek intercepts creek water and a large sand bar is growing. The sandbar helps deflect a portion of the plume to the north along the public beach and around to GVW's 20 m intake. The main body of the plume heads out into the lake, deflected to the right (counter-clockwise) via wind-directed currents, Coriolis force and possibly by currents generated by the creek outflow itself (Figure 2.1). Creek water turbidity rapidly declined in the plume due to particulate settling and dilution after it entered Kalamalka Lake.

Peak freshet dilutes Coldstream Creek's conductivity from the normal 500–800 uS/cm to a dilute 100-280 uS/cm, far less than the 400 uS/cm in the receiving Kalamalka Lake water (Appendix 4). Low conductivity makes the plume buoyant and it travels on top of the lake water column until late freshet. Because the plume spreads out in the surface water, it can raise turbidity by 1 - 10 NTU in the upper water column throughout the North Arm (Figure 2.2).

During early freshet, the N-Kal 20 m intake is below the main plume and usually has an acceptable turbidity of 0.4 – 0.8 NTU in low freshet years and 0.4 – 3.2 (average 1.5 NTU) during the large 2008 freshet. Turbidity was similar at the 20 and 30 m sites in modest freshets such as 2010, but in the large 2008 freshet, higher turbidity was measured at the 30 m site than the 20 m site at the surface where the inflow plume was concentrated and in water at the 30 m depth (Figure 2.1).

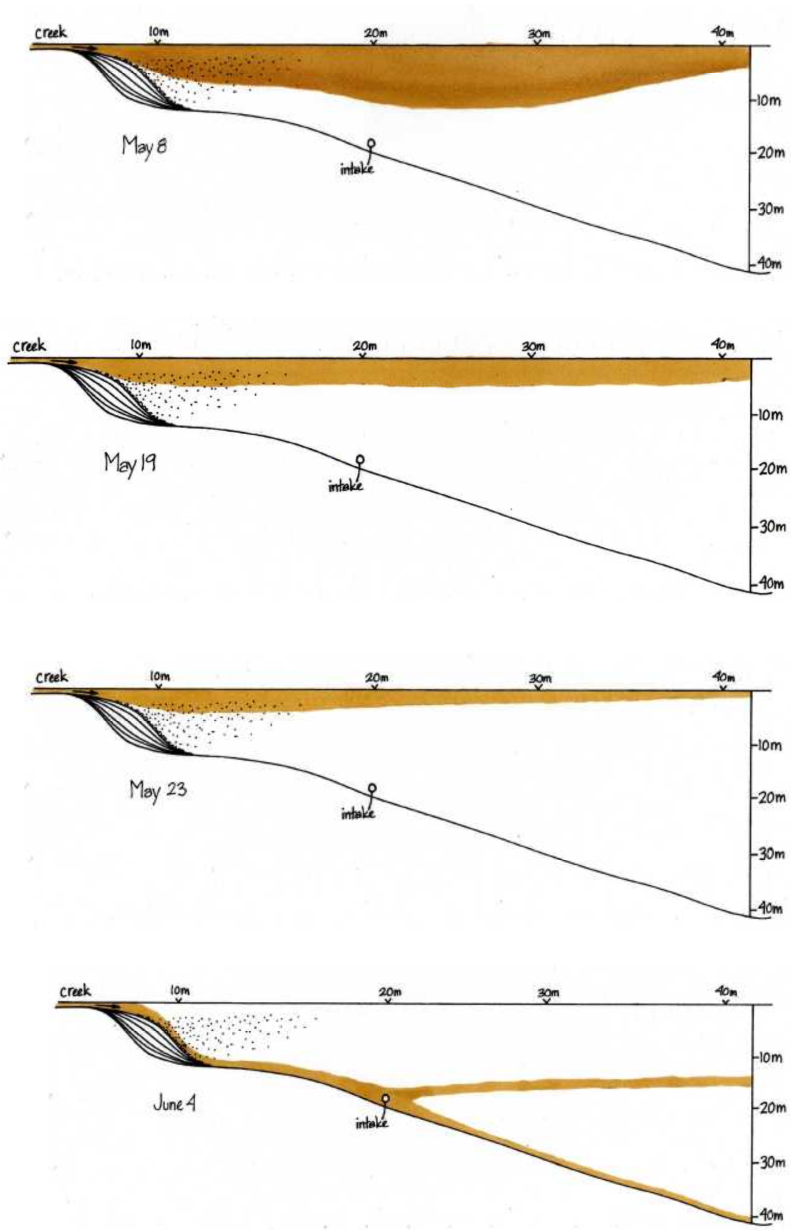
Figure 2.1: Location of Coldstream Creek Freshet Plume in North Arm Kalamalka Lake 2008 (large freshet year)



With normal to low freshets, the 30 m site provides slightly better water quality than the existing 20 m intake site. However, the detailed sampling on the large 2008 freshet proved that extending the intake to 30 m would *increase* GVW's N-Kal Intake exposure to materials settling out from the freshet plume (Figure 2.1). Appendix 4 contains the 2008 freshet YSI multi meter data (kindly loaned to this study by MoE Kamloops).

Every year after freshet flows subside, the Coldstream plume mixes into a wider, deeper band of water column and becomes less concentrated (2008 report). It also mixes to the intake depth in late freshet and increases turbidity, whereas earlier in the season, turbid surface water would only be pulled down to the intake during a seiche. The Coldstream Creek plume brings with it a small increase in turbidity and increased risk of contamination from bacteria and pathogens imported by the creek.

Figure 2.2: Coldstream Creek Freshet Plume in a Large Freshet (2008) in N Arm Kalamalka Lake
Cross Sections



The series of illustrations in Figure 2.2 are based on the 2008 freshet but also incorporates information from Coldstream Creek freshet monitoring to date. The most turbid flows are shown; the entire North Arm exceeds 1 NTU throughout the freshet period. Turbidity was also high along the forming thermocline, indicating a condition known as interflow where most of the creek plume travels along the bottom of the lake but some is suspended in the water column. During interflow, Coldstream Creek water is colder (9-15^{o}C) and more dense than lake surface water (15-22^{o}C). Creek inputs sink and become trapped near the thermocline (10-16 m) with more turbid flows along the bottom of Kalamalka Lake.

Over the years of study, Coldstream Creek's freshet plume behaved as follows;

- During early to peak freshet, the plume enters surface water (0-6 m) and flows across the entire arm, concentrating on the path shown in Figure 2.1. It can be visible from the shore and from the air.
- Deposition of sand and coarse particles occurs near the mouth of Coldstream Creek (Figure 2.2).
- Deposition of fines imported by the plume are distributed through out the arm but deposition is greater where the plume is most concentrated
- In recent years, the inflow plume splits on a sand bar (encouraged by a large dock at the mouth built in 2005) with the majority of the flow travelling out into the arm, deflected to the right, swinging towards the public beach and eventually around to the 20 and 30 m sites (Figure 2.1; 2.3).
- After the plume "cleans up" in late freshet, its conductivity increases and it mixes to depths >16 m and may include the intake depth.
- An intake would have to be >3m above the substrate to evade the freshet flows that travel along the bottom of the North Arm.
- The plume frequently splits with part of the flow travelling along the thermocline (creek and thermocline temperatures are often $<1^{o}$C different) but the majority of the flow from late spring through summer enters the deep water below the thermocline.
- The entire plume enters the hypolimnion in fall prior to overturn (Figure 2.2).
- Seiches influence turbidity at the N-Kal intake.
- The highest *E. coli* measurements at GVW's 20 m intake occurred with freshet 2005, however there are far more frequent late fall/early winter *E. coli* spikes in most years (see section 2.9). The spikes may correlate to winter storms.

Monitoring of Coldstream Creek plume has been discontinued since its behaviour is now understood.

Coldstream Creek Storm Plumes

Storm plumes can be very turbid and the visible section often swings along the North Arm shoreline The duration of a storm plume is much shorter than the 4-6 week long freshet plume. The storm plume path in Figure 2.3 was directed by currents coming into the North Arm. It is much smaller and less forceful than the freshet plumes that occur every year.

Figure 2.3: Coldstream Creek Storm Plume, Dec. 30 2004 and June 3 2010

Photo credit C. Kruger

2.2 Wood Lake

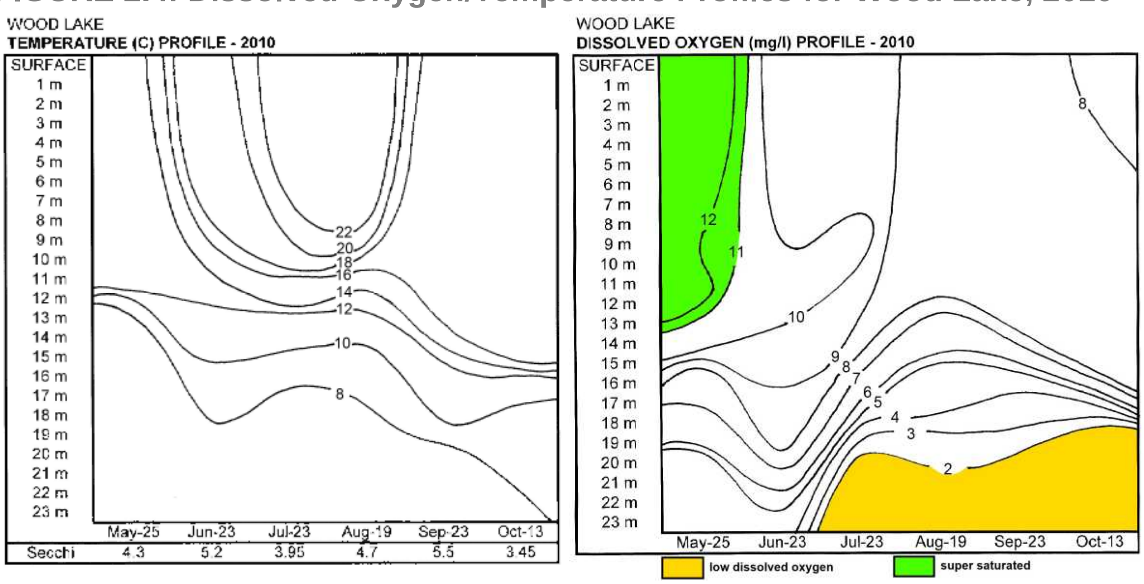
Wood Lake is the other main source of water Kalamalka Lake, accounting for 20% of the average annual inflow. It connects eutrophic Ellison Lake to Kalamalka Lake. Wood Lake is shallower and more productive than Kalamalka Lake. Wood Lake's high nutrient status is maintained by internal recycling during the summer and by high nutrient inflows from Lower Vernon Creek.

There is confusion as to the result of the Hiram-Walker Distillery 1971 - 1992 introduction of Okanagan Lake water into Ellison (Duck) Lake, pushing nutrient-rich water into Wood Lake. Despite the additional flushing and additional hypolimnetic oxygen, it appears that the overall effect was negative on Wood Lake and ultimately Kalamalka Lake (Bryan, 1990). Permanent water quality improvement resulted from the Lake Country sewer project, completed in 2000. Many of the septic fields surrounding Wood Lake were decommissioned by the project.

In 2008 and 2009, Wood Lake experienced a spring blue-green cyanobacteria bloom. The 2008 bloom was large and closed beaches commencing on the May long weekend. Fortunately, cyanobacteria numbers did not attain bloom status in 2010. Oxygen produced by the cyanobacteria contributed to the super-saturated zone shown in green in Figure 2.4.

Dissolved oxygen against the sediments restricts the release of phosphorus, limiting the nutrients available to feed algae blooms. By August in most summers, decomposition occurring below the thermocline depletes oxygen from the bottom water layer, resulting in anaerobic conditions that liberate nutrients including phosphorus (Figure 2.4).

FIGURE 2.4: Dissolved Oxygen/Temperature Profiles for Wood Lake, 2010



Unlike Kalamalka Lake, a zone of low dissolved oxygen-bearing water forms above the Wood Lake sediments during late summer (Figure 2.4). It would be thicker in the deepest zone of the lake, located to the south of the sample site. This bottom water acquired a large nutrient load that mixed with the water column during the fall overturn. A blue-green algae (cyanobacteria) bloom marks the Wood Lake overturn every year, despite the cool, dark November/December conditions. Overturn also coincides with the opening of nutrient-rich Lower Vernon Creek for fish flows.

Wood Lake is a donor of nutrients to Kalamalka Lake every year. During 2010, Wood Lake total nitrogen ranged from 0.27 to 0.60 mg/L while Kalamalka Lake ranged from 0.21 – 0.37 mg/L T-N. Most of Wood Lake's nitrogen is rapidly absorbed by algae production so that Wood Lake nitrate concentrations were usually lower than in Kalamalka Lake. Total phosphorus in Wood Lake after the summer 2010 ranged from 0.007 at the surface to a very high 0.163 mg/L T-P below the thermocline, while in Kalamalka Lake phosphorus was only 0.003 – 0.008 mg/L T-P. According to the literature, phosphate concentrations above 0.020 mg/L will promote plankton or benthic algae blooms (Cooke & Kennedy, 2001). Wood Lake certainly qualifies.

Current Wood Lake phosphorus concentrations have improved from the average of 0.075 mg/L T-P measured in the 1980's prior to the Lake Country sewer system to the 0.040 mg/L T-P measured in 2010 over the March – October period. Wood Lake was classified as eutrophic in the 1980's (Nordin et al, 1988). It was classified as mildly eutrophic in 1990 but would now be classed as mesotrophic based on nutrients, and an average chlorophyll-a of 4.74 ug/L (0-5-10 m). Increased productivity in 2008 may have been caused by increased freshet flows from Lower Vernon Creek.

Secchi depths in Wood Lake averaged:

- **2 – 2.5 m in August, 1939 (hot, dry weather)**
- **<2 m in summer, 1970 – 73 (Hiram –Walker pumping 1971>)**
- **7.7 in summer, 2007 (low productivity summer)**
- **4.5 in summer, 2008 (high productivity summer)**
- **4.9 in summer, 2009 (high productivity, hot summer)**
- **4.5 in summer, 2010 (moderate productivity + marl summer)**

Overall, excess algae production has declined since the 1970's. While lower algae production helps water purveyors, it may also slow down the prized Wood Lake kokanee fishery. Wood Lake has more water column interaction with its nutrient-rich sediments than Kalamalka Lake does with its sediments, making Wood Lake consistently more productive than Kalamalka Lake. Wood Lake has a weaker, sporadic marl precipitation and does not have the summer lull in algae production that Kalamalka Lake has. As usual, Wood Lake's total organic carbon averaged 10.7 mg/L during 2010, more than double the 4.0 mg/L B.C.WQ criteria (Table 2). For comparison, Kalamalka South surface averaged 7.6 mg/L TOC during 2010.

A blue-green, *Anacystis cyanea* bloomed in spring 2006, 2007 and 2009 but in 2008, a severe bloom developed, probably aided by increased nutrient donations from Vernon Creek during freshet. The Wood Lake cyanobacterial species involved in the annual blooms are listed below:

2007
Spring ***Anacystis cyanea Gomphosphaeria aponina***
Summer ***Anacystis cyanea***
Fall ***Anabaena flos-aquae Aphanizomenon flos-aquae***
Early winter ***Aphanizomenon flos-aquae***

2008
Spring ***Gomphosphaeria aponina Anacystis cyanea***
Summer ***Anacystis cyanea***
Fall ***Anabaena flos-aquae Anacystis cyanea Aphanizomenon flos-aquae***
Early winter ***Aphanizomenon flos-aquae***

2009
Spring ***Anacystis cyanea Aphanizomenon flos-aquae***
Summer ***Anacystis cyanea***
Fall ***Anacystis cyanea Gomphosphaeria aponina***
Early winter ***Aphanizomenon flos-aquae Gomphosphaeria aponina***

2010
Spring ***Anacystis cyanea*** **(light)**
Summer ***Anacystis cyanea*** **(moderate)**
Fall **None – Wood Lake marled**
Early winter **None – Wood Lake marled**

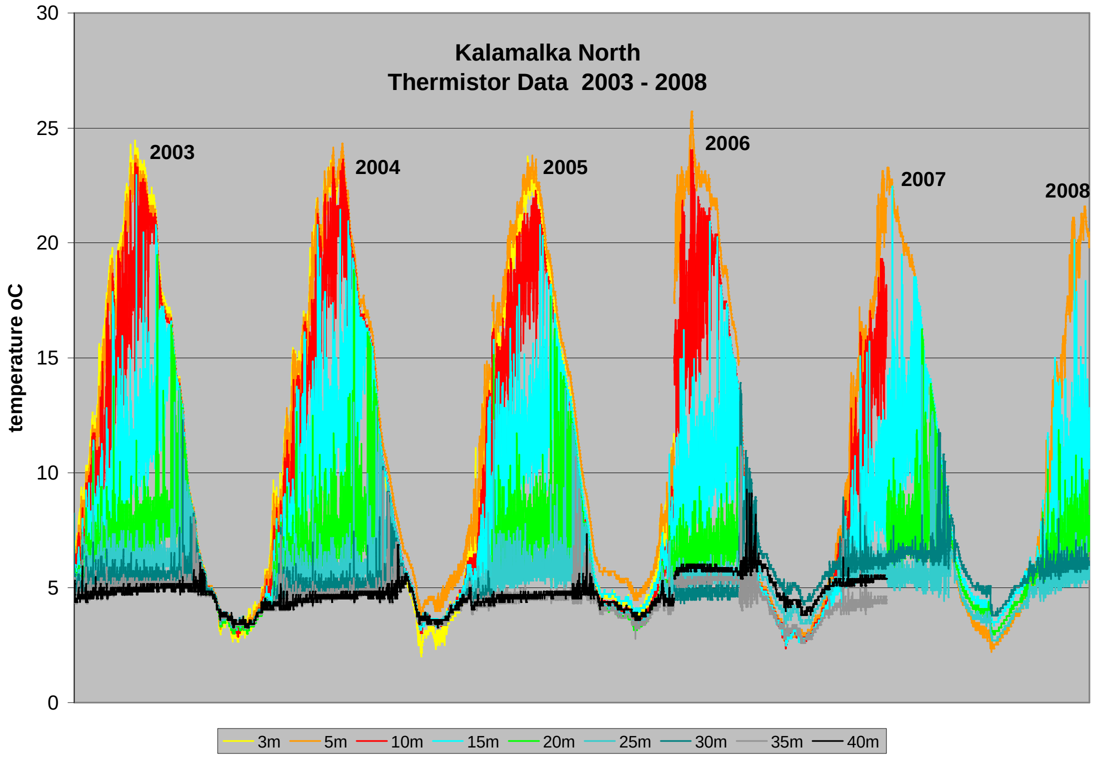
(species are listed from highest densities to lower densities)

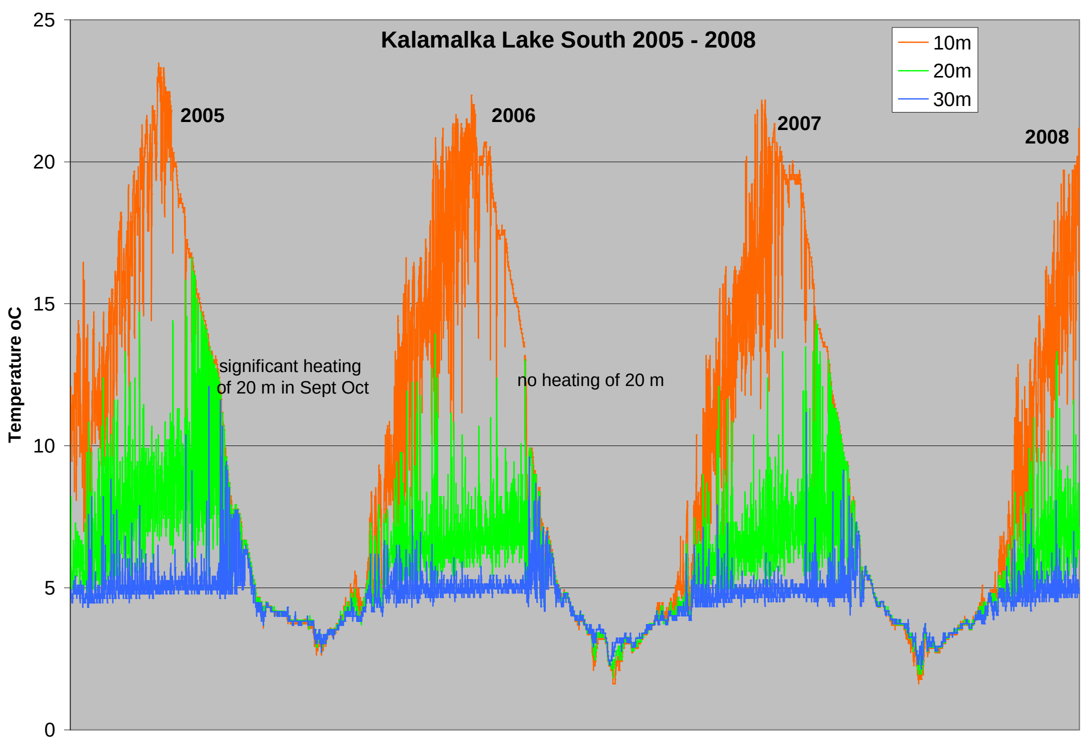
There was a distinct marl precipitation on Wood Lake in 2010 and the cyanobacteria numbers dropped dramatically as the marl stripped phosphorus and small algae cells from the water column. The reduced algae density lasted until the sharp increase in circulating nutrients after the fall overturn mixed bottom water throughout the water column. Near the Oyama Canal, cyanobacteria cells accumulate to dangerous levels after overturn based on a chlorophyll-a of 35 ug/L-2006, 10 ug/L-2007 and 2.6 ug/L-2008. (At 50 ug/L chlorophyll-a, the blue green algae / cyanobacteria cell count approaches 100,000 cells/mL and toxicity is probable). The cyanobacteria common to Wood Lake*, Anabaena, Anacystis and Aphanizomenon,* produce a range of undesirable cyanotoxins. Wood Lake algae density and diversity exceeded that of Kalamalka Lake on all dates.

A bloom of *Aphanizomenon* at low water temperatures is unusual according to the literature. In smaller lakes, they usually occur in late summer when overturn nutrients and sufficient sunlight are available. In Wood Lake, overturn mixing of nutrient-rich bottom water occurs in November/early December and combined with the nutrient rich Vernon Creek inflows, must be the trigger for these blooms despite the short day-length in winter (Figure 1.2).

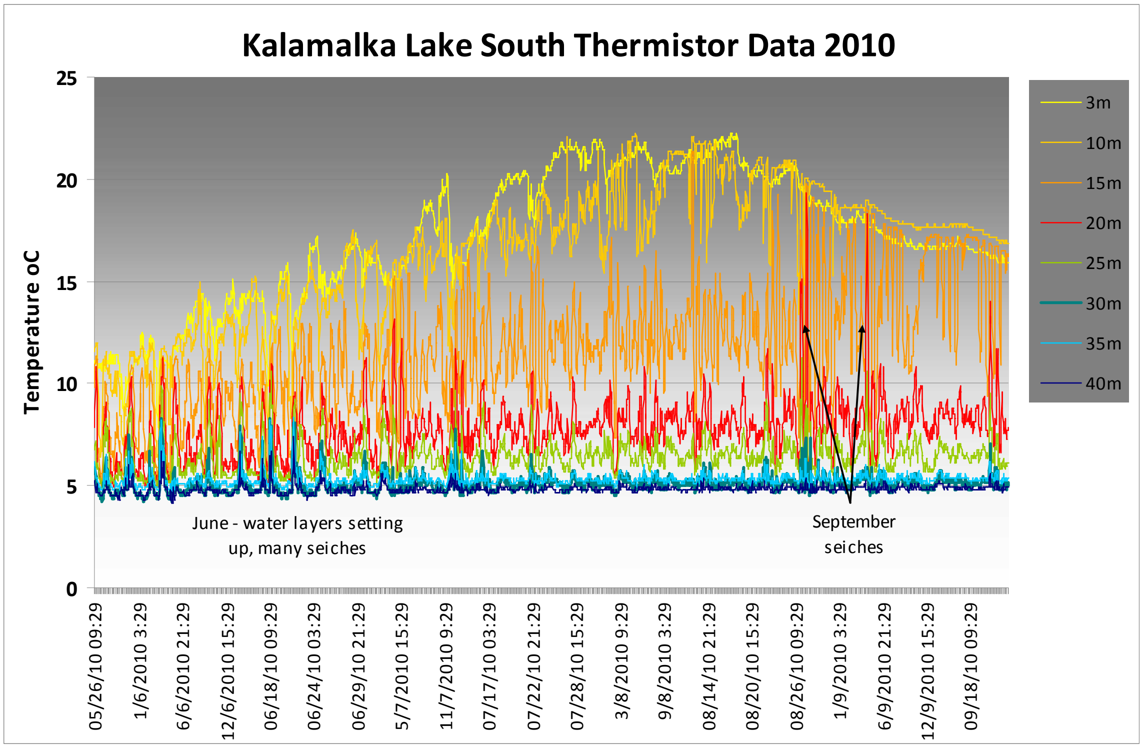
2.3 Kalamalka Lake Thermal Structure

FIGURE 2.5: Kalamalka Lake Thermistor Diagrams





Figure… South Kalamalka June – September 2010 Thermistor Data



Seiches In the summer, both N-Kal and S-Kal intakes draw from the bottom water layer except during seiches. The vertical movement of a seiche is coupled to large internal waves. These seiche-waves break at the sides of the basin like surface waves do and they are significant sources of turbulence (Wetzel, 2001). For the water purveyors, seiches cause increased water temperature and a turbidity spike as surface water is transported down to intakes for a period of 2-10 hours before the oscillating thermocline rises again, returning the bottom water layer to the intake depth (Figure 2.5, 2.6). <u>The main transport mechanism of surface contaminants to the Kalamalka Lake intakes is seiches in the stratified May to October period</u>.

The seiche thermistor data to date shows north or south-west winds with gusts exceeding 30 km/hr can generate a seiche, depending on the duration of the wind event. The bigger the storm, the bigger the seiche and the further down surface water travels. Seiches were tracked using thermistor data collected every 30 minutes and a typical period for the seiche to travel between the thermistor chains (12.1 km) averaged 8-10 hours. The full length of Kalamalka Lake is 15.4 km and since seiches slow down in the narrow North Arm, the actual period on Kalamalka Lake would be approximately 11.7x2 = 23.5 hours. In other words, it takes about a day for a seiche to travel to the opposite end of Kalamalka Lake and back again.

Large summer seiches are common in Kalamalka Lake (Figure 2.5, 2.6). Each year, 7 - 12 major seiches were detected by the N-Kal and S-Kal thermistor chains but there were 16 in 2010 during the long slow spring/early summer. Seiche activity is greatest in the early summer as the water layers set up and again in the early fall as the surface layer cools and loses buoyancy (Figure 2.5, 2.6).

The seiches twist and flex as they push into the North Arm, creating turbulence beneath the surface of the lake. In the most extreme example to date, N-Kal intake water temperature rose from 7.2 to 22.2 ^{o}C for five hours on July 29/30 2002. Temperature fluctuations at 30 and 40 m are very consistent from year to year, with less than 0.5 ^{o}C separating the seiche measurements over 5 years of measurements. The North Arm dampens seiches so that an intake positioned at 30 m would be much less impacted by seiches than the existing intake at 20 m is, even though the distance between the two sites is only 365 m (Figure 1.5).

When all the thermistor data is compiled, the long data run on the N end thermistor chain shows annual change caused by variable weather. Peak summer water temperatures ranged from 22 to 26 ^{o}C measured at 3 m and the winter minimum ranged from 2.5 to 4.0 ^{o}C. During most fall overturns, the impact on a 40 m intake would be a minimal 1.5 ^{o}C deviation while in others such as 2006, temperature deviated by 3 ^{o}C and would be attended by a small turbidity event. Seiches that penetrated to 40 m were less severe and fewer than the ones that penetrated to 20 m.

The S-Kal thermistor chain was moved out by 1.3 km from 30 m to 40 m and the thermistors adjusted to 10/20/40 m in June, 2008. For the summer 2010 deployment, additional thermistors were added for 5 m coverage and were downloaded at the end of September 2010 (Figure 2.5).

At the south end of Kalamalka Lake, seiches penetrate deeper into the water column because of the shape of the southern lake basin. Water temperature changes of 5-8 ^{o}C within 48 hours are routine at the current Lake Country 20 m intake (Appendix 7). During spring seiches, the maximum temperature deviation was 3.2 ^{o}C at 30 m and 3.0 ^{o}C at 40 m. The stronger fall overturn seiches were not captured; the maximum temperature in September 2010 was 2.3 ^{o}C at 30 m and 1.0 ^{o}C at 40 m. The maximum seiche recorded to date raised the water temperature at 30 m by 6 ^{o}C in south Kalamalka Lake.

The compiled S-Kal thermistor data shows a marked seiche impact on the 30 m site every summer. Seiches occur more frequently when heating of the 20 m depths to 12-15 ^{o}C takes place in the fall as in 2005 and 2007 but not 2006 (Figure 2.6). The same heating pattern took place at the N end at 20 m, but was not as distinct. To date, temperature deviations with seiches at the South 30 m site ranged from 4 ^{o}C in a cool summer to 7 ^{o}C in a warm fall with more intense seiches, prompting the move to collect data at the S-Kal 40 m site.

Dissolved Oxygen/Thermal Profiles

Kalamalka Lake's thermocline normally sets up in May and overturns in early November (Bryan, 1990). Peak epilimnion temperatures exceeded 20 ^{o}C from mid-June to mid-September 2010 as it does in most years (Figure 2.7, 2.8). Monthly summer thermal profiles were collected in front of N-Kal intake and in front of the S-Kal intake.

Without seiches, the summer water temperatures at the N-Kal and S-Kal intakes would be stable near 8 – 10 ^{o}C. With seiches, 20 ^{o}C water penetrates to the intake depth several times in the spring and fall (Figure 2.7, 2.8). In a warm summer such as 2005 or 2007, the current 20 m intake temperatures averaged 10.8 ^{o}C while in a cool summer, intake temperatures averaged 7.5 – 8.5 ^{o}C.

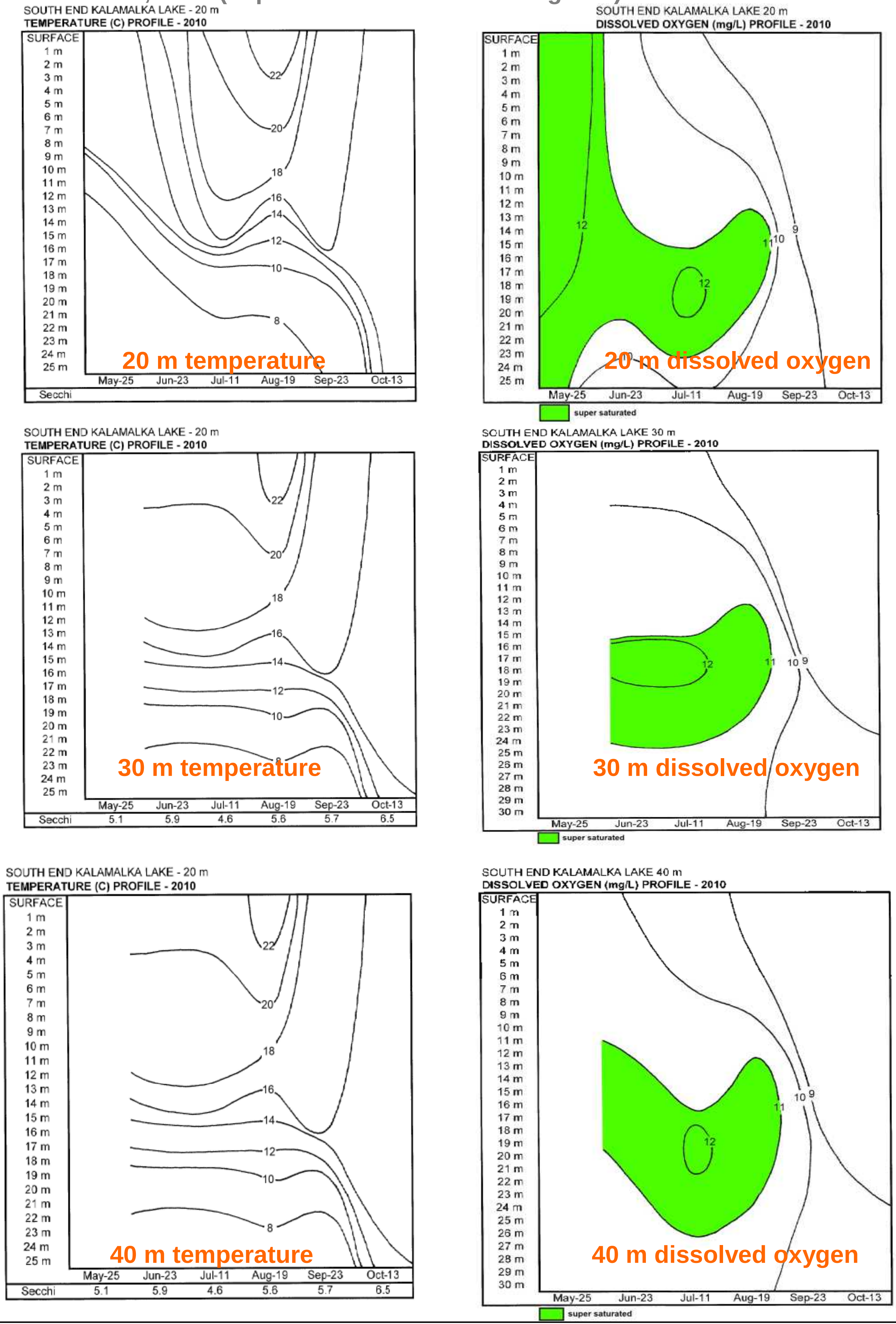
As the cooling lake approaches fall overturn, increased mixing thickens the surface water layer, pushing the thermocline down to the 22 m intake depth by late September (Figure 2.6). GVW experienced a turbidity / taste and odor event in late September 2007 and turbidity exceeded 2 NTU from mid-August to mid-September 2008. During 2009, turbidity exceeded 1 NTU from July through October and peaked at 3 NTU in the first week of September (Figure 2.23). Peak turbidity appears to correlate with seiches. Divers report that the visibility is very poor near the bottom of the lake. The fine marl (calcite) crystals are easily suspended by seiche turbulence.

After the thermocline mixed below 20 m in October 2010, both intakes withdrew water from the cooling surface layer. In every year of this study, mixing beyond the 40 m depth was complete by late November. Mixing continued and is usually complete by early December (Bryan, 1990).

Every summer, dissolved oxygen concentrations were excellent throughout the Kalamalka Lake water column. As in most years, summer 2010 profiles showed oxygen super-saturation from microfloral photosynthesis (Figure 2.7, 2.8).

The large 2008 freshet imported nutrients and caused a large microfloral crop in 2008, increasing the size of the super-saturated zone. 2009's supersaturated zone was also large despite the small, gradual 2009 freshet. Since only 2% of the lake volume exchanges in a year, the nutrients imported in 2008 can affect productivity for several years. By 2010, the supersaturated zone was much smaller than the preceding two years. The 20 m, 30 m and 40 m North end DO/T profiles showed that the super saturated zone occurred below the thermocline in 2010 (Figure 2.7).

FIGURE 2.7: South DLC Intake Site Temperature and Dissolved Oxygen Profiles, 2010 (super-saturated DO area in green)



NOTE: Super-saturation with dissolved oxygen centered on the thermocline in 2009. Increased oxygen concentrations at depth indicate algal or photosynthetic bacterial activity.

FIGURE 2.8: North Kalamalka Intake Site Temperature and Dissolved Oxygen Profiles, 2010

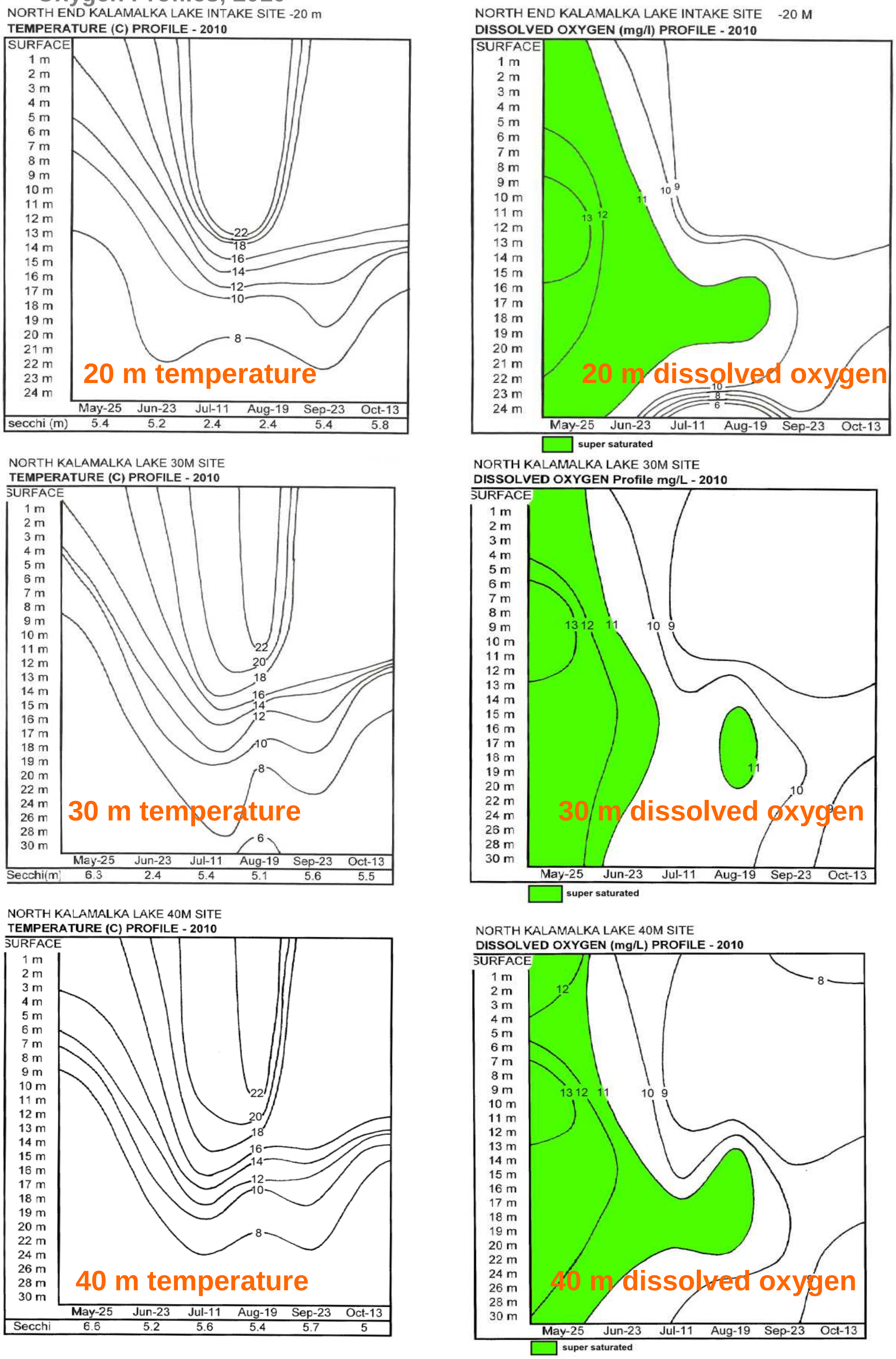


Table 1 presents a summary of the thermocline positions in Kalamalka Lake in 2010. Stable fall weather induced a very distinct thermocline into October of 4°C temperature change in 1 m. The thermocline was more consistent (less water layer tipping) and deeper at the S end of Kalamalka Lake on most 2010 dates. Tipping of the water layers by seiches is particularly evident in the June N end data, reflecting windy weather in those months. The thermocline deflects further in the north, caused by the shape of the N arm and the turbulence it induces.

Table 1: Thermocline Position in Kalamalka Lake, 2010

Thermocline position (m)	N 20 m	N 30 m	N 40 m	S 20 m	S 30 m	S 40 m
May	7	7	8	11	11	11
June	9	11	12	15	16	16
July	13	14	14	16	16	16
August	13	13	13	14	16	16
September	14	14	15	17	17	17
October	14	13	14	23	24	24

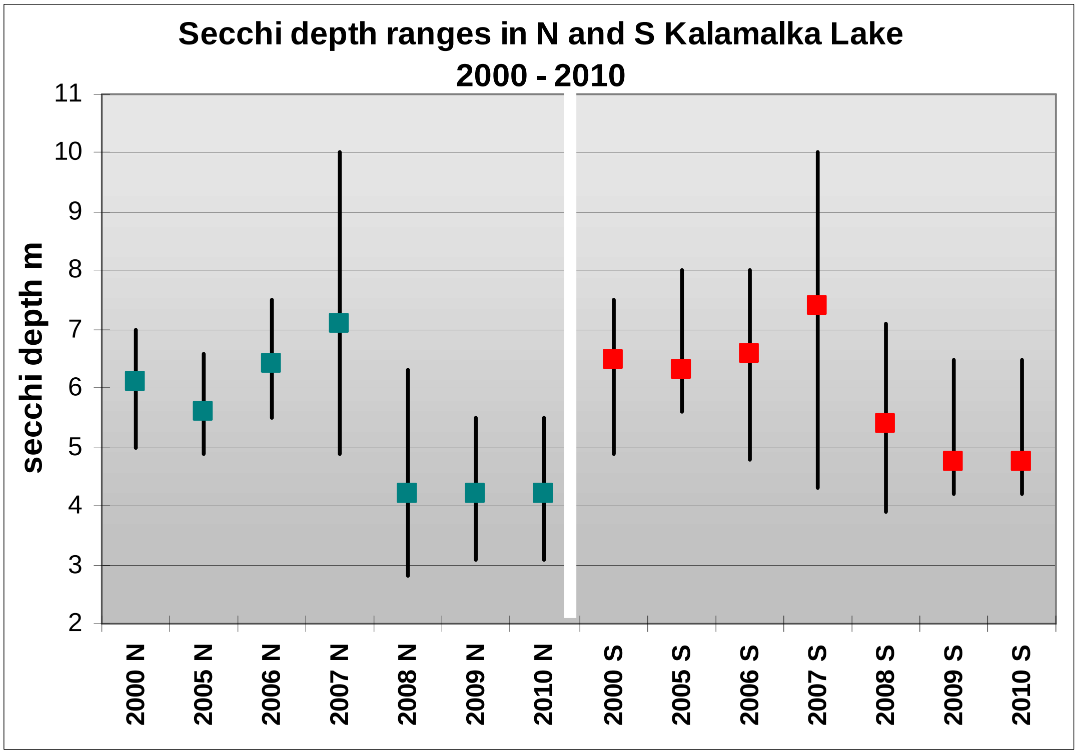
Historic secchi depths from Kalamalka Lake measured 6 – 7 m in 1935 and 3.8 – 10.7 m (avg 6.5 m) from 1975 – 1988 (Bryan, 1990). Within this study, growing season secchi depths ranged from 2.4 m during spring freshet algae production to 10.1 m post-marl precipitation – a similar range to Bryan's work. The average growing season secchi depth reacts to the size of the freshet. Large freshet years such as 2008 had lower overall secchi depths, particularly at the North end (Figure 2.9). (Appendix 1). Secchi depth increases abruptly following the marl precipitation from 4.6 m to 6.3 m – a lower range than normal for Kalamalka Lake. Average secchi depths have been lower in recent years (Figure 2.9).

Table 2: Secchi Depth in Kalamalka Lake, 2010

Secchi depth (m)	N 20 m	N 30 m	N 40 m	S 20 m	S 30 m	S 40 m
May	5.4	6.4	6.6	5.1	5.1	5.2
June	5.2	**2.4**	5.2	5.9	5.5	5.7
July	**2.4**	5.4	5.6	4.6	4.6	4.7
August	**2.4**	5.1	5.4	5.6	**2.3**	5.2
September	5.4	5.6	5.7	5.7	5.7	5.7
October	5.6	5.5	5.0	6.5	6.2	6.6

2008 through 2010 had low secchi depths even after the marl precipitation began clearing from the water column because algae production and/or marl precipitation was greater in those years. There were some unusually low secchi readings including N-30 during freshet and N-20 during the summer (Table 2).

Figure 2.9: Secchi Depth Range and Average in North and South Kalamalka Lake 2000 - 2010



Doubling the secchi disk depth gives an estimate of the depth that enough light penetrates the water column to support photosynthesis. Kalamalka Lake secchi depths average 3 - 4 m in the spring to 6 - 8 m in the late summer/fall, for a photic zone of 8 - 16 m.

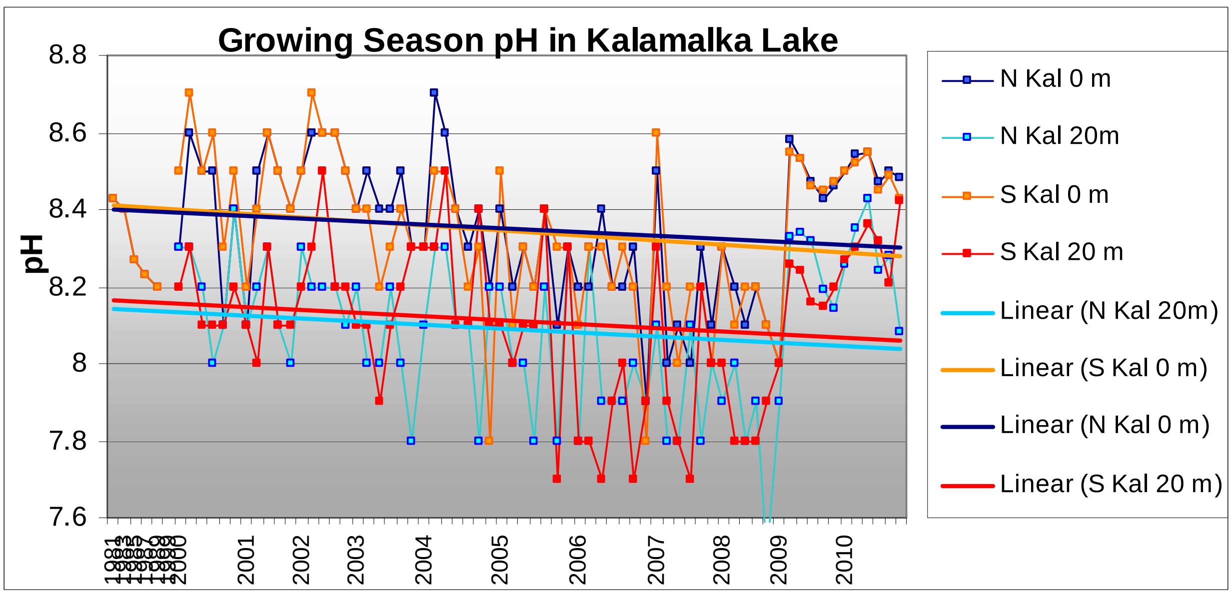
During 2007 and 2008 when light penetrated deeper into Kal Lk, oxygen super-saturation extended beyond 20 m at all sites in the North Arm, strongly suggesting a photosynthetic bacterial and cyanobacterial *(Anacystis; Synechocystis)* component since their light requirements are smaller than those of most algae (some cyanoabteria are myxotrophic).

2.4 General Water Quality & Nutrients

pH pH slowly declined over the twenty year period sampled by MoE but the observed decline may not be significant over a longer time scale. pH measured from 1970 – 1988 averaged 8.19 in the South and 8.60 in the main basin, while Wood Lake averaged 8.22. In Figure 2.10, MoE data collected before 2000 is shown in annual mean; study data collected after 2000 is shown as monthly growing season measurements. Considered independently, the MoE data indicates declining pH up to 2000 and the monthly data since 2000 also shows a slight decrease in pH, but with a recent trend towards higher pH.

Overall, the linear regression lines show decreasing pH but there is considerable pH oscillation in the data set. During 2009 and 2010, pH ranged from 8.08 to 8.55– a higher range than in the preceding six years. These were high algae production years and increased photosynthesis raised the pH of Kalamalka Lake (Figure 2.10).

FIGURE 2.10: Growing Season pH in Kalamalka Lake 1981- 2010



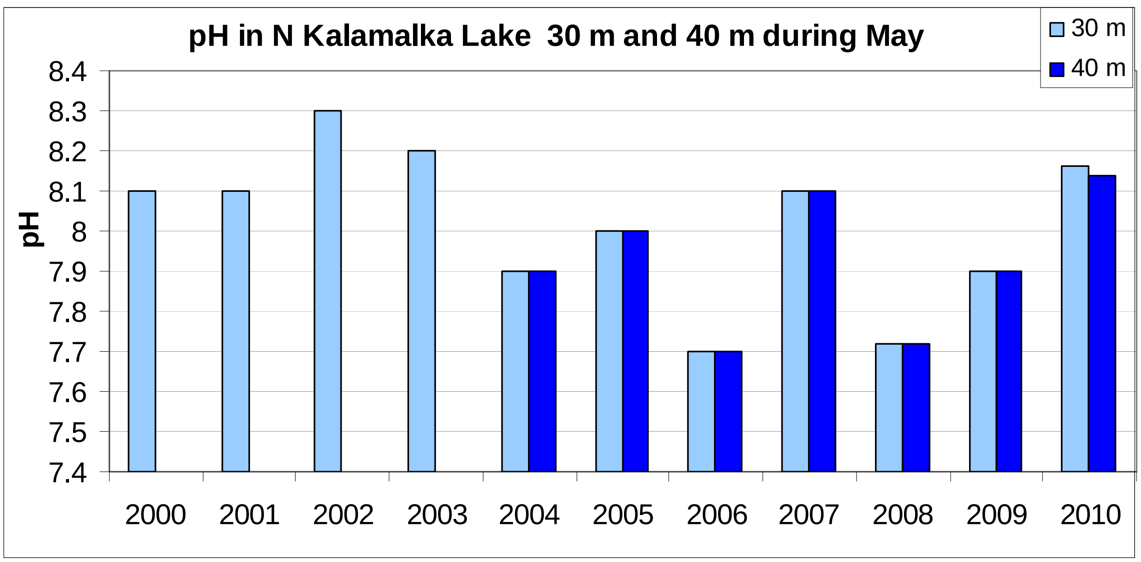
NOTE: This graph emphasizes data from 2000 to present

If the lower pH trend detected in this data was genuine, it could reduce the scale of the summer marl precipitation events and ultimately increase the nutrient balance of Kalamalka Lake, but a lower pH trend is not conclusively demonstrated by this data.

pH drops throughout the North Arm during freshet. In most summer samples, pH was the lowest in deep samples because photosynthesis (raises pH) decreases and decomposition (lowers pH) increases with depth (Figure 2.10, 2.11). During the stable summer months, June, July and August, show the largest decrease in pH both with depth and over time. Average pH at 30 and 40 m in the North Arm was virtually identical every year (Figure 2.11).

pH is impacted by many biochemical factors as well as analytical variability. The data collected to date do not conclusively demonstrate declining pH. For example, the 2006 and 2008 30/40 m spring data had very low pH while 2007 pH was precisely on the data set average of 8.1 (Figure 2.11). This far reaching parameter will be monitored both by lab samples and pH probe on a 50 m cable in 2011.

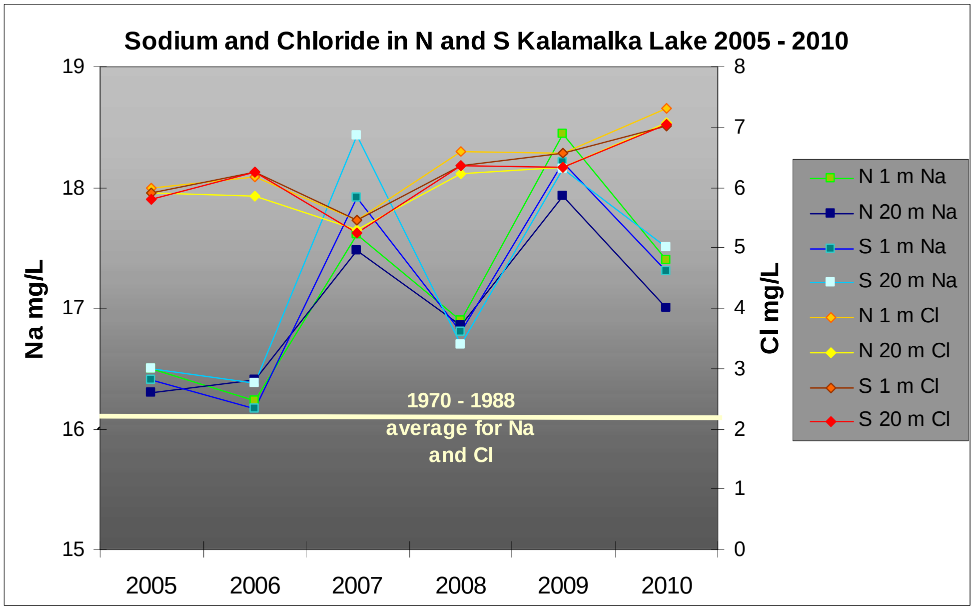
Figure 2.11: Kalamalka Lake pH in May, 2000 - 2010



Sodium and Chloride Sodium and chloride give an indication of animal, human, and storm water impact on a lake system, although in Kalamalka's case, donation of these metals from groundwater and from marine shales in the Noble Canyon section of the Coldstream Valley are additional natural sources.

Sodium averaged 16.1 mg/L in the MoE 1970-1988 data set and has oscillated upward from that level in recent years. During 2010, sodium dropped slightly to 15.7 – 19.8 mg/L at the South end and to 15.9 – 19.1 mg/L at the North end (blue lines Figure 2.12). In most years, sodium and chloride levels climb in October in both Kalamalka and Wood Lakes. Chloride climbed in 2010 to 6.63 – 7.85 mg/L in Kalamalka Lake (Orange lines Figure 2.12). Unlike sodium, chloride concentrations increased three-fold since the 1970's when it averaged 1.88 – 2.01 mg/L (Figure 2.12). While both Na and Cl are increasing, the year-to-year pattern is consistently opposite, suggesting different sources or mobility of these ions.

Figure 2.12:
Annual Average Sodium and Chloride in Kalamalka Lake, 2005-2010



Marl Precipitation Every summer, a spike in deep water turbidity, alkalinity, conductivity and calcium concentrations and an increased surface water clarity herald the marl (calcium carbonate + gypsum) precipitation. Marl precipitation depends on interrelated condition including water temperature, calcium concentrations, algae growth and pH. The marl event literally occurs overnight, with the dates ranging from July 20 1998 to August 6 2008. Precipitated marl slowly drops through the water column to create a turbid layer near the sediments.

Total Organic Carbon Total organic carbon measures microflora and dissolved organic molecules and for that reason, TOC concentrations move in concert with algae growth. High TOC reduces the effectiveness of UV disinfection and increases the potential for undesirable chlorinated byproducts. Figure 2.13 indicates that TOC in Kalamalka Lake has climbed over the decade of monitoring, as it has in Wood Lake. The exact cause(s) of this increase are unknown but will likely prove to be anthropogenic. Historic TOC's were lower in the main basin of Kalamalka Lake than recent TOC measurements. In the 1980's, TOC averaged 6.2 mg/L in the South end of Kalamalka Lake, 2.6 mg/L in the main basin and 5.6 mg/L in Wood Lake (Bryan, 1990). During 2010, surface water TOC was fairly consistent throughout Kalamalka Lake (Table 3; Figure 2.13). Peak TOC usually occurs in late summer/early fall, suggesting the influence of re-circulating bottom water (Table 3). The average TOC concentrations have been oscillating upwards (Figure 2.13).

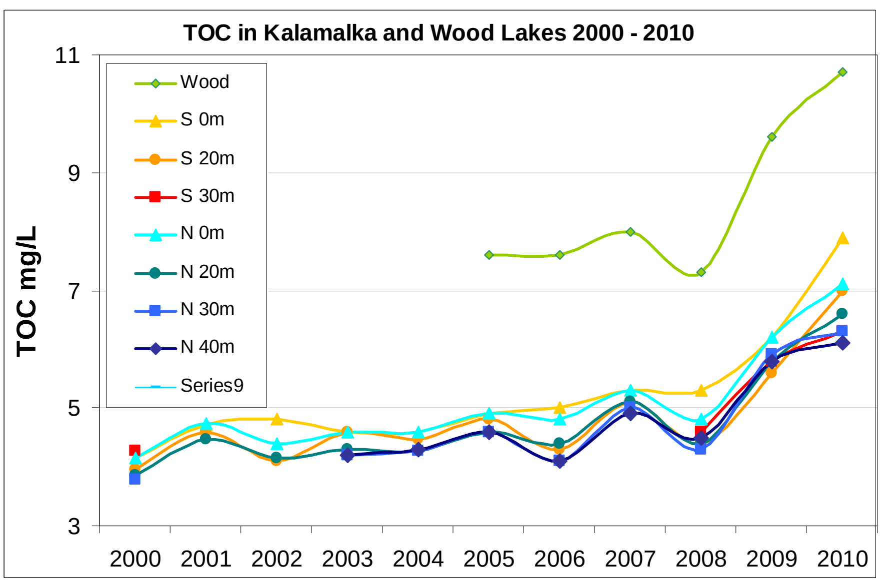
Table 3: Total Organic Carbon in Kalamalka Lake 2010

DATE 2010 TOC mg/L	Wood	South Sample Site 0 m	20 m	30 m	40 m	North Sample Site 0 m	20 m	30 m	40 m
May	12.5	9.9	8.7	7.1	6.7	7.3	7.9	7.1	6.9
June	12.5	8.4	7.8	7.1	7.2	8.0	7.2	6.9	6.6
July	5.6	3.6	3.3	3.1	3.1	3.6	3.4	3.2	3.1
Aug	12.1	7.8	7.8	7.2	7.2	8.6	7.8	7.5	7.3
Sept	**16.2**	**12.3**	**10.5**	**10.1**	**10.0**	**11.4**	**10.1**	**9.9**	**10.0**
Oct	5.5	3.5	3.6	3.1	3.0	3.6	3.2	3.2	2.9
Average	10.7	7.6	7.0	6.3	6.2	7.1	6.6	6.3	6.1

*Highest values are in bold

Wood Lake organic carbon concentrations exceeded the B.C.WQ criteria of 4.0 mg/L throughout the 2010 growing season, particularly in September 2010, which is interesting because there was a marl event but no algae bloom at the time. Pollen, leaf debris and other organic materials contribute to TOC (Table 3). In Wood Lake, average TOC concentrations have increased over the past five years (Figure 2.13).

Figure 2.13: TOC in Kalamalka and Wood Lakes 2000 - 2010



In all cases, TOC decreased with depth, however, the water quality advantage of a 40 m intake over a 20 m intake would be minor i.e. a 0.1 – 0.4 mg/L TOC difference between N-20 and N-40 m and a 0.1 – 0.8 mg/L between S-20 m and S-30 m in 2010, although the spread in TOC over depth appears to be increasing. The data suggests an impact on Kal-S 0 m from Wood Lake.

Taste and Odor Taste and odor events in Kalamalka Lake are infrequent and mild. Algae are the most common cause of off-tastes and odours in surface waters. Living algae excrete organic substances and some of these cause tastes and odours. Decomposition of these compounds and the algae cells themselves constitutes yet another potential source of taste and odour-causing compounds in water supplies. Despite abundant algae growth in 2010, no taste and odor complaints were received on the N-Kal or S-Kal intakes.

An offensive sloughy/earthy/mossy/weedy taste and odour problem triggered complaints commencing in late June 1999. Several residents said that their Brita type filter (activated carbon + ion exchange resin) was not effective, although filter performance depends on how it is used. Other clients offered that boiling and chilling the water eliminated or reduced the problem. Increasing the chlorine dose was helpful, either by oxidizing the offensive compound(s) or by masking it.

Over the years, high algae counts and complaints of fishy or musty taste and odor in Kalamalka Lake water were correlated. Blue-green cyanobacteria and other algae produce a musty, decaying taste and odour when they are decomposed by *Actinomycetes*. During the lake-wide 1999 taste and odor event, cyanobacteria counts exceeded 1700 cells/mL at the intakes. In 2010, potential toxin-forming cyanobacteria counts reached 3465 cells/mL and the total cyanobacteria reached 4425 cells/mL in August. The periodic taste and odour problem occurring in Kalamalka Lake are usually caused by high cyanobacteria concentrations, possibly made worse by A*ctinomycetes* decomposers and re-suspended detritus.

Less frequently, a seiche-induced turbidity/odor event can occur, as on the week of September 22, 2007. In this case, the turbidity particles were primarily detritus and bacteria, rather than algae. An intake right on the bottom of Kalamalka Lake would be much more vulnerable to taste and odor events. The minimum intake clearance should be three meters from the substrate.

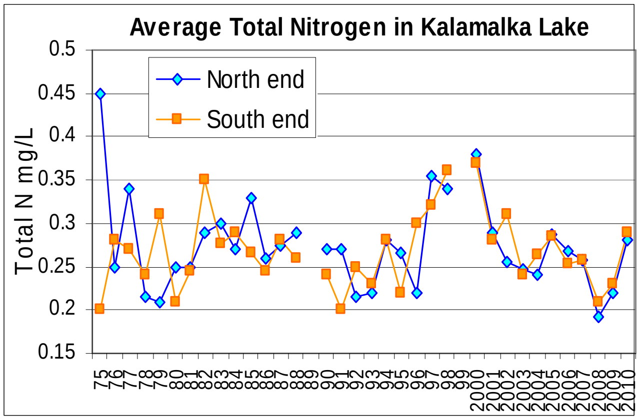
Nutrients Within Kalamalka Lake, the shallow ends are more productive than the main body of the lake. Nutrients at the North and South sites on Kalamalka Lake move in concert, indicating whole-lake influences such as freshet nutrient inflow via Coldstream Creek, inflows from Wood Lake and normal or enriched groundwater seepage from the spray effluent program (Figure 2.14). Wetter years usually had greater nutrient loading from larger inflows. Small peaks in S Kalamalka nutrients or in N Kalamalka nutrients in Figure 2.14 may relate to greater inflow from Wood Lake or Coldstream Creek.

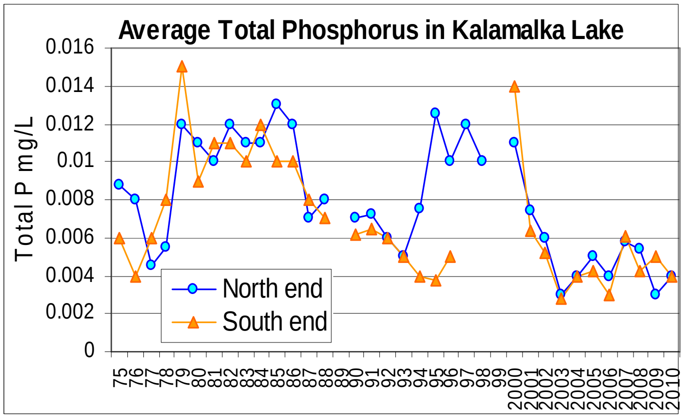
Spring nutrient concentrations in Kalamalka Lake provide a good forecast of the nutrients available to support plant growth during the growing season. In MoE data, spring total nitrogen slowly increased in Okanagan and Kalamalka Lakes over the 1973 - 1998 study period (Ashley et al, 1998). High run-off years import more total phosphorus to Kalamalka Lake, often as a result of particulate phosphorus

inputs. For example, the early 1980's were wet years and phosphorus concentrations were higher (Ashley et al., 1999).
High freshet years also increase nitrogen concentrations because nitrogen is poorly retained by Okanagan soils and nitrate migrates with groundwater (Dill, 1972). The large freshets of 1999 and 2000 resulted in nutrient peaks that were not repeated in the following years (Figure 2.14).

During the large and late 2008 freshet, nitrogen did not increase as the historic data suggests, it actually dropped significantly to near 0.2 mg/L T-N (Figure 2.14). Phosphorus concentrations decreased slightly as well to 0.004 – 0.0055 mg/L T-P. We would have expected an increase in nutrients during 2008. Other factors are obviously important to nutrient concentrations in addition to freshet; for example spring algae consumption, intensity of marl precipitation, recycling within the lake, septic system donations, etc.

FIGURE 2.14: Average Total N and P In Kalamalka Lake 1975 - 2010





MoE objective = 0.008 mg/L TP for Kalamalka Lake;
0.015 mg/L TP for Wood Lake (Nordin et al, 1988)

Over every summer, Kalamalka Lake nitrogen and phosphorus concentrations dropped through algae consumption, and phosphorus levels dropped following co-precipitation during the summer marl event (Appendix 1).

Since marl co-precipitates phosphorous, the timing of the marl precipitation in Kalamalka Lake affects algae growth. Ironically, algae growth also influences the marl precipitation by raising pH. The other key trigger for marl precipitation is water temperature. Warm, dry years such as 2002-2004 favour earlier and larger marl precipitation (Walker et al., 1993). The 2010 marl precipitation was typical, occurring in late July. Marl precipitation not only limits phosphorus availability, it also shades the water column and removes B12 vitamins. These all act to limit algae production in Kalamalka Lake relative to Okanagan Lake, despite their similar summer nutrient concentrations. During 2010, Wood Lake also marled and its productivity plunged afterward.

After all of the additions and consumptions of nutrients are tallied, the resulting N **:** P balance determines the type of algae that grow. In 2008, the average surface DIN **:** DOP ratio was 0.0078 **:** 0.0052 or 1.5 **:** 1 for North Kalamalka Lake and 0.0082 : 0.0040 or 2.1 : 1 for South Kalamalka Lake (DIN = Dissolved inorganic N **:** DOP = Dissolved Ortho P). Both ratios are very low, indicating possible nitrogen limitation, i.e. it is nitrogen shortage that constricts biological production. MoE nutrient enrichment research conducted in the 1970's also indicated that Kalamalka Lake is more deficient in nitrogen than in phosphorus. In practise, both N and P will direct lake productivity during the annual productivity cycles.

Spring nitrate concentrations set the tone for productivity in the subsequent summer. Large nitrate concentrations in the spring lead to larger algae crops. 2008's large freshet caused significantly larger spring nitrate. The early spring MoE measurements in 2009 and 2010 showed high nitrate concentrations (Table 4).

Table 4:
Spring and Fall Nitrate/Nitrite Concentrations in Kalamalka Lake (0-5-10m)

Kalamalka Lake (mg/L)	South	North
Spring 2003	0.016 – 0.024	0.044 – 0.065
Fall 2003	<0.002	<0.002
Spring 2004	0.022 – 0.057	0.002
Fall 2004	0.025 – 0.072	0.002
Spring 2005	0.010	0.009 – 0.015
Fall 2005	<0.002 – 0.013	0.003
Winter 2005	**0.104**	**0.106**
Spring 2006	0.008 – 0.057	0.018 – 0.029
Fall 2006	0.003	0.008
Winter 2006	**0.127**	**0.124**
Spring 2007	0.002 – 0.003	0.004 – 0.035
Fall 2007	0.002	0.003
Winter 2007	**0.069**	**0.084**
Spring 2008	0.040	0.038
Fall 2008	0.005	<0.002
Spring 2009	**0.127**	**0.137**
Fall 2009	<0.002	0.035
Spring 2010	**0.103**	**0.110**
Fall 2010	**0.078**	**0.096**

Note: MoE 2009 and 2010 Spring sampling date was March; in earlier years it was May as part of the Kal Lk study program

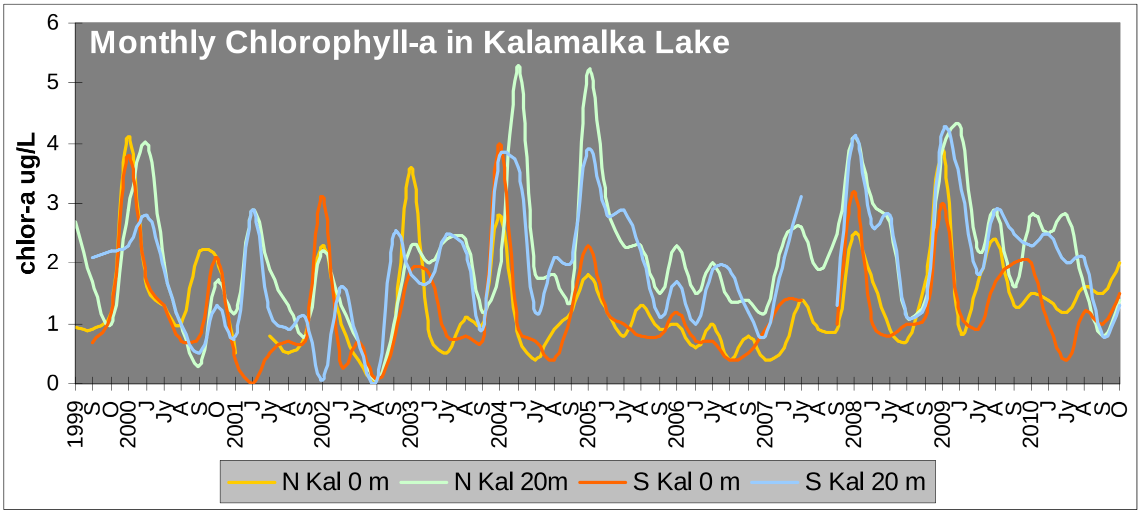
With water layer mixing in the fall, nitrate concentrations were restored by winter (Table 4). Nitrate concentrations in Kalamalka Lake actually exceed those of Wood Lake, possibly because of greater microfloral consumption in the latter. Nutrients made available to the surface water by fall overturn and subsequent winter lake mixing triggered increased blue-green algae growth each year, but not to bloom status as occurs in Wood Lake (Appendix 3).

2.5 Chlorophyll-a Analyses

Figure 2.15 shows annual spring peaks in microfloral production as measured by chlorophyll-a. Chlorophyll-a production usually follows the nutrient trends. Over most summers, algae progressively consume nutrients and their numbers drop in early summer. Minimum algae production occurs after marl precipitation removes phosphorus from solution each year (Figure 2.15):

2004 and 2005 samples showed chlorophyll-a peaks, particularly in deep water
2006 had low chlorophyll-a production
2007 was a moderate year for chlorophyll-a production
2008 and 2009 had increased production again, particularly after freshet at 20 m
2010 had low chlor-a production and as usual; N and S site reacted similarly

FIGURE 2.15: Chlorophyll-a in Kalamalka Lake 1999 - 2010



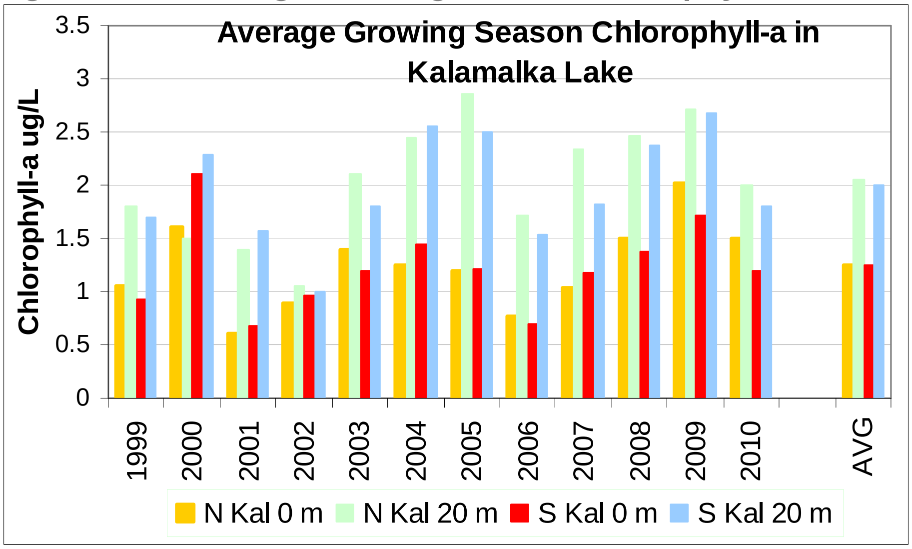
Algae counts and chlorophyll-a were average in 2010. Figure 2.15 shows peaks in the surface and the bottom water chlor-a during 2004, 2005, 2008 and 2009; these peaks may correspond to a nutrient influx in the first year of each pair.

Figure 2.15 and 2.16 were highlighted to show the similarities between the N and S ends of Kalamalka Lake. There is far more correlation by depth than by location. On most dates, the productivity of the 20 m bottom water was far higher than the surface water near both intakes and 2010 was no exception. Generally, the North Arm is more productive than the South End of Kalamalka Lake but both ends of the lake show similar trends in a given year, confirming that whole-lake effects are controlling algae production.

On average, the 20 m samples contained more chlorophyll-a than the surface samples because dying algae settle to the bottom and because storms and seiches create turbulence that suspend microflora from the sediments. Chlorophyll is a resilient molecule that persists even after the algae are dead.

Since 2003, the site with the highest productivity as measured by chlorophyll-a is N Kalamalka 20 m. Samples collected from 30 and 40 m contained less chlorophyll-a than samples from 20 m (Table 5). To realize the benefit of lower algae production at the deeper proposed intake sites, a new intake should be positioned at least 3 m above the substrate.

Figure 2.16: Average Growing Season Chlorophyll-a 1999-2010



Wood Lake's chlorophyll-a production is often strongest following its overturn in late fall, however, both 2008 and 2009 had strong spring blue-green algae blooms with measured peak chlorophyll-a of 15.3 ug/L. In 2010, algae production was very low as measured by chlorophyll-a (Table 5).

Table 5: Chlorophyll-a Concentrations in Kalamalka & Wood Lake, 2010

	Wood	South Sample Site				North Sample Site			
DATE **2010** Chl-a ug/L	0 m	0 m	20m	30m	40m	0 m	20 m	30 m	40 m
May	3.2	2.0	2.3	2.2	2.4	1.5	2.8	1.6	1.4
June	1.2	1.0	2.5	1.0	0.7	1.4	2.5	2.1	1.2
July	**0.6**	0.4	2.0	1.4	0.7	1.2	2.8	2.1	1.4
Aug	1.3	1.2	2.1	2.1	1.9	1.6	1.6	1.8	1.6
Sept	1.9	1.0	0.8	0.9	0.6	1.5	0.8	0.9	0.8
Oct	2.0	1.5	1.3	2.4	1.0	2.0	1.4	1.2	0.6
Average	1.7	1.2	1.8	1.7	1.2	1.5	2.0	1.6	1.2

NOTE: Unusual data is bolded

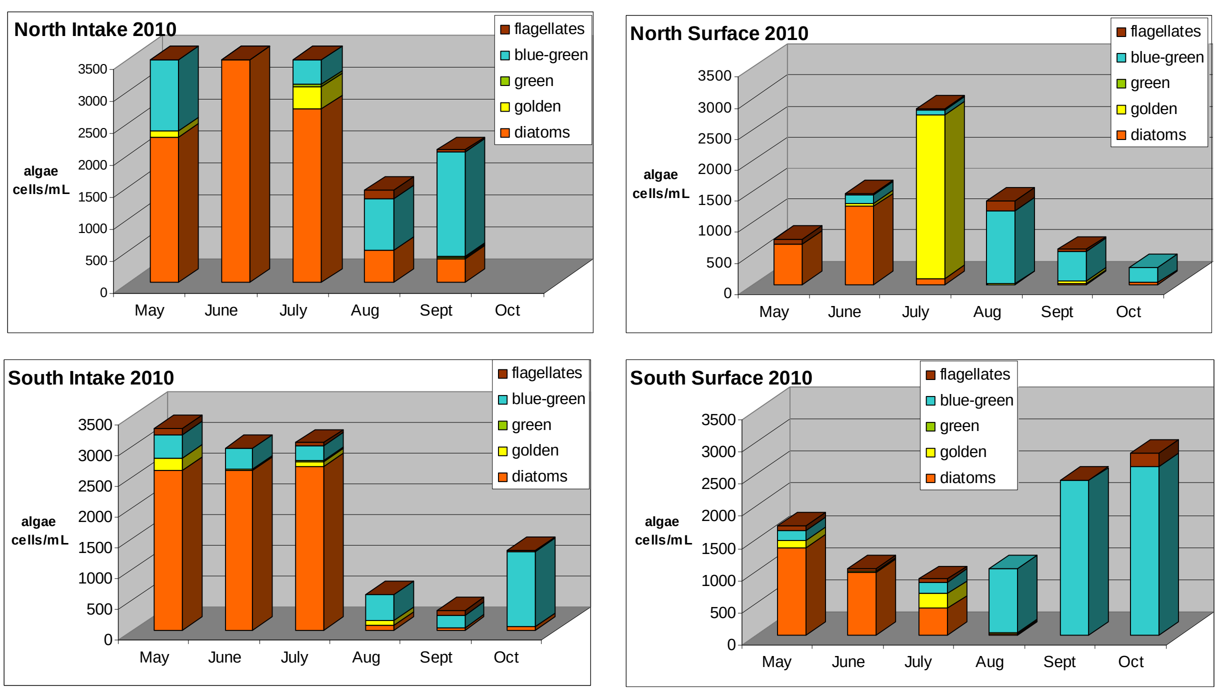
Historically, epilimnion water chlorophyll-a measured 1.80 ug/L at South Kalamalka Lake, and 1.26 ug/L in Kalamalka main basin(Bryan, 1990). Kalamalka Lake samples are similar today, with the exception of the spring algae blooms.

2.6 Algae Analysis

Every year, Kalamalka Lake experiences a spring diatom/blue-green bloom, a summer lull and a smaller fall bloom led by blue-green algae (cyanobacteria). The spring bloom of diatoms and blue-greens occurs in response to circulating freshet nutrients and increasing day length. While the diatoms predominate by volume, the blue-greens predominate numerically. Within this general pattern, there is considerable year-to-year variation. For example, the North surface samples showed unusually high numbers of the golden flagellate, *Dinobryon* – a species noted in E-Kal samples for causing a fishy odor during some years including 2010. Fortunately, *Dinobryon* stays high in the water column and is unlikely to affect the 20 m or deeper intakes. It may be feeding on bacteria coming in from Coldstream Creek as well as using photosynthesis for energy.

Overall algae growth during 2010 was moderate with the exception of a very strong spring bloom of *Cyclotella* – a small diatom that did not cause problems for the water supplies (Figure 2.17). The very high spring production may be related to the nutrients injected by the liquid manure storage failure that occurred in January 2010 on Coldstream Creek. Cyanobacteria counts were very low at all depths except the intake samples and they measured 1500 cells/mL in the spring at the N-Kal intake only. Since the N-20 m sample had low cyanobacteria numbers, it would appear that the cyanobacteria drawn into the intake were associated with the bottom of the lake (Figure 2.17).

FIGURE 2.17: Distribution of Algae Types at 1 m and 20 m Intake Depths, 2010



NOTE blue-green algae (also called cyanobacteria) have very small cells that exaggerates their importance in this graph set relative to the other types of algae

The Kalamalka Lake algae community is highly variable from one year to the next, and within each year. These variations help explain the transient water quality problems with taste and odor and turbidity experienced by GVW and DLC.

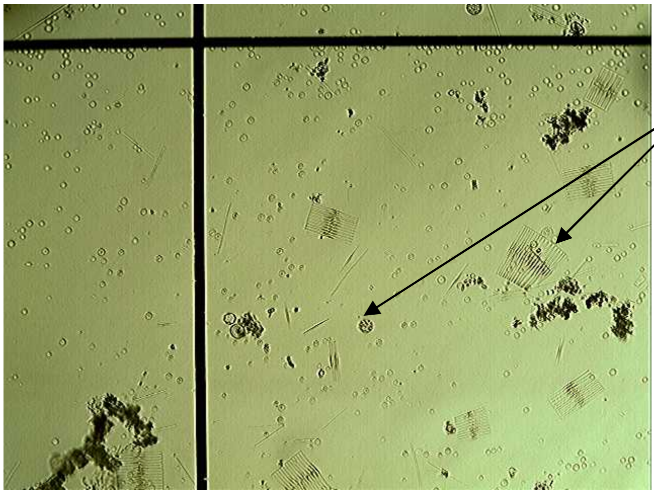
Large freshets play a crucial role in delivering nutrients that in turn control algae production, especially in the North Arm (Figure 2.18). Algae numbers usually remain strong until the marl precipitation removes phosphorus from the water column. This marl precipitation ushers in the summer lull. A smaller fall mixed bloom including a pulse of blue-green algae develops in September/October each year and is normal for this region (Bryan, 1990). It was moderate in 2010.

Summer storms briefly restore peak flows in Coldstream Creek. Based on storm data captured thus far, the response time between a summer rain event and turbid Coldstream Creek flow is less than 24 hours. This rapid reaction time is accelerated by damaged riparian areas through the agricultural areas and from subdivision storm water reporting to Coldstream Creek. Storm-induced seiches set up within hours of a storm and both the turbid inflow and the seiche combine to elevate turbidity in the N Arm for about one week.

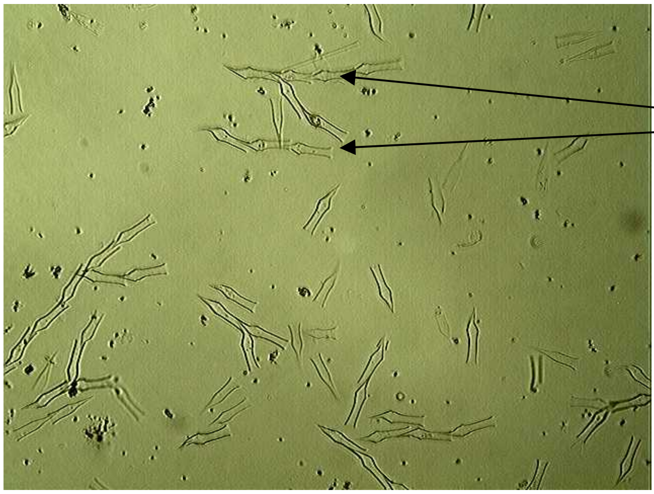
Winter storms are also important to North Arm water quality. Figure 2.3 shows a winter storm plume captured by satellite on December 30, 2004. The unfortunate January 2010 manure storage failure during a rain storm on the still-frozen watershed impacted Coldstream Creek. Within two weeks, cyanobacteria production in the North Arm spiked. When creek inflows added nutrients into the North Arm of Kalamalka Lake, they apparently stimulated a complex algae bloom. Samples collected from Kalamalka Lake on February 4th showed unusually high counts of filamentous blue-green algae (cyanobacteria) and micro-flagellates/bacteria (Appendix 3). Greater Vernon Water (GVW) was informed by the Okanagan Spring Brewery that an unacceptably high ATP value forced a plant shut-down on February 4th 2010. Material washed from the filters provided by the Brewery collected very large and uncountable concentrations of algae originating from Kalamalka Lake (Figure 2.19). Additional raw water samples were collected on February 9th from N-Kal intake and E-Kal Intake. Both samples showed relatively high blue-green algae counts were still occurring, but micro-flagellate numbers had moderated.

Figure 2.18: Photographs of Algae Samples from 2010

Aug 2010
Pink slime from turbidity meter was zooplankton accumulating from the inflowing water – they travel to the depths where they find suitable conditions



June 20 2010 N-Kal Intake sample showing spring diatom abundance that occurs with varying intensity every year



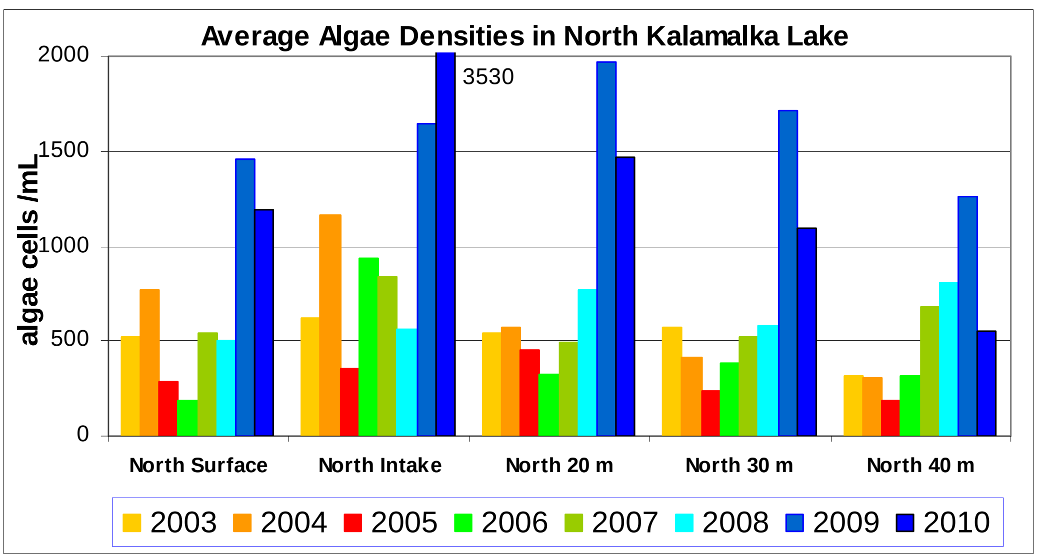
July 22 2010 E-Kal Intake sample showing tube-shaped flagellate Dinobryon that became abundant in the upper water column and gave the water a fishy odor

Over the ten years of this study, the prevalence of blue-green cyanobacteria appears to be increasing, particularly in 2009, although 2010 counts were moderate. MoE data also shows a gradual increase in the blue-green component since the 1970's. Every year, a total of 13 -15 blue-green cyanobacterial species are counted in Kalamalka Lake and every year they are dominated by *Lyngbya limnetica and Anacystis cyanea.* There is considerable variation in the dominance of the other species from year to year. In order of prevalence during 2010 they were: (*Anacystis cyanea >> Lyngbya limnetica >> Anabaena planktonica > Limnothrix sp.> Planktothrix anghardii > Synechocystis sp >>Dactylococcopsis sp > Oscillatoria spp).*

In years with high cyanobacteria production in Wood Lake, *Anacystis* numbers in South Kalamalka Lake trended with Wood Lake in late summer, suggesting that algae donation from Wood Lake is significant. Several of the cyanobacteria found in Kalamalka Lake are known to produce toxins (*Anacystis, Lyngbya, Anabaena, Limnothrix, Planktothrix),* but were not present in amounts sufficient to impair water quality (Figure 2.17).

During this study, algae counts in the North intake are frequently higher than counts collected near the surface or at 20 m in the lake (Figure 2.19). The clearance of the N-Kal intake from the sediments is implicated since the S-Kal intake has smaller algae counts and is spaced 2 m from the bottom versus N-Kal intake that is only 0.6 m from the substrate.

FIGURE 2.19: Algae Distribution with Depth, North Kalamalka Lake

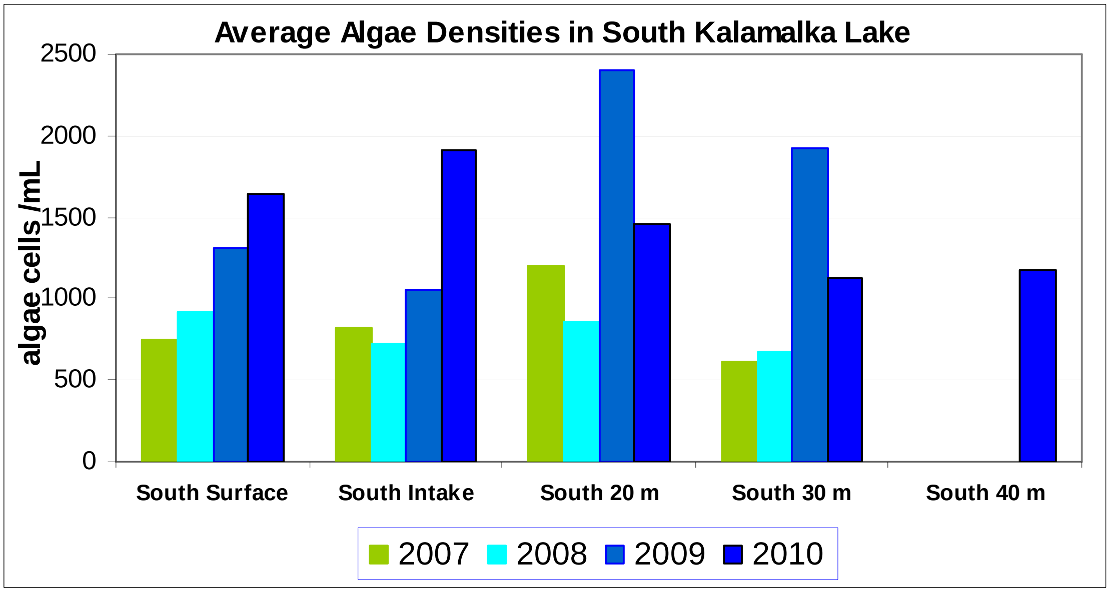


NOTE: Figure 2.20 shows high algae numbers at the 20 m intake due to seiches and the smallest concentrations at 40 m

In some years including 2009 and 2010, there was significantly less algae at North 40 m than at N 30 or N 20 m, but in 2007 and 2008 samples, there was no advantage to a deeper site over the current 20 m intake in terms of reducing the amount of algae entering GVW's distribution system. This study has also demonstrated that there was a significant difference between the algae counts at North 30 m versus N 20 m only during a high productivity year such as 2010 (Figure 2.20).

In South Kalamalka Lake, 30 m algae samples often showed a distinct advantage over 20 m samples. It is important to note that summer samples from 30 and 40 m still routinely contained 200 – 800 cells/mL of cyanobacteria with spikes of 2180 cells/mL during 2010 (Appendix 3;Figure 2.20).

FIGURE 2.20: Algae Distribution with Depth, South Kalamalka Lake

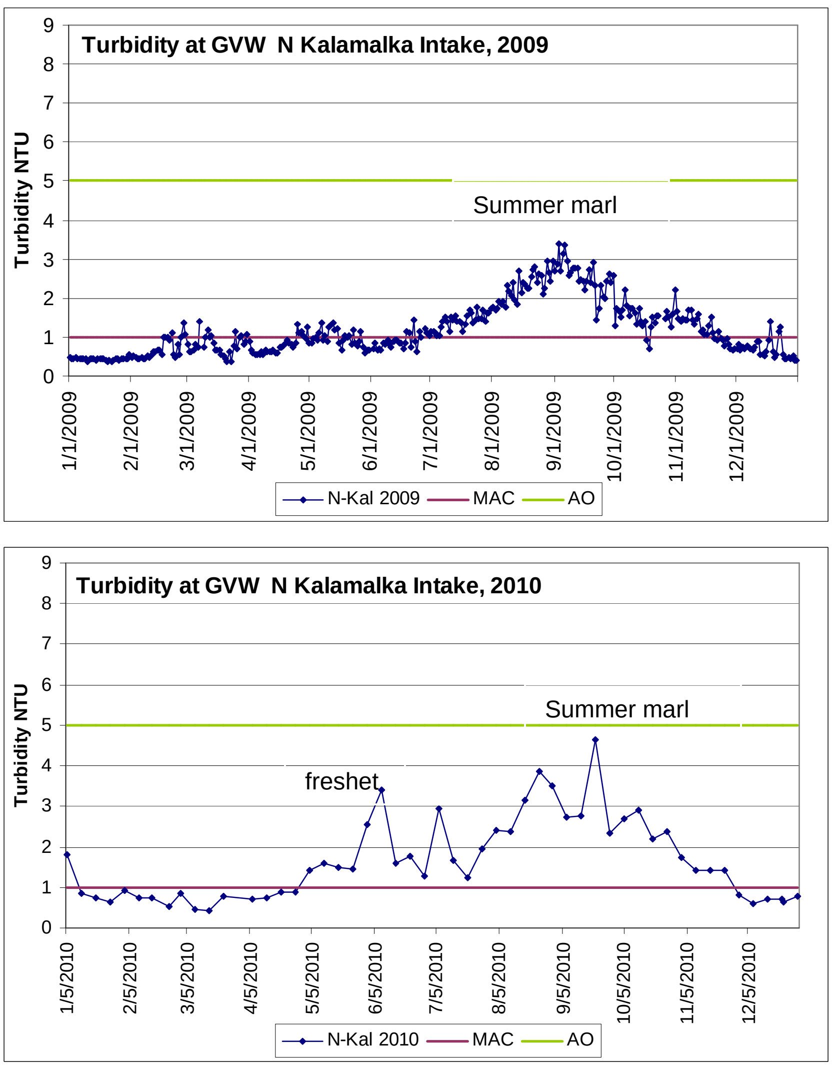


Algae and Taste and Odor Events High algae counts and complaints of fishy or musty taste and odor in Kalamalka Lake water are correlated. Many blue-green cyanobacteria generate the compounds (MIB and geosmin) that are responsible for musty disagreeable odors. Other algae produce a musty, decaying taste and odour when they are decomposed by *Actinomycetes*. The key to musty taste and odor problem is the quantity of these algae and the relative abundance of *Actinomycetes.* Except for 2001 and 2002 when blue-greens were confined to September, these algae are common throughout the growing season and a large increase in their numbers triggers a taste and odor problem. During the lake-wide 1999 taste and odor event that prompted this study, counts of blue-green algae (cyanobacteria) exceeded 1700 cells/mL at the N-Kal intake. For comparison, in May 2010, the highest count that occurred at the North intake was 1780 blue-green cells/mL while the South intake was only 380 cells/mL (Appendix 3). The counts increased again in October at both intakes to 1100 - 1600 cells/mL of blue-green cyanobacteria. 2005, 2006 and 2009 had mild odor events caused by algae, while the counts in 2010 did not trigger complaints. A faint odor may have occurred but most consumers accept a very mild odor as natural. In the twelve years of research to date, none of the intake samples have exceeded the 2000 cyanobacteria cells/mL threshold of concern.

There are other causes of taste and odor events in Kalamalka Lake besides algae blooms. During 2007, a seiche-induced turbidity/odor event took place in late September. In this case, the turbidity particles were primarily detritus and bacteria, and decaying algae, rather than viable algae from the water column. An intake right on the bottom of Kalamalka Lake would be much more vulnerable to taste and odor events than one positioned more than 3 meters from the substrate. For example, the N-Kal intake with a clearance of only 0.6 m experiences more problems with taste and odor than the S-Kal 20 m intake.

Turbidity Turbidity is naturally high in Kalamalka Lake, near 0.4 – 1.5 NTU in the surface water layer from July to October due in large part to the marl precipitation. Other natural sources of turbidity include freshet silt/debris that contributes much of the spring turbidity in the North Arm, and algae pulses throughout the lake. Figure 2.23 shows the data collected by GVW at the intake. A perennial bulge in turbidity in August – October was caused by marl.

Figure 2.23: Turbidity at the GVW North Kalamalka Intake, 2009 and 2010



Detailed freshet sampling was completed for 2005 through 2008 (Table 6).

2008's freshet was late and large. Turbidity in the Coldstream Ck mouth measured 35 - 121 NTU and 30 – 113 NTU at 10 m site out in front of the creek mouth. Please refer to section 2.1 for a discussion of plume behaviour. Turbidity at the intake site and depth ranged from 1.4 – 2.6 NTU while the N 30 m site and depth was significantly higher at 1.7 – 3.6 NTU (Table 6). The Coldstream freshet plume has a greater impact on the N-30 m site than the existing N 20 m intake site. *Extending the intake to 30 m would actually increase GVW's exposure to freshet turbidity during a large freshet.*

2010's freshet was initially low and slow because of cool early spring weather, but that was followed by a record wet late spring. Spring 2010 turbidity at the N-Kal 20 m intake and at the 30 m site was low at 0.6 NTU while the N 40 m site was slightly lower at 0.5 NTU; all far lower than the ranges shown in 2008's large freshet (Table 7). A small Coldstream freshet plume does not have a greater impact on the N-30 m site than the existing N-20 m intake site.

While freshet caused brief turbidity spikes, extended high summer turbidity exceeding 1.0 NTU was frequently measured in August throughout Kalamalka Lake during the marl precipitation. In 2010, peak turbidity of 1.4-1.8 NTU was measured at both ends of Kalamalka Lake (Table 6). The Kalamalka 20 m summer samples with high turbidity contained precipitated marl and also contained higher concentrations of cyanobacteria and detritus.

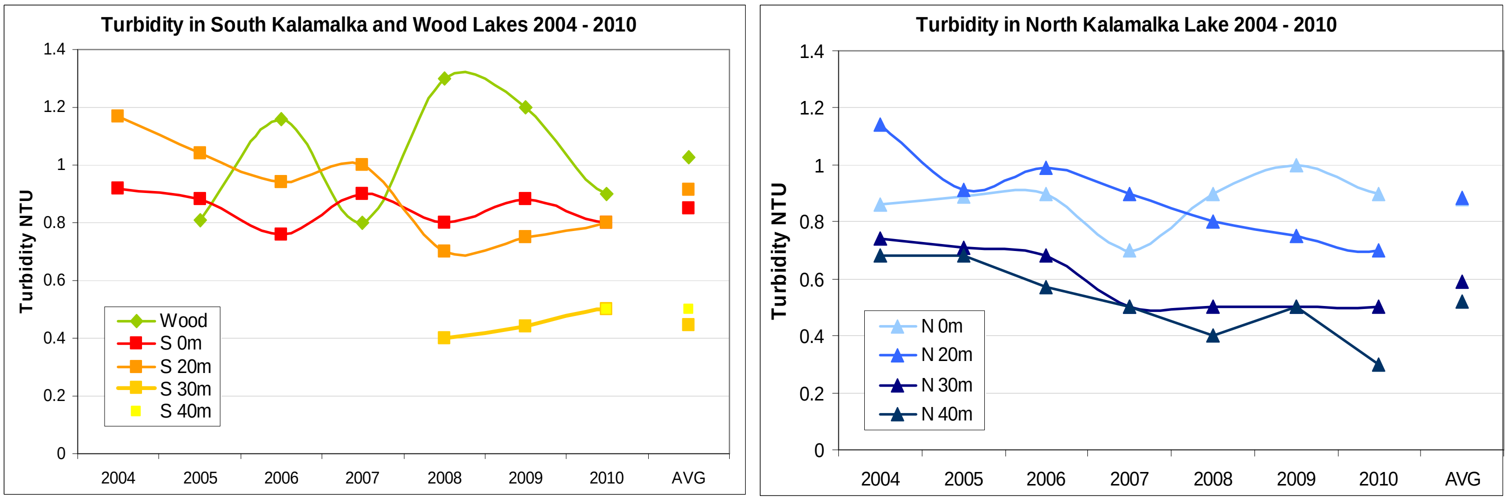
TABLE 6:
Growing Season Turbidity (NTU) at Kalamalka & Wood Lakes, 2010

	Wood	**South** Kalamalka				**North Kalamalka**			
2010 turbidity	0 m	0 m	20 m intake	30 m	40 m	0 m	20 m intake	30 m	40 m
May	0.8	0.8	0.5	0.3	0.4	0.6	0.6	0.6	0.5
June	0.8	0.4	0.6	0.3	0.3	0.5	0.6	0.4	0.5
July	0.9	0.6	0.7	0.4	0.2	0.7	0.6	0.4	0.4
Aug	**1.5**	**1.4**	**1.8**	0.8	0.9	**1.8**	**1.4**	0.3	0.4
Sept	0.5	0.7	0.8	0.6	0.5	0.8	0.5	0.6	0.7
Oct	0.9	0.6	0.5	0.6	0.4	**1.0**	0.4	0.7	0.6
Average	0.9	0.8	0.8	0.5	0.5	0.9	0.7	0.5	0.5

- numbers in bold exceed 1 NTU

Surface turbidity averaged 0.73 NTU in Kalamalka Lake from 1973 – 1989. Turbidity in the main body of Kalamalka Lake appears to be relatively stable in the range of 0.7 – 1.0 NTU over the course of the growing season. At the N-Kal intake, 2010 turbidity samples spiked over 5 NTU on 4 occasions (Figure 2.21). Despite these spikes, average declined at both the 30 m and 40 m depths during 2004 – 2010, and there was seldom a significant difference between these two depths (Figure 2.22). Overall, the 40 m samples had the lowest turbidity and averaged half of the surface or 20 m turbidity. Turbidity and taste and odor events often coincide in Kalamalka Lake.

Figure 2.22:
Annual Average Turbidity in Kalamalka Lake and Wood Lake, 2004 - 2010



For some reason the annual average turbidity in Wood Lake is opposite to the pattern demonstrated by the South Kalamalka averages (Figure 2.22).

Turbidity exceeding 2 NTU occurred in late summer at the N-Kal intake every year since 2004 (Figure 2.23). This is significantly more that what is measured in the lake at 20 m where the samples are taken 3 m off the bottom and again implicated the 0.6 m insufficient clearance between the intake and the bottom of the lake.

There are five types of events on Kalamalka Lake that increase turbidity at the N-Kal intake**:**

1) **Freshet** During the freshet, turbidity measured at the North intake was as high as 3 NTU during the freshet but that was dilute compared to the 8-9 NTU passing over the intake in the surface water.

2) **Summer turbidity events** Turbidity was consistently better in the surface water than at either the North GVW intake (0.6 m above substrate) or the South LC intake (2.0 m above substrate), respectively, during a summer turbidity event (Table 6). (Appendix 3). After the marl precipitation, turbidity rises in the deep water (Figure 20).

3) **Seiches** Severe wind storms cause large seiches and triggered a turbidity event on Oct 18/19 2006 and on November 12 2007.

4) **Fall Overturn** Turbulence generated by the fall overturn increases turbidity briefly to as much as 3.2 NTU at the GVW intake. Algae counts on this date were modest, but large amounts of fine detritus confirm seiche penetration to the intake depth (20 m) (Appendix 3).

5) **Rototilling (bottom disturbance)** A final cause of high turbidity (>5 NTU) was rototilling in the vicinity of the N intake (2007). Rototilling on the North beach area is "upstream" of the GVW intake due to the general flow of water in Kalamalka Lake. Water samples collected from the GVW intake on December 4 during rototilling had the highest organic detritus and fine silt counts ever encountered in Kalamalka Lake water samples. These sediments components accumulate in aquatic plant beds. Since December is usually a low turbidity time of year, rototilling should be deferred to the freshet months to avoid additional turbidity notifications.

Because GVW has UV disinfection as well as chlorine, and because turbidity is naturally high in Kalamalka Lake, turbidity can reach 3.5 NTU (24 hour average) before a water quality advisory is discussed with IHA.

2.8 UV Transmissivity

Measurements of turbidity and transmissivity do not show matched patterns because dissolved organic molecules lower transmissivity but do not affect turbidity. Most sample sites on Kalamalka Lake had their lowest transmissivity in freshet (May/June), peak marl, or during fall overturn.

Spring transmissivity is lowered by the freshet, particularly in the surface water at the North end. The 2008 freshet transmissivity of 66% measured at the surface is beyond the range for effective UV disinfection. It is fortunate for GVW that the freshet plume is buoyant. By comparison, North end transmissivity only dipped to 87.8% in 2009 and to 91.1% during 2010 (Table 7).

TABLE 7: Growing Season UV Transmissivity (% at 254 nm) at Kalamalka and Wood Lakes, 2010

	Wood	**South Sample Site**				**North Sample Site**			
2010 UV trans	0 m	0 m	20 m	30 m	40 m	0 m	20 m	30 m	40 m
May	**85.1**	89.6	90.4	91.0	90.8	91.8	92.2	92.1	92.0
June	**85.6**	89.5	89.5	89.9	89.5	91.1	90.8	90.5	92.1
July	**83.2**	90.5	89.9	89.2	90.6	90.8	91.6	90.8	91.1
Aug	**82.9**	90.1	88.7	90.1	88.9	90.2	90.6	90.3	90.7
Sept	**86.2**	91.3	91.2	91.5	90.5	91.9	92.4	92.9	92.4
Oct	**85.2**	91.6	91.5	90.6	91.6	91.4	91.1	91	90.6
Average	**84.7**	90.4	90.2	90.4	90.4	91.2	91.5	91.3	91.5

NOTE: numbers in bold exceed tolerance of most UV treatment; UV transmissivity measurements above 88% indicate that UV disinfection is readily accomplished with a cost-efficient dose of UV light.

The effect of dissolved organics is clearly seen on the reduced Wood Lake average transmissivity of 84.7% as opposed to the average of 90.2- 91.5 % for Kalamalka Lake water. The gradually increasing TOC in Kalamalka Lake may increase the light dose needed for UV disinfection if this trend continues. None of the UV transmissivity samples collected from intake depths in 2009 or 2010 indicates a problem for UV disinfection. While the turbidity/transmissivity advantage of an intake at N 40 m versus N 20 m is negligible during most of the growing season, there is a clear advantage to locating intakes further from Coldstream Creek inflow during freshet and during intense summer storms. Similarly, the South 20 m intake and the proposed 30 m and 40 m intake depths had identical UV transmittance.

2.9 *E. coli* and Fecal Bacteria

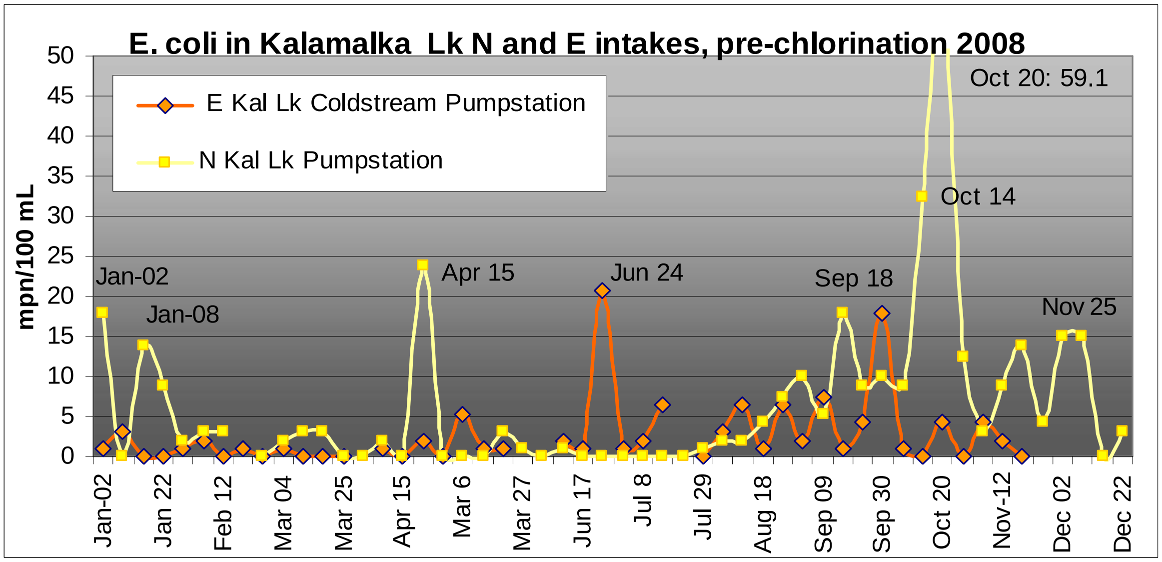
The fall velocity of bacteria and cyanobacteria is very slow and water currents can transport bacteria many kilometres into Kalamalka Lake before they settle The highest peaks in *E. coli* counts in the 20 m deep N-Kal intake, and the 5 m deep E-Kal Intake occurred in the fall/winter period, not in spring freshet when they might be expected based on Coldstream Creek *E. coli* measurements (Figure 2.24). A similar pattern in *E. coli* events occurred at Lake Country, but the counts were much lower; 1 – 4 cfu/100mL. The S-Kal intake counts may be biased low due to chlorination interference, however the S end in-lake samples were all <1 - 2 cfu/mL whereas the N-Kal 20 m samples were 8 – 270 cfu/100 mL on the same dates (Appendix 1). Based on this data, the high *E. coli* counts are primarily a North Arm problem. The S-Kal intake bacterial counts were more in line with studies on Kalamalka Lake from 1973 – 1989 that gave fecal coliforms at 2.0 mpn/100 mL (Bryan, 1990). The N Arm counts are very high compared to historic data.

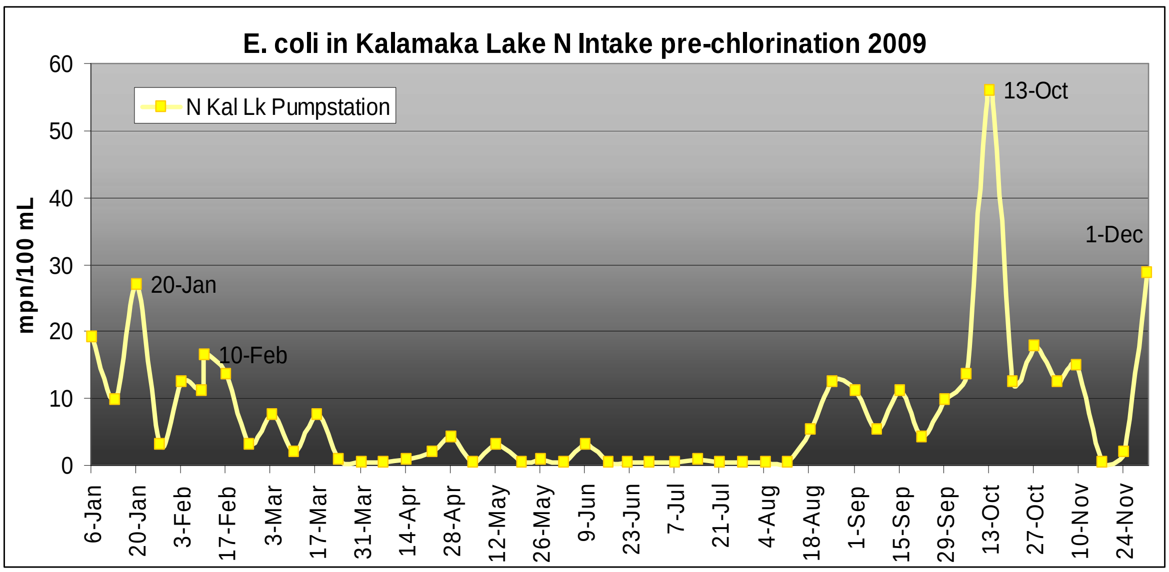
The highest peaks in fecal bacteria and *E. coli* counts in the S-Kal intake occurred in winter or with severe storms. For example, a storm with a seiche on August 22, 2006 delivered 300 fecal mpn/100 mL and 25 *E. coli* mpn/100 mL to the intake. A severe storm on October 19, 2009 caused a fecal count of "overgrown without fecal bacteria" and 1 mpn/100 mL *E. coli.* Both storms must have introduced storm water to the intake area and/or kicked up bottom sediments. 2009 and 2010 in-lake samples from the South end of Kalamalka Lake were all <1 cfu/mL except Sept 23, 2010 that had a low 2 *E. coli*/100 mL result (Appendix 1).

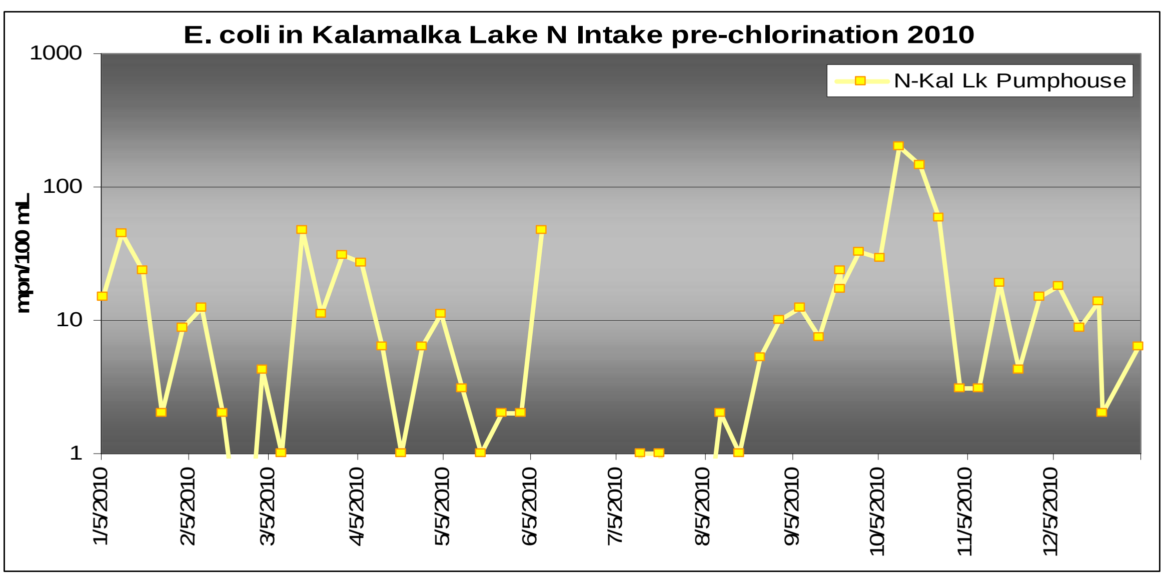
In the North Arm, peak *E. coli* counts occurred from October 13 to October 20 every year, regardless of weather (Figure 2.24). This unusual timing is unlikely to be weather or waterfowl driven – rather this narrow one week high *E. coli* window is likely to correlate to a seiche or a human activity such as returning cattle or a routine effluent release. Results from the bacterial source tracking study will provide more information on this unusual pattern.

In September 2009, a remote sampler was repeatedly dropped into the sediment near the N-Kal intake before retrieving a sample 1 m above the substrate. The intent was to mimic seiche turbulence to see if the sample would account for the turbidity spike that accompanies a seiche according to the North intake SCADA system (Figure 2.23). Unlike the sediment samples from Okanagan Lake, and South Kalamalka, the sediment that is easily stirred up near the N-Kal intake contained uncountable numbers of coliform bacteria, and 27 *E. coli.* These results indicate a significant risk of *E. coli* loading from north end sediments and any turbulence causing sediment re-suspension poses a pathogenic risk. Re-suspended sediment also increases turbidity, THM precursors and lowers UV transmissivity. The high *E. coli* counts in the routine North intake water samples tend to correlate to freshet and storms that could suspend sediments.

FIGURE 2.23:
***E. coli* at GVW Kalamalka Lake Intakes (raw water) 2008- 2010**







Coldstream Creek itself always contains large numbers of *E. coli.* It ranged from 110 – 1500 cfu/100 mL in the 2009 summer sampling to a very high 1200 - 11,000 cfu/100 mL *E. coli* in the 2010 summer sampling (Table 8; Figure 2.24). The creek is probably a key source of *E. coli* to the North Arm water and sediments.

Table 8: Coldstream Creek Summer Sampling, 2010

Coldstream Creek 2010

Parameter mg/L	26-May-10	23-Jun	22-Jul-1(	19-Aug-1	23-Sep-1	13-Oct-1(
pH	8.28	8.19	8.31	8.31	8.43	8.33
Alkalinity	194	192	194	194	291	287
Calcium	66.5	83	62.8	62.8	91.8	91.9
Conductivity uS/cm	454	479	479	479	716	716
Chlorine	8.68	15	10.6	10.6	19.1	20
Sodium	10.2	13.8	13.3	13.3	19.6	21.1
Total Coliforms CFU/10	DGT1200	46000	11000	DGT 160(	4600	DGT1800
Background Colonies	> 200			>200	> 200	> 200
E.coli CFU/1(	180	11000	2400	480	300	250

In summary, the fall/winter spikes in *E. coli* in North Kalamalka Lake can be the result of numerous factors:

- The cattle come off range and onto the Coldstream farms in the fall
- Rains flushing the Coldstream system and storm water inflows can cause failures from farm land into Coldstream Creek.
- Sediment disturbance during rototilling for Eurasian milfoil control could cause brief *E. coli* spikes because viable bacteria can re-suspend from surface sediments.
- Canada Geese and gulls congregate in calm water areas near the shoreline
- If they occur, effluent discharges will cause significant *E. coli* spikes.
- Seiches can kick up sedimented bacteria from the sediments into the bottom water of the N arm if they were recently deposited
- Finally, natural UV sunlight disinfection would be lowest during the winter months. Sunlight UV deactivation of bacteria is greatest near the surface in water with low turbidity and high transmissivity.

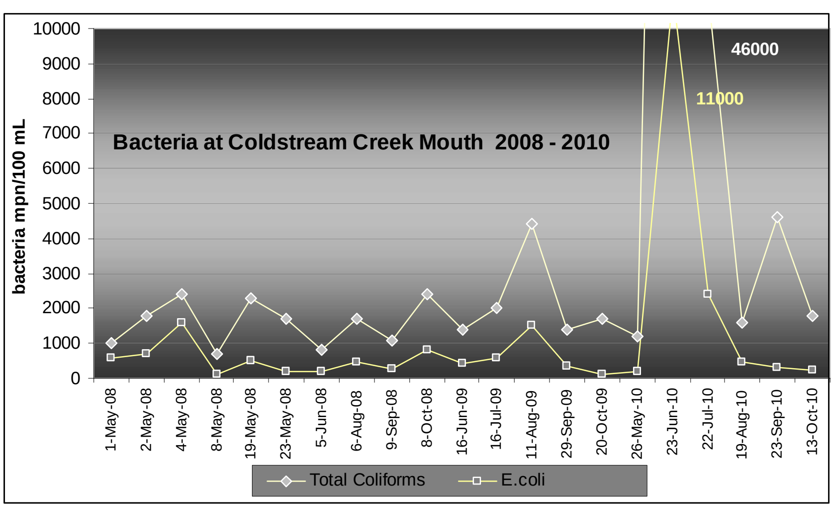


Figure 2.24 :

Bacteria at Coldstream Creek Mouth 2009 - 2010

3.0 Summary of Kalamalka Lake Study to date (1999 – 2010)

FRESHET

- The Coldstream Creek freshet plume varies in size, duration and intensity from year to year and also within each freshet.
- During early freshet, Coldstream Creek water flows over the surface of Kalamalka Lake and affects the entire North Arm.
- During late freshet, the inflow plume loses buoyancy and interflows into Kalamalka Lake; a portion of the flow travels along the bottom and affects the GVW N-Kal intake.
- In a large freshet, the water quality at 30 m is inferior to the water quality at the existing 20 m intake.
- During freshet, the 40 m site has better quality than the 30 m site. During the balance of the year, there is little difference between the water quality at these two potential intake extension sites.
- During freshet and summer storms, Coldstream Creek responds within 24 hours with higher flows and turbidity spikes. Local storm drain water and disturbed riparian areas on Coldstream Creek contribute to this rapid response to storms.

SEICHES

- The main transport mechanism of surface contaminants to the Kalamalka Lake intakes is seiches.
- North or south-west winds with gusts exceeding 30 km/hr could generate a seiche depending on the duration of the wind event. A typical period for the seiche to travel from the N to the S chain (15.4 km) would be approximately 11.7x2 = 23.5 hours.
- Turbulence and seiches are more intense at the South end of Kalamalka Lake than they are at the North due to the shape of the lake basin.
- GVW's N thermistor chain indicates that an intake positioned deeper than 30 m would be much less impacted by seiches than the existing 20 m intake.
- Lake Country's S thermistor chain recorded a 6 ^{o}C excursion at 30 m during 2005 but a 2-3 ^{o}C fluctuation is more common. A future intake may need to be positioned closer to 40 m to evade all seiches.
- Seiches produce noticeable spikes in water temperature, conductivity, turbidity, color and algae densities at the existing N-Kal and S-KAl 20 m intakes. Seiches have the biggest impact on abstracted water quality during the spring and fall.
- 2004 through 2010's profiles also show oxygen super-saturation near the thermocline during the summer due to bacterial and cyanobacterial photosynthesis. The super-saturated zone was small in 2010 compared to recent years.
- Seiche activity is smaller in Wood Lake because its basin is smaller and shallower.

WATER CHEMISTRY

- Over the past century, water quality was relatively stable in Kalamalka Lake (Bryan, 1980). Its unique marl precipitation provides some protection to Kalamalka Lake from phosphorus loading arising from human activities.
- Every year, the single greatest impact on water quality in Kalamalka Lake is the size of the freshet, affecting nitrogen, phosphorus, pH, calcium, sulphate and organic/inorganic particulate inputs. Low inflow years import far less phosphorus to Kalamalka Lake since P adheres to soil particles. Modest freshet flows usually result in small microfloral densities. Inflowing nutrients can impact several years of lake production because only 2% of the lake water exchanges each year
- In general**,** nutrient concentrations at the North and South sites on Kalamalka Lake move in concert, indicating whole-lake influences such as freshet (P) or groundwater (N) nutrient inflow.
- During the course of this study, pH appears be in slow decline. The trend toward lower pH may signal a reduction in the intensity of the marl precipitation events but it is impacted by photosynthesis – a high productivity year such as 2009 will significantly increase pH measurements.
- Marl co-precipitates phosphorus and B12, causing a rapid drop in summer algae production and this helps to conserve Kalamalka Lake water quality.
- Most water quality parameters are consistent throughout the summer and only minor change occurs with depth. The marl precipitation causes a small increase in calcium, conductivity and hardness in deeper water.
- Chloride concentrations have tripled since the 1970's probably through road salt storage and application
- Wood Lake is smaller and receives more nutrients from internal loading than Kalamalka Lake does. It is productive and donates nutrients to Kalamalka Lake when its water elevation exceeds that of Kalamalka Lake. Marl precipitation occurs sporadically in Wood Lake, assisted by inflow from Kalamalka Lake. Wood Lake's nutrient concentrations are declining with the DLC sewer system and it is now mesotrophic.
- TOC production in Kalamalka Lake has oscillated upwards over the ten years of this study.

MICROFLORAL PRODUCTION, TASTE AND ODOR EVENTS

- A correlation between large freshets and greater algal production was noted in this study and previously by MoE.
- Years with large freshets are more likely to experience algal water quality problems such as increased turbidity, chlorine demand, taste and odor and lowered UV transmissivity.
- Seiches create turbulence that suspend fine sediment and algal material from the substrate and increase turbidity at the intakes. An intake right on the bottom of Kalamalka Lake would be much more vulnerable to taste and odor events.
- Super-saturation of dissolved oxygen at depth indicates heavy microfloral growth. Periods of super-saturation coincided with elevated turbidity at the intakes. Super-saturation extended beyond 20 m at all sites in the North Arm, strongly suggesting a photosynthetic bacteria / cyanobacteria component since their light requirements are smaller than those of most algae.
- Based on cell numbers, there was a predominance of blue-green algae (cyanobacteria) in most growing seasons. Over the years of this study, the prevalence of blue-green algae appears to be increasing.

- Overall algae densities are usually but not always lower at 40 m compared to surface, 20 & 30 m samples.
- Samples collected from 30 and 40 m contained less chlorophyll-a than samples from 20 m (Table 4). To realize the benefit of lower algae production at the 30 or 40 m sites, a new intake should be positioned at least 3 m above the substrate.
- The evidence to date indicates that the periodic taste and odour problem occurring in Kalamalka Lake are caused by unusually high blue-green algae concentrations, possibly made worse by A*ctinomycetes* decomposers and re-suspended detritus.
- Blue-green algae blooms are perennial in Wood Lake in the spring and late fall. The 2008 bloom was severe enough to close beaches on the May long weekend, 2008. A smaller bloom occurred in spring 2009 as well, but not in 2010.
- Algae production in 2009 was unusually large with both diatom and cyanobacteria blooms.
- A January 2010 nutrient influx from Coldstream Creek to the North Arm immediately triggered a complex algae bloom and also contributed to an unusually large spring diatom bloom.

TURBIDITY, UV TRANSMISSIVITY & PARTICLE SIZE

- The IHA now requires a water quality advisory when turbidity exceeds 1.0 NTU, yet Kalamalka Lake has natural turbidity near 1 NTU due in part to marl precipitation. (The N-Kal intake with UV treatment is allowed 3.5 NTU before an advisory is called).
- Turbidity exceeding 1-2 NTU occur at both intakes. Samples with high turbidity also contained unusually high concentrations (>1000 cells/mL) of blue-green algae, detritus, bacteria and marl.
- UV transmissivity ranged from 86 – 94 % in Kalamalka Lake with an average at the intakes of 90-91%.
- Turbidity is consistently better in the surface water than the intake 20 m depths during the summer turbidity events, suggesting that distancing the N intake from the bottom by more than the current 0.6 m and the S intake by more than the current 2.0 m would be advisable (>3 m is recommended).
- Turbidity was significantly lower at both the 30 m and 40 m depths with only the 40 m depth showing immunity to the Coldstream freshet.
- In some years, UV transmissivity is superior in deeper water during freshet and late summer but in 2005 through 2009, there was no significant difference between transmissivity at 20, 30 and 40 m in the North or between 20 and 30 m in the south (< 1.2%).
- Particle sizes were generally small with all particles less than 75 microns in diameter. Very fine (<1.5 microns) particles of marl are abundant and increase the turbidity and sedimentation rate of Kalamalka Lake.
- *E. coli* bacteria and protozoan cysts are very small and are imported by Coldstream Creek inflows. Since cysts have been detected in the North Arm of Kalamalka Lake, improved riparian protection and storm water management is needed in the Coldstream Valley.
- Rototilling on the main N end beach caused a large turbidity/ *E. coli* incident for GVW's N-Kal intake. A disturbed sediment sample from 20 m contained 27 cfu/100 mL
- *E. coli* spikes of >10 cfu/100mL occur in the N arm, usually in the fall/early winter.

3.1 Summary of Extended, Deeper Intake Benefits:

Intake extensions provide a theoretically lower risk of contaminants from land-based activities, such as Coldstream Creek plume, Oyama Canal and waterfowl habitat. When all measured physical, chemical and biological parameters are considered, the advantages of an extended intake in Kalamalka Lake are:

North 30 m

- It would experience fewer seiches (4/year); maximum temperature deviation = 1.5 – 10^{o}C
- Narrower and lower pH range, usually 7.9 – 8.2 (vs 7.5 – 8.3 at 20 m)
- Lower turbidity, usually 0.3 – 0.7 NTU (except during large Coldstream Ck freshet when turbidity reaches 1.7 – 3.6NTU)
- Negligible change in UV transmissivity (except during large Coldstream Ck freshet)
- *E. coli usually range from <1 – 40 cfu/100 mL* (vs <1 – 8 CFU/100mL at 20 m)

North 40 m

- It would evade most seiches; maximum temperature deviation = 1.5 – 4^{o}C (only one seiche reached 40 m in 2009; it caused a 4^{o}C rise in the fall)
- Narrower and lower pH range, usually 7.9 – 8.2 (vs 7.5 – 8.3 at 20 m)
- Lower turbidity, usually 0.3 – 0.7 NTU (vs 0.4 – 1.2 NTU at 20 m)
- Slightly higher transmissivity
- Usually non-detectable *E. coli* (vs <1 – 270 CFU/100mL at 20 m)

South 30 m

- 8 – 10 seiches reach 30 m; maximum temperature deviation = 3.2 – 6^{o}C
- Slightly lower pH, usually 7.6 – 8.23 (vs 7.8 – 8.26 at 20 m)
- Lower turbidity, usually 0.2 – 0.7 NTU (vs 0.5 – 1.2 NTU at 20 m)
- Negligible change in UV transmissivity (except during fall overturn)
- Lower algae production, chlor-a usually 1.2 – 2.4 ug/L (vs 1.1 – 4.1 ug/L at 20 m) Algae blooms can put 30 m >4.0 ug/L chlor-a as in 2009; usually a 20% decrease in algae cell count
- <1 – 2 CFU/100 mL E. coli; <1 -8 CFU/100 mL total coliforms or excellent source water

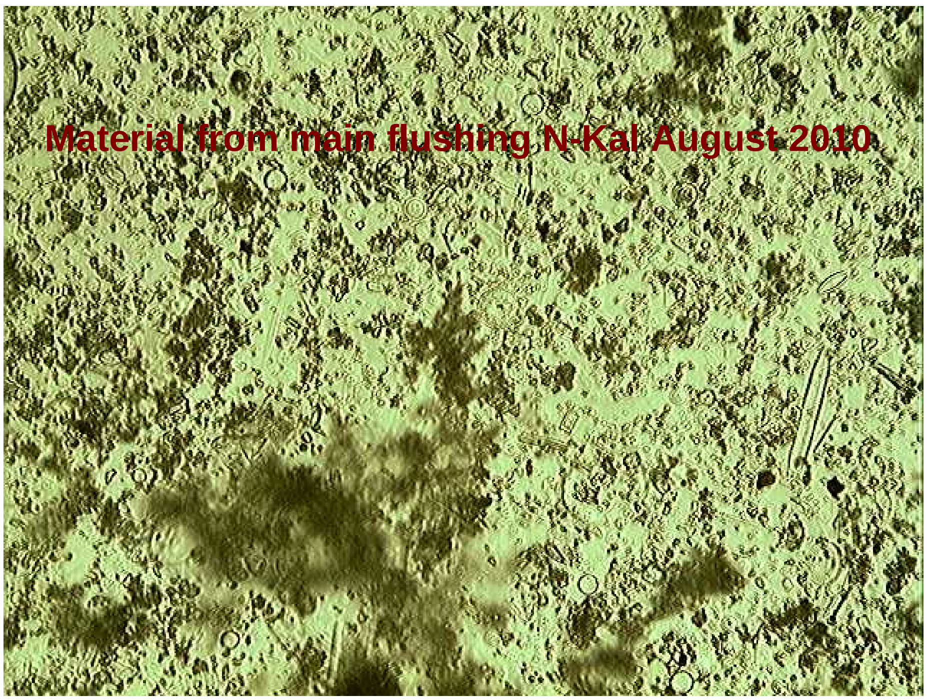
South 40 m

- 4 – 5 seiches reach 40 m; maximum temperature deviation = 3^{o}C
- Slightly lower pH, usually 7.6 – 8.23 (vs 7.8 – 8.26 at 20 m)
- Lower turbidity, usually 0.2 – 0.7 NTU (vs 0.5 – 1.2 NTU at 20 m)
- Negligible change in UV transmissivity (except during fall overturn)
- Lower algae production, chlor-a usually 1.2 – 2.4 ug/L (vs 1.1 – 4.1 ug/L at 20 m) Algae blooms can put 30 m >4.0 ug/L chlor-a as in 2009; usually a 20% decrease in algae cell count ie no change from 30 m
- Non-detectable E. coli; <1 – 3 CFU/100 mL total coliforms or excellent source water

In both the N-Kal and S-Kal cases, the largest disadvantage to the extended intakes is the cost of installation. The *minimum* distances to the preferable 40 m depths are large:

Kalamalka Lake	N end	S end
Intake extension to 30 m	365 m	205 m
Intake extension to 40 m	1275 m	1260 m

[the distance to clear the North Arm for the N-Kal intake is 3700 m (3.7 km)]



4.0 Recommendations

4.1 Recommendations for Kalamalka Lake Management

Ongoing efforts to limit contaminant introduction to Coldstream Creek and Kalamalka Lake could be focussed on re-directing storm water, farming practise changes and restricting motorized boating. Grants to fund riparian restoration could be pursued, perhaps with the assistance of local volunteer groups.

4.2 Recommendations for Intake Modifications

While extending the current DLC S-Kal intake to 30 m would provide improved water quality, extending the GVW N-Kal intake would provide inferior water quality during a heavy freshet year because the intake would be physically closer to the plume path. In both cases, a 40 m intake would provide water with lower temperature, fewer seiches, lower turbidity and better UV transmittance, but the substantial cost would have to be weighed against the benefits of other forms of water treatment.

4.3 Recommendations for Modifications to 2011 Sampling Program

Long-term maintenance of the Kalamalka Lake water quality and microfloral databases begun by Ministry of Environment is important for tracking and forecasting trends on this vital water supply. MoE will be conducting complementary nutrient studies of Kalamalka Lake in 2011.

4.4 Implement Source Assessment Recommendations

Recognition of intake protection zones (IPZ) and exclusion of new, high risk activities from these zones is important enough that a License of Occupation or a head-lease should be considered so that protection of critical riparian areas around an intake come under the more focussed attention of the local municipal government.

4.5 Proposed Sampling Program for 2011

North and South 20 m intake sites

New sampling items proposed for 2011 are in grey italics

1) Monitor plankton algae, shoreline algae, benthic algae, thermal structure, and chlorophyll-a on a monthly basis, May – October, 2011. ***Put more effort into clarifying the August turbidity exceeding 1 NTU during twice weekly trips in 2011***. If a high turbidity phase occurs, samples will be collected from every 5 m for turbidity, YSI and microfloral identification, within the week where turbidity exceeds 2 NTU.

2) Collect water quality samples on a monthly basis, May through October 2011. Sample locations should include the raw intake water, surface water, and the intake depths (20 m), including any proposed depths for extended intakes. In order to better determine the nutrient inputs to Kalamalka Lake, sample sites in Coldstream Creek and Wood Lake were added to the monthly routine during

2006. A 30 m South sample was added in 2008 and a 40 m site in 2010 to the South Kalamalka sites to help forecast water quality at a deeper intake.

3) Sampled parameters should include those that show significant change – the stable parameters can be shifted to every second year and will NOT be sampled in 2011:Total Alkalinity, Total Calcium, Total Iron, Total Hardness, Total Magnesium, Sulphate and Suspended Solids

pH, total organic carbon, sodium and chloride will be analysed at Caro Labs, Kelowna, BC. A new LAC Hanna multi-meter will be used to collect profiles for pH conductivity, ORP Temperature and dissolved oxygen commencing in 2011. MoE will conduct March and autumn samples for nitrate + nitrite, ammonia, total N, ortho P, total dissolved P, total P at Maxxam Labs. All of these water quality parameters are needed for this study, for MoE work and for the benefit of future water treatment.

North and South deep sites

4) Continue with regular *E. coli* monitoring at all sites including 30 and 40 m at both ends of the lake

5) Collect annual sediment sample by disturbing the substrate under the intake and analyse for bacterial parameters.

6) Maintain the S-Kal 40 meter deep thermistor chains to continuously measure water temperature and track seiches until it fails. This data complements the data collected on Coldstream Ck by MoE.

7) *Repeat drogue studies to confirm the size and shape of the intake protection zone on regular sample dates*

Coldstream Creek

8) *E. coli* should be collected from Coldstream Creek monthly to attempt to correlate to *E. coli* spikes in the lake; sample monthly above the Kirkland bridge May - October.

2010 Report Prepared By:

Mrs. Heather Larratt
Aquatic Biologist R.P.Bio.

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