



Water Quality

State of Water Quality of Glen Lake 1981-1995

Canada - British Columbia Water Quality Monitoring Agreement

**Water Quality Section
Water Management Branch
Ministry of Environment, Lands and Parks**

April, 1996

Executive Summary

Glen Lake is located on southern Vancouver Island near Victoria, B.C. (Figure 1). The watershed for this small lake is 11.9 km².

This report assesses 12 years of water quality data and makes the following conclusions:

- Glen Lake is classified as a mildly dystrophic lake. Dystrophic lakes receive a large quantity of organic material, are acidic (low pH), and have low productivity.
- Spring overturn sampling indicates that in recent years there was less total phosphorus in the water column. However, nitrogen values (e.g., nitrate/nitrite nitrogen) are increasing in the water column.
- Phosphorus is the limiting nutrient for algal growth in Glen Lake.
- The Capital Regional District's Health Protection and Environmental Division has posted advisory notices at Glen View Beach on several occasions between 1980 and 1995, warning of the potential for increased risk to bathers' health. These notices were posted when the geometric mean exceeds 200 fecal coliforms/100 mL over a 30-day period.
- Three water quality indicators (total manganese, total iron, and total zinc) exceeded the criterion for protecting aquatic life.
- True colour exceeded the desirable criterion for recreational use.

We recommend that the following water quality objectives be set for Glen Lake:

- Total phosphorus
- True colour
- Total manganese
- Total iron
- Total zinc
- Dissolved oxygen

These objectives would set the goals for a remediation plan, which we recommend be developed for Glen Lake.

We recommend monitoring:

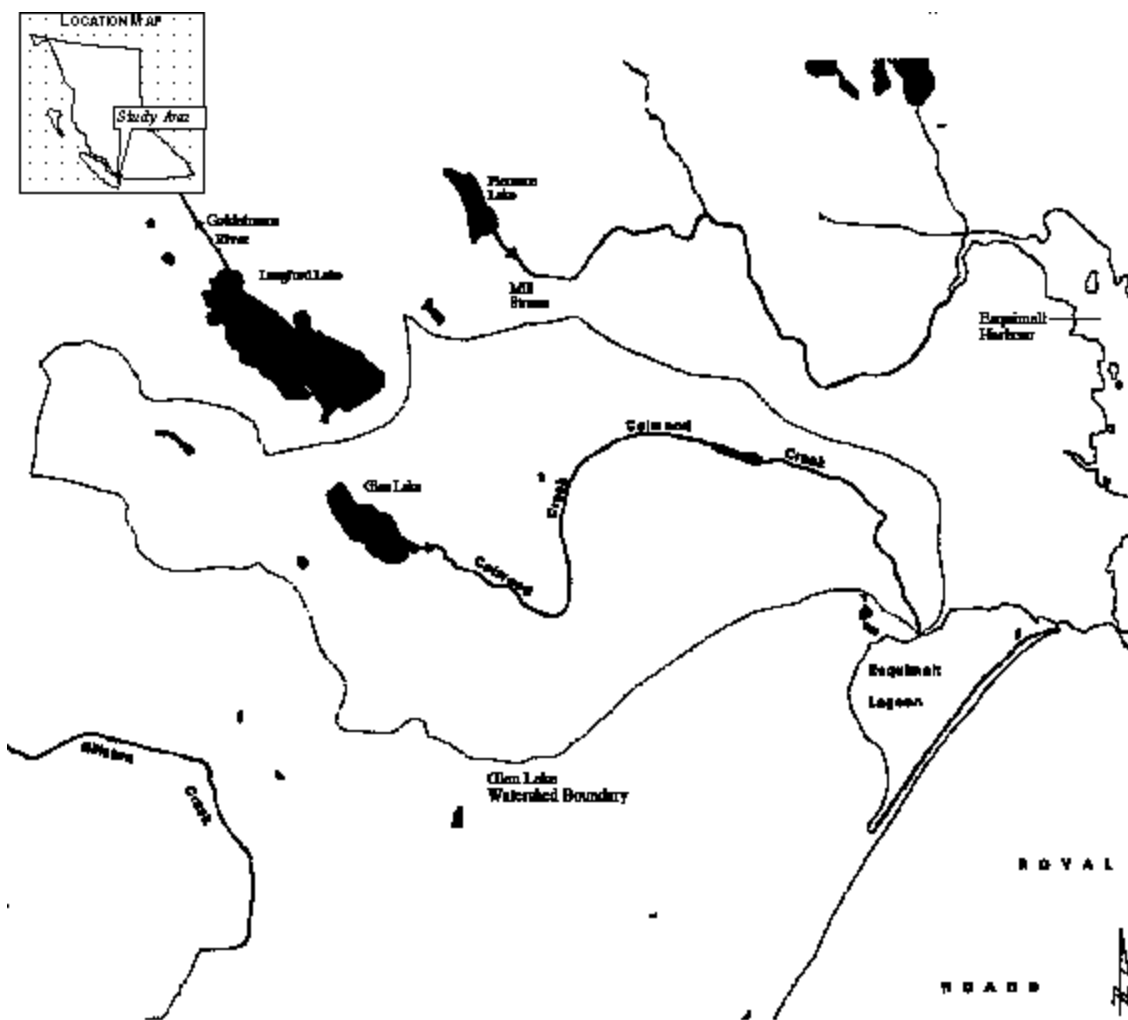
- to determine whether water quality objectives are being met.
- to identify changes in water quality attributed to activities within the watershed such as urbanization, changes in nonpoint discharge, biological activity, and lake aeration.

These monitoring programs could be implemented by a Glen Lake stewardship group with assistance from the Ministry of Environment, Lands and Parks.

- to determine whether the public beach is suitable for bathing.

The monitoring program is continuing to be implemented by the Capital Regional District's Health Protection and Environmental Program.

Figure 1 Glen Lake Watershed (Scale 1:50,000)



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Acknowledgements

Drafts of this report were sent to Lloyd Erickson and John Deniseger, Environmental Protection in Nanaimo, Peter Law, Fisheries in Nanaimo, Gary Gibson, Capital Regional District, Barry Boettger Public Health Protection, Rick Nordin and Larry Pommen, Water Quality Branch, and Lanny Seaton, Glen Lake Ratepayers Association. Valuable comments were provided and incorporated into this report.

Introduction

Glen Lake is located on southern Vancouver Island near Victoria, B.C. (Figure 1). The watershed for this small lake is 11.9 km². The surface area of the lake is 16.9 ha and is comprised of one main basin. The lake has a maximum depth of 14 m and a mean depth of 6.4 m (Figure 2). Glen Lake has a flushing rate of 1.43 times /year. (Perrin,1995). There is one inflow stream and Colwood Creek drains Glen Lake into Esquimalt Lagoon.

The Ministry of Environment, Lands and Parks monitored the water quality at the deepest point (14 m) of the basin between 1981 and 1995. The data are stored on the provincial data base, SEAM, under station numbers 1130202 and 1130025 (Figure 2). The two purposes for monitoring the water quality of Glen Lake are to identify:

- long-term changes in water quality as a consequence of development within the watershed; and
- how these changes may impinge on certain uses of water from the lake.

The Capital Regional District's Health Protection and Environmental Division collected fecal coliform samples from the one bathing beach (Glen View Beach) on Glen Lake (Figure 2). Weekly sampling begins in April each year and continues through the bathing season, ending in September. Fecal coliform results from five samples collected within a 30-day period are used to establish a geometric mean at the beginning of the season. A beach advisory notice, warning of the potential for increased risk to bathers' health, is considered for posting if the geometric mean exceeds 200 fecal coliforms/100 mL over a 30-day period. More intense sampling may occur if the results of a single sample exceeds 400 fecal coliforms/100 mL.

This report assesses 14 years of water quality data. These data consist of:

- 14 years (1981-1995) of spring overturn water quality data,
- 14 years (1980-1986, 1988, 1990-1995) of fecal coliform sampling data,
- 7 years (1983-1986,1993-1995) of spring and summer water quality data, and
- three years (1984-1986) of year-round water quality data.

The water quality data are plotted in Figures 3 to 14 and summarized in Tables 1 and 2.

The box plots in Figures 3 to 14 represent the variability of water quality indicators collected at the surface, mid depth, and near the bottom of the lake. The plot is comprised of a rectangle with the top portraying the upper quartile (75th percentile of the data series, $Q(0.75)$), the bottom portraying the lower portion (25th percentile of the data series, $Q(0.25)$), and a horizontal line within the rectangle portraying the median. Vertical lines extend from the ends of the rectangle to the adjacent values, also known as "whiskers", and are defined by:

- computing the interquartile range, $IQR=Q(0.75)- Q(0.25)$;
- defining the upper adjacent value as the largest observed value between the upper quartile and the upper quartile plus 1.5 X IQR;

- defining the lower adjacent value as the smallest observed value between the lower quartile and the lower quartile minus 1.5 X IQR.

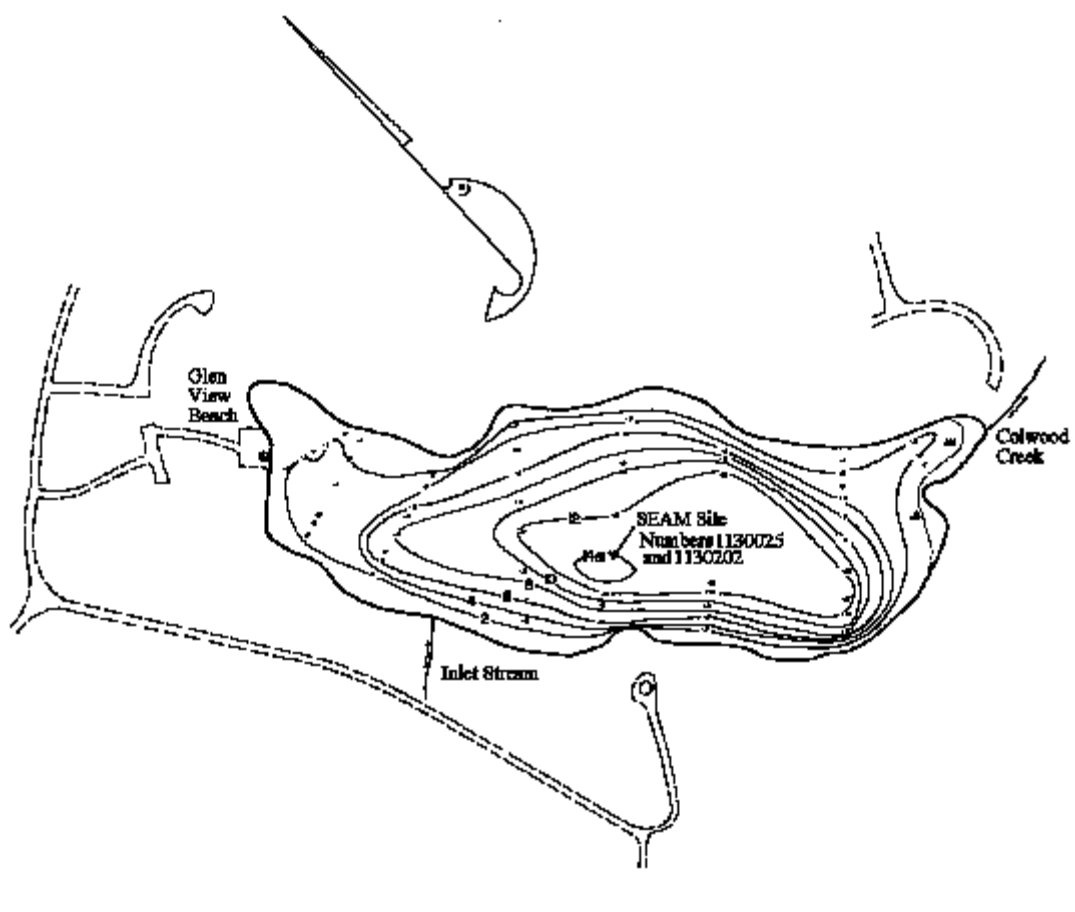
Values that fall outside the range of the adjacent values are defined as "outside values" and are plotted as asterisks (*). Values are defined as "far outside values" if they are located outside the outer range which is defined as the upper quartile plus 3 X IQR or the lower quartile minus 3 X IQR. These values are plotted as empty circles (O).

Trends in water quality data collected at different depths and at different frequencies over time are assessed by comparing yearly changes in median values in conjunction with the size of sample variability. The size of sample variability is represented in the box plots by the rectangle, whiskers, and the two types of outliers. A change is observed when the median values and sample variability do not overlap.

Quality Assurance

The water quality plots were reviewed. On May 29, 1995, total zinc values were collected from three depths (1 m, 7 m, 14 m) in Glen Lake. These values ranged from 352 mg/L to 385 mg/L and are considered to be errors and were not included in the assessment.

Figure 2 Bathymetric map of Glen Lake (Scale 1:2500)



State of the Water Quality

The state of the water quality is assessed by comparing the values to any site specific water quality objectives or to Ministry of Environment, Lands and Parks' Approved and Working Criteria for Water Quality (Nagpal *et al.*, 1995) if objectives have not been set. Any levels or trends in water quality that are deleterious to sensitive water uses are noted.

Hay (1984) identified the potential of Glen Lake as an urban fishery. Also, Glen Lake has a swimming beach (primary-contact water recreation). These uses were threatened by excessive phosphorus loading from agricultural runoff, septic fields, and from the lake sediments. A free-floating full-lift hypolimnetic aerator was installed in 1985 to provide oxygen to the deep waters of the lake and to reduce the amount of phosphorus released by the lake sediments (Brown, 1995).

Spring Overturn

The water in Glen Lake is vertically mixed (no thermal stratification) between November and the end of April. A key time for sampling is in the spring during this period of mixing. The objective of this monitoring is to assess water quality from year to year and to estimate the potential algal growth during the summer months in Glen Lake.

Total phosphorus (Figure 3) values before thermal stratification, average of samples taken at different depths within the water column, were outside the limits (0.005-0.015 mg/L) for protecting aquatic life between 1981 and 1986, 1988, and between 1990 and 1992. Values were within the limits for aquatic life in the last three years (1993-1995). All of the total phosphorus values before thermal stratification, with the exception of 1994, exceeded the criterion (0.010 mg/L) for protecting recreational use.

Total phosphorus values (Figures 3 and 4) generally decreased over time, except for an increase in 1992. This decrease of total phosphorus in the water column may be attributed to several factors including:

- an increase in Ultra Violet light (UVb) penetration in the water column,
- an increase in phosphorus uptake by aquatic plants,
- an increase in phosphorus fixing by lake sediments,
- a result of the free-floating full-lift hypolimnetic aerator,
- a reduction in phosphorus loading to the lake, and
- an increase in the flushing rate of Glen Lake.

Nitrogen, dissolved ammonia values (Figure 5) were below all criteria (30-day average 1.89 mg/L) designated to protect aquatic life from toxicity. **Nitrate/nitrite** (Figure 6) values were below the criterion (10 mg/L) for recreational water. Nitrate/nitrite values increased over time. **Kjeldahl nitrogen** (Figure 8) and nitrate/nitrite concentrations are added together to represent total nitrogen in the lake. These concentrations are used to calculate the N:P ratio (Figure 9). The dissolved ammonia:nitrate ratio (Figure 7) was highly variable. The N:P ratio (Figure 9) has increased over time as total phosphorus has decreased and nitrate/nitrite has increased. Phosphorus is the limiting nutrient for algal growth in Glen Lake (N:P > 15:1). Also, the trends in these ratios indicate that there are some changes occurring in the lake systems (e.g., land use, biological activity) which affect water quality.

Fecal Coliform values ranged between less than 3 MPN/100 mL to 2400 MPN/100 mL at Glen View Beach. Fecal coliform values from this beach site may not be similar to values collected elsewhere in the lake. Resident waterfowl populations make these areas unique and may cause fecal coliform values to be higher than at other sites in the lake. The Capital Regional District's Health Protection and Environmental Division has posted advisory notices at Glen View Beach on several occasions between 1980 and 1995, warning of the potential for increased risk to bathers' health. These notices were posted when the geometric mean exceeds 200 fecal coliforms/100 mL over a 30-day period.

Total residue (i.e., dissolved plus suspended solids) were highly variable in 1984 (90-140 mg/L) and relatively constant between 1985 and 1995 (80-120 mg/L). There are no criteria for total residues. Dissolved solids (filterable residues) and suspended solids (non-filterable residues) values were collected between 1984 and 1986. There was insufficient suspended solids data to apply the criterion for the protection of aquatic life. Also, **Specific conductivity ($\mu\text{S}/\text{cm}$)** can be used to estimate dissolved

solid concentrations. These values were relatively constant (115-150 $\mu\text{S}/\text{cm}$) and were below all criteria for specific conductivity.

Total calcium (Figure 10) values show that the lake has a low sensitivity to acid inputs (the lake is well buffered).

True colour (Figure 11): 70% of the values exceeded the true colour desirable criterion for recreational use (15 TCU). The lake is mildly dystrophic (Nordin, 1995. Personal comm.). This type of lake is characterized by its brown-coloured water which results from large amounts of humic organic matter being supplied to the lake. Typically, terrestrial plants are the supply of this type of organic material to the lake.

Total magnesium values met all criteria.

Total manganese (Figure 12): 75% of the values exceeded the lower total manganese criterion for protecting aquatic life (0.10 mg/L), but did not exceed the upper criterion (1.0 mg/L). Dissolved oxygen concentrations, acidity, iron concentrations, and organic composition of lake sediments, are factors which regulate the amount manganese in the water column.

Total iron (Figure 13) all iron values exceeded the maximum total iron criterion for protecting aquatic life (0.3 mg/L). Dystrophic lakes characteristically have moderate concentrations of iron due to acidity of the lake water and the organic composition of lake sediments.

Total zinc: 4 of the 14 total zinc values exceeded the criterion for protecting phytoplankton (0.014 mg/L). These values occurred in 1984, 1992, and 1995. 3 of the 14 total zinc values exceeded the maximum criterion for protecting aquatic life (0.03 mg/L). 6 of the 14 values were at the minimum detection limit of 0.01 mg/L. Analysis of samples from Glen Lake for zinc should use a minimum detectable limit at least 10 times lower than the lowest criterion (e.g., 0.001 mg/L). This would provide more accurate data for comparison to the criterion (0.014 mg/L) for protecting phytoplankton.

Dissolved silica values were collected in 1992 (< 0.5 mg/L), 1993 (15.8 mg/L, 16.4 mg/L), and 1995 (11.7 mg/L, 15.1 mg/L). Dissolved silica was the limiting nutrient (i.e., values were less than 0.5 mg/L) for diatom growth in Glen Lake in 1992 (Wetzel, 1975).

Chloride values met all criteria.

pH (Figure 14) values met all criteria. These values ranged between 6.6 and 7.7.

Dissolved oxygen, extinction depth, and water temperature were measured in 1981, 1983, and 1994. There were insufficient values to compare to criteria. Brown (1995) reported that hypolimnetic oxygen values are continuing to decrease in Glen Lake. An increase in oxygen demand or a decrease in the effectiveness of the free-floating full-lift hypolimnetic aerator may be the cause of this decrease.

Conclusions - State of Water Quality

Glen Lake is classified as a mildly dystrophic lake. These lakes are characterized by:

- brownish coloured water indicating a high content of humic organic mater in the water column,
- low to moderate planktonic productivity,
- increase in littoral plant systems,
- moderate release of iron, potassium, nitrogen and phosphorus into the water column,
- high release of organic carbon into the water column, and
- acid conditions (low pH).

These characteristics may have contributed to the following conclusions:

- Spring overturn sampling indicates that in recent years there was less total phosphorus in the water column. This may be attributed to the aerator affecting a decrease in the release of phosphorus from the lake sediments, to a decrease in phosphorus entering the lake or to an increase in biological production. However, nitrogen values (e.g., nitrate/nitrite nitrogen) are increasing in the water column.
- Phosphorus is the limiting nutrient for algal growth in Glen Lake.
- The Capital Regional District's Health Protection and Environmental Division has posted advisory notices at Glen View Beach on several occasions between 1980 and 1995, warning of the potential for increased risk to bathers' health. These notices were posted when the geometric mean exceeds 200 fecal coliforms/100 mL over a 30-day period.
- Three water quality indicators (total manganese, total iron, and total zinc) exceeded the criteria for protecting aquatic life.
- True colour exceeded the desirable criterion for recreational use.

A free-floating full-lift hypolimnetic aerator was installed in 1985 to provide oxygen to the deep waters of the lake and to reduce the amount of phosphorus released by the lake sediments. Brown (1995) concluded that hypolimnetic oxygen values are continuing to decrease in Glen Lake. The effectiveness of the aerator to improve water quality in Glen Lake has not been conclusively proven by the data presented in this report.

Recommendations for Water Quality Management

Remediation

Water quality objectives should be set for Glen Lake. We recommend that the following water quality objectives be set for Glen Lake:

- Average total phosphorus values at spring overturn should not exceed the criterion (0.010 mg/L) for protecting recreational use, or be outside the limits (0.005-0.015 mg/L) for protecting aquatic life.
- True colour values should not exceed the desirable criterion (15 TCU) for recreational use.
- Total manganese should not exceed the criterion (0.10 mg/L) for protecting aquatic life.

- Total iron should not exceed the criterion (0.30 mg/L) for protecting aquatic life.
- Total zinc should not exceed the criterion (0.014 mg/L) for protecting phytoplankton.
- Dissolved oxygen values, during the summer months, should exceed 5 mg/L 1 m above the lake sediments for protecting aquatic life.

These objectives would set the goals for a remediation plan which we recommend be developed for Glen Lake. This plan should:

- evaluate the effectiveness of the aerator in reducing the amount of phosphorus released by the lake sediments and providing oxygen to the deep waters of the lake, and in improving water quality in Glen Lake.
- determine the different land use activities within the watershed and their affect on water quality (e.g., urban runoff, septic tanks, agricultural runoff),
- describe the hydrological and limnological processes of Glen Lake (e.g., internal nutrient loading, flushing rates, sources and quality of water entering the lake),
- evaluate other remediation actions (e.g., stormwater retention ponds, land use by-laws) to achieve the desired water quality in Glen Lake, and
- recommend a course of action to implement these remediation actions.

Monitoring

We recommend that monitoring at SEAM site 1130025 between June and September. Samples should be taken at the surface and at three different depths within the water column. The purpose of this monitoring program is to determine whether water quality objectives are being met and to evaluate remediation activities. The monitoring program would require sampling of the following water quality indicators:

- water temperature and dissolved oxygen profiles,
- average annual total phosphorus,
- chlorophyll a sampled near the surface
- total colour,
- total manganese, total iron, and
- total zinc (with a minimum detectable limit of 0.001 mg/L).

A minimum of three years of water quality information from this monitoring program would form the basis of the assessment.

We recommend that sampling at the surface and at depth during spring overturn be continued at SEAM site 1130025. The focus of this monitoring will be to identify changes in water quality attributed to activities within the watershed such as urbanization, changes in nonpoint discharge, biological activity, and lake aeration. This monitoring program would include the following water quality indicators:

- water temperature and dissolved oxygen profiles,
- total phosphorus, dissolved ammonia, nitrate/nitrite, kjeldahl nitrogen, total and dissolved organic carbon, true colour, turbidity, dissolved silica from 3 samples taken 1 m below the surface, at mid depth and 1 m above the bottom;
- chlorophyll a, taken near the surface; and

- extinction depth (i.e., Secchi depth) and UVb absorption.

These monitoring programs could be implemented by a Glen Lake stewardship group with assistance from the Ministry of Environment, Lands and Parks.

We recommend that bacteriological sampling continue at Glen View Beach. The monitoring program is currently being conducted by the Capital Regional District's Health Protection and Environmental Division. In future, local interest groups (e.g., Glen Lake stewardship group, Municipality of Langford) could assist with this ongoing monitoring.

Figure 3 Total phosphorus (average in the water column before stratification) from Glen Lake

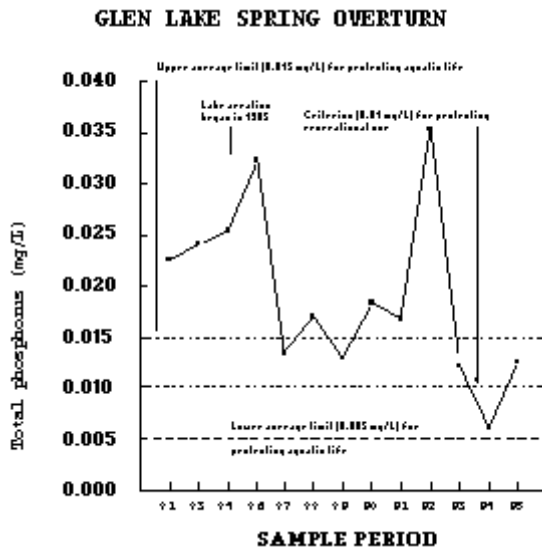


Figure 4 Total phosphorus from Glen Lake

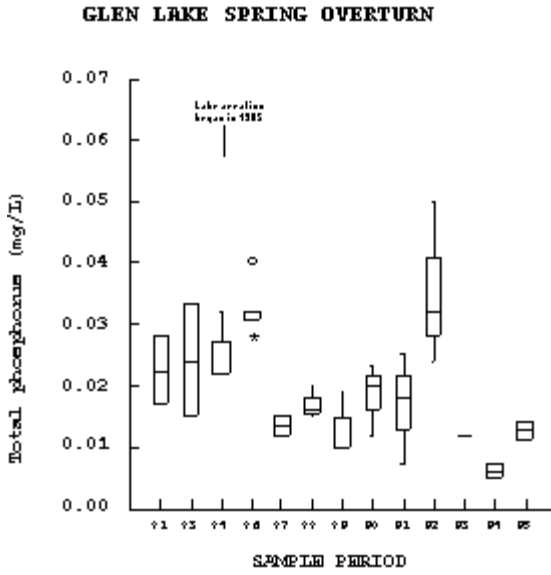


Figure 5 Dissolved ammonia from Glen Lake

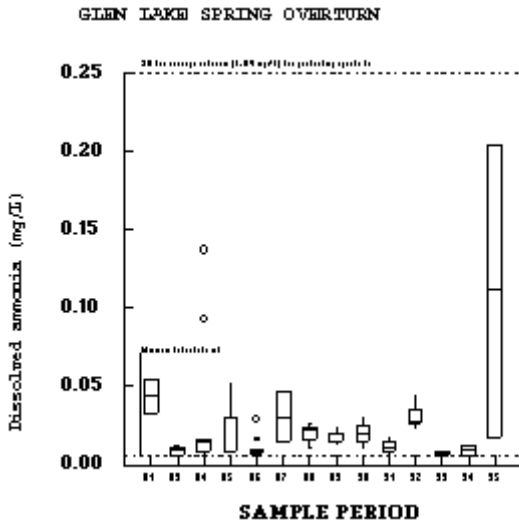


Figure 6 Nitrate/Nitrite from Glen Lake

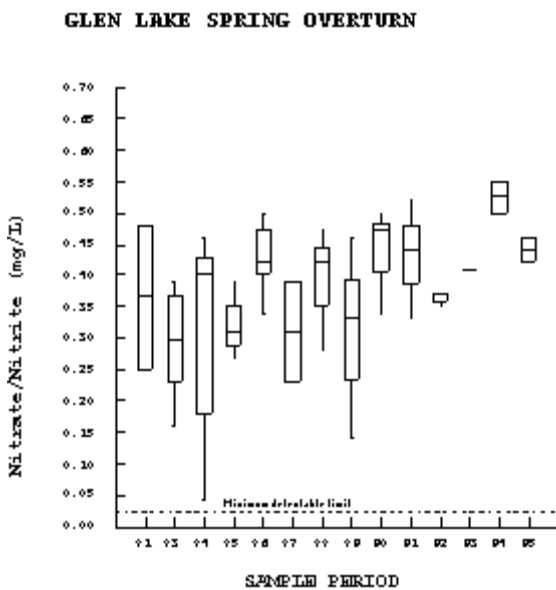


Figure 7 Dissolved ammonia:nitrate ratio from Glen Lake

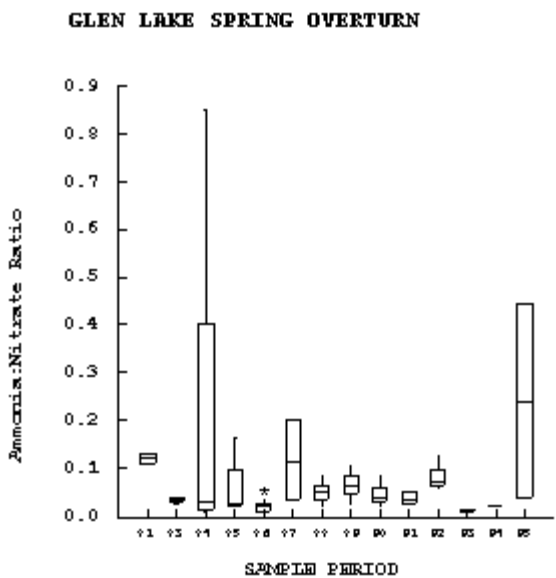


Figure 8 Kjeldahl nitrogen from Glen Lake

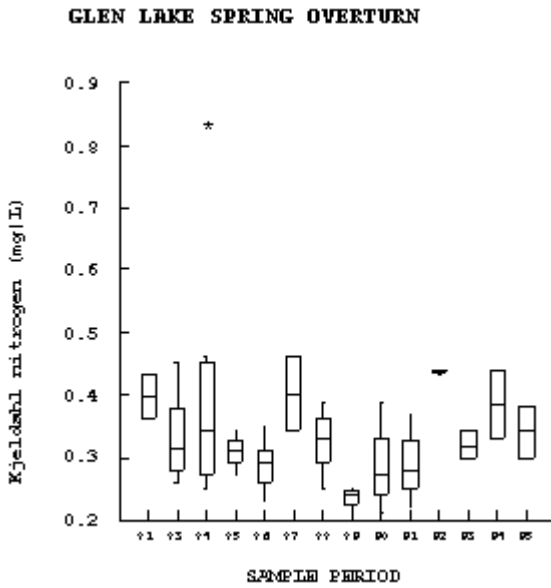


Figure 9 N:P ratio from Glen Lake

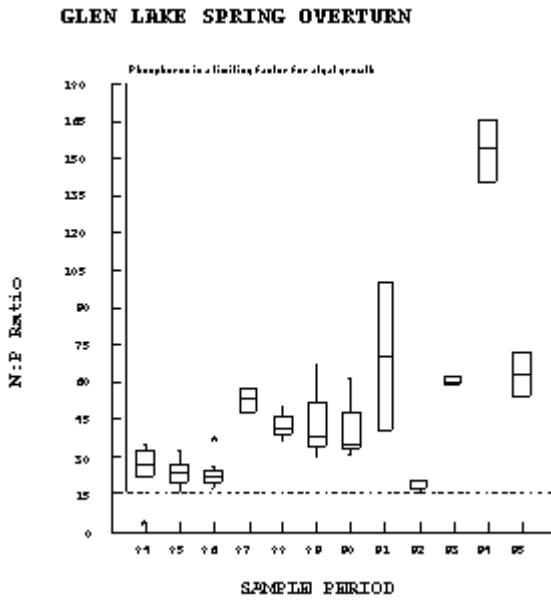


Figure 10 Total calcium from Glen Lake

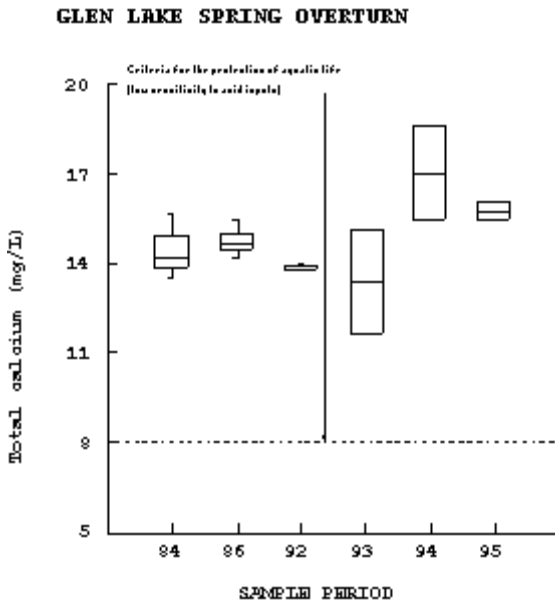


Figure 11 True colour from Glen Lake

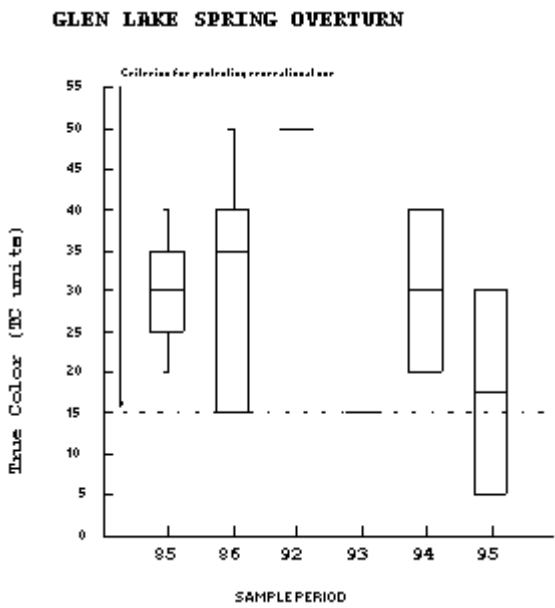


Figure 12 Total manganese from Glen Lake

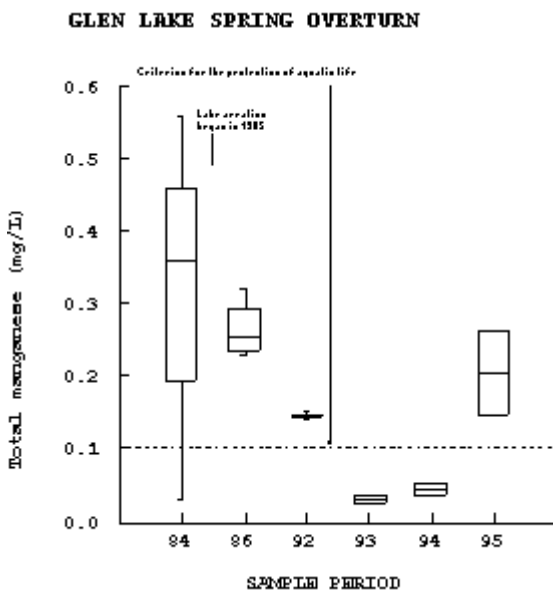


Figure 13 Total iron from Glen Lake

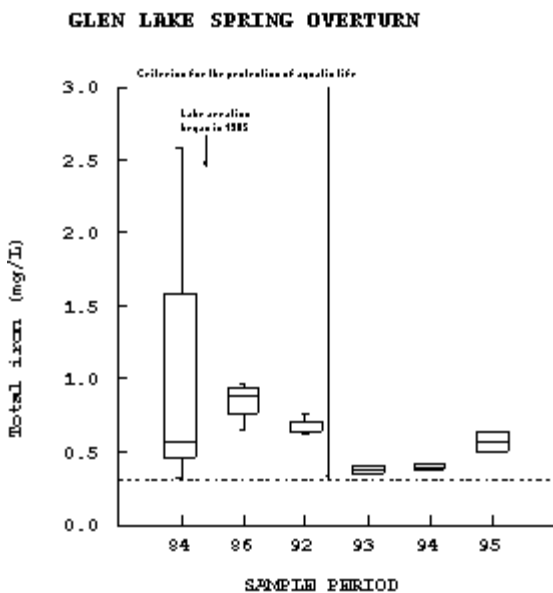


Figure 14 pH from Glen Lake

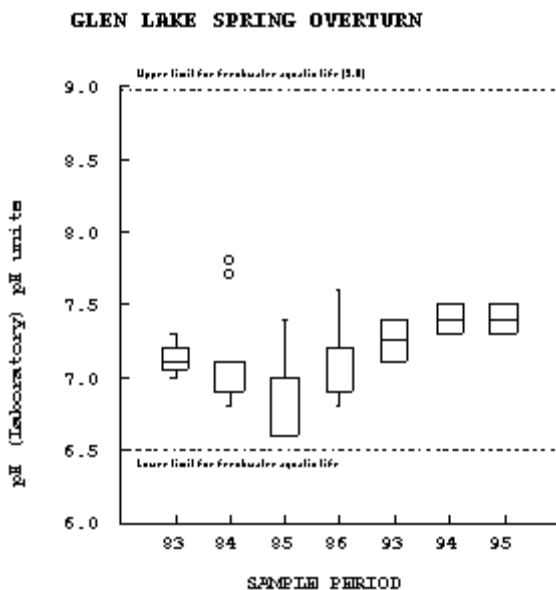


Table 1 Summary of water quality data from Glen Lake (SEAM 1130202, 1130025)

Water Quality Indicator	Average	Std Dev	Number of samples	Maximum	Minimum
SPRING OVERTURN MONITORING					
Water Clarity and Colour					
Turbidity (NTU)	2.1	1.25	29	5.8	0.7
Color, true (TCU)	30	13.9	35	60	5
Residues, non-filterable (mg/L)	4	4.3	53	30	1
Extinction depth (m)	3.0	0.13	4	3.1	2.8
General Ions					
pH (pH units)	7.11	0.341	68	7.8	6.42
Residues, filterable (mg/L)	105	12.4	24	133	84
Residues, total (mg/L)	106	11.5	61	140	86
Specific conductivity (μ S/cm)	138	9.8	63	156	116
Calcium, total (mg/L)	14.7	1.77	40	18.9	10.4
Chloride, dissolved (mg/L)	9.4	1.31	12	11.4	7.8
Magnesium, total (mg/L)	4.05	0.427	40	4.79	2.87
Silica, dissolved (mg/L)	8.6	7.76	7	16.4	0.5
Sulphate, dissolved (mg/L)	0.5	0	24	0.5	0.5
Temperature, water ($^{\circ}$ C)	9	3.6	16	20	5
Nutrients					
Carbon, total organic (mg/L)	18	2.0	24	22	15

Carbon, total inorganic (mg/L)	14	2.8	24	19	9
Nitrogen, total (mg/L)	0.61	0.181	43	1.01	0.3
Nitrogen, ammonia (mg/L)	0.047	0.100	93	0.51	L 0.005
Nitrogen, Kjeldahl (mg/L)	0.36	0.152	90	0.99	0.21
Nitrogen, organic (mg/L)	0.33	0.095	42	0.7	0.18
Nitrogen, Nitrate+Nitrite (mg/L)	0.28	0.164	93	0.55	L 0.02
Total Phosphorus (mg/L)	0.028	0.0260	96	0.201	L 0.005
Phosphorus, ortho (mg/L)	0.009	0.0129	78	0.068	L 0.003
Phosphorus, total dissolved (mg/L)	0.014	0.0136	93	0.079	L 0.003
Oxygen, dissolved (mg/L)	6.6	2.43	16	9.9	1
Metals
Aluminum, total (mg/L)	0.05	0.029	40	0.13	L 0.02
Antimony, total (mg/L)	.	.	9	L 0.02	L 0.02
Arsenic, total (mg/L)	.	.	40	L 0.25	L 0.04
Boron, total (mg/L)	0.06	0.012	9	0.08	L 0.04
Barium, total (mg/L)	0.005	0.0019	9	0.008	0.003
Beryllium, total (mg/L)	.	.	9	L 0.001	L 0.001
Bismuth, total (mg/L)	.	.	9	L 0.02	L 0.02
Cadmium, total (mg/L)	.	.	39	L 0.01	L 0.002
Cobalt, total (mg/L)	.	.	40	L 0.1	L 0.003
Chromium, total (mg/L)	.	.	40	L 0.01	L 0.002
Copper, total (mg/L)	0.006	0.0080	40	0.02	L 0.001
Iron, total (mg/L)	1.38	1.869	40	7.19	0.07
Lead, total (mg/L)	.	.	40	L 0.1	L 0.001
Manganese, total (mg/L)	0.40	0.399	40	1.39	0.01
Molybdenum, total (mg/L)	.	.	40	0.02	L 0.0005
Nickel, total (mg/L)	.	.	40	L 0.05	L 0.008
Selenium, total (mg/L)	.	.	9	L 0.03	L 0.03
Sodium, dissolved (mg/L)	5.9	0.60	8	6.9	5.4
Silicon, total (mg/L)	6.3	0.61	9	7.2	5.1
Silver, total (mg/L)	.	.	9	L 0.03	L 0.01
Strontium, total (mg/L)	0.041	0.005	9	0.051	0.031
Tin, total (mg/L)	.	.	9	L 0.02	L 0.02
Vanadium, total (mg/L)	.	.	36	L 0.01	L 0.001
Zinc, total (mg/L)	0.037	0.034	14	0.13	L 0.005

Note: L = less than

Table 2 Summary of Capital Regional District's Health Protection and Environmental Division's Bacteriological data (fecal coliforms/100 mL) from Glen Lake (at Glen View beach)

Year	Maximum	Minimum	Geometric Mean	Number of samples
1980	29	13	23.1	8
1981	34	7	16.6	4
1982	460	L 3	18.5	20

1983	16	6	7.5	10
1984	32	8	14.3	11
1985	10	4	6.4	14
1986	2400	3	66.6	8
1988	1100	3	19.4	37
1990	28	4	10.6	5
1991	97	5	21	12
1992	83	10	27	13
1993	156	2	18.8	12
1994	86	6	20.2	13
1995	750	5	49.0	10

Note: L = less than

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